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Ishita

Basic Electrical Engg.
CE-1st Sem.

1

TRANSFORMER (T/F)

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> A transformer is a static device, which transfers electrical energy from one part of a magnetic circuit to another part of a magnetic circuit by mutual induction. During this transformation, frequency is constant. It's also step up and step down the voltage level.

> Classification of Transformer

* According to construction	* According to use	* According to winding	* According to cooling
→ Core type	→ Instrument T/F [current T/F [Potential T/F	→ Single-phase T/F	→ Natural cooled
→ Shell type	→ Distribution T/F [Step up T/F [step down T/F	→ 3-φ Transformer	→ forced air cooled
→ Berry type (circular shell)	→ Power Transformer	→ Auto transformer	→ Water cooled.

> Advantages of Transformer:-

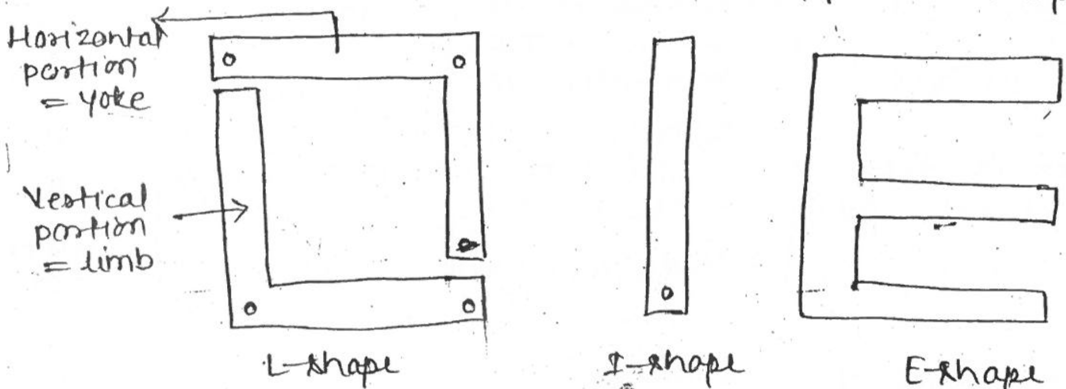
- It's economic to transmit the energy at high voltage
- It's also used for distribution purpose.
- Efficiency of T/F is very high.
- In electronics & control circuit, it matches the impedance of a source and its load for max. power transfer.
- Simple in construction & robust.
- No moving part - static in nature.
- Isolate one circuit from another.

wdg → ... wg

Construction in Detail:-

→ There are two basic part of transformer
  (i) Magnetic core
  (ii) Winding - Primary wdg & sec. wdg (1-ϕ T/F)
  Primary, secondary, ~~tertiary~~ wdg (3-ϕ T/F

→ To making a core, various type of stamping & lamina-tions are used as L-shape, I-shape or E-shape



→ These laminations are isolated by enamelled varnish to reduce eddy current losses.

→ To avoid airgap & to increase mechanical strength overlapped laminations and staggered joints are used.

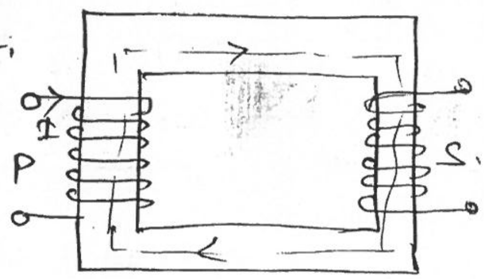
→ In a transformer, there is only HV & LV winding. And ~~which~~ winding which is connected to a load is secondary wdg & which is connected to excitation is called primary wdg.

→ HV - high voltage wdg
→ LV - Low voltage wdg.

Core-type transformer :-

→ It has single magnetic circuit.

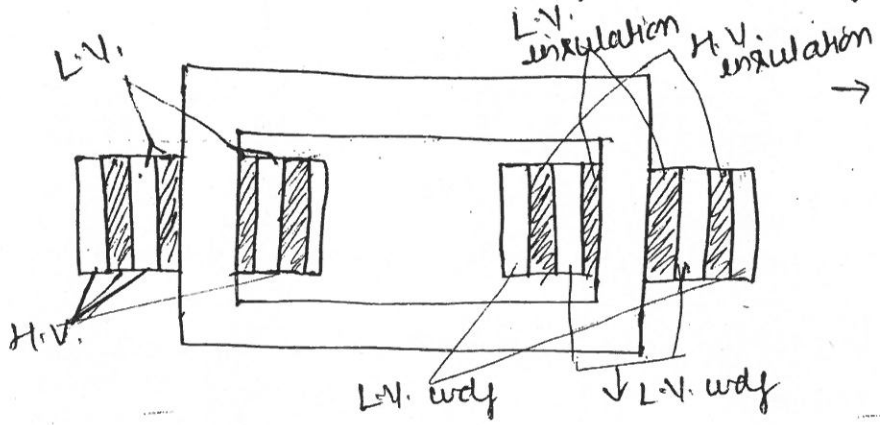
→ Magnetic core is rectangler in shape of uniform ~~cr~~ cross-section.



→ Both winding are the encirclid the both limbs as (P) primary & secondary wdg(S).

→ Coils are wound the limb in helical layer & coils are cylindrical type.

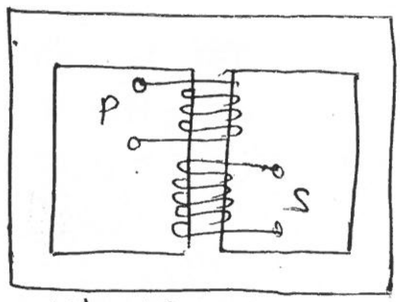
→ Core is made up of large no. of thin laminations.



→ Low voltage coil is placed inside near the core while high voltage coil surrounds the low-voltage coil.

→ Wdgs are uniformly distributed over two limb & natural cooling is more effective.

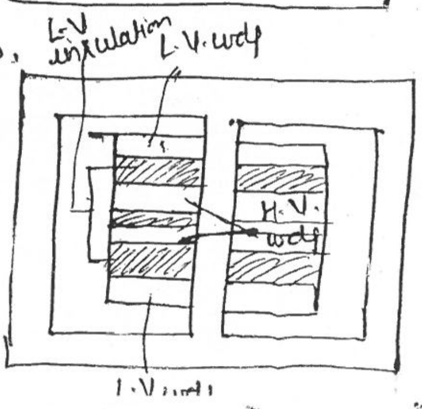
Shell-type Transformer :-



→ Magnetic circuit are divided into two or more parts.

→ Core has three or more limbs.

→ Both primary & secondary, H.V. & L.V. wdgs are placed on central limb.



→ L.V. wdgs are near to top & bottom of yokes & H.V. wdg are placed b/w L.V. wdgs.

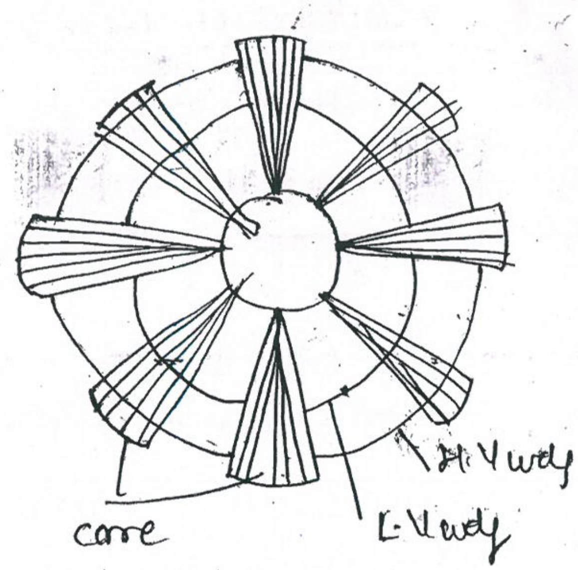
→ Coil are multilayer disc or sandwich type & wdg are surrounded by core so natural cooling doesn't exist.

➤ Berry-type T/F :-

→ Distributed magnetic ckt

→ Core construction is like ~~a~~ spokes of a wheel.

→ Rugged construction and provide better cooling

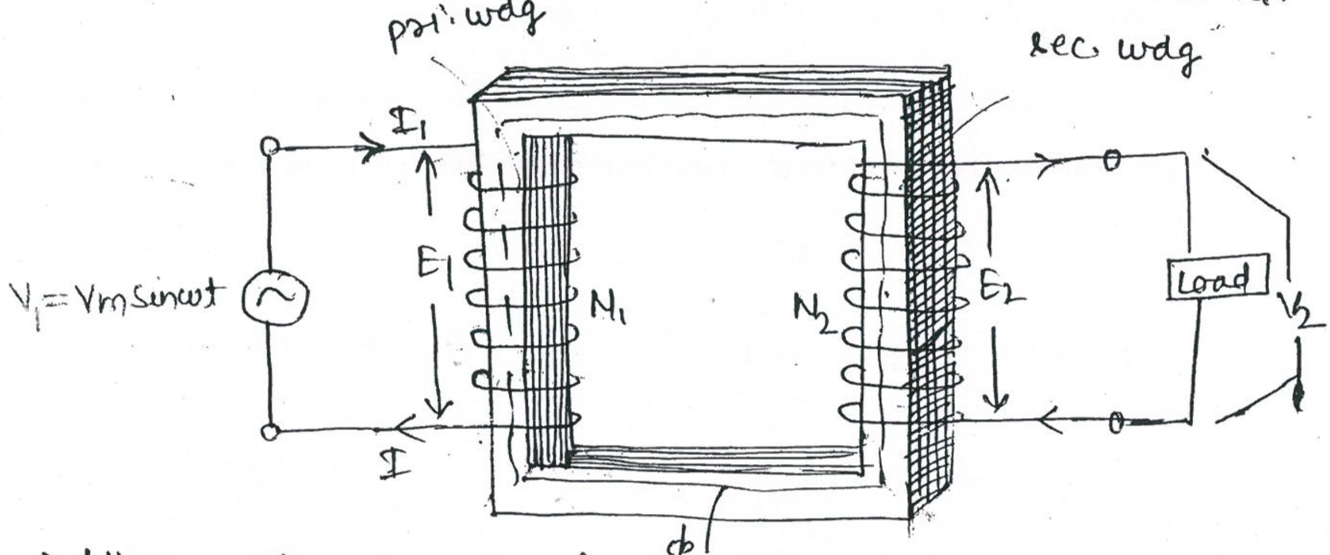


⇒ Comparison b/w core-type & shell-type T/F

Core type	Shell-type
① It has only single magnetic ckt	① It has twice magnetic ckt.
② The core has two limbs.	② The core has three limbs.
③ Both Pri. & sec. wdg are on different limbs.	③ Both pri. & sec. wdg are placed on central (same) limb.
④ Cylindrical coil are used.	④ Multilayer & sandwich type coils are used.
⑤ H.V wdg are ~~near~~ surrounds the L.V wdg & L.V. wdg are placed near the core (limb).	⑤ L.V. wdgs are surrounds the H.V wdg and L.V. wdg are placed near the yoke.
⑥ Wdg are uniformly distributed on two diff't limbs than natural cooling is effective. & removed easily for maintenance	⑥ Wdg are surrounded by core so natural cooling doesn't exist & coils cannot be removed easily.
⑦ Preffered for Low-voltage transformer	⑦ Prefferred for high voltage T/F

Working Principle and Emf equation of T/F

→ Faraday law of mutual induction ~~which~~ states that when two coils are inductively coupled and if current in one coil is changed uniformly than an emf gets induced in the other coil. This emf can drive a current on sec. wdg when a closed path is provided to it.



→ When primary wdg is excited by an alternating voltage. then it circulates an alternating current and produces an alternating flux ϕ which (in common magnetic core) is confined its magnetic path completely via secondary wdg. Thus mag flux which is alternating in nature is linked with secondary wdg.

→ As the flux is alternating, according to the Faraday's law of electromagnetic induction, mutually induced emf gets developed in secondary wdg. If now load is connected to the secondary winding, then this emf drives a current through it.

→ Thus, there is no electrical contact between two wdgs, an electrical energy gets transferred from pri. to secondary.

emf equation → $V_1 = V_m \sin\omega t \rightarrow E_1 = E_m \sin\omega t$

→ An alternating voltage V_1 is confined the primary wdg of N_1 turn there due to self induction E_1 is developed across pri. wdg.

→ The flux established by pri. wdg is linked with sec. wdg through magnetic core & induced mutual emf on sec. wdg which is termed as E_2 across N_2.

