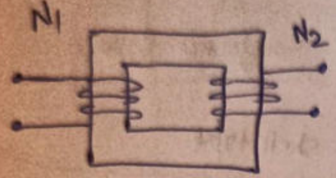
Transformer

① one electrical circuit to other electrical circuit by maintaining constant frequency (supply frequency = 50hz)

② Principle = Mutual Inductance

③



The 2 circuit in a transformer are electrically isolated but magnetically coupled to each other.

The circuit or winding which is directly connected to supply known as primary winding.

whereas the binding which the reverse electrical energy to the load is known as secondary winding.

The electro magnetic energy conversion can take place both from ①' High value to low voltage,
② low voltage to high voltage at constant frequence

Classification of Transformer -

① on Basis of application

① step up
② step down

② on basis of construction

① Core type
② Shell type

③ on basis of phase

① I-Φ
② III-Φ

④ ~~Location~~
on basis of Location

① Power
Distribution

Power Industry, Power system,
n Transformer for DC isolated to AC

Contruction of Transformer core.

Shell type

① core is surrounded by binding

② E-L strips

③ less copper required

④ 3 limbs

⑤ less insulation required

⑥ 1 mag. ckt

⑦ less

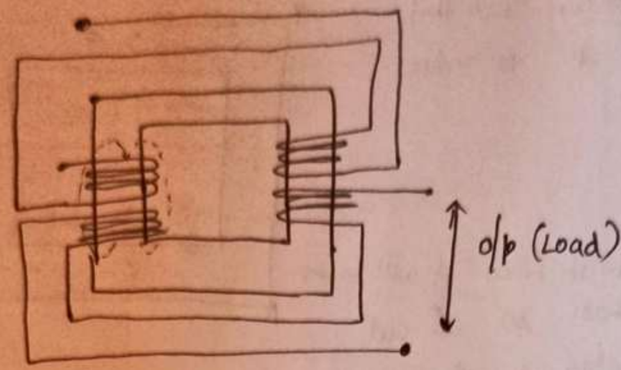
⑧ difficult

AC

"Transformer Type"

① Core type :-

(To reduce leakage flux)
arrangement of
practical core type
transformer)



② Shell type :-

(interlimbed / sandwitch binding)

LV = Lowvoltage binding
HV = high " "

Q) why 2extreme HV binding has low cross-sec^n area?

Ans) To reduce the cost of lamination.

ⓐ Thin laminated steel-sheets are used as transformer core
ⓑ CRGO – cold rolled Grain Oriented sheet-steel

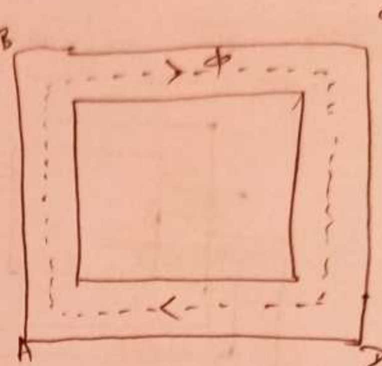
Properties: ① it has high permeability.
② high resistivity ⟶ (so that ed current loss ↓ses) [for it has Si content 4-5%]
③ smaller hysteresis loop
④ high value of saturation flux density.
⑤ thickness (0.35 to 0.4mm) of each laminated sheet

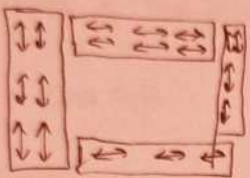
thats why CRGO's are used over other sheet ~~she~~steels

$\boxed{\text{eddy Current + hysteresis loss} \longrightarrow \text{Core/Iron loss}}$ because it taking place in magnetic material present in iron made core.

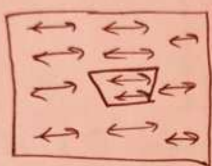
① Core type:

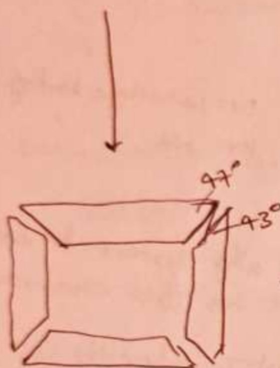
we have to assamble the core such that parallel to direction of ϕ to reduce losses in the core.





but at corners it will become tear so we cut edges at ~~47°~~ 47° and 43°





there will be n-number of sheets

diff b/w^n core & shell! (HW)

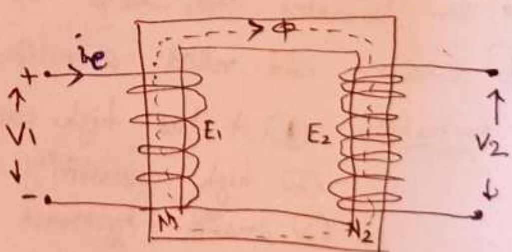
Working principle & emf equation of Transformer:

Let core type Transformer

flux is also alternating as V_1 is alternating & static emf is induced.

