IES/GATE

Electrical Engineering

VOLUME-VII

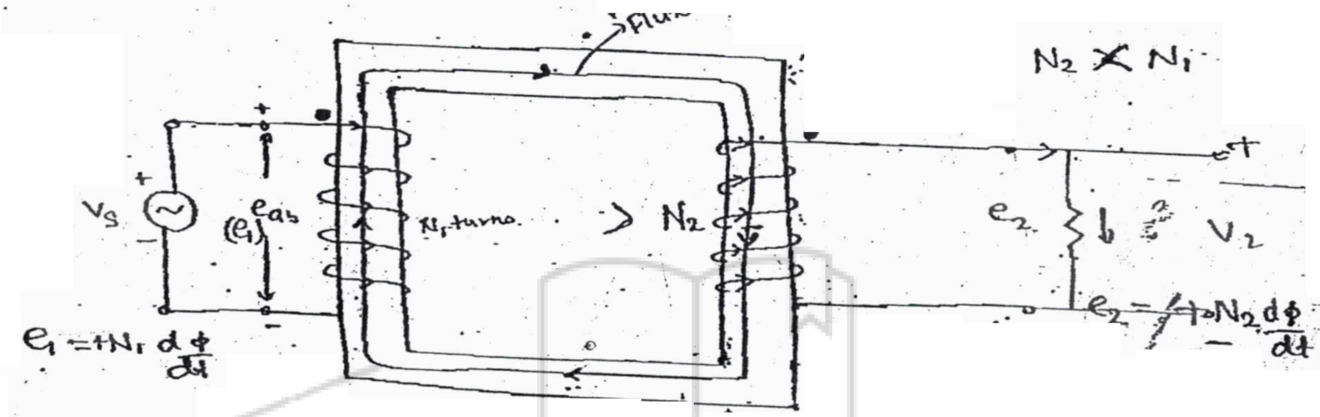
Electrical Machines

CONTENT

Electrical Machines

Capable of continuous Electromechanical Conversion is called Electrical machines.

Transformers



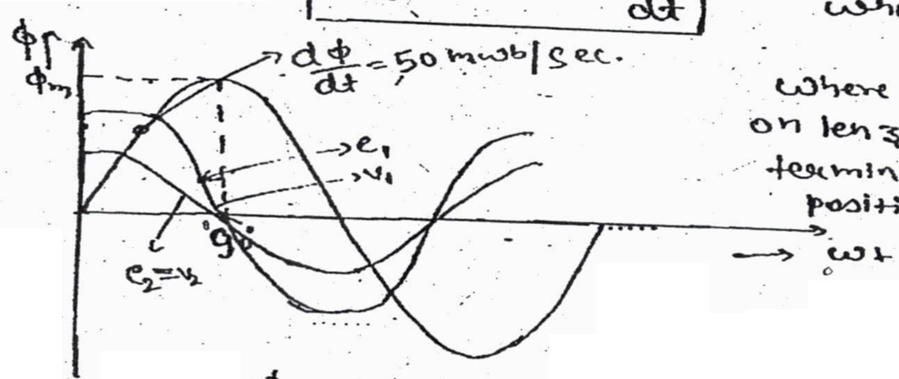
Core :- Provide low reluctance magnetic path

* According to lenz law, the direction of induced emf is such that if it is allow to cause a current by Short circuiting the coil then the current so produced opposes the causes. Thus, $e = \pm \frac{d\lambda}{dt}$

$$\boxed{e_{ab} = + N_1 \frac{d\phi}{dt}}$$

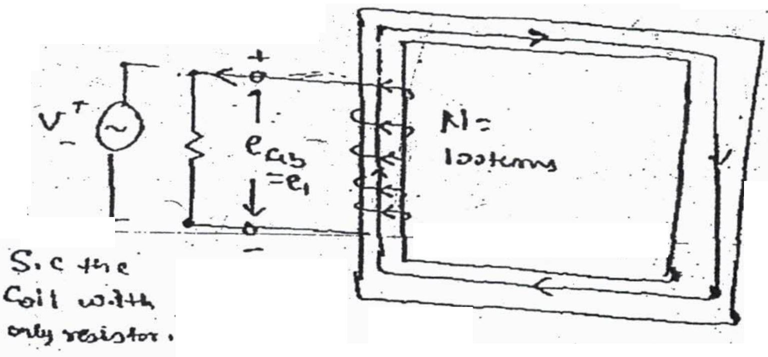
when λ = flux linkage $= N\phi$.

where the sign depends on lenz law and which terminal is taken as positive.



