

# **IES / GATE**

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**Electronics &  
Telecommunication  
Engineering**

**VOLUME-I**

**Basic Electrical Engineering  
Basic Electronics Engineering**

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## Basic Electrical Engineering →

(A) Transformer

(B) D.C. Machine → Generator  
→ Motor

(C) Induction machines → Motor  
→ Generator

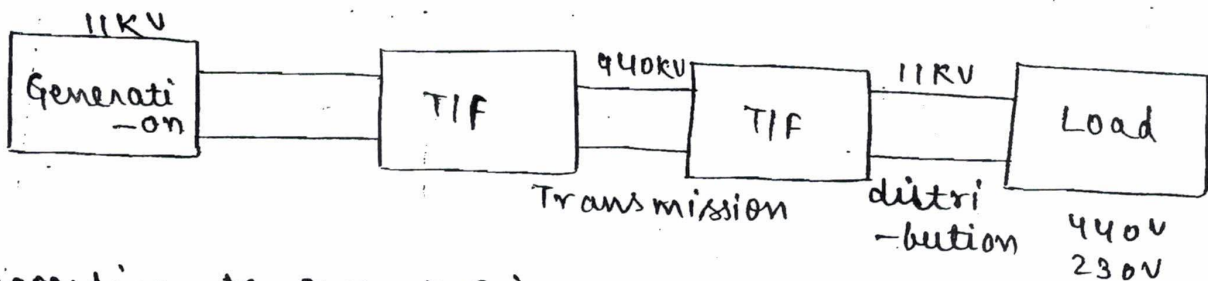
(D) Synchronous machines

↓ Generator      ↓ Motor

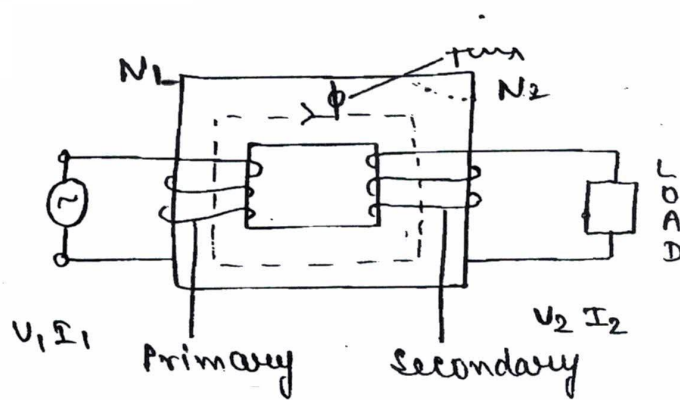
(E) ① Thermal      ② Nuclear      ③ Hydro      ④ Wind  
      ⑤ Solar        ⑥ Batteries.

{ 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. ckt. 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  $N_1 > N_2 \rightarrow$  step-down transformer

ii) If  $N_1 < N_2 \rightarrow$  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.

iv) 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.

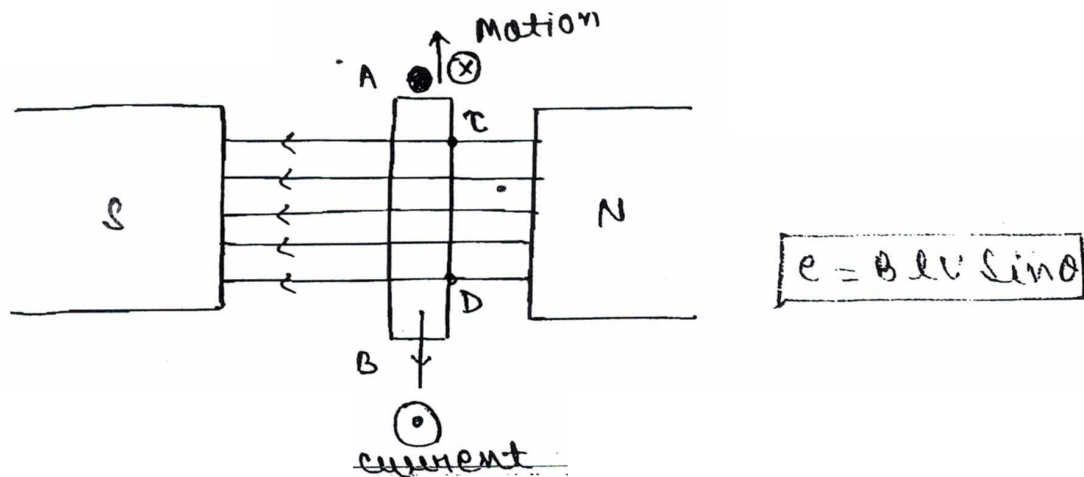
When the conductor cuts a magnetic lines of force, an emf induced in the conductor.