$V_1 \rightarrow i_m \rightarrow \phi \rightarrow E_1$

$\quad\quad\quad\quad\quad\quad \hookrightarrow E_2$ (due to mutual induction)



$\boxed{E_1 \simeq -V_1}$ due to lenz law

[if we use DC over AC transformer may burn].

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

so $e = -N\frac{d\phi}{dt} = -N\phi_m \omega \cos \omega t$

$$e = -N\phi_m(2\pi f)\cos(\omega t) = 2\pi f N\phi_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

max^n emf

$$\boxed{e_m = 2\pi f N\phi_m}$$

therefore $$\boxed{E_{rms} = \frac{e_m}{\sqrt{2}} = \sqrt{2}\pi f N\phi_m}$$

core &

therefore

$$\boxed{\begin{aligned} E_1 &= 4.44 f\phi_m N_1 \\ E_2 &= 4.44 f\phi_m N_2 \end{aligned}}$$

so induced emf ratio is $\left[\frac{E_1}{E_2} = \frac{N_1}{N_2}\right]$.

15 NOV

I_e = 3 to 5% of full load current

using KVL

$$V_1 - I_e Z_e = E_1 \qquad \& \qquad \boxed{V_2 = E_2}$$

$$\boxed{V_1 \simeq E_1} \qquad \text{so} \left[\frac{V_1}{V_2} = \frac{N_1}{N_2}\right]$$

for Ideal Transformer – (no loss, $\eta = 100\%$)

The efficiency of a Transformer operating at full load condition is about 97 to 98%. For an ideal Transformer, the efficiency is 100% therefore, input power = output power

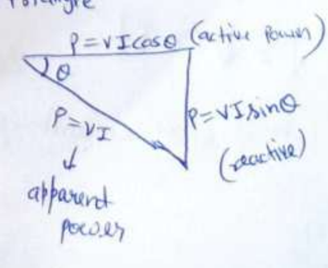
I/p Power = o/p Power

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1}$$

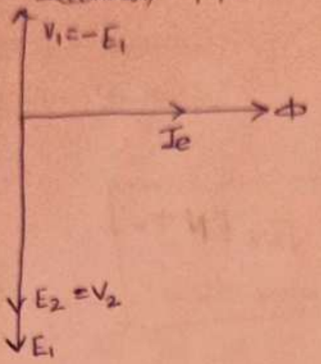
so $$\boxed{\frac{I_2}{I_1} = \frac{N_1}{N_2}} \Rightarrow \boxed{N_1 I_1 = N_2 I_2}$$

Power triangle



that is primary ampere turns is equal to the secondary ampere turns
primary MMF = secondary MMF.

phasor diagram-



(for step-down - Transformer)

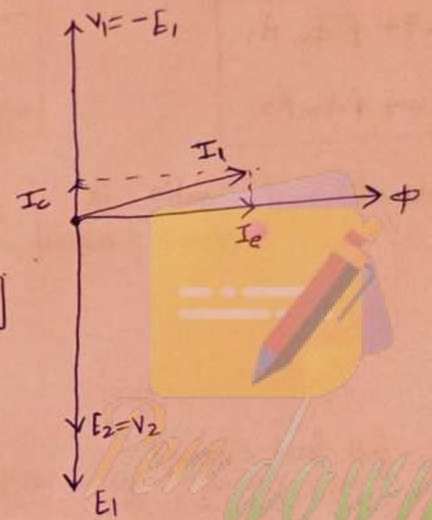
ⓐ for ideal Transformer at no load condition