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

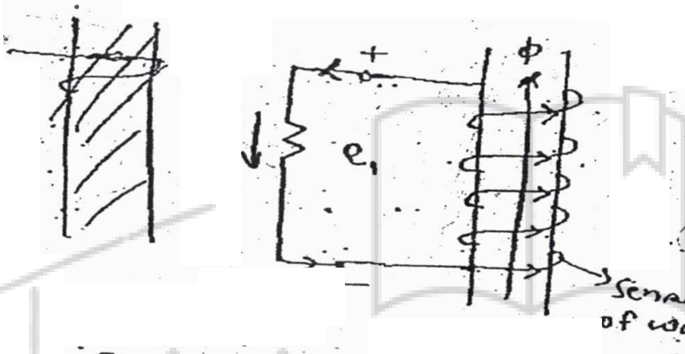
welson deitero



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

$$= 100 \times 50 \times 10^{-3}$$

$$= 5 \text{ volt}$$



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

$$= -100 \times 50 \times 10^{-3}$$

$$= -5\,V$$

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

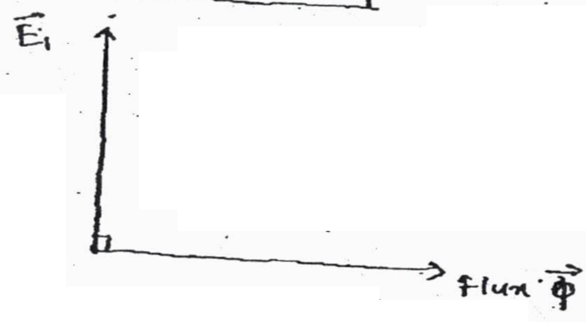
$$= N_1 \frac{d}{dt}(\phi_m \sin\omega t)$$

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

$$= N_1 \phi_m \omega \sin(\omega t + 90^\circ)$$

$$E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}}$$

$$\boxed{E_1 = \sqrt{2}\,\pi f \phi_m N_1}$$ Induced Emf equation



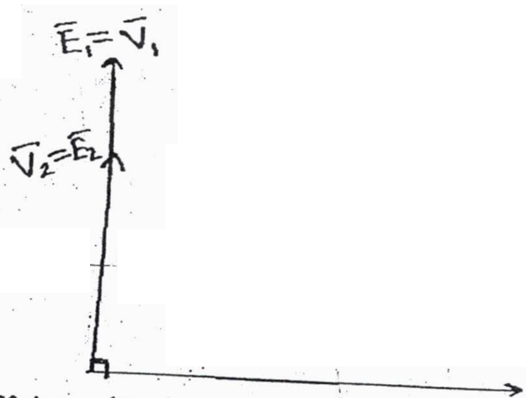
Concept of phasors

$$\Sigma V = 0$$

$$-e_1 + v_1 = 0$$

$$\Rightarrow v_1 = e_1$$

$$\Rightarrow \vec{E}_1 = \vec{V}_1$$



Phasor diagram of Ideal X-former on no-load

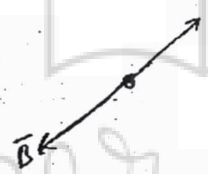
Vector has a fixed magnitude & fixed direction.

But, Sinusoids are the Phasors not the vectors.

Phasors diagrams only shows phase relation.

$\bar{E}_1 = \bar{V}_1$, it does not mean $\bar{V}_1$ supports $\bar{E}_1$

but in vector,



$\bar{A}$ (Concept of vector)

$\bar{A} + \bar{B} = 0$ (They are opposing)

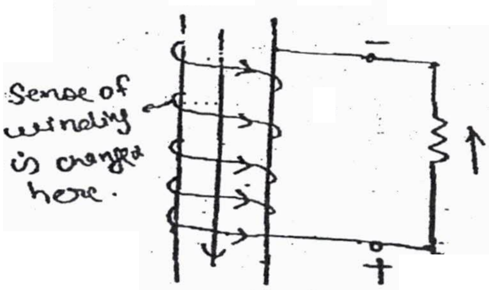
but in phasor, it is not determined.

Concept of phasors

→ A phasor diagram has no meaning without ckt diagram and vice-versa.

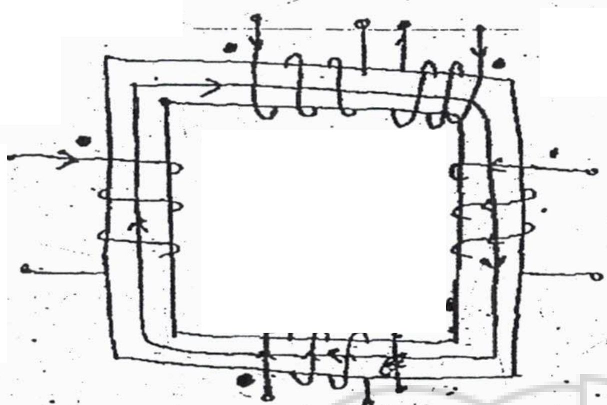
→ Phasor diagram only show that both $\bar{E}$ & $\bar{V}$ are rising together or decaying together and lag & lead and nothing else.

→ They are supporting and opposing each other is determined by circuit diagram.



Dot Convention

If the currents enters or leaves through the dot simultaneously, then the fluxes are additive.



Only the first dot is assigned. The remaining dots follows automatically depending upon the sense of winding.

As applied to transformer, therefore if the current enters through the dot in one winding then it should leave through the dot from the other winding to satisfy lenz law. In other words, the dots have the same instantaneous polarity.

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

$$= +N_2 \phi_m \omega \cos\omega t$$

$$= N_2 \phi_m \omega \sin(\omega t + 90^\circ)$$

$$\Rightarrow E_2 = \frac{N_2 \phi_m \omega}{\sqrt{2}}$$

$$\boxed{E_2 = \sqrt{2}\pi f \phi_m N_2}$$

Ideal transformer

1) No losses
2) Infinite permeability

$$\Phi = \frac{NI}{S} \text{ -Reluctance}$$

$$\Rightarrow NI = \phi S = \phi \frac{l}{\mu A} \Rightarrow NI = \phi \times \frac{l}{\infty \times A}$$

$$= 0 \text{ though } \phi \neq 0$$

⟶ No winding losses
⟶ No core losses
⟶ No exciting current required
⟶ Zero magnetizing current.

