IES/GATE

Electrical Engineering

VOLUME-VI

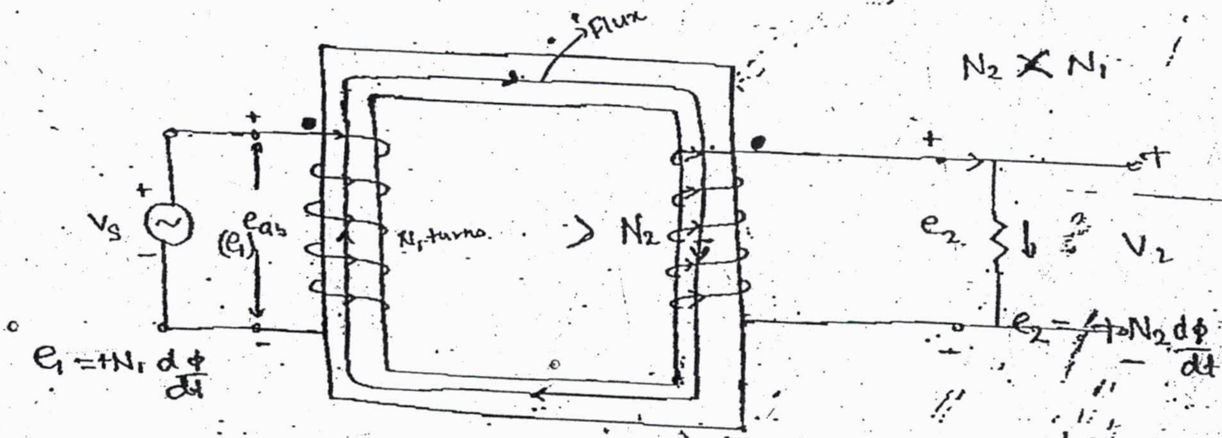
Electrical Machines

Contents

Electrical Machines

Capable of Continuous Electromechanical Conversion is called Electrical machines.

Transformers



Core :- Provide low reluctance magnetic path.

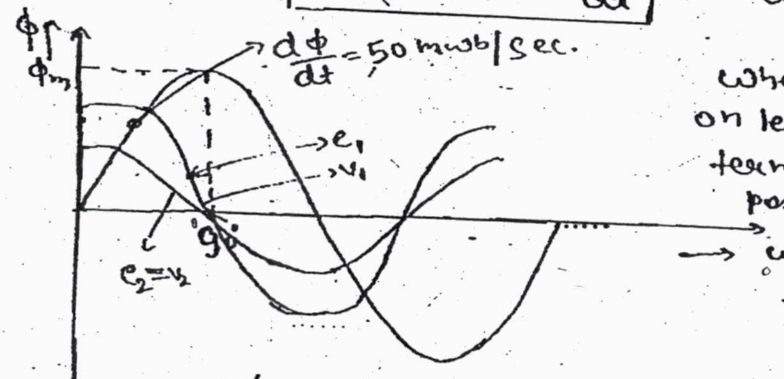
* According to lenz law, the direction of induced emf is such that if it is allow to cause a current by Short circuiting the coil then the current so produced opposes the causes.

Thus, $e = \pm \frac{d\lambda}{dt}$

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

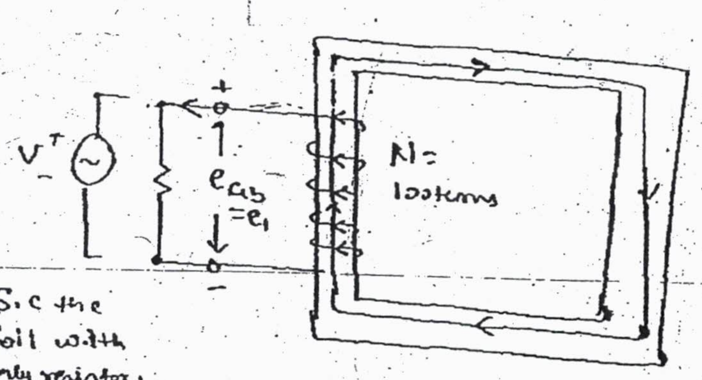
when λ = flux linkage $= N\phi$.

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



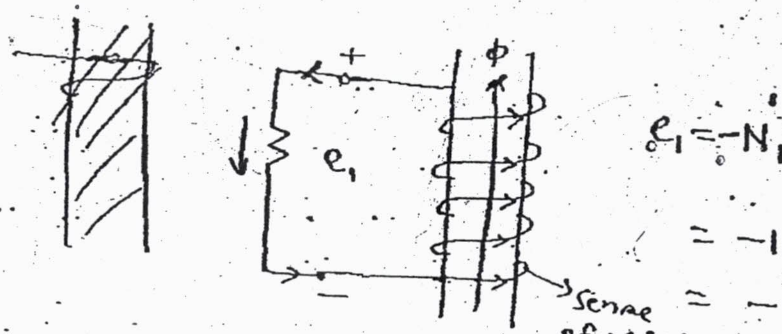
$\phi = \phi_m \sin\omega t$

welson del tero



S.C the Coil with only resistor.