ⓑ Actual Transformer at no load condition

(core loss take place)

$$\left[I_1 = I_e + I_c \right]$$

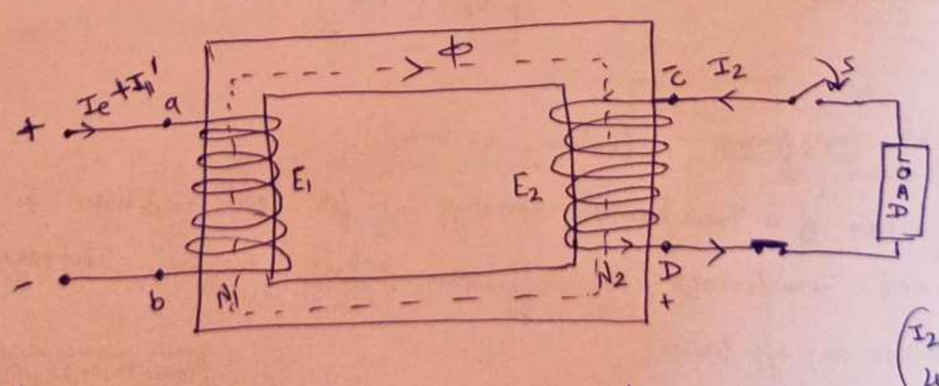
$\boxed{V_1 I_c = \text{core loss}}$



(inductive axis)

flux = inductor
loss = resistor
so loss will be resistive hence phase diff of 90° & lead

#



(I_2 dirⁿ by Lenz law)

if $\Phi \downarrow \Rightarrow E \downarrow$ & $V_1 \propto E_1 \Rightarrow V_1 \downarrow$ but not possible

so a extra current is drawn in primary coil & that I_1' will compensate loss

current I
should be
the upfull
and also
the trans
(I_1') fro

Phasor diag

Let step up

(ideal) -

Practical

at
factor

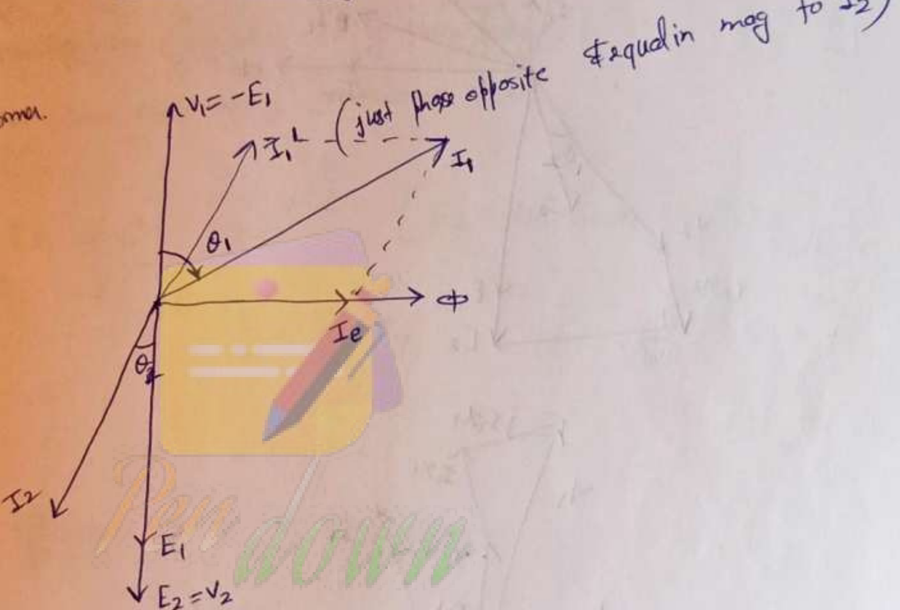
when load is connected across the secondary winding of the transformer, a current I_2 will flow through it however the direction of I_2 should be such that the secondary side mmf ($F_2 = N_2 I_2$) should oppose the useful flux (ϕ). any reduction in ϕ will tend to reduce E_1 and also E_2, therefore in order to maintain a constant flux in the transformer core, the transformer draws an extra current (I_1') from the external supply, such that

$$\boxed{N_2 I_2 = N_1 I_1'}$$

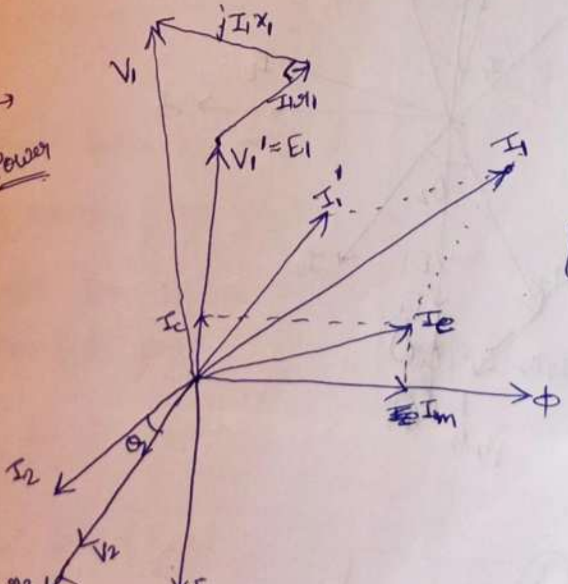
Phasor diagram:

Let step up Transformer.