→ So, alternating current provided by V_1 established alternating flux by alternating mmf (NI – AT)

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

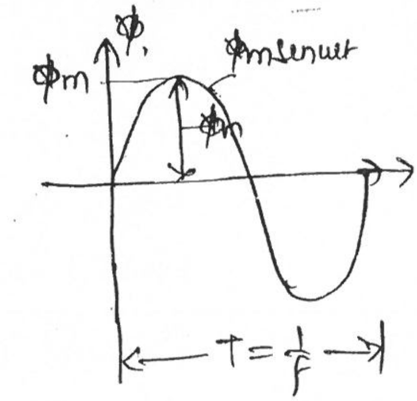
→ Then $e_1 = -N_1 \dfrac{d\phi}{dt}$ & $e_2 = -N_2 \dfrac{d\phi}{dt}$

$$e_1 = -N_1 \frac{d}{dt}(\phi_m \sin\omega t) \qquad e_2$$

$$= -N_1 \omega \phi_m \cdot \cos\omega t \qquad e_2 = -N_2 \omega \phi_m \cos\omega t$$

$$= -N_1 \omega \phi_m \sin(\pi/2 - \omega t)$$

$$= N_1 2\pi f \phi_m \sin(\omega t - \pi/2)$$



$$\boxed{e_1 = 2\pi f N_1 \phi_m \sin(\omega t - \pi/2)}$$

R.M.S value per turn $= E_m/\sqrt{2}$

$$= \frac{2\pi f \phi_m}{\sqrt{2}}$$

$$= 4.44 f \phi_m$$

R.m.s value of primary side $\boxed{E_1 = 4.44 f \phi_m N_1}$ volts

similarly $\boxed{E_2 = 4.44 f \phi_m N_2}$ volts

→ Voltage Ratio & current Ratio of T/F

$E_1 = 4.44 f \phi_m N_1$, $E_2 = 4.44 f \phi_m N_2$

$$\frac{E_1}{E_2} = \frac{N_1 \, 4.44 f \phi_m}{N_2 \, 4.44 f \phi_m} \Rightarrow \boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}}$$

but $\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = K}$ = voltage Transformation Ratio or turn Ratio

$\cancel{E_2 \propto V_2}$ $V_2 \propto E_2$ & $V_1 \propto E_1$

then $\boxed{\frac{V_2}{V_1} = \frac{E_2}{E_1} = K}$ → only for Ideal T/f.

Now Ideal T/F has following properties [Voltage regulation = 0, $\eta = 100\%$.]

(i) No winding resistance - No winding losses.

(ii) No leakage flux - same flux links with both the wdgs

(iii) No iron losses - Eddy ~~&~~ current & hysteresis loss in the core.

(iv) High permeability - negligible current is required to establish the flux in it.

so, Current Ratio in ideal case

Input VA = $V_1 I_1$ output VA = $V_2 I_2$

For Ideal T/F $\boxed{\text{Input VA} = \text{Output VA}}$

$$V_1 I_1 = V_2 I_2$$

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

→ Types of T/F based on K = $K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

(1) If $N_2 > N_1$ i.e $K > 1$ then

$E_2 > E_1$ → step-up transformer

(2) If $N_1 > N_2$ for $K < 1$ then

$E_1 > E_2$ → step down transformer

(3) $\boxed{N_1 = N_2}$ then $K = 1$

$\boxed{E_1 = E_2}$ → Isolation T/F of 1:1

→ Rating of T/F :→ (VA, KVA, MVA)

Rating of T/F = $V_1 \times I_1$ (VA) input VA

or $V_2 \times I_2$ (VA) output VA

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

Nameplate Rating 4400/440V, 10 KVA, 50Hz

V_1 ↑ pri. voltage, V_2 ↑ Sec voltage, ↑ KVA rating

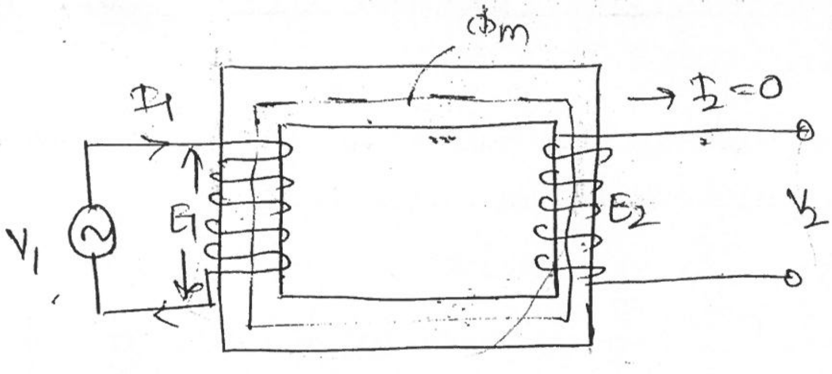
VA → apparent power [P + JQ] Active & Reactive Power

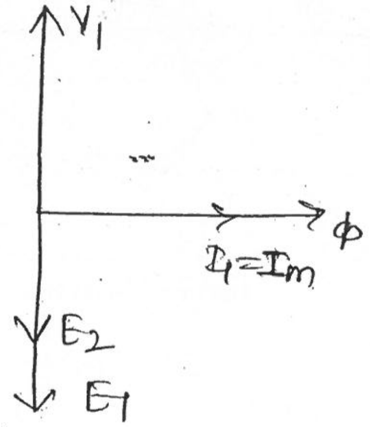
→ Actually output of transformer supply is depends upon the load and load p.f.

→ Then manufacturer doesn't known about the nature of load at manufacturing time, & load can be changed then output of T/F is also changed. Hence the max. power supplying capacity is given as rating.

Ideal Transformer on No load:-

No load means secondary has no power loss i.e sec. is open circuited, $R_L = \infty$





→ Actually, primary current $I_1 = 0$ ideally but practically a small current called magnetizing current (very small) is required to magnitize the transformer core.

→ Assume primary wdg $R_1 = 0$ i.e purely inductive then V_1 is leads by this I_m and the flux ϕ is in time phase with I_m

→ Now flux link both the wdgs & producing induced emf E_1 & E_2 in primary & sec. wdg respectively. But A/c to to Lenz's law, the induced emf opposes the cause i.e V_1. Hence $E_1 \propto -V_1$ & its mag. depands upon N_1.

→ E_2 also oppose V_1 & its magnitude depands upon N_2.

so power input to the T/F $= V_1 I_1 \cos(V_1 \wedge I_1)$

$$= V_1 I_1 \cos(90^\circ)$$

$$= 0$$

→ This is because no load output power is 0 for ideal transformer & there are no power loss bcoz input power is 0.

Practical T/F on No load

→ Same losses are included in practical T/F

* Hysteresis loss and eddy current loss

→ Use high grade material as silicon steel to minimize the hysteresis loss

→ To reduce the eddy current loss, stacks of thin laminations are used.

* Some iron loss is also present

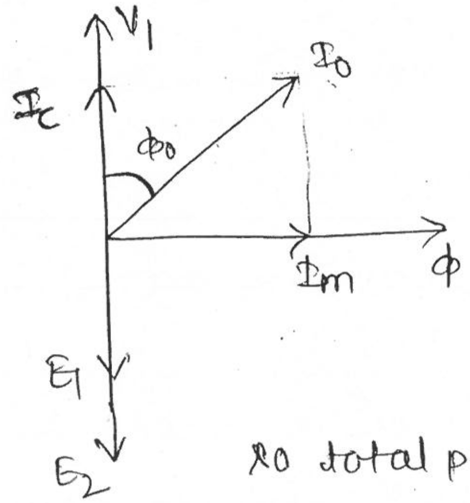
* Same copper loss is also considered due to certain resistance occured (present) in primary wdg.

Then primary current at no load I_0 has two component

↦ I_m · purely reactive component → magnetising component is required to produce the flux. It is also called wattless component.

↦ I_c - active component which supplies total losses at no load, called power component, or wattful component or core loss component

so I_0 cannot be 90° leg but ~~at~~ legs behind by $\phi_0 < 90°$



$$\bar{I_0} = \bar{I_m} + \bar{I_c}$$

$$\boxed{\begin{aligned} I_m &= I_0 \sin\phi_0 \\ I_c &= I_0 \cos\phi_0 \end{aligned}}$$

I_0 is very small 3–5% of rated current

$$I_0 = \sqrt{I_m^2 + I_c^2}$$

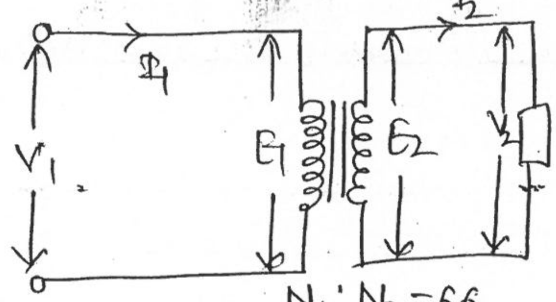
$\cos\phi_0$ → no load p.f.

so total power input at no load =

$$P_c = P_w = \boxed{W_0 = V_1 I_0 \cos\phi_0 = V_1 I_c}$$

$$\boxed{\text{\& Iron loss} = V_1 I_0 \cos\phi_0 = P_i}$$

$Q^{n}1$ – A 2000/200V, 20KVA transformer has $N_2 = 66$ turns. Calculate
(i) N_1 – primary turns
(ii) Primary & Secondary full-load ~~voltage~~ currents. Neglect losses.



$N_1 : N_2 = 66$

Rating (given) $= \underbrace{2000}_{\substack{\text{primary}\\ \text{voltage}\\ V_1}} / \underbrace{200}_{\substack{\text{sec side}\\ \text{voltage}\\ V_2}}$, 20KVA → KVA

$$K = \frac{V_2}{V_1} = \frac{200}{2000} = \frac{1}{10}$$

(i) $K = \frac{V_2}{V_1} = \frac{N_2}{N_1} \Rightarrow \frac{1}{10} = \frac{N_2}{N_1} \Rightarrow N_1 = 10 \times N_2 = 10 \times 66$
$= 660$ turns.

(ii) $V_1 I_1 = V_2 I_2 = 20 \times 10^3$ VA at neglect losses

$$I_1 = \frac{20 \times 10^3}{V_1} \quad \& \quad I_2 = \frac{20 \times 10^3}{V_2}$$

$$= \frac{20 \times 10^3}{2000} \quad \& \quad I_2 = \frac{20 \times 10^3}{200}$$

$$= 10 \text{ Amp} \qquad = 100 \text{ amp}$$

$Q^{n}2$:- A single phase ~~turn~~ 2200/250 V, 50 Hz T/F has net core area $= 36\ cm^2$ and max. flux density of 6 Wb/m². Calculate the no. of turns of primary & sec.

Sol^n:- $\phi_m = B_m a = 6 \times 36 \times 10^{-4} = .0216$ wb

$E_1 = 4.44 f \phi_m N_1 \Rightarrow N_1 = \frac{E_1}{4.44 f \phi_m} = \frac{2200}{4.44(50) \times .0216} = 459$

$E_2 = 4.44 f \phi_m N_2 \Rightarrow N_2 = \frac{E_2}{4.44 f \phi_m} = 52$

Qn3:- A 200/50 V, 50Hz 1φ-T/F is connected to a 200V, 50Hz supply with sec. open. $N_1 = 400$ turns

(i) $\phi_m = ?$ if $N_1 = 400$ turns

(ii) $\phi_m = ?$ if primary voltage is 200 V, 25Hz ?.

Soln:- (i) We know $E_1 = 4.44 f \phi_m N_1$

$$\phi_m = \frac{200}{4.44 \times 50 \times 400} = 2.25 \text{ mWb.}$$

(ii)

$$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{200V}{4.44 \times 25 \times 400} = 4.5 \text{ mWb.}$$

Qn4:- 1-φ T/F, $N_1 = 350$, $N_2 = 1050$, $a = 55 cm^2$.
$E_1 = 400$ V, 50Hz, calculate:-

① ϕ_m in the core & flux density (ii) voltage induced at sec.

Soln:- $N_1 = 350$, $N_2 = 1050$, $E_1 = 400V$

①

$$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{400V}{4.44 \times 50 \times 350} = 5.15 \times 10^{-3}$$

$$\phi_m = B_m a \Rightarrow B_m = \frac{5.15 \times 10^{-3}}{55 \times 10^{-4}} = .936 \text{ Wb/m}^2$$

②

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} \quad \Big| \quad E_2 = E_1 \times \frac{N_2}{N_1} = 400 \times \frac{1050}{350} = 1200V$$

Qn5:- 1φ T/F $N_1 = 400$, $a = 60 cm^2$, $l = .8m$, $E_1 = 500V$, 50Hz
Find I_m-magnetizing current if $\mu_r = 2000$

Ans:-

$$N \cdot I_m = mmf \Rightarrow I_m = \frac{mmf(AT)}{N_1} = \frac{\text{flux} \times \text{reluctance}}{N_1}$$

$$N_1 \times I_m = \phi_m \times \frac{l}{\mu_0 \mu_r a} = \phi_m \times \frac{.8}{4\pi \times 10^{-7} \times 2000 \times 60} \times \frac{1}{} \quad ①$$

$$E_1 = 4.44 f \phi_m N_1 \Rightarrow \phi_m = 5.63 \times 10^{-3}$$

$$N_1 \times I_m = 5.63 \times 10^{-3} \times 5.3 \times 10^{5} = 2.987 \times 10^{2}$$

$$\boxed{I_m = .746} \qquad (I_m)_{rms} = \frac{.746}{\sqrt{2}} = .528 A$$

Qn: 8 A voltage $v = 200 \sin 314t$ is applied to T/F wdg in a load test, resulting $i = 3 \sin(314t - 60°)$. Determine core loss and no load approx. parameter of equivalent ckt.