Property of a magnetic ckt.

If any magnetic ckt. is applied with an alternating excitation then it must produce an emf. which is equal and opposite in nature.

MMF balance of ideal x-former:-

$$N_1 \bar{I}_1 - N_2 \bar{I}_2 = 0$$

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

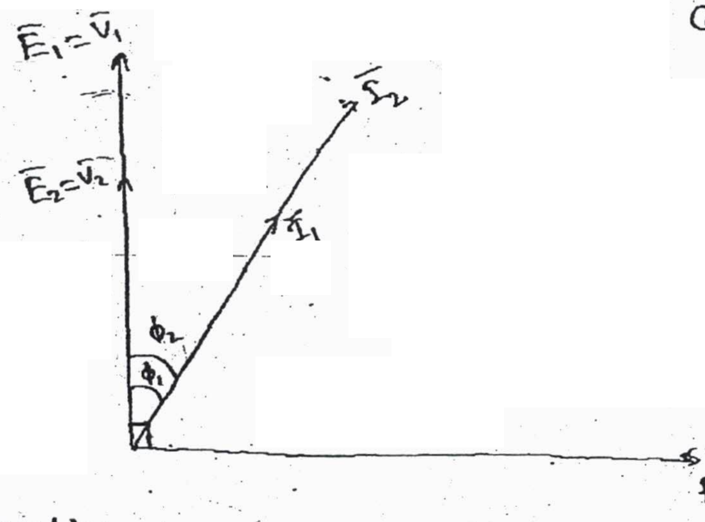
$$\Rightarrow \bar{I}_1 = \frac{N_2}{N_1} \times \bar{I}_2 = \frac{I_2}{a} = \bar{I}_2'$$ Primary current referred to secondary

$$\frac{\bar{V}_1}{\bar{V}_2} = \frac{\bar{E}_1}{\bar{E}_2} = \frac{N_1}{N_2} = a = \frac{\bar{I}_2}{\bar{I}_1} = \frac{I_2^*}{I_1^*}$$

a ⟶ Turns ratio or Voltage ratio

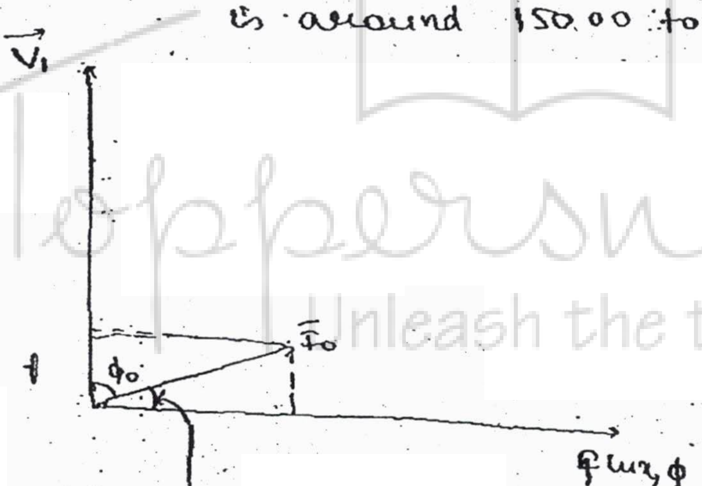
$$\Rightarrow \vec{V}_1 \vec{I}_1^* = \vec{V}_2 \vec{I}_2^*$$
$$\& \ \bar{E}_1 \bar{I}_1^* = \bar{E}_2 \bar{I}_2^*$$
$$\Rightarrow \bar{S}_1 = \bar{S}_2$$

Constant flux device



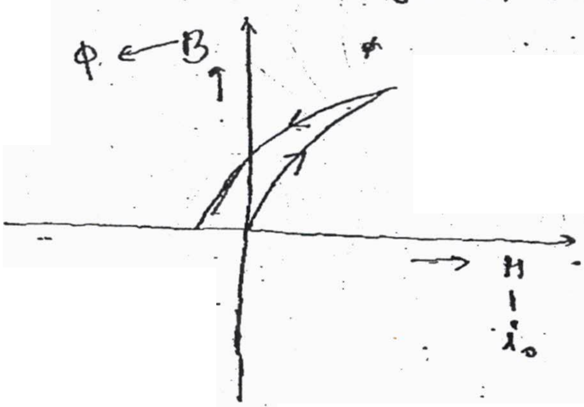
Magnetizing current $\rightarrow$ 2 to 3%

becz we donot have any intentional gap
we have a Iron core whose permeability
is around 150.00 to 20,000.



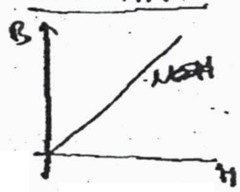
Angle of Hysteretic Advance
or
Hysteretic lag angle

decided by position of observer



i_0 lead when observer seen from ϕ.