$$e_1 = e_{as} = N_1 \frac{d\phi}{dt}$$
$$= 100 \times 50 \times 10^{-3}$$
$$= 5 \text{ volt}$$



$$e_1 = -N_1 \frac{d\phi}{dt},$$
$$= -100 \times 50 \times 10^{-3}$$
$$= -5V$$

$$e_1 = N_1 \frac{d\phi}{dt}$$
$$= N_1 \frac{d}{dt} (\phi_m \sin\omega t)$$
$$= N_1 \phi_m \omega \cos\omega t$$
$$= N_1 \phi_m \omega \sin(\omega t + 90°)$$
$$E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}}$$
$$\boxed{E_1 = \sqrt{2}\pi f \phi_m N_1}$$
Induced Emf equation

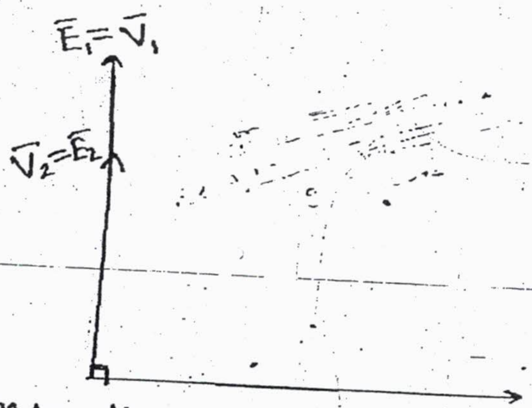
Concept of phasors

$\Sigma V = 0$

$-e_1 + v_1 = 0$

$\Rightarrow v_1 = e_1$

$\Rightarrow \vec{E_1} = \vec{V_1}$



Phasor diagram of Ideal X-former on no-load

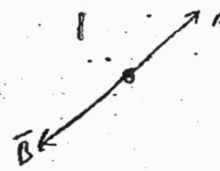
Vector has a fixed magnitude & fixed direction.

But Sinusoids are the phasors not the vectors.

Phasor 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,



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

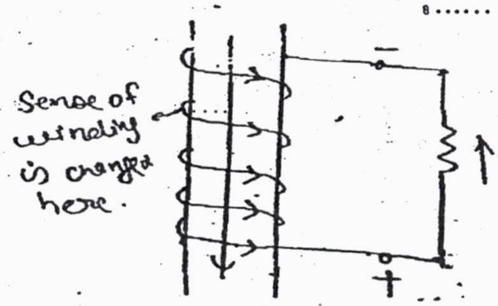
but in phasor, it is not determined.

Concept of phasor

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

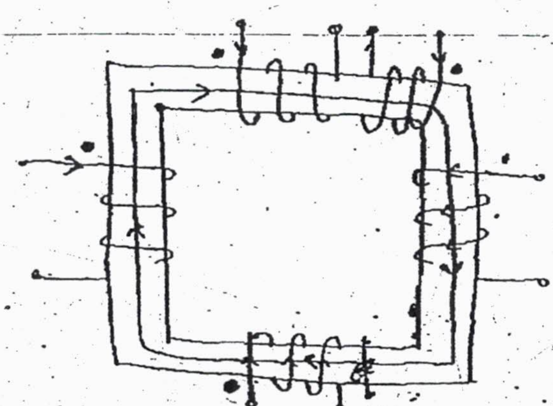
→ Phasor diagram only show that both $\bar{E}$ & $\bar{V}$ are rising together or decaying together and lag & lead and nothing else.

→ 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

$$\phi = \frac{NI}{S} \quad S\text{ - Reluctance}$$

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

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

→ 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:-

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

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

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

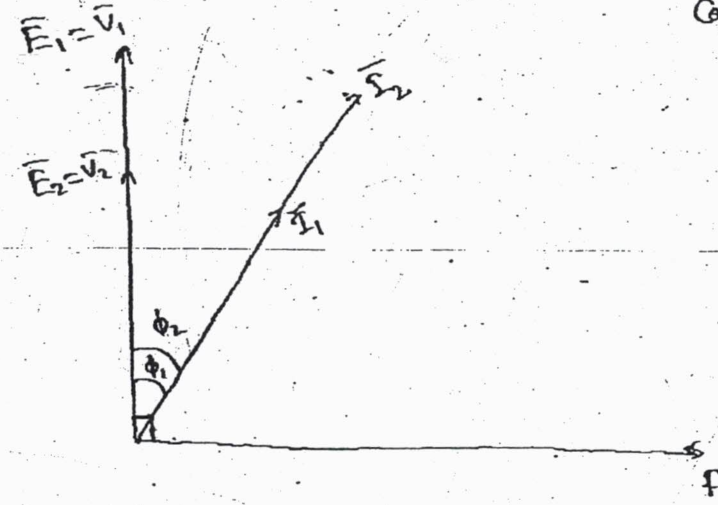
$$\frac{\bar{V}_1}{\bar{V}_2} = \frac{\bar{E}_1}{\bar{E}_2} = \frac{N_1}{N_2} = a = \frac{\bar{I}_2}{\bar{I}_1} = \frac{I_2^*}{I_1^*}$$