Soln:- $V_1 = \frac{200}{\sqrt{2}}$, $I_0 = \frac{3}{\sqrt{2}}$ $\boxed{\phi_0 = 60°}$

$$W_0 = V_1 I_0 \cos\phi_0$$
$$= \frac{200}{\sqrt{2}} \times \frac{3}{\sqrt{2}} \cos 60°$$
$$= 150W.$$

component of core loss I_c. $I_w = I_0 \cos\phi_0$
$$= \frac{3}{\sqrt{2}} \cos 60° = 1.061$$

magnetizing current $I_m = \sqrt{I_0^2 - I_w^2}$
$$= \sqrt{(3/\sqrt{2})^2 - 1.061} = 1.837$$

$$\Rightarrow I_0 = [I_0 \cos\phi_0 - jI_0 \sin\phi_0]$$
$$= [1.061 - j1.837]$$

$$R = \frac{V_1}{I_0 \cos\phi} = \frac{200/\sqrt{2}}{1.061} = 133.291\,\Omega$$

$$X = \frac{V_1}{1.837} = \frac{200/\sqrt{2}}{1.837} = 76.98\,\Omega$$

Q^n 6 A transformer takes a current of ·6A & absorb 64W when primary is connected to its normal supply 240V, 50Hz, the sec. being on open circuit. Find the magnetizing and iron loss current.

Sol^n:- Iron loss component or active component

No load pri. power ~~$I_w = V_1 I_0 \cos\phi_0 = 64W$~~

$W_0 = V_1 I_0 \cos\phi_0$ & Iron loss component $I_w = I_0 \cos\phi_0 = I_c$

$W_0 = V_1 I_w$

$$I_w = \frac{64}{240} = \cdot 267 \text{ amp}$$

& $I_0 = \cdot 6$ then $I_0 = \sqrt{I_m^2 + I_w^2}$

$$I_m = \sqrt{I_0^2 - I_w^2} = \sqrt{(\cdot 6)^2 - (\cdot 267)^2} = \cdot 5375$$

Q^n 7:- A 230V/2300V T/F takes no load current of 6.5A and absorbs 187W. If resistance is ·06Ω. Find (i) Core loss (ii) no load p.f (iii) Active component of current (iv) magnetizing current

Sol^n:- $W_0 = V_1 I_0 \cos\phi_0$

(ii) $$\cos\phi_0 = \frac{187W}{230 \times 6\cdot5} = \cdot 125 \text{ lagging}$$

(iii) active component of current $I_w = I_0 \cos\phi_0$

$= 6\cdot5 \times \cdot125 = \cdot813A$

(iv) $I_0 = \sqrt{I_m^2 + I_w^2} \Rightarrow I_m^2 = \sqrt{I_0^2 - I_w^2}$

$$I_m = \sqrt{(6\cdot5)^2 - (\cdot813)^2} = 6\cdot4A.$$

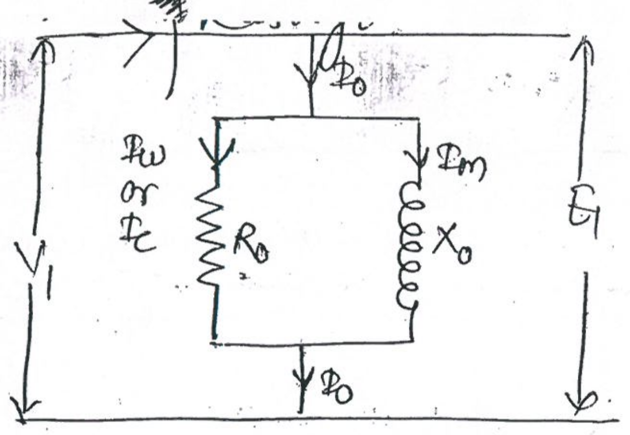
(i) ~~$W_0 = V_1 I_0 \sin\phi_0$~~ Primary cu loss $= I_0^2 R_1 = (6\cdot5)^2 \times \cdot 06$

$= 2\cdot535W$

core loss = Iron loss = $187 - 2\cdot5 = 184\cdot5W$.

Shivam Srivastava T2 SHS

→ No load equivalent circuit

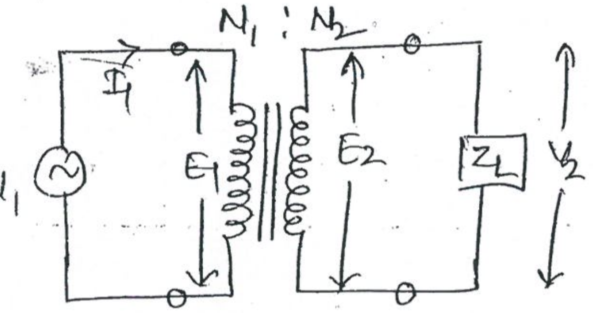


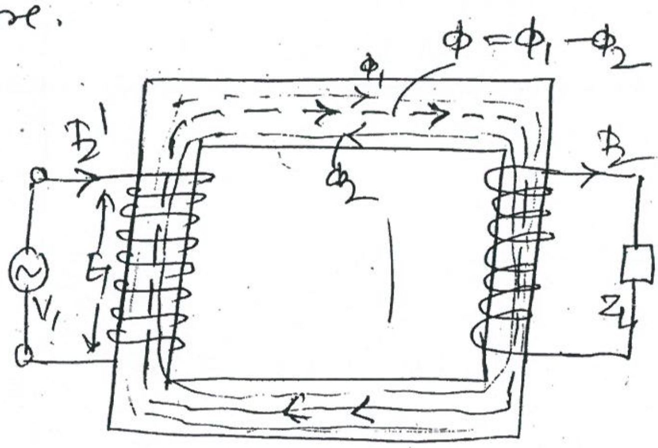
I_w – active component
supply core losses.

core losses
- Hysteresis &
- Eddy current losses.

$I_m \to X_0$ – wattless component
– use for megnetizing the core.

Ideal T/F on Load :-





Sumit Maheshwari

* When a certain Load $Z_L = R_L + jX_L$ (L type) is connected to the sec. wdg. of T/F, a finite I_2 current starts flowing. & due to inductive load I_2 leg behind by V_2 by ϕ_2 angle
* As per lenz's law, the I_2 current will oppose the cause of producing it. Hence it oppose the flux set-up in magnetic core. This is demegnetizing effect of I_2, and this ~~current~~ flux weakened the primary wdg setup flux & hence reduced the emf induced at E_1, Hence vector difference $\bar{V}_1 - \bar{E}_1$ increases and corresponding draws more current from current, this additional current drawn due to load, hence it's shown by I_2'
* Now I_2' will set-up the flux ϕ_2' which help the ϕ_1 but oppose the $\phi_2 \sim I_2$. Hence I_2' is in antiphase I_2. Now mmf produced by such change is $N_1 I_2'$ balance the $N_2 I_2$ and net flux in the core is again maintained i.e. Transformer is constant flux machine.

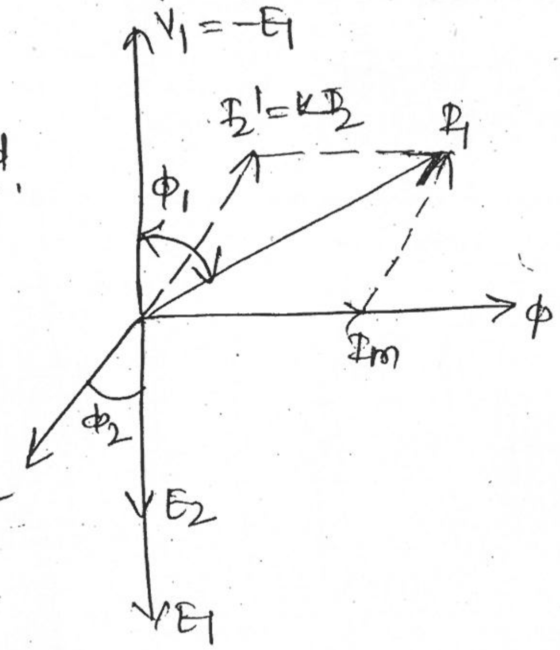
$$N_1 I_2' = N_2 I_2$$

$$I_2' = \frac{N_2}{N_1} I_2 = K I_2 \quad \& \ I_2' \text{ is } 180^\circ \text{ out of phase } I_2$$

so net primary current

$$\bar{I}_1 = \bar{I}_2' + \bar{I}_m$$

Ideal
Transformer phasor
diagram at on load



~~Numerical :- A 400/200 V T/F takes 1Amp current at p.f .4 on no load if secondary supply a load current 50A at .8 legging~~

Practical T/F on Load

Load classification	Load current
Purely Resistive (R)	I_2 in same phase V_2
(R+L) type (mixed load)	I_2 legs with V_2
(R+C) type	I_2 leads with V_2

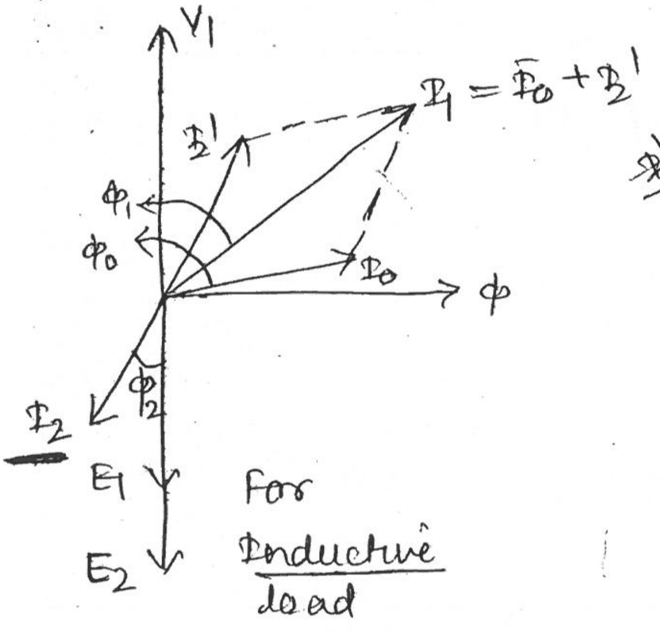
→ As t/f is loaded, I_2 will start flowing. As load increase, I_2 increases & hence mmf (Amp-turn, NI) $N_2 I_2$ will also increase, and hence flux ~~...~~, setup by $N_2 I_2$, ϕ_2 increases & oppose the main flux ϕ_1.

→ Now we know that if load is inductive, this I_2 is legs behind E_2. & due to load current increase ϕ_2 oppose ϕ_1 & $\bar{V}_1 - \bar{E}_1$ difference increase the additional current flow which is $\bar{I}_1 = \bar{I}_2' + \bar{I}_0$

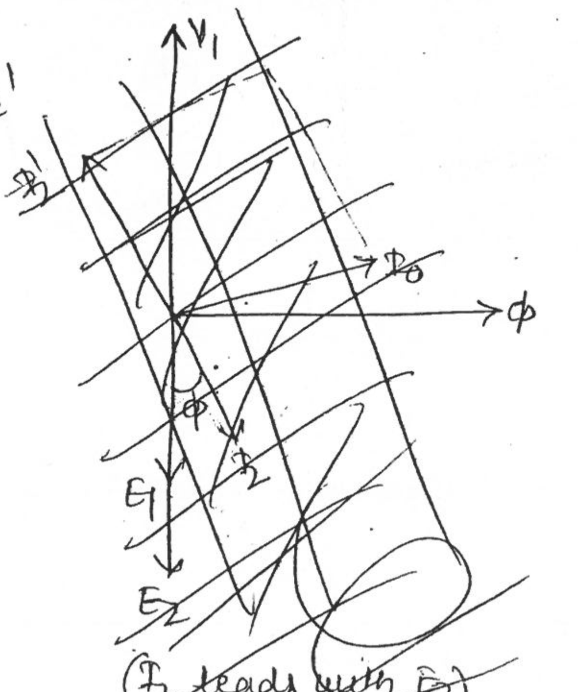
Here $N_2 I_2 = N_1 I_2'$ & $I_0 = \bar{I}_m + \bar{I}_w$ (or $\bar{I}_c$)

$$I_2' = \frac{N_2}{N_1} I_2 = K I_2$$

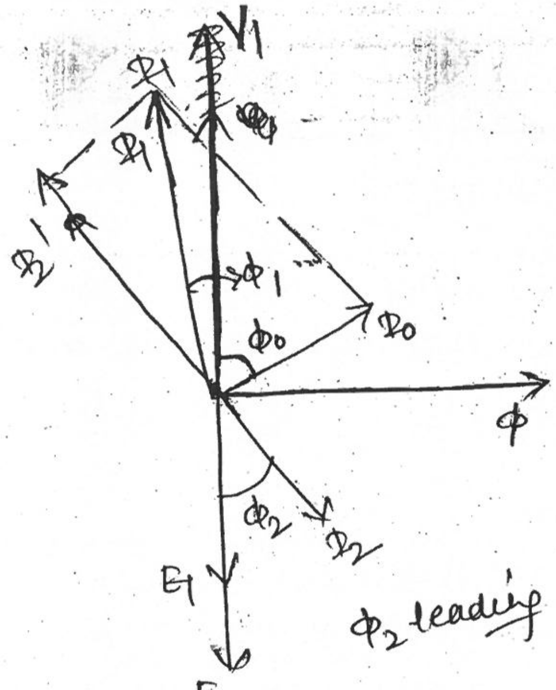
→ Here I_0 is not adjact 90° legs with E_1 but make same angle ϕ_0 due to inductive coil N_1 (pri. side).