(Ideal) →



Practical Transformer → at lagging power factor load.

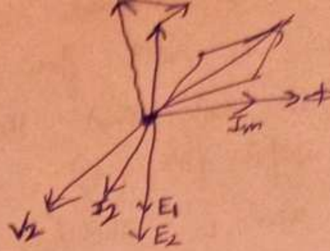


$E_2 = V_2 + I_2 Z_2$

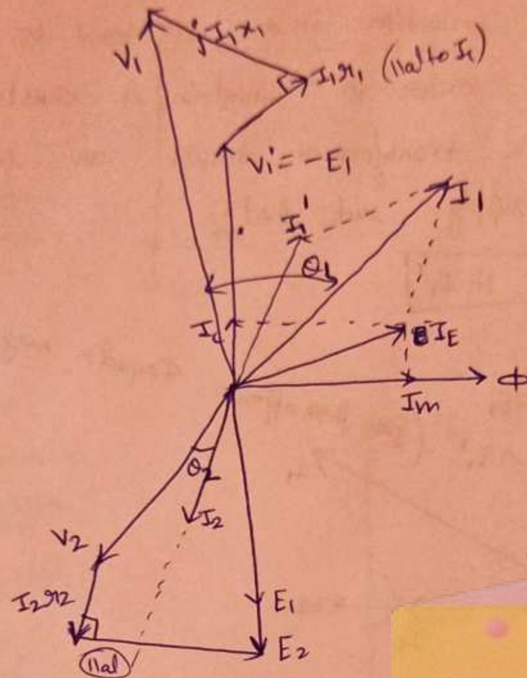
$[E_2 = V_2 + I_2 r_2 + jI_2 X_2]$

$[V_1 = V_1' + I_1 r_1 + jI_1 x_1]$

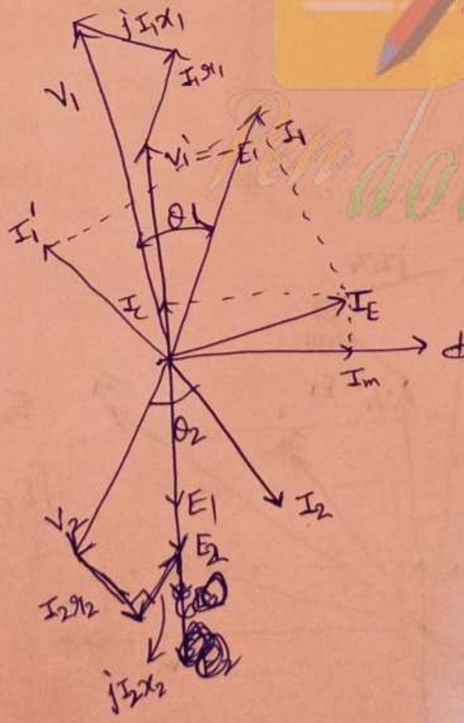
Leading Power factor load :- (I_2 will lead V_2)



(a)



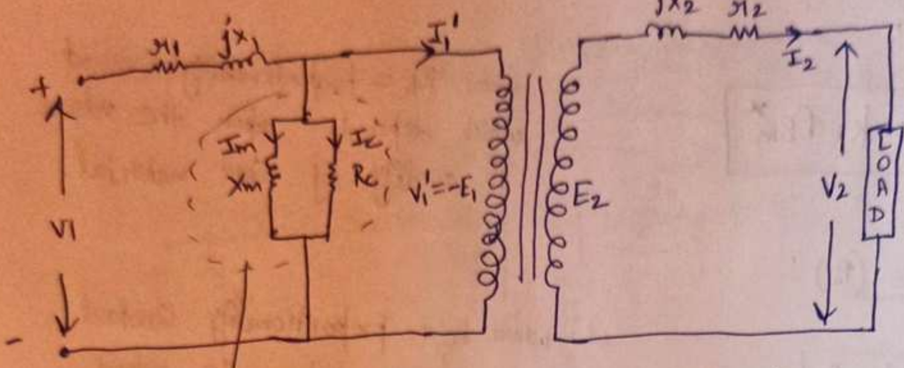
(b)