For Air



$B = \mu_0 H$

MMF Balance of practical transformer

$$N_1 \bar{I}_1 - N_2 \bar{I}_2 = N_1 \bar{I}_0$$

$$N_1 \bar{I}_1 = N_2 \bar{I}_2 + N_1 \bar{I}_0$$

$$\Rightarrow N_1 \bar{I}_1 = N_2 I_2 + N_1 I_0$$

$$\bar{I}_1 = \frac{N_2}{N_1} \times \vec{I}_2 + \vec{I}_0$$

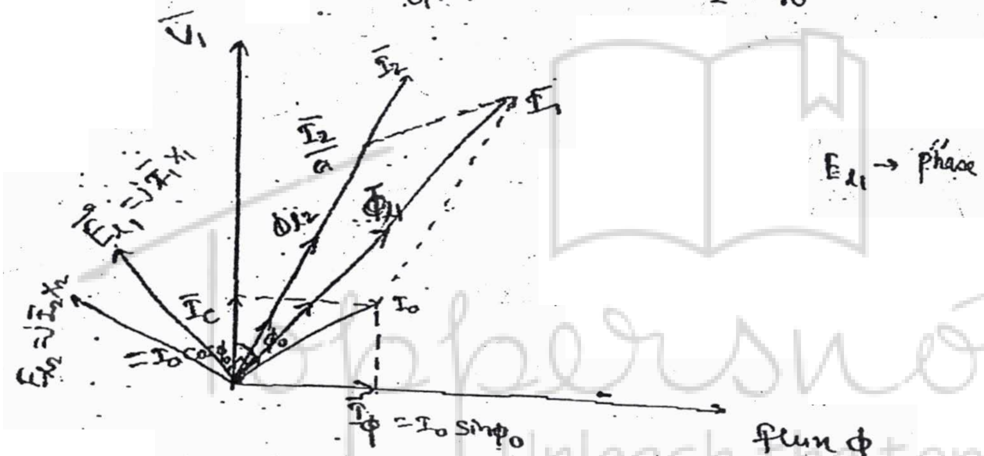
$$= \frac{I_2}{a} + \bar{I}_0 \Rightarrow I_2' + \bar{I}_0$$

$I_0 \rightarrow$ No load current / Exciting current.

$I_0 \Rightarrow$ magnetizing current if it is ideal transformer

I_ϕ = magnetizing current

I_c = core loss component



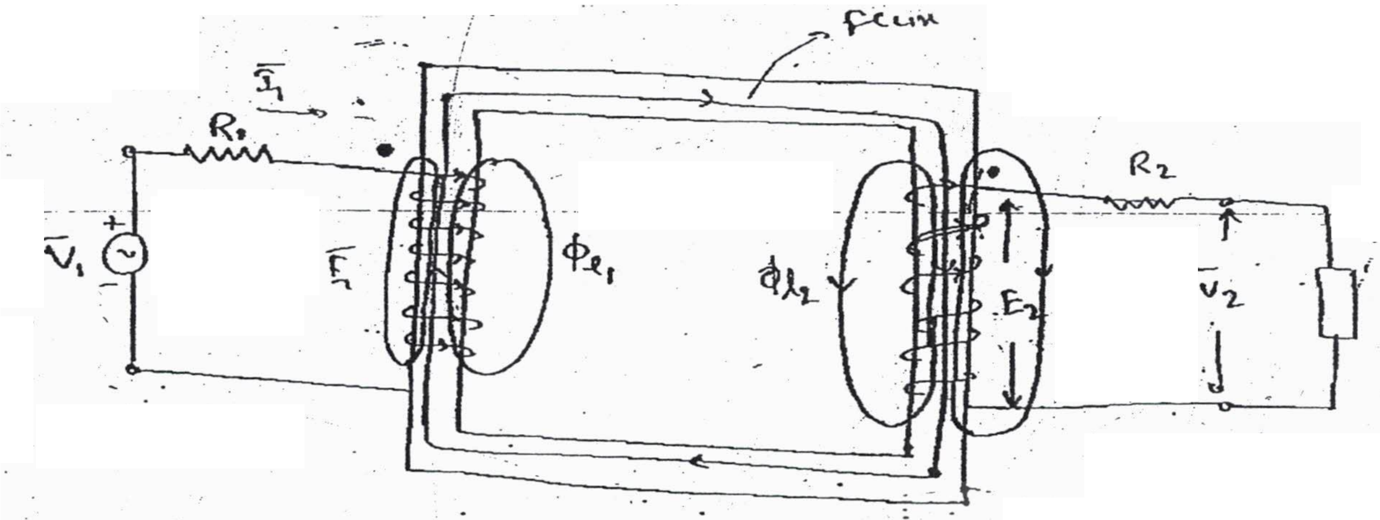
ϕ_0 = no load pf load (around 80°)

R_1 = Primary winding resistance
R_2 = Secondary winding resistance } (Shown outside the winding in diagram)

ϕ_{lm} = leakage flux in magnetic ckt.

Electric ckt. → Electric current confined by the insulation & not deviate from its path, if there is a leakage that will be very minute.

Magnetic ckt. → Magnetic flux will made itself in the free space or air. Also there is leakage that is considerable.