For Inductive load
(I_2 legs behind E_2)

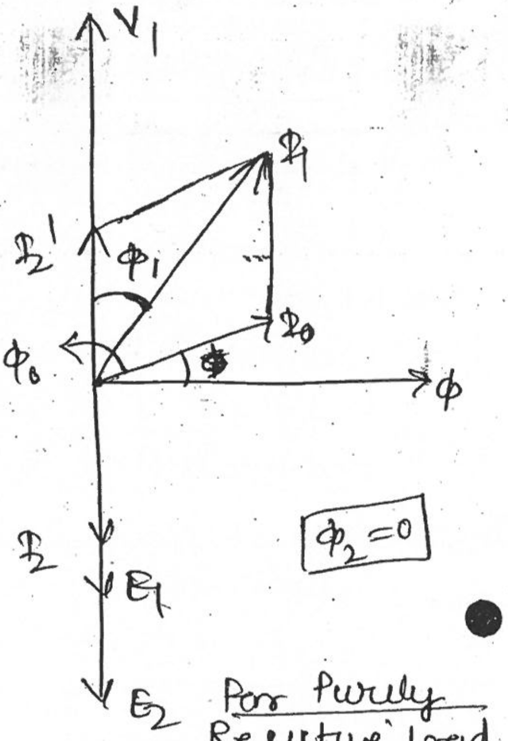


(I_2 leads with E_2)



For capacitive load

(I_2 leads with E_2)



For Purely Resistive load

(I_2 are in same phase with E_2)

Qn:- A 400/200 V T/F takes 1A at a power factor of ·4 on no load if the secondary supplies a load current of 50 A at ·8 lagging p.f. Calculate primary current.

Soln:- $I_0 = 1A$ at $\cos\phi_0 = \cdot 4$, $I_2 = 50A$ at $\cos\phi_2 = \cdot 8$ lagging

$\phi_0 = 66.42$ $\qquad$ $\phi_2 = 36.86$

~~$I_0 = I_0\cos\phi_0 + jI_0\sin\phi_0$~~

$K = \frac{E_2}{E_1} = \frac{200}{400} = \cdot 5$ & $I_2' = K I_2$

$= \cdot 5 \times 50$

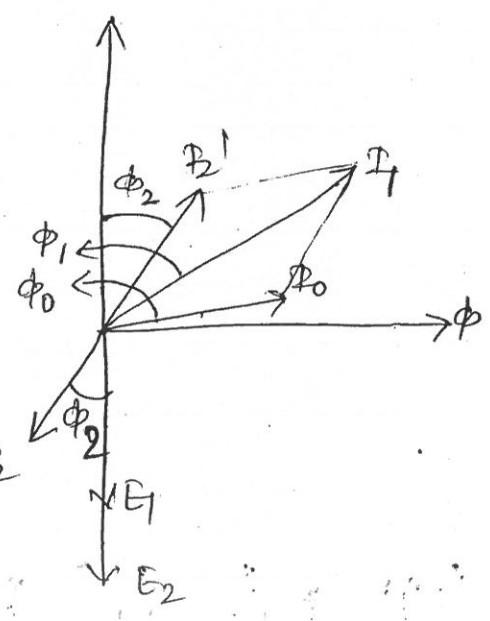
$= 25A$

$(\phi_0 - \phi_2) = 29.56$

so $I_1^2 = I_0^2 + I_2'^2 + 2 I_0 I_2' \cos(\phi_0 - \phi_2)$

$I_1^2 = 1 + 625 + 43.5$

$\boxed{I_1 = 25.87}$



Circuit Impedence

→ Equivalant Resistance ~~& Reactance~~ & Reactance

Voltage drop of primary wdg $= I_1 R_1$

Voltage drop of secondary wdg $= I_2 R_2$

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

Total copper loss $= I^2 R$

$$= I_1^2 R_1 + I_2^2 R_2$$

$$= I_1^2 \left[R_1 + \left(\frac{I_2}{I_1}\right)^2 R_2 \right]$$

[Refer to pri side]

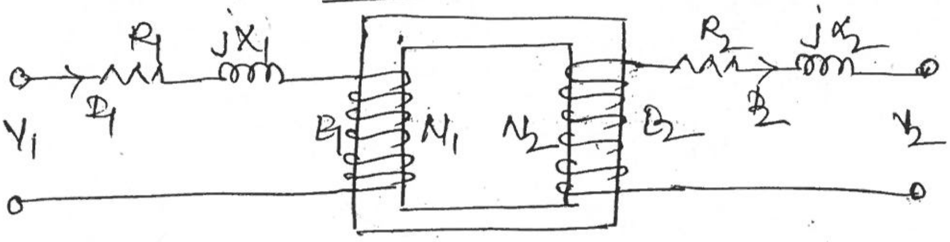
$$= I_1^2 \left[R_1 + \frac{R_2}{K^2} \right] = I_1^2 \left[R_1 + R_2' \right]$$

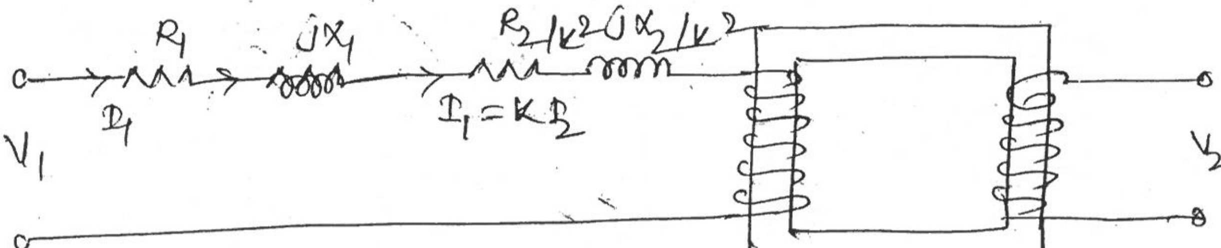
$$= I_1^2 R_{1e}$$

R_{1e} → total resistance referred to primary side

$\boxed{R_{1e} = R_1 + R_2'}$ where $R_2' = \frac{R_2}{K^2}$

similarly $\boxed{X_{1e} = X_1 + X_2'}$ where $X_2' = \frac{X_2}{K^2}$





Refer to secondary side

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

Total copper loss $= I_1^2 R_1 + I_2^2 R_2$

$$= I_2^2 \left[\left(\frac{I_1}{I_2}\right)^2 R_1 + R_2 \right]$$

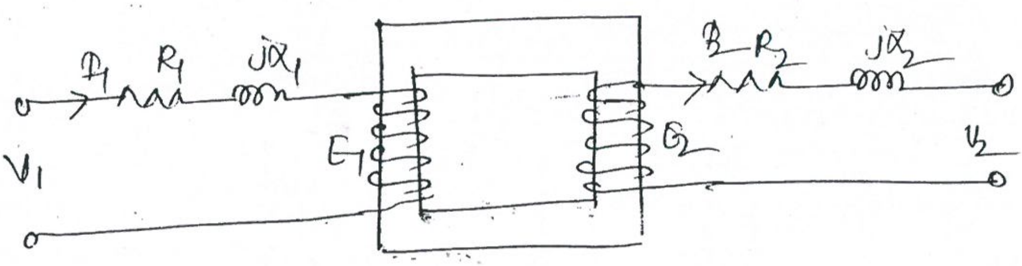
$$= I_2^2 \left[K^2 R_1 + R_2 \right]$$

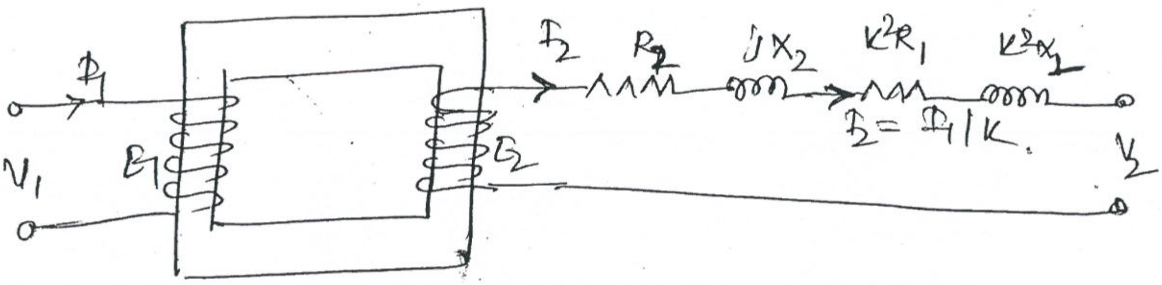
$$= I_2^2 \left[R_2 + R_1' \right] = I_2^2 R_{2e}$$

$R_{2e} \rightarrow$ total resistance referred to sec. side

$\boxed{R_{2e} = R_2 + R_1'}$ where $R_1' = K^2 R_1$

similary Reactance $\boxed{X_{2e} = X_2 + X_1'}$ where $X_1' = K^2 X_1$



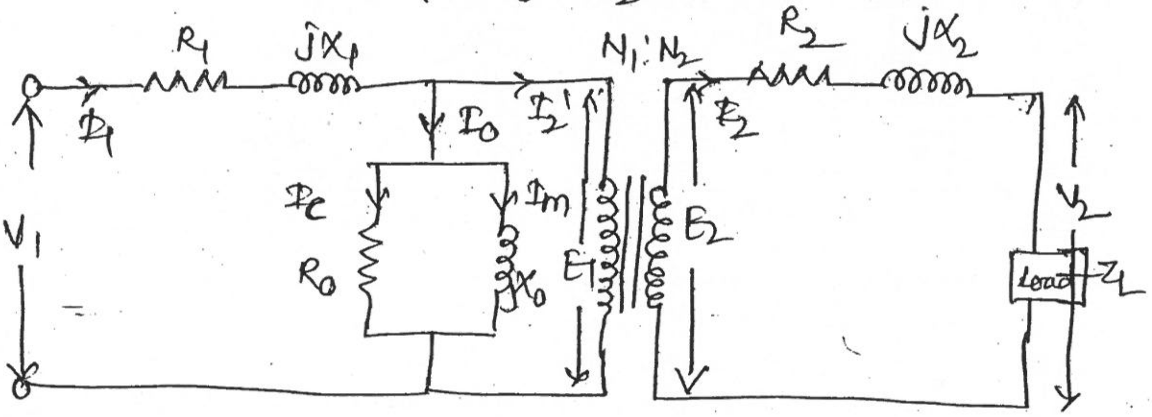


Equivalent circuit of a T/F:-

① No load primary current I_0

② Anticipating or addition current I_2'