↓ Turns ratio or Voltage ratio

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

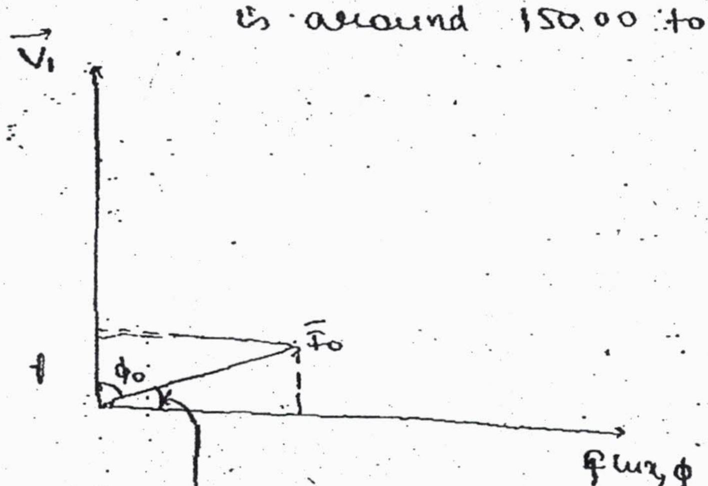
$$\text{\& } \bar{E}_1 \bar{I}_1^* = \bar{E}_2 \bar{I}_2^* \quad \Bigg\} \Rightarrow \bar{S}_1 = \bar{S}_2$$

Constant flux device

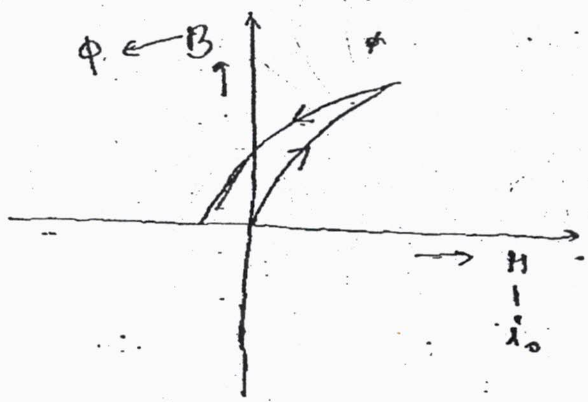


Magnetizing current → 2 to 3%.

becz we donot have any intentional gap we have a Iron core whose permeability is around 15000 to 20,000.

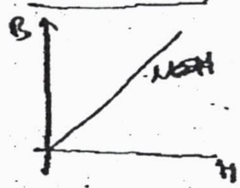


Angle of Hysteretic Advance or Hysteretic lag angle } decided by position of observer



i_0 lead when observer seen from ϕ.

For Air



$B = \mu_0 H$

MMF Balance of practical transformer

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

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

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

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

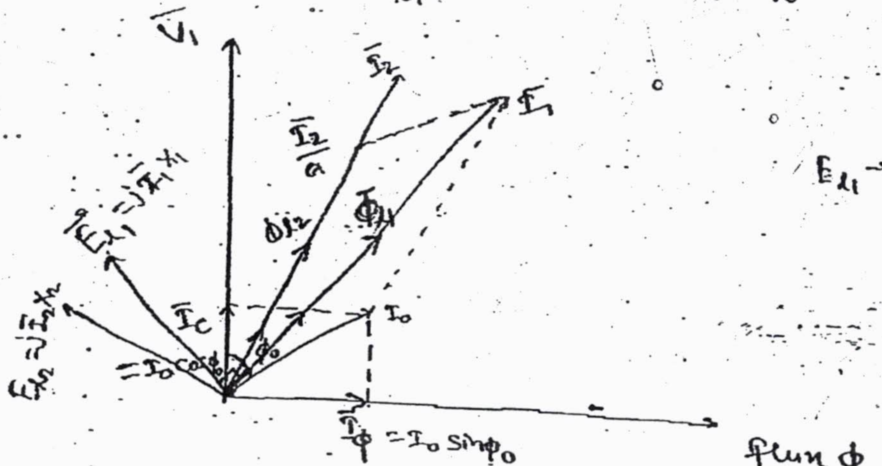
$$= \frac{\bar{I}_2}{a} + \bar{I}_0 \Rightarrow \bar{I}_2' + \bar{I}_0$$

$\bar{I}_0 \rightarrow$ No load current / Exciting current.