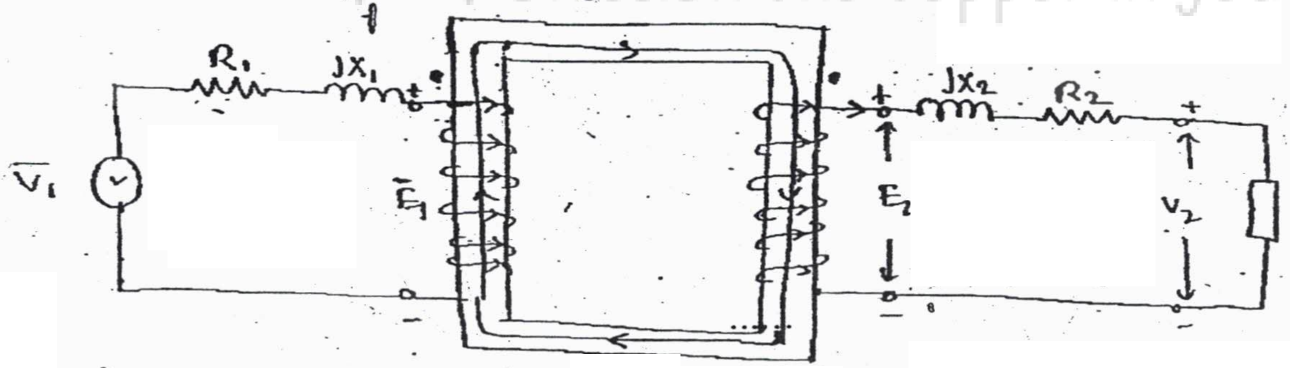
→ ϕ_{l1} is in phase with I_1

$$B = \mu_0 H$$

↓ permeability of air

→ Mutual flux is responsible for transfer of power in any electrical m/c

→ Leakage flux is only a chock in series which only drops voltage



1) $\bar{E}_2 = \bar{V}_2 + \bar{I}_2 R_2 + j\bar{I}_2 X_2$

$\Rightarrow E_2 = \bar{V}_2 + \bar{I}_2 (R_2 + jX_2)$ $\quad$ Z_2 = Secondary leakage impedance

$\Rightarrow E_2 = \bar{V}_2 + \bar{I}_2 \bar{Z}_2$

2) $\bar{E}_1 = a\bar{E}_2$

3) $\bar{I}_1 = \dfrac{\bar{I}_2}{a} + \bar{I}_0$

$= \vec{I}_2{}' + \bar{I}_0$ where $\vec{I}_0 = \bar{I}_c + \bar{I}_\phi$

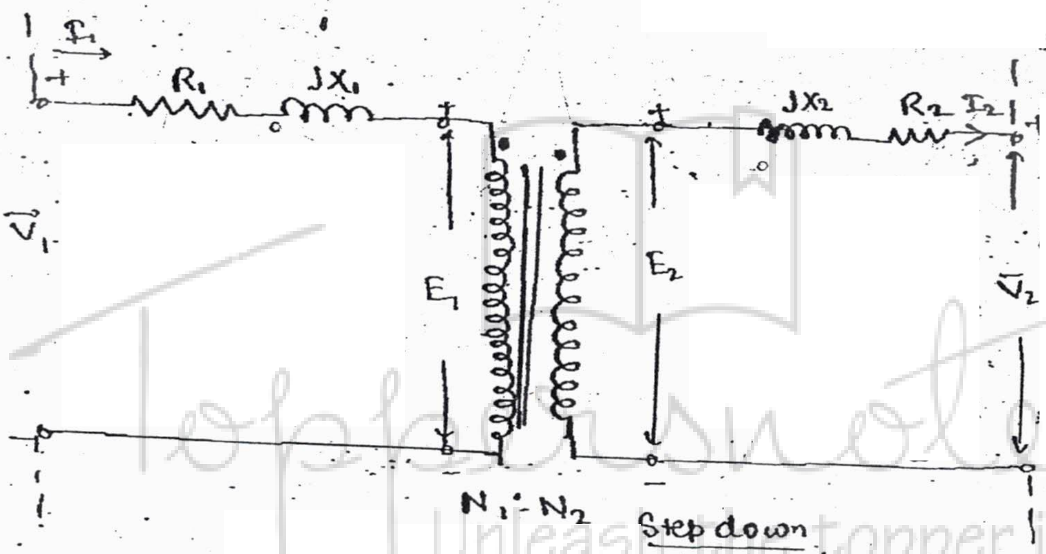
$\bar{I}_c$ → Phase with $\bar{E}_1$; $\bar{I}_\phi$ → phase with flux m

4) $\vec{V}_1 = \bar{E}_1 + \bar{I}_1 R_1 + j\bar{I}_1 X_1$

$= \bar{E}_1 + \bar{I}_1 (R_1 + jX_1)$

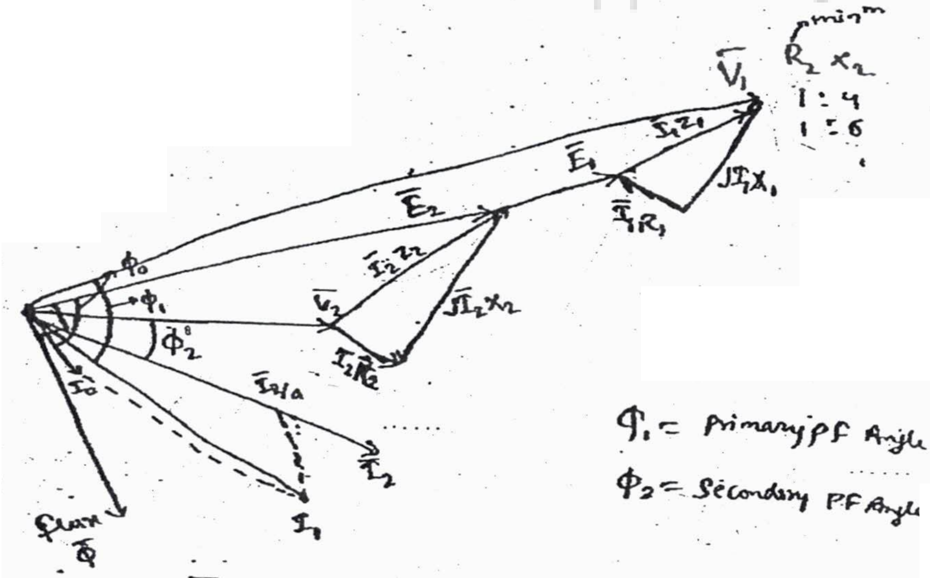
$V_1 = \vec{E}_1 + \bar{I}_1 \vec{Z}_1$

||| → Shows tight coupling



Step down

Lagging P.F :