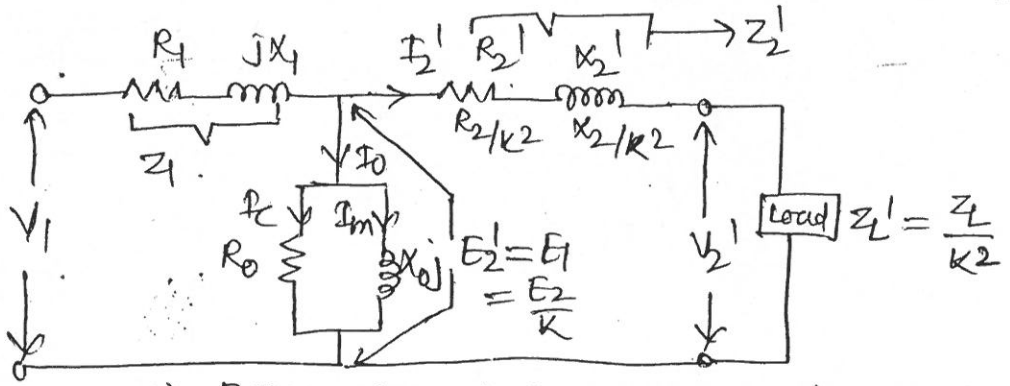
$$\therefore I_1 = I_0 + I_2'$$



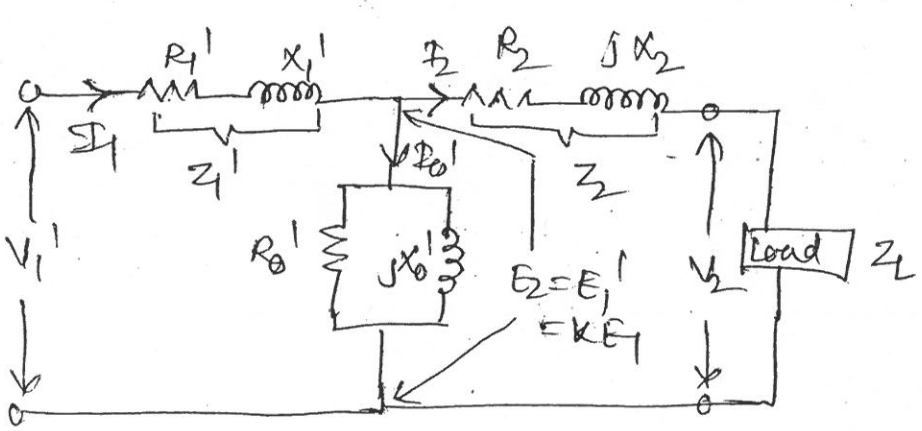
Now we referred our parameter $\frac{E_2}{E_1} = K$.

a) Exact Equivalent ckt referred to primary side.

b) Exact Equivalent ckt referred to sec. side



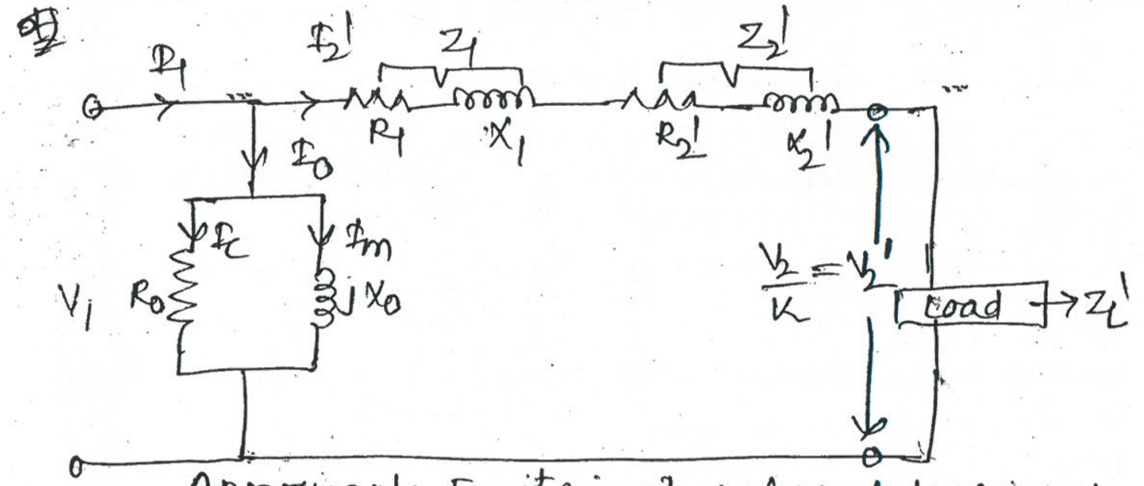
a) E.E.C. referred to primary side



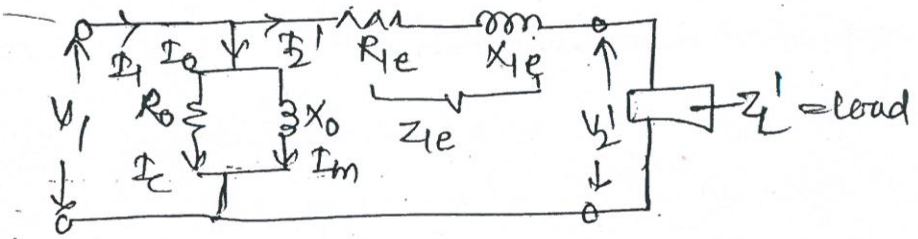
b) Exact Equivalent ckt referred to sec. side

Approximate equivalent circuit:-

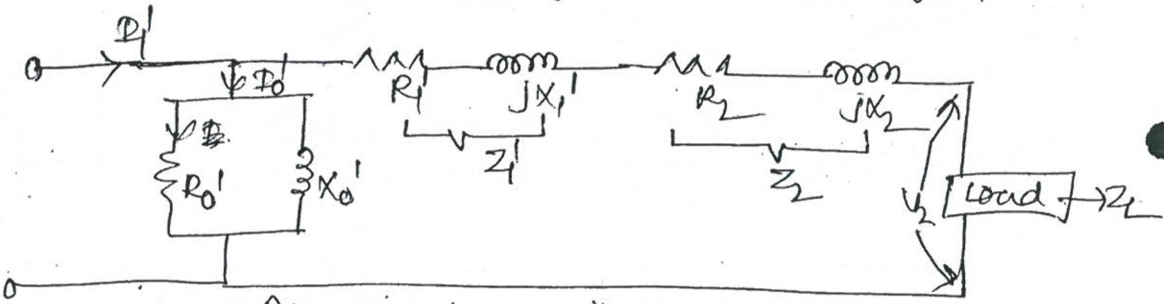
c) shift No load primary current to the left of Z_1



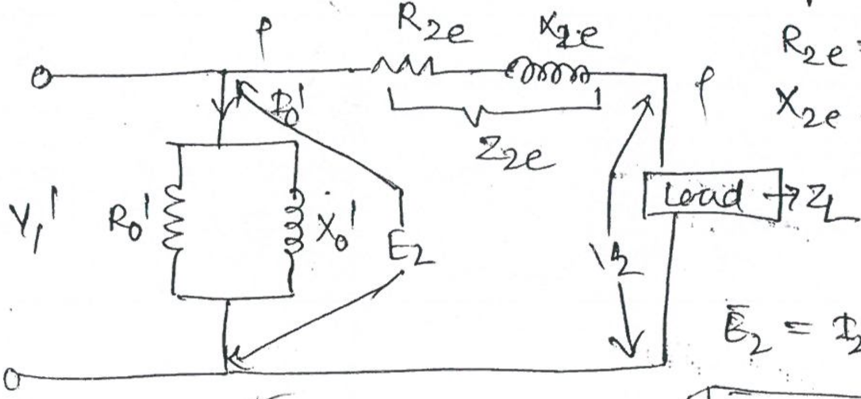
Approximate Equi. circuit referred to pri. side



d) Shift No load primary to the left of Z_1'



Approximate equi. circuit referred to sec. side



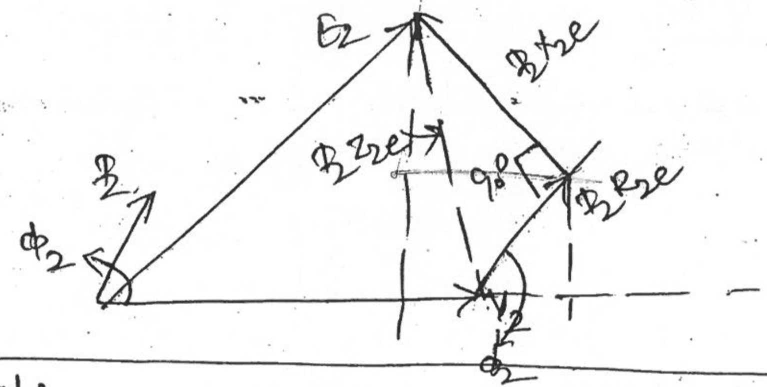
$R_{2e} = R_2 + R_1'$

$X_{2e} = X_2 + X_1'$

$$\bar{E}_2 = I_2(R_{2e} + jX_{2e}) + \bar{V}_2$$

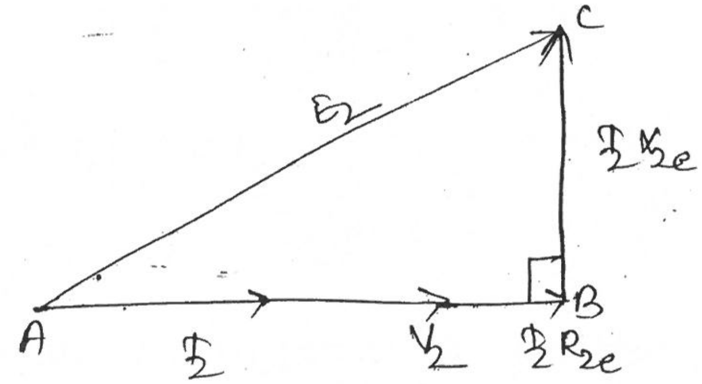
$$\boxed{\bar{E}_2 = \bar{V}_2 + I_2 Z_{2e}}$$

* For leading p.f :-



Approximate valtage drop	=	$I_2 R_{2e} \cos\phi_2 - I_2 X_{2e} \sin\phi_2$	referred to sec
	=	$I_1 R_{1e} \cos\phi_1 - I_1 X_{1e} \sin\phi_1$	referred to pri

3* For unity p.f. :-



So, Approximate valtage drop $= E_2 - V_2 = I_2 R_{2e}$ referred to sec.
$= I_2 R_{1e}$ referred to pri.

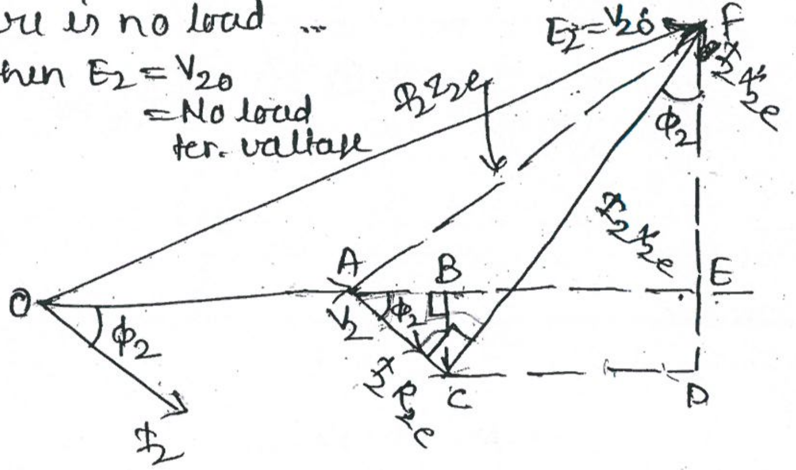
General formula for Approx. valtage drop	=	$I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \cos\phi$
		$I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi$

+ → sign for lagging p.f. , − sign for leading p.f.

Approximate equivalent phasor diagram

(1) For legging p.f. $\boxed{E_2 = V_2 + I_2(R_{2e} + jX_{2e})}$

When there is no load $I_2 = 0$ then $E_2 = V_{20}$ = No load ter. voltage



Approximate voltage drop $= \bar{AE} = \bar{AB} + \bar{BE}$ ——(1)

For $\bar{AB}$, ΔABC: $\cos\phi_2 = \dfrac{\bar{AB}}{I_2R_{2e}} \Rightarrow \bar{AB} = I_2R_{2e}\cos\phi_2$

For BE, ΔCFD: ~~$\cos\phi_2$~~ $= \sin\phi_2 = \dfrac{CD \text{ or } BE}{I_2X_{2e}}$

$\therefore \bar{BE} = I_2X_{2e}\sin\phi_2$

So from eqn (1) $\bar{AE} = I_2R_{2e}\cos\phi_2 + I_2X_{2e}\sin\phi_2$

Let $\phi_2 = \phi_1 = \phi$ (Approx.) $\Rightarrow \boxed{\bar{AE} = I_2R_{2e}\cos\phi \pm I_2X_{2e}\sin\phi}$

If parameter are referred to primary side then analgeously

$\boxed{\text{Approximate voltage drop} = I_1R_{1e}\cos\phi + I_1X_{1e}\sin\phi}$

Voltage Regulation :-

• ~~Resistance and Leakage Reactance~~

$$\% \text{ voltage Regulation } R = \frac{E_2 - V_2}{V_2} \times 100$$

where $\frac{E_2 - V_2}{V_2}$ is called per unit regulation.

* Actually, due to presence of pri & sec. impedence, the sec. terminal voltage drop from its no-load value (E_2) to the load value V_2.

* As load current increases, the voltage drops tend to increase means V_2 drops more. This voltage drop should be as small ~~as much less~~ as possible. Hence less the regulation better is the performance.

* In case of legging power power $E_2 > V_2$ & we get +ive voltage regulation, while for leading power factor $E_2 < V_2$ & we get negative voltage regulation.