$\bar{I}_0 \Rightarrow$ magnetizing current if it is ideal transformer

I_ϕ = magnetizing current

I_c = core loss component



$E_{l1} \rightarrow$ phase

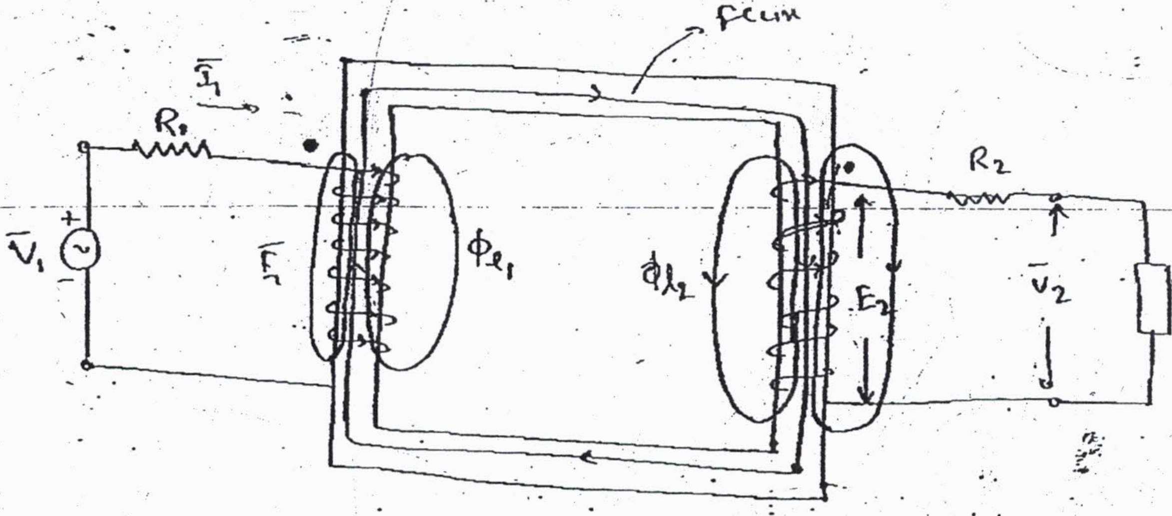
ϕ_0 = no load pf load (around 80°)

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.

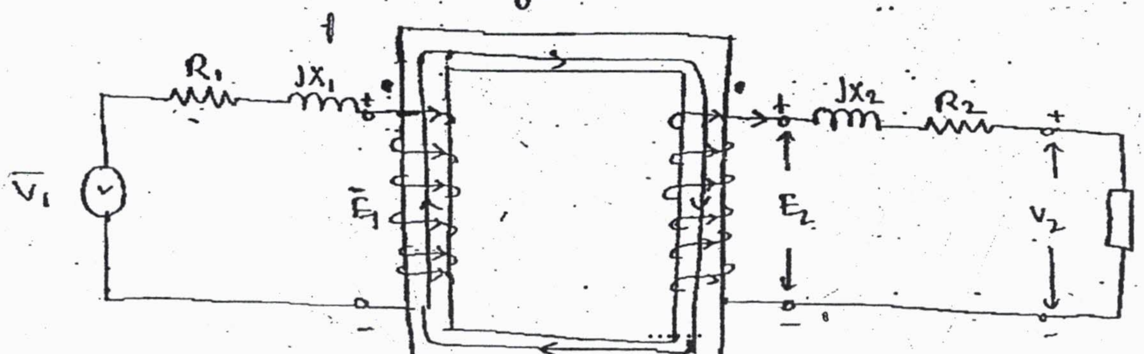


→ ϕ_{l_1} is in phase with I_1

$\therefore$ $B = \mu_0 H$
↓
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) $\bar{I}_1 = \frac{\bar{I}_2}{a} + \bar{I}_0$

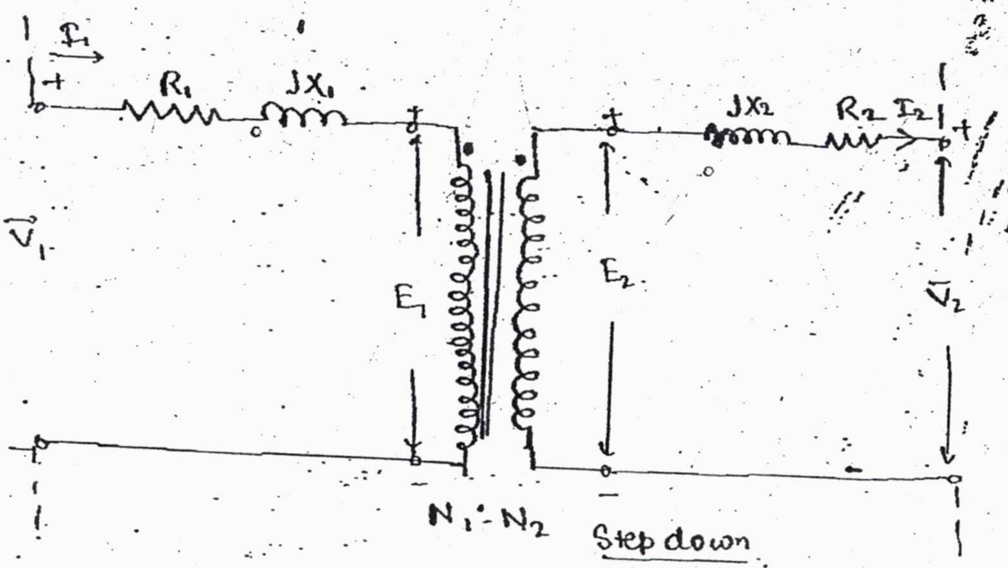
$= \vec{I}_2' + \bar{I}_0$ where $\vec{I}_0 = \bar{I}_c + \bar{I}_\phi$