Faraday's 2<sup>nd</sup> law →

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

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





$e =$

$l =$  Active length of conductor (CD).

$v =$  linear velocity of conductor.

$\theta =$  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.

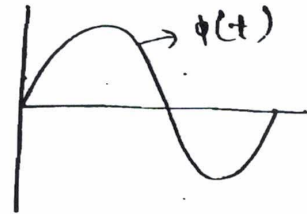
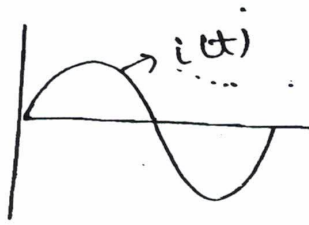
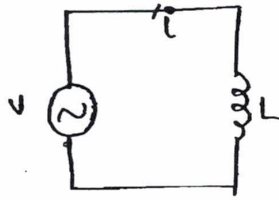
Thumb Indicates motion of the conductor.

Forefinger Indicates direction of flux (from N to S).

Middle finger Indicates dir<sup>n</sup>. 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 statically induced emf.



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

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

$v, i, \phi, e$   
 Lenz's law

(-)  $\rightarrow$  Lenz's law

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

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

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

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

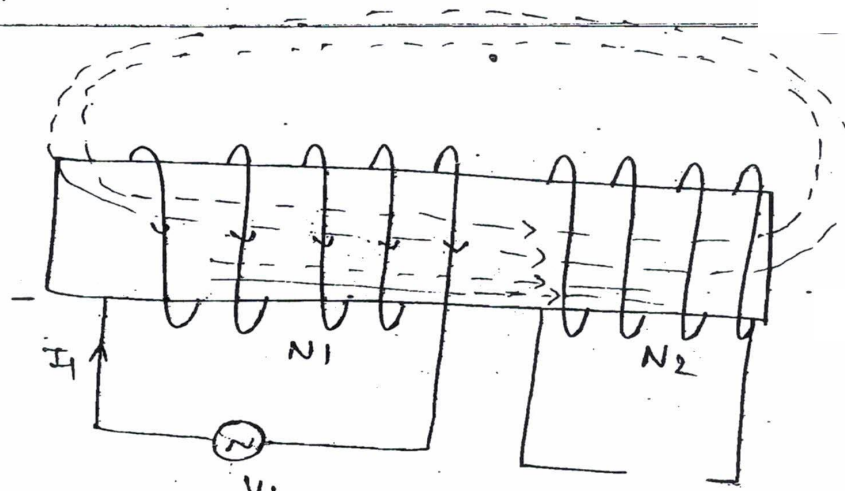
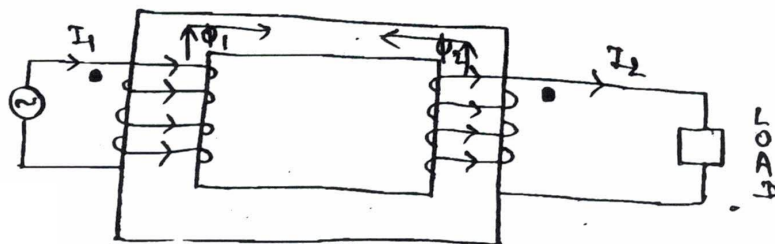
$$e_1 = -L_1 \frac{di_1}{dt}$$

$\rightarrow$  self induced emf ( $e_1$ )

$e_1$  &  $e_2$  are statically induced emf.

Magnetic coupling  $\rightarrow$

Case 1.