* Here, sec. terminal voltage also depends upon the nature of the power factor of the load.

$$\% R = \frac{E_2 - V_2}{V_2} \times 100 = \frac{\text{Total voltage drop}}{V_2} \times 100$$

we already derived the approx. voltage drop.

$$\boxed{\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100 \quad \text{or} \quad \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100}$$

→ Ref. to sec. side

→ Ref. to pri. side

+ive sign for lagging powerfactor.

-ive sign for leading power factor.

Zero Voltage Regulation :-

~~equivalent diagram of T/F~~

Actually for lagging p.f & unity p.f $V_2 < E_2$ & we get $+R\%$

But as load becomes capacitive, V_2 starts increasing then there must be a point $E_2 - V_2 = 0$, at this point the regulation becomes zero & $\%R = 0$

i.e $\Rightarrow E_2 = V_2$

$\Rightarrow E_2 - V_2 = 0 \Rightarrow$ voltage drop $= 0$

$\Rightarrow I_1 R_{1e} \cos\phi - I_1 X_{1e} \sin\phi = 0$

$\Rightarrow V_R \cos\phi - V_x \sin\phi = 0$

$\Rightarrow \tan\phi = \dfrac{V_R}{V_x}$

$$\Rightarrow \boxed{\cos\phi = \cos\left\{\tan^{-1}\left(\frac{V_R}{V_x}\right)\right\}}$$

This is leading p.f at which voltage regulation becomes zero while supplying the load.

Qn :- 250/125V, 5 KVA, 1ϕ T/F has $R_1 = \cdot 2\Omega$, $X_1 = \cdot 75$, $R_2 = \cdot 05\Omega$, $X_2 = \cdot 2\Omega$

(i) Determine its regulation while supplying full load on ·8 leading p.f

(ii) The secondary terminal voltage on full load & ·8 leading p.f.

Soln :- $K = \dfrac{125}{250} = \cdot 5$ $\qquad I_2 (f.L) = \dfrac{5 \times 10^3}{125} = 40A$

$R_{2e} = R_2 + K^2 R_1$
$= \cdot 05 + \cdot 25 \times \cdot 2 = \cdot 1\Omega$

$X_{2e} = X_2 + K^2 X_1$
$= \cdot 2 + (\cdot 5)^2 \times \cdot 75 = \cdot 3875\Omega$

(i) $\cos\phi = \cdot 8$ leading $\quad \sin\phi = \cdot 6$

$\%R = \dfrac{I_2 R_{2e}\cos\phi - I_2 X_{2e}\sin\phi}{V_2} = \dfrac{40[\cdot 1 \times \cdot 8 - \cdot 3875 \times \cdot 6]}{125} \times 100$

$= -4\cdot 88\%$

(ii) $\%R = \dfrac{E_2 - V_2}{V_2} \times 100 \Rightarrow -4\cdot 88 = \dfrac{125 - V_2}{V_2} \times 100$ $\quad \boxed{E_2 < V_2}$

$V_2 = ?$ $\qquad \boxed{V_2 = 131.11}$

... 2000/200V, ... $R_1 = 1.5\Omega$, $X_1 = 2\Omega$ &
$R_2 = .015\,\Omega$ & $X_2 = .02\,\Omega$ respectively. The no load current of T/F is 1A at .2 pf. Determine

(i) Equivalent Resistance, Reactance & Impedance referred to pri.
(ii) Supply current (iii) Total copper loss.

Soln:- $K = \dfrac{V_2}{V_1} = \dfrac{200\,V}{2000\,V} = .1$

(i) $R_{1e} = R_1 + R_2' = R_1 + \dfrac{R_2}{K^2} = 1.5 + \dfrac{.015}{(.1)^2} = 3\,\Omega$

$X_{1e} = X_1 + \dfrac{X_2}{K^2} = 2 + \dfrac{.02}{(.1)^2} = 4\,\Omega$

Answers

$Z_{1e} = R_{1e} + jX_{1e} = 3 + j4 \Rightarrow |Z_{1e}| = \sqrt{3^2+4^2} = 5\,\Omega$

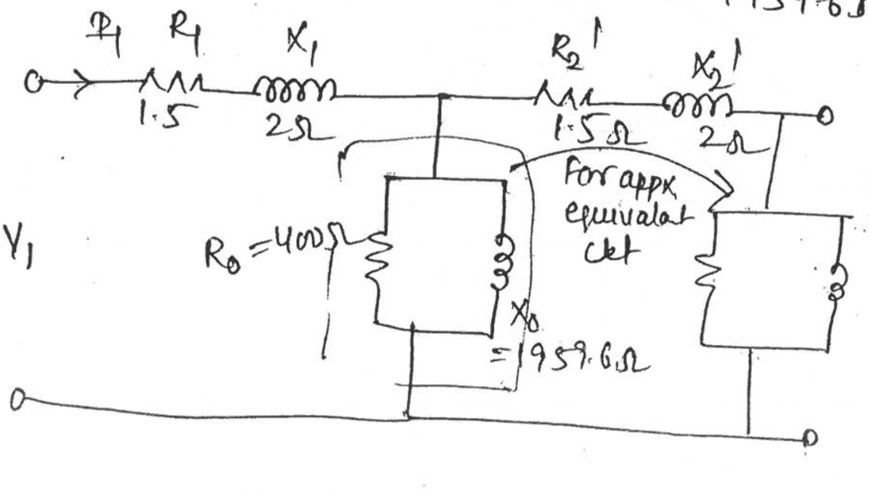
(ii) Supply current $I_{1fl} = \dfrac{KVA\,(V_1 I_1)}{V_1} = \dfrac{20 \times 10^3}{2000} = 10A$

on loaded T/F. $I_1 = \dfrac{V_1}{Z_1} = \dfrac{2000}{5} = 400A$

(iii) Total Cu loss $P_{cu(loss)} = I_1^2 R_{1e} = (400)^2 \times 3 = 480\,kW$

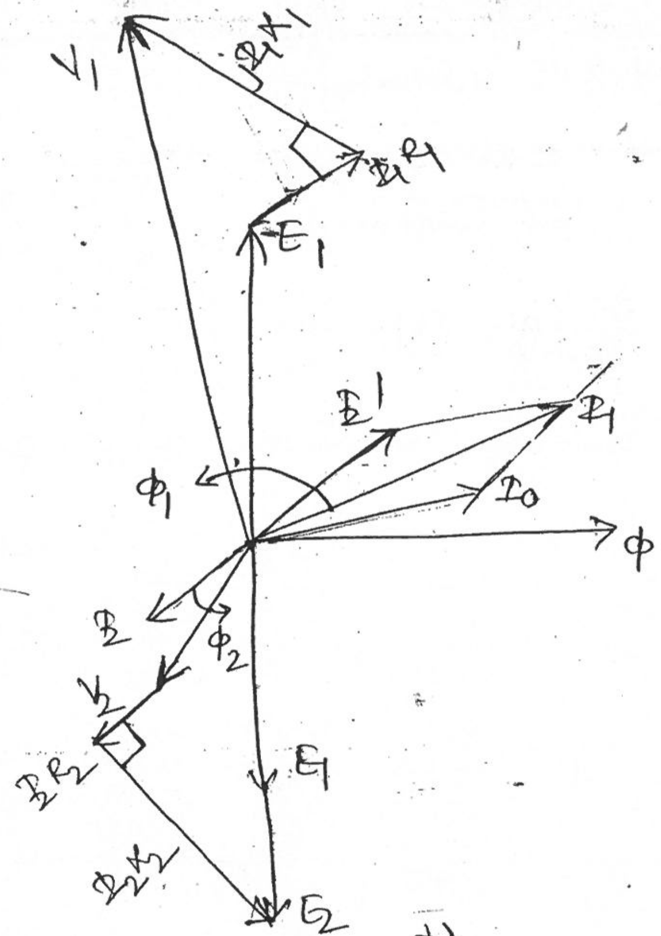
$Z_0 = \dfrac{V_1}{I_0} = \dfrac{2000}{1} = 2000\,\Omega$ $\cos\phi_0 = .2$

~~$Z_0 = 2000\angle$~~ $R_0 = Z_0 \cos\phi_0$ $X_0 = Z_0 \sin\phi_0$
$= 2000 \times .2$ $= 2000 \times \sin(78.46°)$
$= 400\,\Omega$ $= 1959.6\,\Omega$

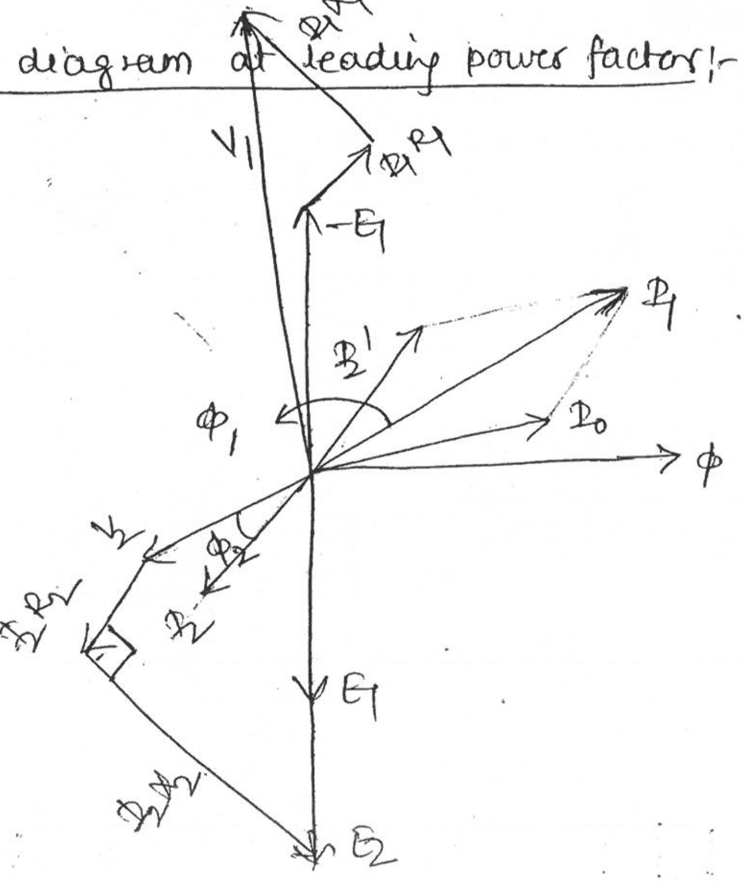


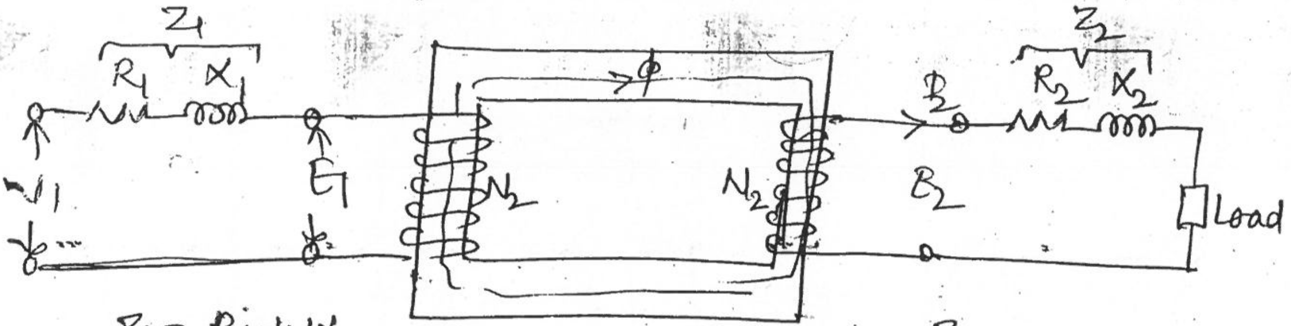
Phasor diagram at lagging power factor

(Actual transformer on load)