H.W

make phasor
at unity power factor (I_2 will along V_2)

* Equivalent ckt diagrams!



representing core (magnetic ckt of transformer)

X_m = Loss component of Transformer core

$[V_1 - I_1 r_1 - j I_1 x_1 = V_1']$

$[E_2 = V_2 + I_2 r_2 + j I_2 X_2]$

Losses & efficiency of 1-Φ Transformer -

Losses

- Iron/core loss
  - hysteresis loss (P_h)
  - Eddy current loss (P_e)

  (It is a constant loss because useable flux is constant in ckt)

  [constant loss]

  (It uses max^m value of flux)

- Cu-loss / winding loss

  (It depend on I^2R)

  [variable loss]

Loses :-

① Hysteresis loss (P_h) :-

$$\boxed{P_h = k_h f B_m^x}$$

where k_h = proportionality constant which depends upon the volume & quality of core material.

② Eddy current loss (P_e) :-

$$\boxed{P_e = k_e f^2 B_m^2}$$

where k_e = proportionality constant which depends upon the volume, resistivity & thickness of laminates.

B_m = max. flux density in transformer core

x = constant whose value lie b/w 1.5 to 2.5 depending upon the quality of core material.

we know that,

$$V = 4.44 f \phi_m N$$

$$V = 4.44 f B_m A N$$

$$B_m = \frac{V}{4.44 f A N}$$

in ① & ②

$$P_h = k_h f \left(\frac{V}{4.44 f A N} \right)^x$$

or

$$\boxed{P_h \propto k_h f^{1-x} V^x}$$

$$P_e = k_e f^2 \left(\frac{V}{4.44 f A N} \right)^2$$

$$\boxed{P_e \propto V^2}$$

$$\boxed{P_e = K_E V^2}$$

* Eddy current loss is independent of the frequency.

③ C

(Ab

[due to

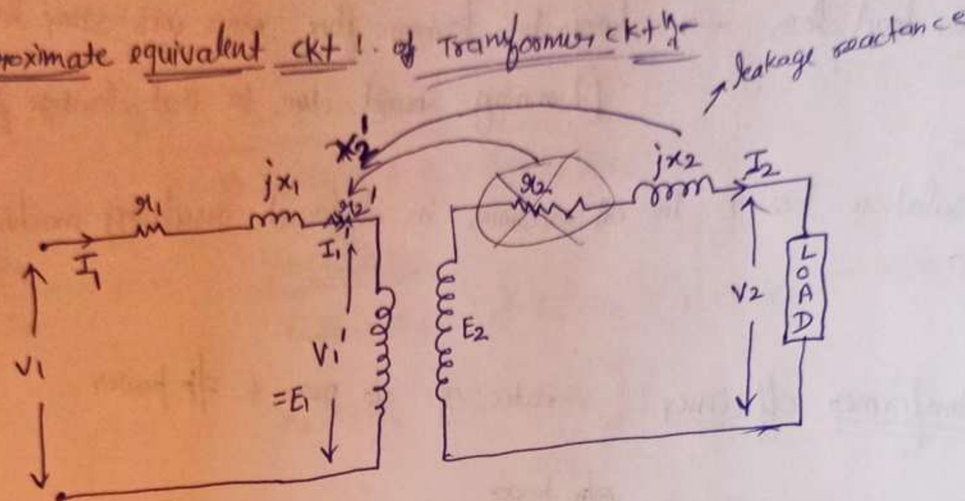
theref

&

Total

③ Copper loss :- (in both windings of Transformer)

Approximate equivalent ckt :- of Transformer ckt :-



[due to leakage reactance → E_1 & E_2 both reduced]

if $I_1^2 r_2' = I_2^2 r_2$

$$\boxed{r_2' = r_2\left(\frac{I_2}{I_1}\right)^2 = r_2\left(\frac{N_1}{N_2}\right)^2}$$

This is the reffered value of resistance.

therefore equivalent resistance $R_e = r_1 + r_2' = r_1 + r_2\left(\frac{N_1}{N_2}\right)^2$

& $X = \frac{\mu N^2 A}{l} \Rightarrow X \propto N^2$

$x_2' \propto N_1^2$

$x_2 \propto N_2^2$

$$\boxed{x_2' = x_2\left(\frac{N_1}{N_2}\right)^2}$$

Total copper loss

$\boxed{P_{cu} = I_1^2 R_e}$ where R_e → total resistance of Transformer (reffered to primary side)

at (75°C)

Some other losses:

④ Stray load loss → larger be leakage flux more will stray load loss (humming sound due to that leakage flux)

⑤ Insulation loss → in all machines in different insulating machine.