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

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

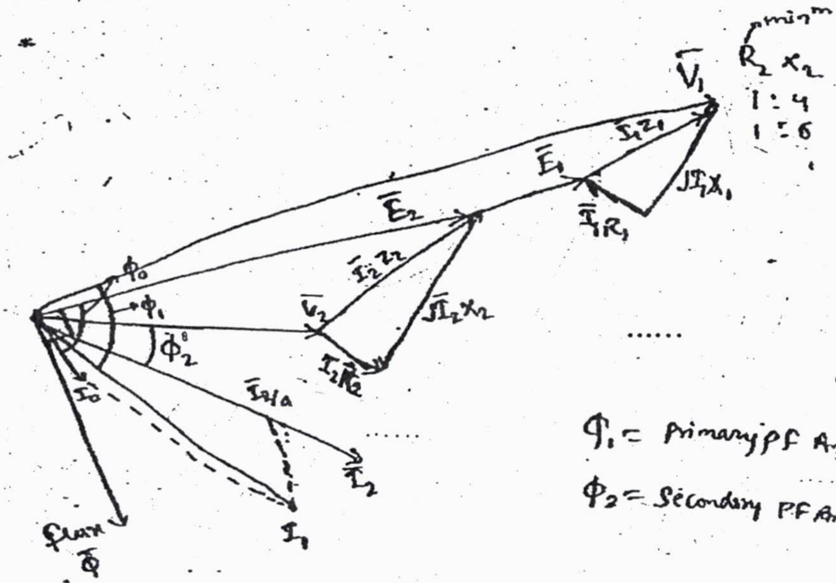
$= \bar{E}_1 + \bar{I}_1 (R_1 + jX_1)$

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



Step down

Lagging PF :



ϕ_1 = Primary pf Angle

ϕ_2 = Secondary PF Angle

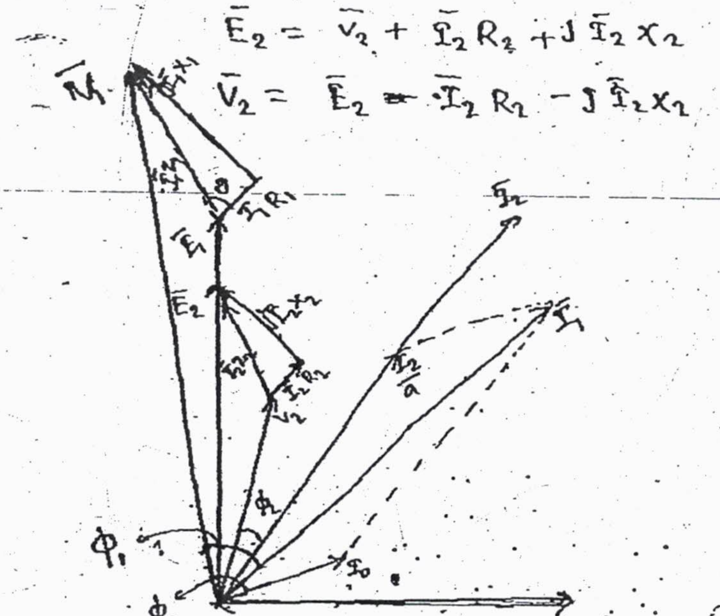
$\bar{V}_2$ Horizontal

Flux horizontal

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

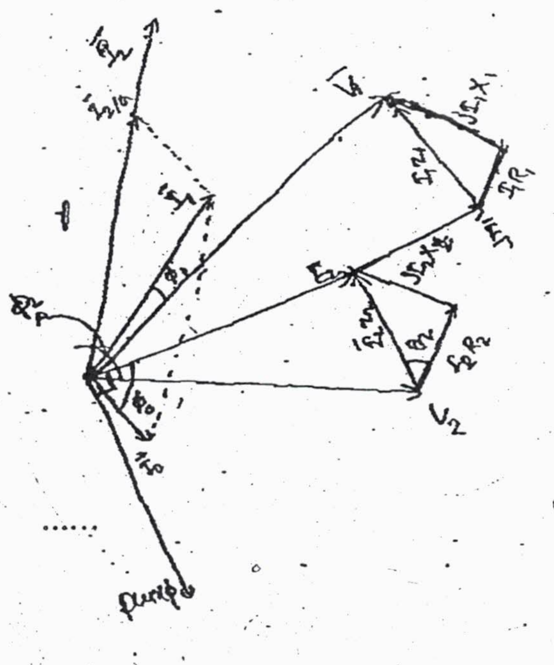
$\bar{V}_2 = \bar{E}_2 - \bar{I}_2 R_2 - j \bar{I}_2 X_2$

Known to unknown



Leading pf

V2 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.