➤ Phasor diagram at leading power factor:-



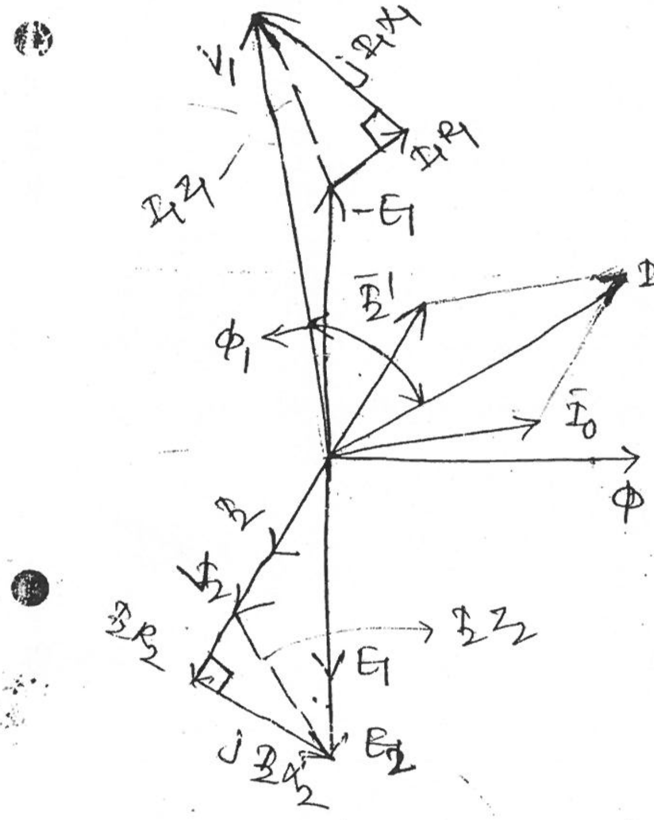


$Z_1 = R_1 + jX_1$ $\qquad$ $Z_2 = R_2 + jX_2$

Phasor diagram on different load with leakage R & X

(1) ~~inductive load~~ Purely Resistive load i.e $\phi_2 = 0$

For unity Power factor

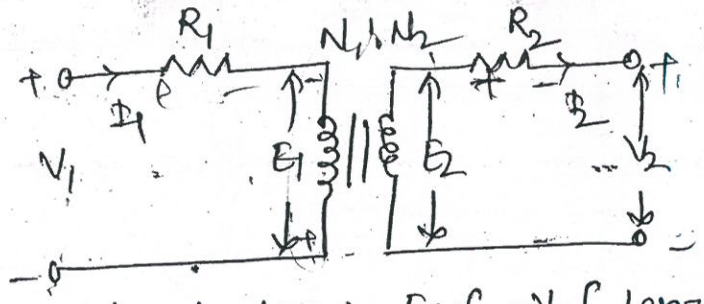


$$V_1 = -E_1 + I_1(R_1 + jX_1)$$

$$\bar{E}_2 = \bar{V}_2 + I_2(R_2 + jX_2)$$

Resistance & leakage Reactance

* In actual, both primary and secondary wdg have certain resistances R_1 & R_2 which causes copper losses and voltage drop.



we already know $E_1 \propto -V_1$ [Lenz's Law]

KVL at primary side

$$V_1 + E_1 - I_1 R_1 = 0$$

$$\cancel{V_1 = -E_1}$$

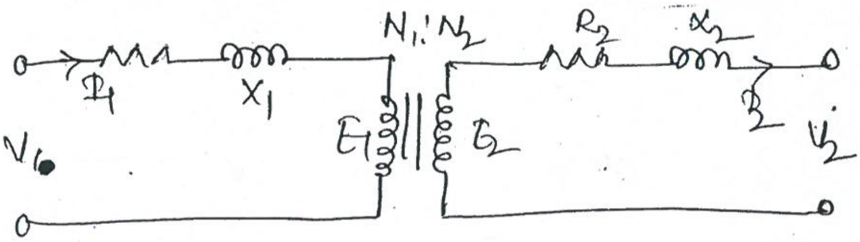
$$\boxed{-E_1 = V_1 - I_1 R_1}$$

KVL at secondary side

$$E_2 - V_2 - I_2 R_2 = 0$$

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

* Similarly, both primary and secondary wdg also have same leakage reactance X_1 & X_2 respectively which produces same flux leaks out in both pri. & sec. wdg.



KVL at primary side

$$\bar{V}_1 + \bar{E}_1 - \bar{I}_1 R_1 - j\bar{I}_1 \bar{X}_1 = 0$$

$$\boxed{V_1 = -\bar{E}_1 + \bar{I}_1 Z_1}$$

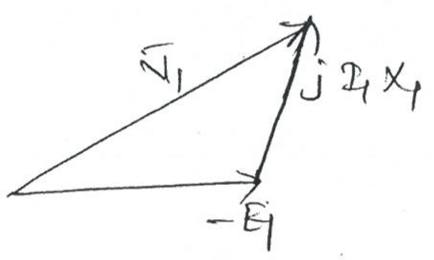
where $Z_1 = R_1 + jX_1$

KVL at sec side

$$\bar{E}_2 - \bar{V}_2 - \bar{I}_2 R_2 - j\bar{I}_2 X_2 = 0$$

$$\boxed{\bar{V}_2 = \bar{E}_2 - \bar{I}_2 Z_2}$$

where $Z_2 = R_2 + jX_2$

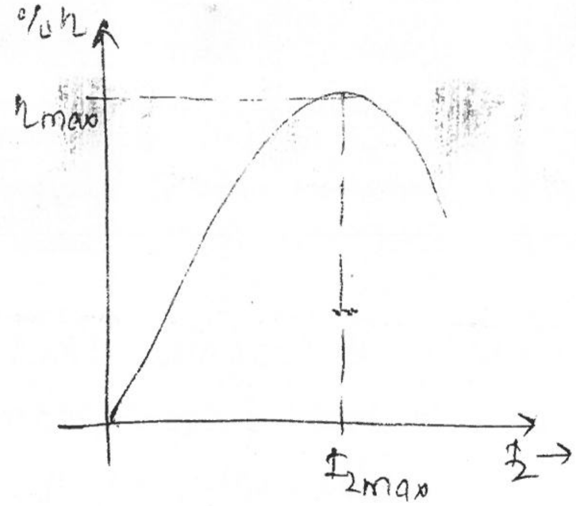


T3 547

Sumit Maheshwari

Condition for maximum efficiency :-

Transformer works on constant input voltage & freq. the η efficiency varies with the load. As load increases, η increases. And at certain load current, it attains max. value. & further increment in load draws more load current hence η decreases.



$$\frac{d\eta}{dI_2} = 0 = \frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}}\right]$$

$$= \frac{\left[V_2 I_2 \cos\phi + P_i + I_2^2 R_{2e}\right] \cdot V_2 \cos\phi_2 - V_2 I_2 \cos\phi_2 \left[V_2 \cos\phi_2 + 2 I_2 R_e\right]}{\left[V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{2e}\right]^2} = 0$$

$$= V_2^2 I_2 \cos^2\phi_2 + P_i V_2 \cos\phi_2 + I_2^2 R_{2e} V_2 \cos\phi_2 - V_2^2 I_2 \cos^2\phi_2 - V_2 I_2 2 I_2 R_{2e} \cos\phi_2 = 0$$

$$\Rightarrow V_2 \cos\phi_2 \left[P_i - I_2^2 R_{2e}\right] = 0$$

$$\Rightarrow P_i = I_2^2 R_{2e} = P_{cu}$$

means condition for achieving max. efficiency is $\boxed{P_{cu\ loss} = P_{iron\ loss}}$

> **Load current I_{2m} at maximum efficiency :-**

$$I_{2max}^2 R_{2e} = P_i \Rightarrow I_{2m} = \sqrt{\frac{P_i}{R_{2e}}}$$

$$\frac{I_{2m}}{I_2(FL)} = \frac{1}{I_2(F.L)}\sqrt{\frac{P_i}{R_{2e}}} = \sqrt{\frac{P_i}{I_2^2(F.L)\,R_{2e}}}$$

$$\boxed{I_{2m} = I_2(F.L)\sqrt{\frac{P_i}{P_{cu}(FL)}}}$$

> **KVA supply at max. efficiency :-**

$$(KVA)_m = V_2 I_{2m} = V_2 I_2(FL)\sqrt{\frac{P_i}{P_{cu}(FL)}} = \boxed{KVA_{rated}\sqrt{\frac{P_i}{P_{cu}}}}$$

so, $\% \eta = \dfrac{V_2 I_{2m} \cos\phi_2}{V_2 I_2 \cos\phi_2 + 2P_i} \times 100$

$$\boxed{\% \eta = \frac{(KVA)_{\eta max} \cos\phi_2}{(KVA)_{\eta max} \cos\phi_2 + 2P_i} \times 100}$$

Q^n:- A 500 KVA T/F has an iron loss 500 W & full load copper loss of 600 W. Calculate η at 3/4th full load & .8 p.f. Also calculate the η_{max} at that p.f.

Sol^n:-

$$\% \eta = \frac{n\,(KVA\ rating) \cos\phi}{n\,(KVA\ rating) \cos\phi + P_i + n^2 P_{cu}(F.L)} \times 100$$

$$= \frac{.75 \times 500 \times .8 \times 10^3}{.75 \times 500 \times 10^3 \times .8 + 500 + (.75)^2 \times 600} \times 100$$

$$= 99.7216\%$$

$$(KVA)_{for\ \eta max} = (KVA)_{F.L} \times \sqrt{\frac{P_i}{P_{cu}(FL)}} = 500 \sqrt{\frac{500}{600}}$$

$$= 456.435\ KVA$$

$$\% \eta = \frac{456.435 \times 10^3 \times .8}{456.435 \times 10^3 \times .8 + 500 + 500} = 99.7268\%$$

Q^n:- A 1-ϕ T/F on full load has an impedence drop of 20 V and Resistance drop of 10 V. Calculate the p.f when the regulation will be zero.

Sol^n:- $E_2 = V_2$ at zero voltage regulation

$I_1 Z_{1e} = 20$, $I_1 R_{1e} = 10$ then

$$I_1 X_{1e} = \sqrt{(20)^2 - (10)^2} = 17.32$$

$$\phi = \tan^{-1}\left[\frac{I_1 R_{1e}}{I_1 X_{1e}}\right] = \tan^{-1}\left[\frac{10}{17.32}\right]$$

$$\phi = 30°$$

$$\boxed{\cos 30° = .866\ \text{leading}}$$

$\eta = 98.77\%$ of 400KVA T/F, when delevering full load of ·8 p.f and $\eta = 99.13$ at half load unity p.f.

Calculate ① Iron loss ② Full load Cu loss

Soln:- At full load at ·8 p.f.

$$\eta = \frac{(\text{KVA rating})\cos\phi}{(\text{KVA rating})\cos\phi + P_i + P_{cu}} \times 100$$

$$\frac{98.77}{100} = \frac{400 \times 10^3 \times .8}{400 \times 10^3 \times .8 + (P_i + P_{cu})}$$

$$P_i + P_{cu(FL)} = 3985W \quad \text{—①}$$

At half power unity p.f

$$\eta = 99.13 = \frac{400 \times 10^3 \times 1 \times \frac{1}{2} \times 100}{\frac{1}{2} \times 400 \times 10^3 + P_i + \left(\frac{1}{2}\right)^2 P_{cu(HL)}}$$

$$P_i + \frac{P_{cu(HL)}}{4} = 1755.2W \quad \text{—②}$$

Solve ① & ② ∴ $P_{cu} = 2973W$ & $P_i = 1012W$ Answers.

Qn:- A 40KVA T/F has a core losses of 400 watts and full load cu loss of 800 watts, If load pf is ·9 lagging

① The full load efficiency &

② % of full load at which max. efficiency occurs.

Answer:- KVA = 40 , $P_i = 40$, $P_{cu} = 800W$, $\cos\phi = .9$

$$\eta = \frac{(\text{KVA rating}) \times 10^3 \cos\phi}{(\text{KVA rating}) \times 10^3 \cos\phi + P_i + P_{cu}}$$

$$= \frac{40 \times 10^3 \times .9}{40 \times 10^3 \times .9 + 400 + 800} = 96.77\%$$

Calculate load at max. efficiency

$$\text{KVA for max. efficiency} = \text{Full load KVA} \times \sqrt{\frac{P_i}{P_{cu}}}$$

$$= 4\sqrt{\frac{400}{800}} = 28.28 \text{ KVA}$$

Qn:- Calculate the Regulation of a T/F in which ohmic drop is 1% and reactance drop is 5% of the voltage if p.f are (i) ·8 lagging pf (ii) ·8 leading pf.

| $\cos\phi = \cdot 8$ then $\sin\phi = \cdot 6$

Soln:- $\% R = \dfrac{I_2 R_{2e}\cos\phi \pm I_2 X_{2e}\sin\phi}{V_2} \times 100$

$= \left[\dfrac{I_2 R_{2e}}{V_2}\cos\phi \pm \dfrac{I_2 X_{2e}}{V_2}\sin\phi\right] \times 100$

$= \left[\text{pu resistance}(\cos\phi) \pm \text{pu reactance}(\sin\phi)\right] \times 100$

$= \left[\dfrac{1}{100}\cos\phi \pm \dfrac{5}{100}\sin\phi\right] \times 100$

(i) When $\cos\phi = \cdot 8$ lagging → Assume +ive sign

$\% R = [1 \times \cdot 8 + 5 \times \cdot 6] = 3.8\%$

(ii) When $\cos\phi = \cdot 8$ leading → Take -ive sign

$\% R = [1 \times \cdot 8 - 5 \times \cdot 6] = -2.2\%$ Answer -

Qn:- A 1φ T/F delivers 10 A, 220V to a resistive load while the primary draws 6 A at ·9 lagging pf from 450 V, 50 Hz supply, K = ·5. Calculate η efficiency & voltage regulation %R = ?