Transformer efficiency: ratio of o/p power & I/p power.

$$\eta = \frac{\text{o/p power}}{\text{I/p power}}$$

& i/p power = o/p power + losses

$$\boxed{\eta = \frac{\text{I/p} - \text{losses}}{\text{I/p power}} = 1 - \frac{\text{losses}}{\text{I/p}}}$$

$$\boxed{\text{o/p power} = V_2 I_2 \cos\theta_2}$$

[P_c = core loss
P_{cu} = copper loss]

$$\boxed{\%\eta = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + P_c + \underbrace{P_{cu}}_{(I_2^2 r_e)}} \times 100}$$

Rating of Transformer is in KVA because rating depend on power loss i.e depend on current & core loss depend on voltage..

Condition of max^n efficiency: if load powerfactor is constant.

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_c + I_2^2 r_{e2}}$$

$$\frac{d\eta}{dI_2} = 0 = \frac{(V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2})(V_2 \cos\theta_2) - V_2 I_2 \cos\theta_2 \left[V_2 \cos\theta_2 + 2 I_2 r_{e2} \right]}{\cancel{\quad}}$$

$$\cancel{V_2} \cancel{I_2} \cancel{\cos}\theta_2 \left[V_2 \cos\theta_2 + 2 I_2 r_{e2} \right] = V_2 \cancel{\cos}\theta_2 \left[V_2 \cancel{I_2} \cos\theta_2 + P_c + I_2^2 r_{e2} \right)$$

$$\cancel{V_2 \cos\theta_2} + 2 I_2^2 r_{e2} = \cancel{V_2 \cos\theta_2} + P_c + I_2^2 r_{e2}$$

$$\boxed{P_c = I_2^2 r_{e2}}$$

i.e Core loss = Copper loss

i.e $\boxed{\text{constant loss = variable loss}}$ Ans

$$\boxed{\begin{array}{l} \text{If } I_2 = \text{Const.} \\ \eta = \text{max at } \cos\phi_2 = 1 \end{array}}$$

Q) The efficiency of a 20kVA, 2500/250 V single phase transformer at unity power factor is 98% at rated load and also at half rated load. determine the transformer core loss and ohmic loss.

solⁿ)

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + \underbrace{}_{P_c} + \underbrace{I_2^2 R_{e2}}_{P_{cu}}}$$

$$0.98 = \frac{V_2 I_2}{V_2 I_2 + P_c + P_{cu}}$$

$\boxed{V_2 I_2 = 20kVA}$

at full rated - $$0.98 = \frac{20\times10^3}{20\times10^3 + P_c + P_{cu}} \quad --- (i)$$

at half rated → $I_2' = \frac{I_2}{2}$

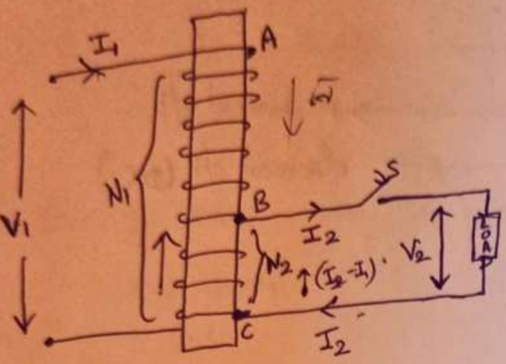
$$0.98 = \frac{10\times10^3}{10\times10^3 + P_c + \frac{P_{cu}}{4}} \quad --- (ii)$$

$P_{cu} = I^2 R$

$P_{cu}' = \frac{P_{cu}}{4}$

from equⁿ (i) & (ii) P_c ✓ P_{cu} ✓

Introduction to Auto Transformer -



If losses are ignored

i/p power = o/p power

$$\boxed{V_1 I_1 = V_2 I_2}$$

$$\boxed{\frac{V_1}{V_2} = \frac{I_2}{I_1}}$$

Total o/p power by → Induction
→ Conduction

Power transferred to load by
Induction :- $\underline{\underline{(V_1 - V_2) I_1}}$ & power transferred to load by conductn

is $= V_1 I_1 - (V_1 - V_2) I_1 = \underline{\underline{V_2 I_2}}$

portion of power transferred to load.