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

$$e_2 = -N_2 \frac{d\phi_2}{dt}$$

$$e_2 = -N_2 \frac{d\phi_2}{di_1} \times \frac{di_1}{dt}$$

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

$$\because [M = \frac{N_2 \phi}{i_1}]$$

$\rightarrow$  (mutual induced emf)

Direction of flux magnetic coupling is classified as -

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

Case 1. -ve magnetic coupling →

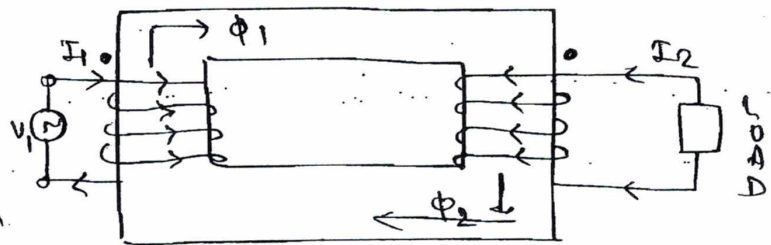
1) When the flux in the two inductors are completing closed path in the opposite direction then it is called as -ve magnetic coupling.

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

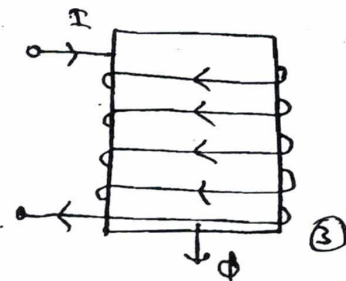
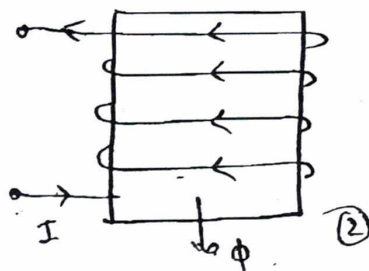
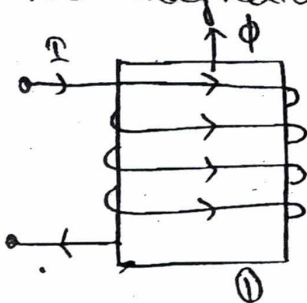
3) In the TIF to maintain constant induced  $v_1$  &  $v_2$  -ve magnetic coupling is preferred.

Case 2.

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



2) 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- $\phi$  transformer.

(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 -

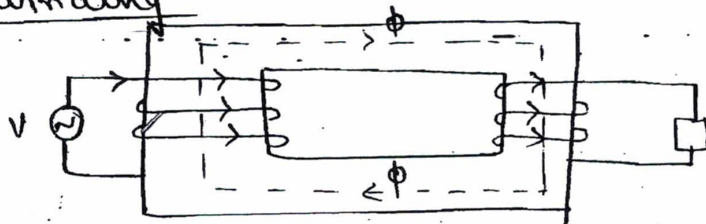
- Isolation t/f.
- Impedance matching t/f.
- Pulse TIF.

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.

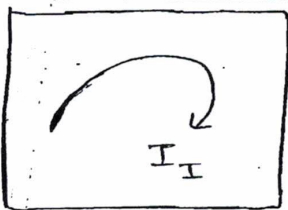
→ Eddy current losses are resistive losses in core.  
 To reduce the eddy current losses, core is laminated.

2) winding



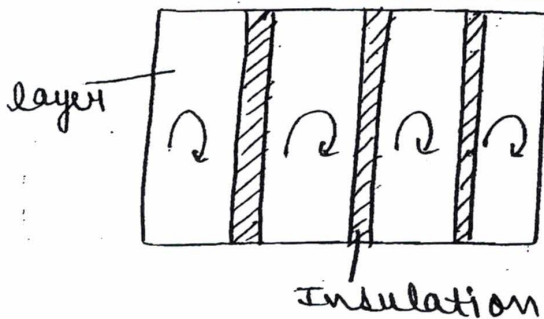
$E I, I I, I I^2 R I \uparrow \text{Temp}$   
 Eddy current losses

Solid core



$R = \frac{\rho l}{A}$

Laminated core



$R = \frac{\rho l}{A}$

→ 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, so

maintain rated (constant) flux, more magnetizing current is required [ $I_m$  = magnetizing current].