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

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

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

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

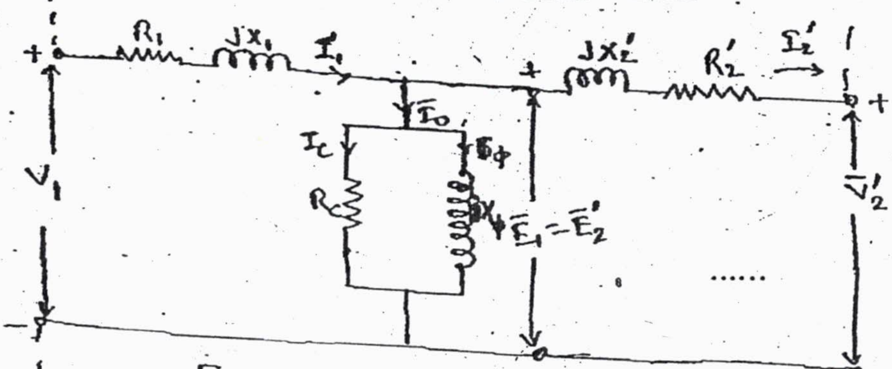
$$= \bar{V}_2' + \bar{I}_2' R_2' + j \bar{I}_2' X_2'$$

R_2' → Secondary resistance referred to primary

X_2' → secondary leakage reactance referred to primary

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

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



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

Exact Equivalent Ckt. referred to Primary

R_c = core loss equivalent resistance

X_ϕ = magnetizing reactance

X_ϕ & R_c is || Element as it is dependent on applied voltage.

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

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°

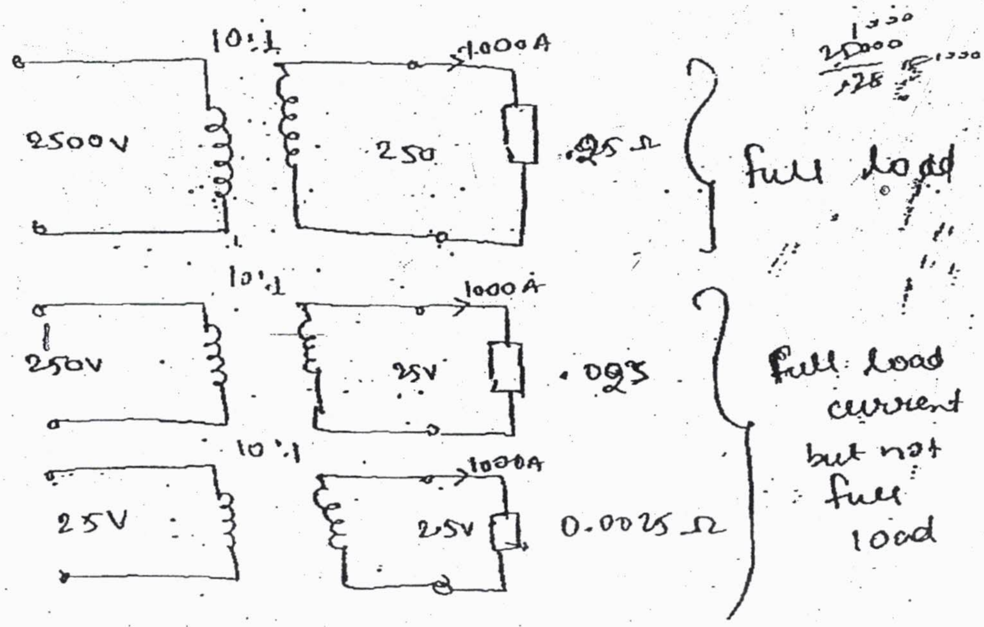
$E_1' = E_1/a$

$I_1' = a I_1$

$R_1' = R_1/a^2$

2500V / 250V

aV_2 / V_2



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

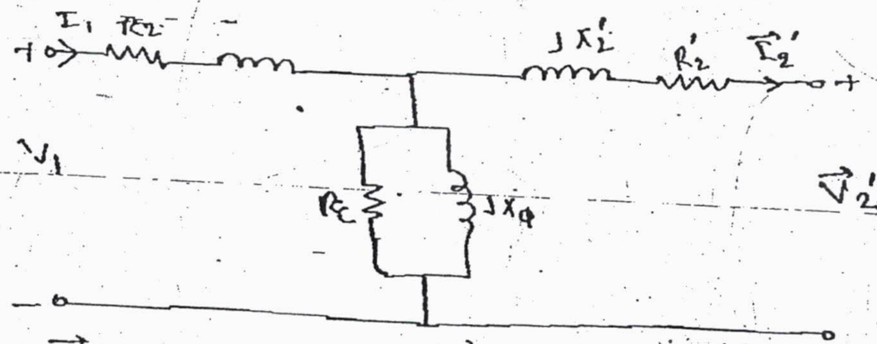
Q. The parameters of Equivalent Ckt. of 150 kVA, 2400V/240V transformer are. $R_1 = 0.2\Omega$ $R_2 = 2m\Omega$

$X_1 = 0.45\Omega$ $X_2 = 4.5 m\Omega$

$R_C = 10k\Omega$ $X_\phi = 1.55k\Omega$

using the ckt. referred to primary determine primary i/p voltage, i/p current & input pf of x-former operating at rated load with 0.8 lagging pf

Q.