ϕ_1 = Primary PF Angle

ϕ_2 = Secondary PF Angle

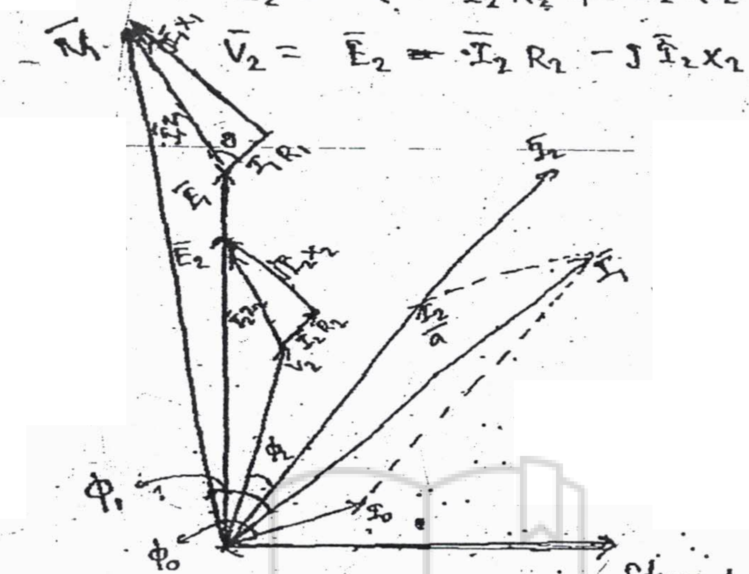
$\bar{V}_2$ Horizontal

Flux horizontal

$$\bar{E}_2 = \bar{V}_2 + \bar{I}_2 R_2 + j\,\bar{I}_2 X_2$$

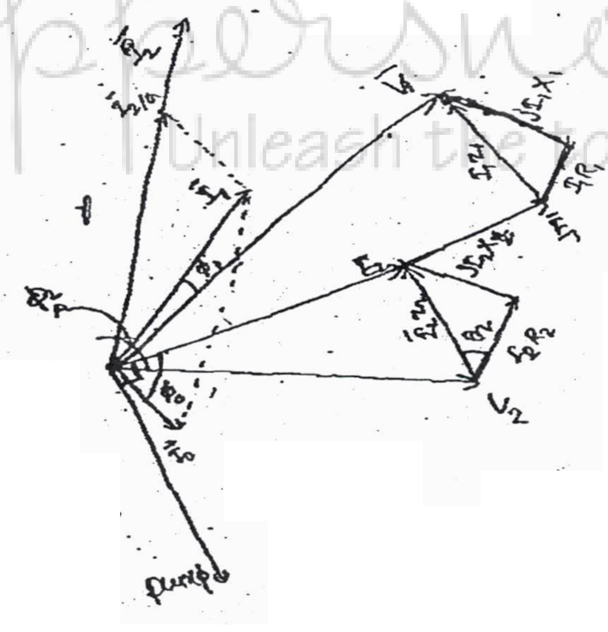
$$\bar{V}_2 = \bar{E}_2 - \bar{I}_2 R_2 - j\,\bar{I}_2 X_2$$

Known to unknown



~~Sketch~~ Leading pf

V_2 horizontal



Equivalent Ckt. of Transformer

* Representation of any device by standard active, & Passive ckt. elements that can be used to analyse and predict the performance of the device is its equivalent ckt.

$$\bar{E}_2 = \bar{V}_2 + \bar{I}_2 R_2 + j\,\bar{I}_2 X_2$$

mutiplying by $\frac{N_1}{N_2} = a$

$$\Rightarrow a\bar{E}_2 = a\bar{V}_2 + a\,\bar{I}_2 R_2 + j a\,\bar{I}_2 X_2$$

$$\Rightarrow \bar{E}_1 = \bar{E}_2' = \bar{V}_2' + \left(\frac{\bar{I}_2}{a}\right)(a^2 R_2) + j\left(\frac{\bar{I}_2}{a}\right)(a^2 X_2)$$

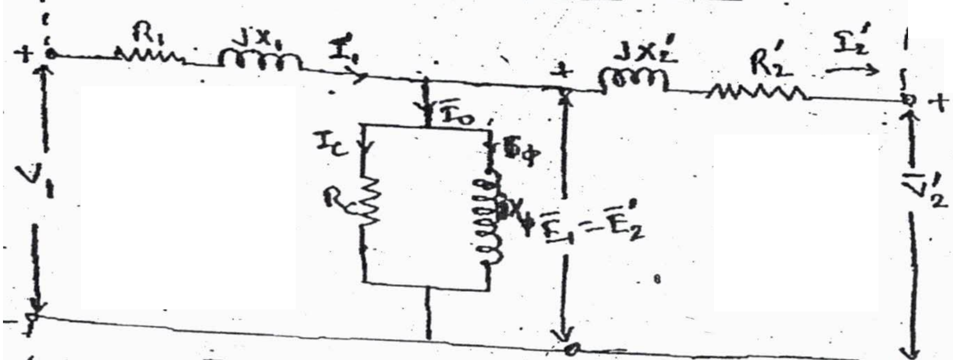
$$= \bar{V}_2' + \bar{I}_2' R_2' + j\,\bar{I}_2' X_2'$$