(1.)  $I \longrightarrow R$   
 $\phi \longrightarrow S$

$S_{air} > S_m$

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

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

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

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

$\mu_r$  = Relative permeab.

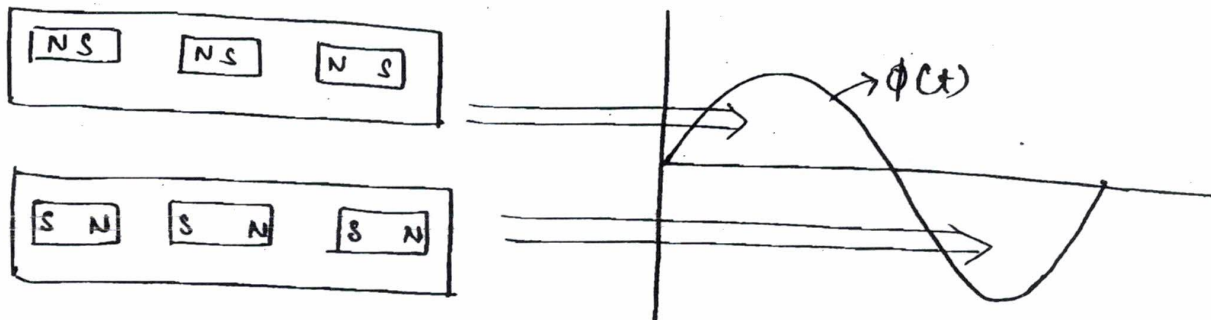
$S$ : Reluctance

( $\mu_r = 1 = \text{air}$ ).

(2.) Magnetostriction - due to magnetostriction it produces more noise (humming noise), it may cause 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

- Good magnetic properties. (Ferromagnetic material)
- High mechanical strength
- Good conducting properties.

Silicon

- Good magnetic Properties.
- Resistivity is high.
- Low hysteresis coefficient
  - ✓ → desirable
  - ✗ → undesirable

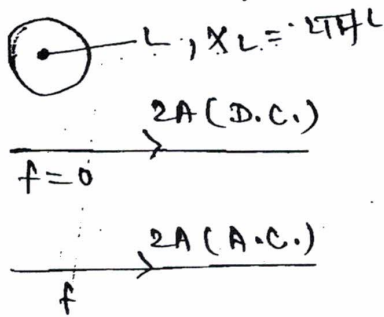
For very high rating transformers, to decrease the size of TIF for the silicon steel CRGO (Cold Rolled grain Orientation) process is done.

By doing CRGO process flux density of material increases.

$$\boxed{\uparrow B = \frac{\Phi}{A \downarrow}} \quad \cdot \quad A \downarrow \text{ size } \downarrow$$

2.) Winding →

disadvantages due to single strand wire



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

→ Due to high area of cross-section of <sup>cond</sup> skin effect is high. thereby effective resistance of the conductor increases

$$\boxed{\uparrow R = \frac{\rho l}{a \downarrow}} \\ R_{D.C.} < R_{A.C.}$$

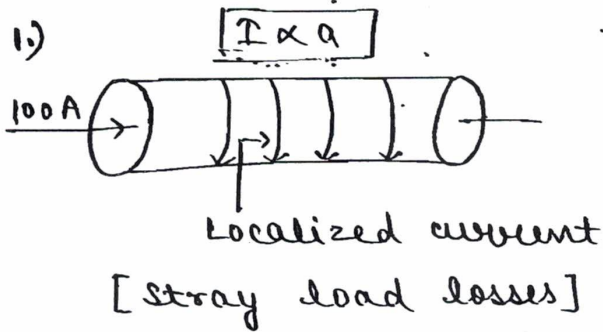
Due to overcome above this

effective resistance wire is present.

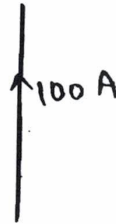
disadvantages, ~~now~~ multi-strand

Flux linkage at centre of conductor increases.