$\vec{V}_2' = a V_2 \angle 0°$

$= 10 \times 240 \angle 0°$

$= 2400 \angle 0°$ volts.

$\vec{I}_2 = \dfrac{150 \times 10^3}{240} \angle -\cos^{-1}(0.8)$

$= 625 \angle -36.87°$ A

$\therefore \vec{I}_2' = \dfrac{\vec{I}_2}{a} = \dfrac{625}{10} \angle -36.87°$ A

$= 62.5 \angle -36.87°$

$\vec{Z}_2' = a^2 \vec{Z}_2$

$= (10)^2 [(2 + j4.5) \times 10^{-3}]$

$= (0.2 + j0.45)\ \Omega$

$\vec{E}_1 = 2400 \angle 0° + 62.5 \angle -36.87° \times (0.2 + j0.45)$

$= 2426.92 \angle 0.35°$ volts

$\vec{I}_c = \dfrac{E_1}{R_c} = \dfrac{2426.92 \angle 0.35°}{10\ k\Omega} = 0.2427 \angle 0.35°$ A

$\vec{I}_\phi = \dfrac{\vec{E}_1}{jX_\phi} = \dfrac{2426.92 \angle 0.35°}{1.55 \angle 90°\ k\Omega} = 1.5658 \angle -89.65$

$\vec{I}_0 = \vec{I}_c + \vec{I}_\phi$

$= 0.2427 \angle 0.35 + 1.5658 \angle -89.65$

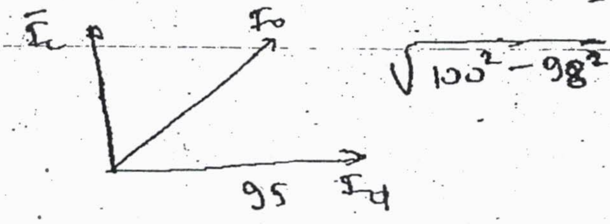
$= 1.5845 \angle -80.84$

Kingsley-Sharvard, program.

[$I_q = 98\%$ 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

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

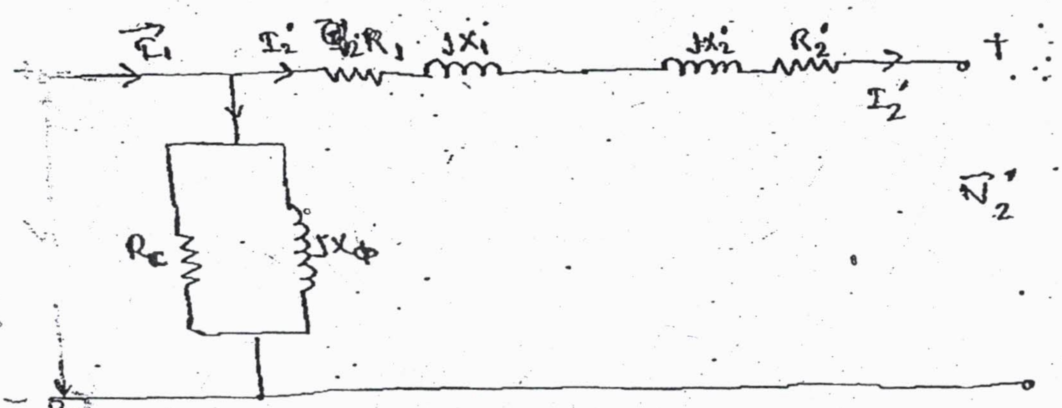
$= 2426.92 \angle 0.35^\circ + 63.65 \angle -37.86^\circ \times (0.2 + j0.45)$

$= 2454.68 \angle +0.69^\circ$

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

$= \cos 38.55^\circ$ lag.