R_2': Secondary resistance refered to primary

X_2': secondary leakage reactance referred to primary

$$= \bar{V}_2' + \bar{I}_2' (R_2' + jX_2')$$

$$\Rightarrow \boxed{\vec{E}_1 = \bar{E}_2' = \bar{V}_2' + \bar{I}_2' \vec{Z}_2'}$$



Exact Equivalent Ckt. refered to Primary

R_c = core loss equivalent resistance

X_ϕ = magnetizing reactance

Because of shape of ckt., it is known as (T-equivalent)

X_ϕ & R_c is $\parallel$ Element as it is dependent on applied voltage.

Secondary Side Parameters when Referred to Primary.

$R_2' = a^2 R_2$ or $\frac{R_2}{k^2}$ $\left\{ \text{when } a = \frac{N_1}{N_2} \text{ \& } k = \frac{N_2}{N_1} \right\}$.

$X_2' = a^2 X_2$ or $\frac{X_2}{k^2}$

$$\left\{ \begin{array}{ll} R_{01} = R_1 + R_2' & X_{01} = X_1 + X_2' \\ X_{02} = X_2 + K^2 X_1 & \\ \quad\ = X_2 + X_1' & \end{array} \right\}$$

$I_2' = \frac{I_2}{a}$ or $k I_2$

$E_2' = a E_2$ or $\frac{E_2}{K}$. & $V_2' = aV_2$ or $\frac{V_2}{K}$.

Pu reactance drop referred to $1^\circ = \frac{I_1 X_{01}}{E_1}$

" " " " " $2^\circ = \frac{I_2 X_{02}}{E_2}$.

* Pu reactance drop on both sides of TF is same.

$\therefore$ $\boxed{\frac{I_1 X_{01}}{E_1} = \frac{I_2 X_{02}}{E_2}}$.

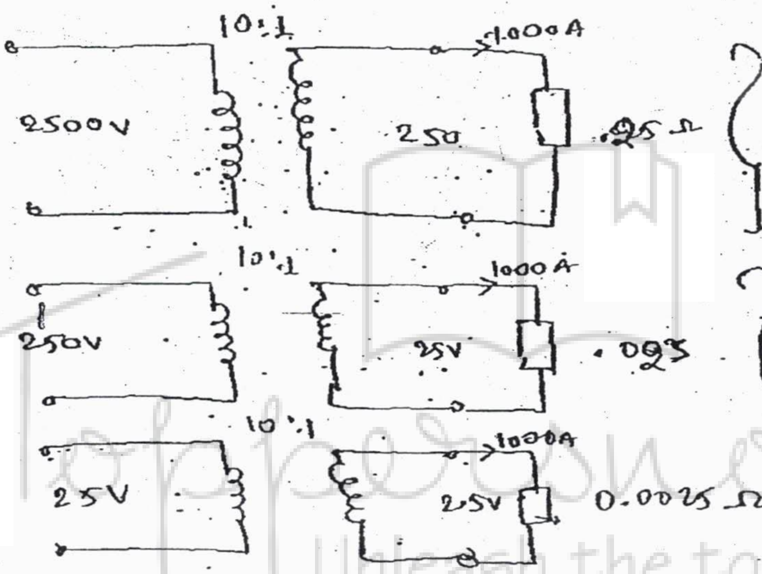
$\% X = \frac{I_1 X_{01}}{E_1} \times 100$ or $\frac{I_2 X_{02}}{E_2} \times 100$.

2° referred to 1°
$E_1 = a E_2 = E_2'$
$I_2' = \frac{I_2}{a}$
$R_2' = a^2 R_2$

1° referred to 2°
$E_1' = E_1/a$
$I_1' = a I_1$
$R_1' = R_1/a^2$

250 KVA , 2500V/250V
(delivered O/P power) : 100A → 1000A
O/P terminal voltage

2500 V / 250 V
aV_2 / V_2



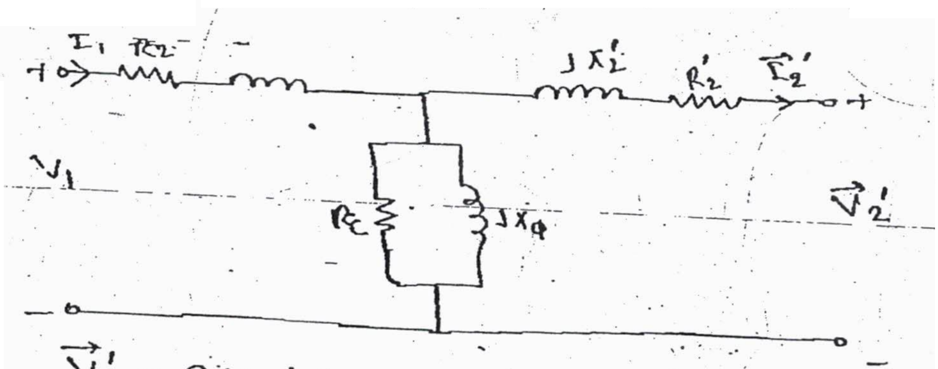
full load

Full load current but not full load

full load → full load current is delivered at rated voltage.