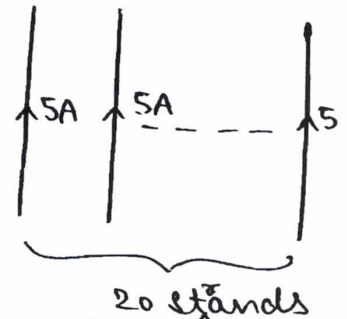
$$L \rightarrow \uparrow \rightarrow X_L \uparrow$$



single-strand wire



multi-strand wire



2)  $\text{Skin effect} \propto d^2$

where  $d$  = diameter of conductor.

$I \propto ad$

$I$  decreases due to  $a \downarrow$ .

Ideal Transformer →

Assumptions →

- 1) Permeability is very high (approximately equal to  $\infty$ ).
- 2) Iron losses are neglected.
- 3) Leakage flux equal to zero (coefficient of coupling  $K = 1$ ).
- 4) Internal resistance of primary & secondary windings are neglected.

Case 1. No load:

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

$$\phi = \frac{\text{MMF}}{s} = \frac{N i}{s}$$

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

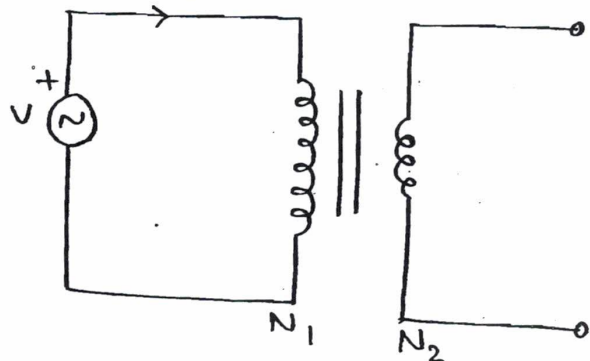
$$\phi(t) = \phi_m \sin \omega t$$

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

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

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

$I_0$   $I_0$ : No Load current



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

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

$$e_1(t) = \{E_{m1}\} \sin(\omega t - 90^\circ)$$



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

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

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

similarly for 2nd inductor -

$$e_2 \propto \frac{d\phi_2}{dt} \quad e_2 = + N_2 \phi_m \omega \sin(\omega t - 90^\circ)$$

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

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

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

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

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

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

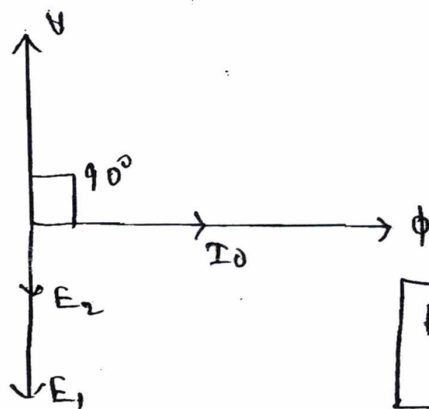
$$E_{2RMS} = 4.44 N_2 f \phi_m \quad \text{--- (2)}$$

$$\frac{Eqn. (1)}{Eqn. (2)} = \frac{E_1}{E_2} = \frac{4.44 N_1 \phi_m f}{4.44 N_2 \phi_m f} = \frac{N_1}{N_2} \Rightarrow \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$\boxed{\text{emf/turn} = \frac{E_1}{N_1} = \frac{E_2}{N_2}}$$

For primary & secondary  
emf/turn is equal.

Phasor diagram at No load condition  $\rightarrow$



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

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

$$\boxed{E_1 = 4.44 B_m f N_1 A}$$

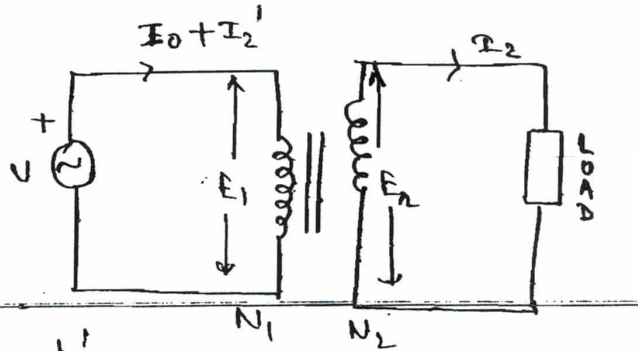
$$E_1 = 4.44 N_1 \phi_m f$$

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

$$\left| \Phi_m \propto \frac{E_1}{f} \propto \frac{V}{f} \right| \text{ i.e. } \left| \Phi_m \propto \frac{V}{f}, B_{max} \propto \frac{V}{f} \right| \quad E_1 = V = \text{source } \frac{V}{f}$$