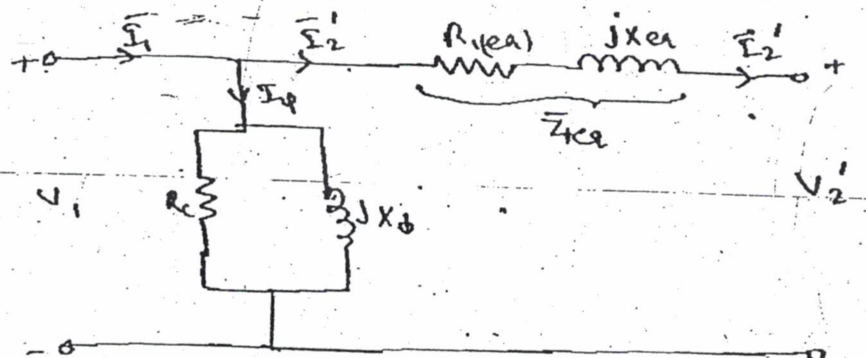
$= 0.7821$ lag //



(Just like Cantilever ckt) — 1st Approx. ckt. (~~due to complexities~~ in

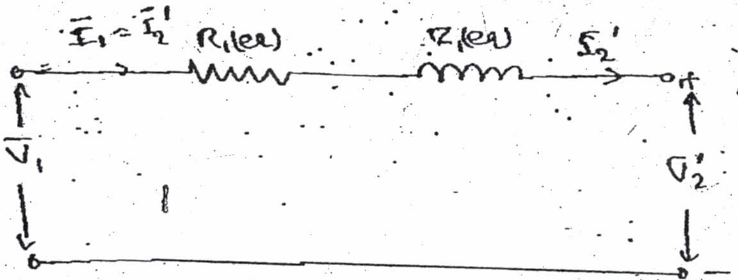
∴ Through magnetic ckt we can transfer energy very efficient because magnetic flux density of is 25000 times ~~more~~ that of electric field density.

So most of load is magnetic.



1st Approx eq. ckt

$$\bar{V}_1 = \bar{V}_2' + \bar{I}_2' \bar{Z}_{1eq} = 2453.93 \angle 0.7^\circ \text{ volt.}$$

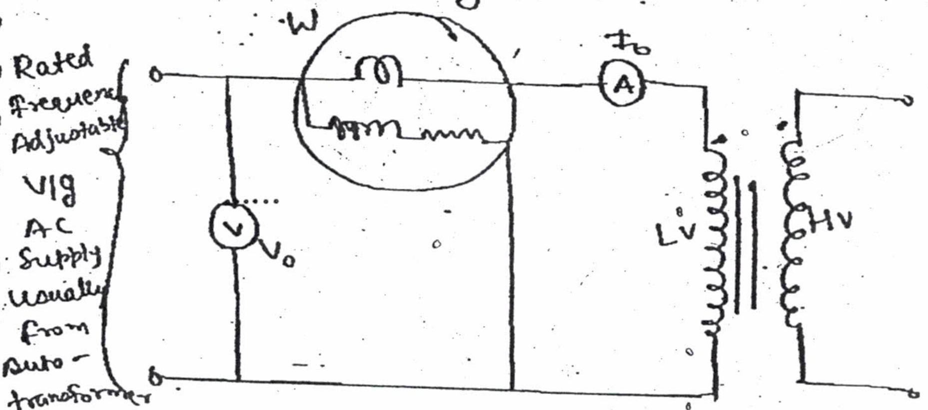


2nd Approximat eqv. ckt

Open ckt. Test or Short ckt. Test

Objective of O.C Test

To predict the performance of x-former without actually loading it.



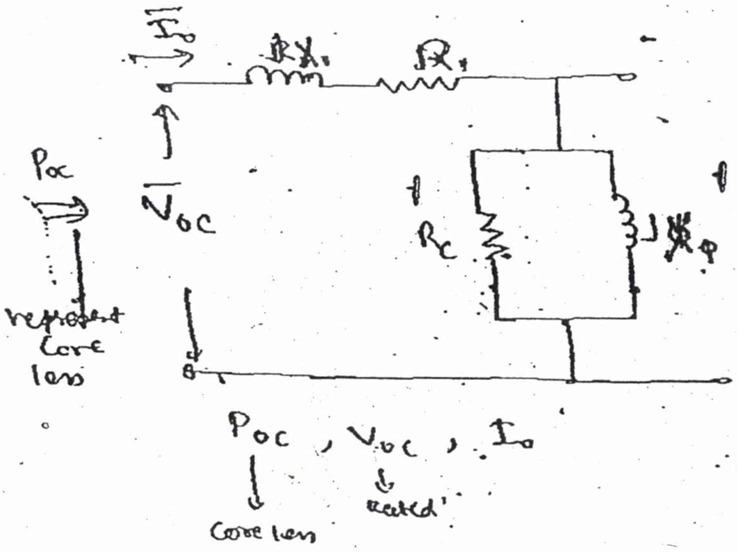
O.C Test

* O.C Test

* Open ckt. Test is carried out at rated frequency & rated v/g to determine the core loss.

* The core loss is then treated as constant despite minor variation in voltage & frequency during actual operation.

* This test is carried out with instruments placed on the low voltage side and leaving the high v/g side open ckted. This is because, it is easier to arrange rated voltage at low voltage level rather than at high voltage level. Also it is safer to work on the LV side and the instruments used are of low cost.



$R_1 = 0.5\%$

$X_0 = 5\%$

O.C : $I_0^2 R_1$

$= 0.00125\%$

[So we ignore this loss.]

$I_0 = 5\%$ $\quad R_1 = 5\%$

$$\text{V/g drop} = I_0 Z_1 = 0.05 \times 0.05 \times 100 = 0.25\% \text{ of } V_{oc}$$

(So neglect v/g drop across of R_1)