Q. The parameters of Equivalent Ckt. of 150 kVA, 2400V/240V transformer are. $R_1 = 0.2\,\Omega$ $R_2 = 2\,m\Omega$
$X_1 = 0.45\,\Omega$ $X_2 = 4.5\,m\Omega$
$R_C = 10k\,\Omega$ $X_\phi = 1.55\,k\Omega$
using the Ckt. referred to primary determine primary i/p votage, i/p current & input pf of x-former operating at rated load with 0.8 lagging pf

Q.



$$\vec{V_2}' = a V_2 \angle 0^\circ$$
$$= 10 \times 240 \angle 0^\circ$$
$$= 2400 \angle 0^\circ \text{ volts.}$$

$$\vec{I_2} = \frac{150 \times 10^3}{240} \angle -\cos^{-1}(0.8)$$
$$= 625 \angle -36.87^\circ \text{ A}$$

$$\vec{I_2}' = \frac{\vec{I_2}}{a} = \frac{625}{10} \angle -36.87^\circ \text{ A}$$
$$= 62.5 \angle -36.87^\circ$$

$$\vec{Z_2}' = a^2 \vec{Z_2}$$
$$= (10)^2 [(2 + j4.5) \times 10^{-3}]$$
$$= (0.2 + j0.45)\ \Omega$$

$$\vec{E_1} = 2400 \angle 0^\circ + 62.5 \angle -36.87^\circ \times (0.2 + j0.45)$$
$$= 2426.92 \angle 0.35^\circ \text{ volts}$$

$$\vec{I_c} = \frac{E_1}{R_c} = \frac{2426.92 \angle 0.35^\circ}{10\ k\Omega} = 0.2427 \angle 0.35^\circ \text{ A}$$

$$\vec{I_\phi} = \frac{\vec{E_1}}{jX_\phi} = \frac{2426.92 \angle 0.35^\circ}{1.55 \angle 90^\circ\ k\Omega} = 1.5658 \angle -89.65$$

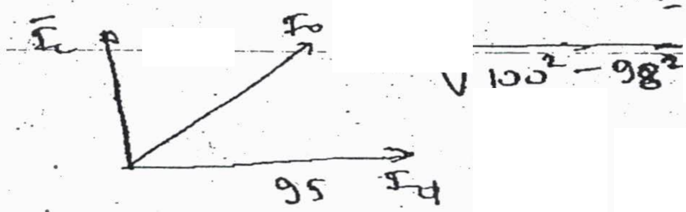
$$\vec{I_0} = \vec{I_c} + \vec{I_\phi}$$
$$= 0.2427 \angle 0.35 + 1.5658 \angle -89.65$$
$$= 1.5845 \angle -80.84^\circ$$

Kingley-Sharvard, propose

[$I_\phi = 98\%$ of I_0

then what is $I_c = ?$ $I_c = \sqrt{100^2 - 98^2}$]

$= 15\%$



$\vec{I_1} = \vec{I_2}' + \vec{I_0}$

$= 63.65 \angle -37.86^\circ$ A

$\vec{V_1} = \vec{E_1} + \vec{I_1} \vec{Z_1}$

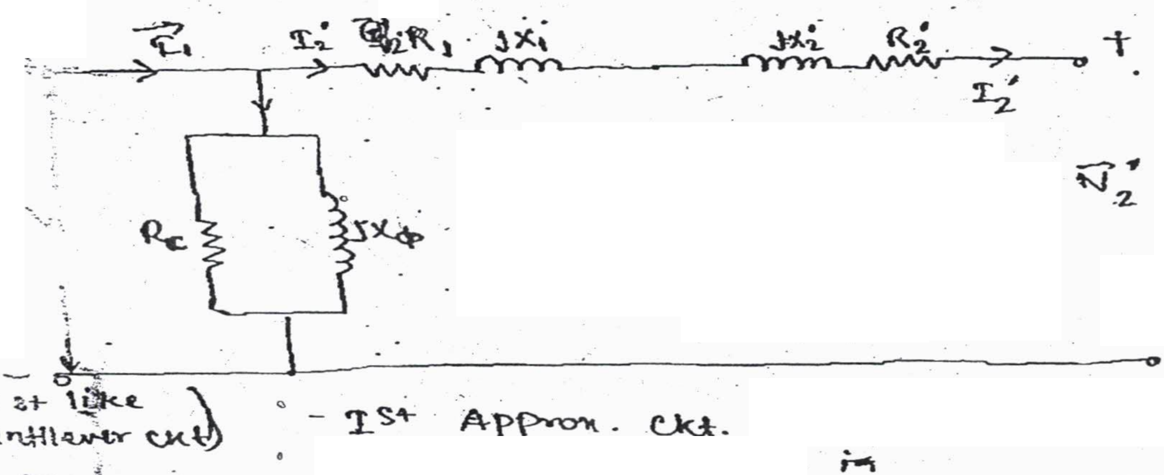
$= 2426.92 \angle 0.35^\circ + 63.65 \angle -37.86^\circ \times (0.2 + j0.45)$

$= 2454.68 \angle +0.69^\circ$

Input PF $= \cos [0.69^\circ - (-37.86^\circ)]$

$= \cos 38.55^\circ$ lag.

$= 0.7821$ lag//



(Just like Cantilever ckt) - I^{st} Approx. ckt.

∴ Through magnetic ckt. we can transfer energy very efficient because magnetic flux density is 2500 times that of Electric field density.