Case 2. Load:-

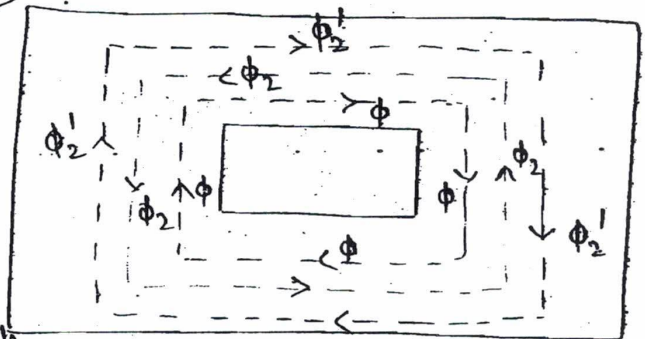
1)  $\phi, E_2, I_2, \phi_2$   
 (Lenz's Law)



2)  $\phi_2, \Phi_{net} = \phi - \phi_2', E_1, I_2', \phi_2'$   
 (Lenz's law)

$$\Phi_{net} = \phi - \phi_2' + \phi_2'$$

$I_2'$  (due to load)



(i) Transformer is designed such

that  $\cancel{N}$  MMF of the ~~primary~~ primary ( $N_1, I_2'$ ) and MMF of the secondary ( $N_2, I_2$ ) are equal and in opposite dir<sup>n</sup>. thereby corresponding flux also equal

$$N_1 I_2' = N_2 I_2 \rightarrow \boxed{\phi_2' = \phi_2}$$

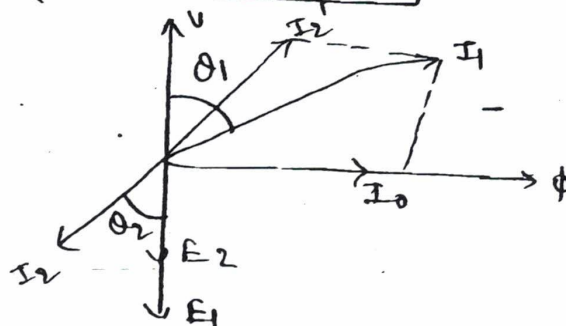
(ii) Transformer is also called as constant flux device.

since flux magnitude independent on the load curve

$$\Phi_{net} = -\phi_2' + \phi_2' + \phi = \phi$$

Phasor diagram  $\rightarrow$

R-L Load  
 [lag by  $< 90^\circ$ ]



Due to  $I_0$

$$\boxed{\theta_1 \neq \theta_2}$$

$$N_1 I_2' = N_2 I_2$$

$$\therefore I_1 = I_0 + I_2'$$

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

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

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

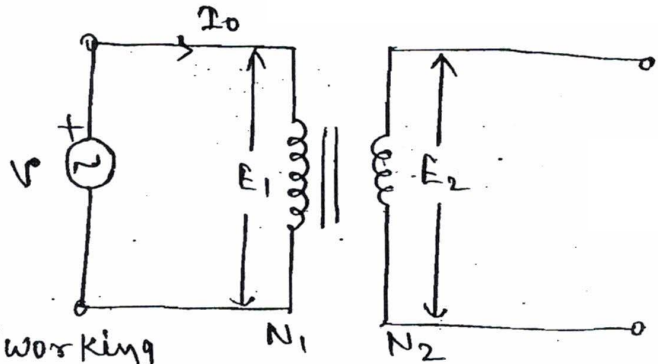
$$\therefore \boxed{I_1 \approx I_2'} \quad I_0 = \text{very less}$$

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

### Practical Transformer →

#### Case 1. (No Load) -

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



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

$I_w \rightarrow$  Iron losses

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

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

$I_\mu \rightarrow$  Flux

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

$I_m =$  magnetizing current used to produce flux.

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

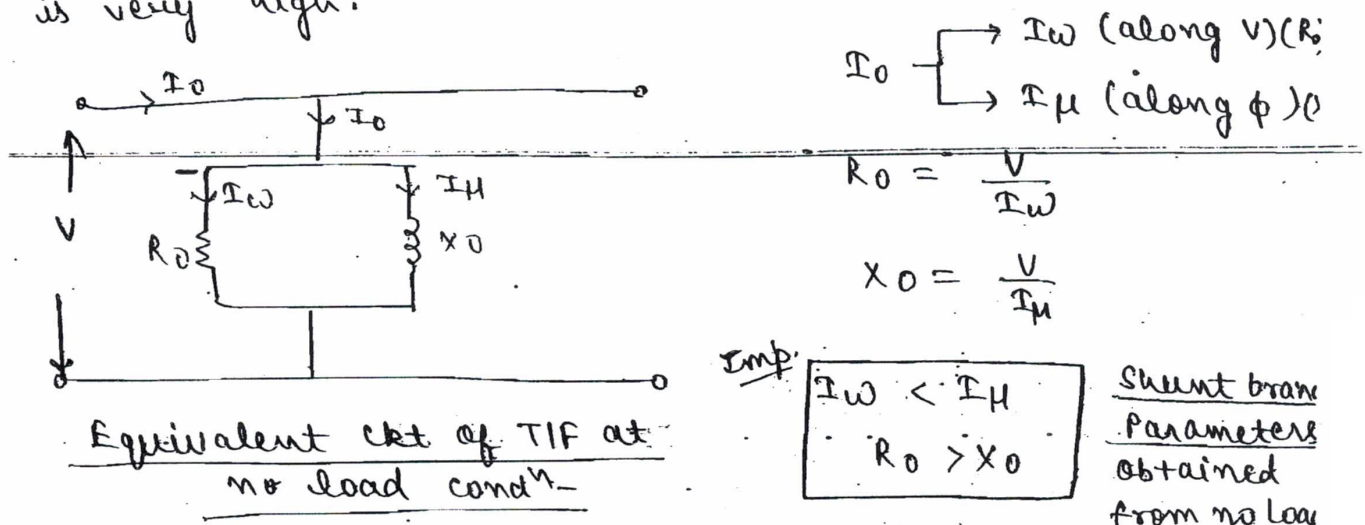
$$\boxed{I_\mu = (2 \text{ to } 3) I_w}$$

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

Active compo.  $\downarrow$   
 along source  $\sqrt{VI}$   
 Reactive compo.  $\downarrow$   
 Phase is  $90^\circ$  with  $V$ .

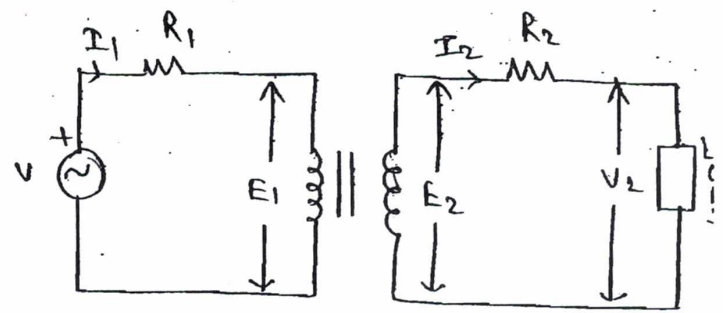
\*  $\left[ \begin{array}{l} \cos \theta_0 \approx 0.2 \text{ (lag)} \\ \theta_0 \approx 70 \text{ to } 75^\circ \end{array} \right]$  (No Load... condition)

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



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.



$V = E_1 + I_1 R_1$        $E_2 = V_2 + I_2 R_2$   
 drop:  $I_1 R_1$       drop:  $I_2 R_2$   
 Copper losses in Primary:  $I_1^2 R_1$       Copper losses in sec.:  $I_2^2 R_2$

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

$I_1^2 R_2' = I_2^2 R_2$   
 $R_2' = \left( \frac{I_2}{I_1} \right)^2 R_2$   
 $R_2' = \left( \frac{N_1}{N_2} \right)^2 R_2$

$R_2'$  = Primary equivalent of secondary resistance.