Soln:- (i) $\eta = \dfrac{V_2 I_2 \cos\phi_2}{V_1 I_1 \cos\phi_1}$

[∵ Load is Resistive then $\cos\phi_2 = 1$
∵ pri. is inductive then $\cos\phi_1 = \cdot 9$]

$= \dfrac{220 \times 10 \times 1}{450 \times 6 \times \cdot 9}$

$= \dfrac{2200}{2430} = \cdot 9053$ or $90 \cdot 53\%$

(ii) $\% R = \dfrac{E_2 - V_2}{V_2} \times 100$

[$\dfrac{E_2}{E_1} = \dfrac{N_2}{N_1} = 2$
$E_2 = \cdot 5 \times E_1$
$= \cdot 5 \times 450 = 225V$]

$= \dfrac{225 - 220}{220} \times 100$

$\boxed{\% R = 2.27\%}$

Qn :- A 20KVA, 440/220V, 1φ T/F, 50Hz has $P_e = 324W$, $P_{cu} = 100W$ at half load current, Determine —

(i) η at full load current .8 lagging pf

(ii) % full load load KVA when η will be max.

Soln :-

(i) Output at .8 lagging pf $= 20 \times 10^3 \times .8$

$= 16\ KW$

$$(P_{cu})_{1/2\ load} = (n)^2 (P_{cu})_{F.L} \qquad n = \tfrac{1}{2}$$

$$100 \times 4 = (P_{cu})_{F.L} = 400W = .4KW$$

$$P_i = 324W = .324KW$$

$$\text{Total losses} = = .724KW$$

$$\eta \text{ at full load .8 lagging pf} = \frac{\text{output}}{O/T + T.Losses} \times 100 = \frac{16}{16 + .724} \times 100 = 95.67\%$$

(ii)

$$KVA \text{ at max } \eta = (KVA)_{F.L} \sqrt{\frac{P_i}{P_{cu(FL)}}}$$

$$= (KVA)_{FL} \sqrt{\frac{324}{400}} = (KVA)_{F.L} \times .9$$

Efficiency max. at 90% full load KVA....

Qn :- A 25 KVA, 2200/220V, 1φ T/F has Pri. resistance & sec. resistance are 1Ω & .01Ω respectively. Find full load efficiency at .8 pf if iron losses in T/F is 200W.

Soln :-

$$(I_2)_{FL} = \frac{25 \times 10^3}{220} = 133.6A$$

$$R_{2e} = R_2 + k^2 R_1 = .01 + \left(\frac{220}{2200}\right)^2 \times 1 = .02\Omega$$

$$\text{Cu loss } (P_{cu\ F.L}) = (I^2_{2\ F.L}) R_{2e} = (113.6)^2 \times .02 = 258W$$

Total losses $= 258 + 200 = .458\ KW$

$$\text{Full load efficiency} = \frac{25 \times .8}{25 \times .8 + .458} \times 100 = 97.68$$

Qn :- A 600 KVA, 1ϕ T/F when works at unity pf has 92% efficiency at full load & also at half full-load. Determine η at unity pf and 60% of full load.

Soln :- There is same efficiency at two different loading condition, so we calculate P_{cu}, & P_i

At Full load

$\rightarrow$ output $= 600 \times 1 = 600 KW$

$\rightarrow \eta = \frac{output}{input}$ then input $= \frac{600}{.92} = 652.2 KW$

$\rightarrow$ Total FL loss $= 652.2 - 600 = 52.2 KW$

$P_i + P_{cu FL} = 52.2 KW$ —— (1)

At half load output $= 300 KW$

input $= 300/.92 = 326.1$

$P_i + \left(\frac{1}{2}\right)^2 P_{cu} = 326.1 - 300 = 26.1 KW$ —— (2)

Eq (1) & (2) $\boxed{P_c = 34.8 KW, \ P_i = 17.4 KW}$

Efficiency at 60% full-load $= \frac{.6 \times 600 \times 1}{.6 \times 600 \times 1 + 17.4 + (.6)^2 \times 34.8} \times 100$

$\boxed{\eta \text{ at } 60\% \text{ full-load} = 96.3\%}$

Qn :- A 400 KVA T/F has $P_i = 2 KW$ & max. efficiency occured at .8 p.f when load is 240 KW. Calculate

(i) max efficiency at unity pf

(ii) efficiency on full-load at .71 pf lagging.

Soln :- KVA at max. efficiency $= \frac{240 KW}{.8} = 300 KVA$

& at max. efficiency $\boxed{P_i = P_{cu}}$

(i) then η at unity pf $= \frac{300 \times 1}{300 \times 1 + 2 + 2} \times 100 = 98.6\%$

(ii) $P_i = 2 KW$, $P_{cu FL} = \left(\frac{400}{300}\right)^2 \times 2 = 3.55 KW$

$\eta_{\text{at } .71 \text{ pf}} = \frac{400 \times .71}{400 \times .71 + 2 + 3.55} \times 100 = 98\%$

Ans

Indirect Loading Tests of T/F   T-3 / I Sem

AIM:- To calculate efficiency and regulation on any given load condition and at any power factor can be predetermined by such tests w/o actual load testing. That's why we can save power losses during actual load tests & results are effective in Indirect loading Tests which are –

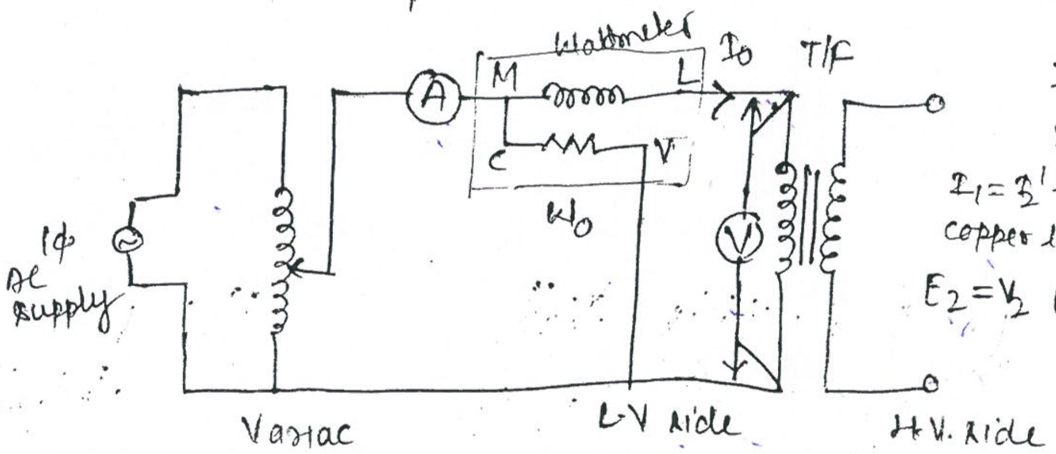
(i) Open circuit Test (O.C. test)

(ii) Short circuit Test (S.C. test)

<Auto transformer>

Open Circuit Test :- (Iron loss determination) <Constant for all loads>

- Transformer primary side (L.V side) is connected to a a.c. supply through ammeter, wattmeter and variac.
  - W → input power
  - A → input current
  - V → rated pri. voltage
- Transformer secondary side (H.V. side) is kept open. Sometime very high resistance is applied at sec.; here secondary is treated as open.



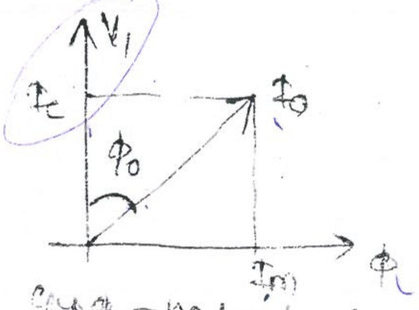
$I_2 = 0$ hence $I_2' = 0$ &

$I_1 = I_2' + I_0 = I_0$ hence copper loss are very ≅ low

$E_2 = V_2$ (open)

* By Primary side, we observed pri. side rated values.

V_0 (Volt)	I_0 (amp)	W_0 (watts)
Rated		



$\cos\phi_0$ – no load p.f.

* When sec. is open, T/F is on no load

$I_m = I_0 \sin\phi_0$, $I_c = I_0 \cos\phi_0$

$\boxed{W_0 = V_0 I_0 \cos\phi_0 = P_i = \text{iron loss}}$

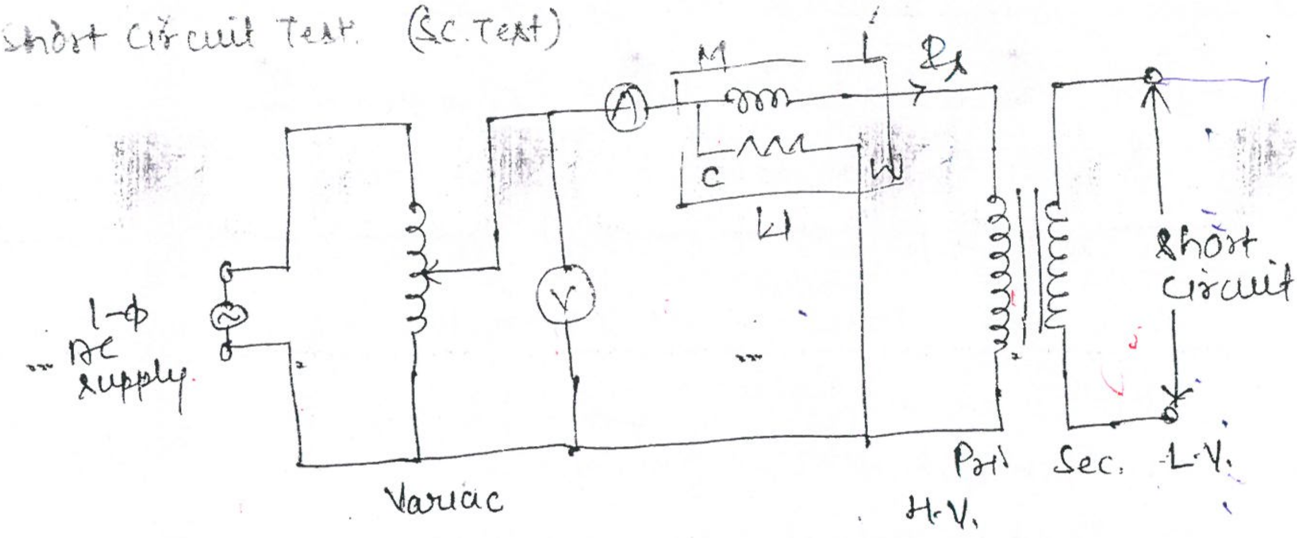
$I_c = I_0 \cos\phi_0$

$I_m = I_0 \sin\phi_0$

* Now we can calculate

$R_0 = \frac{V_0}{I_c}$ & $X_0 = \frac{V_0}{I_m}$

(2) Short Circuit Test (S.C. Test)



- Primary wdg is connected to ac supply 1-ϕ through variac, voltmeter, ammeter, and wattmeter.
- The sec. is short circuited by thick copper wire. We know high voltage side is always low current side.

~~That's~~ Then why →? H.V. side – pri. side (supply side)
L.V. side – sec. side (shorted side)

- For shorting sec. side, very-2 low resistance connect which draws very large current. Due to very large current, overheating and burning of T/F may happened. To limit this large short circuit current, primary is supplied to very Low voltage ~~side~~ & adjusted by variac. Hence it's also termed as low voltage test.

- pri. side – applied voltage is low & iron losses are fn of applied voltage. i.e iron losses are very-2 small.

-

V_{sc} (volt)	I_{sc} (A)	W_{sc} (watts)
	Rated	

- sec. side experienced rated current i.e we get total full load copper losses.

$W_{sc} = (P_{cu})_{losses\ F.L} = V_{sc} I_{sc} \cos\phi_{sc} = I_{sc}^2 R_{1e}$

$\boxed{\cos\phi_{sc} = \frac{W_{sc}}{V_{sc} I_{sc}}}$ then $\boxed{R_{1e} = \frac{W_{sc}}{I_{sc}^2}}$

$\boxed{Z_{1e} = \frac{V_{sc}}{I_{sc}} = \sqrt{R_{1e}^2 + X_{1e}^2}}$ ⇒ $\boxed{X_{1e} = \sqrt{Z_{1e}^2 - R_{1e}^2}}$

→ Efficiency Calculation from O.C. & S.C tests :-

(1) from O.C $W_0 = P_i$

from S.C. $W_{sc} = P_{cu}\,(F.L)$

& We know

$$\eta\% = \frac{V_2 (I_2)_{F.L} \cos\phi}{V_2 (I_2)_{FL} \cos\phi + W_0 + W_{sc}} \times 100$$

means for any given p.f $\cos\phi$, we determined the efficiency.

(2) For fractional load

$$\%\eta = \frac{n V_2 I_2 \cos\phi}{n V_2 I_2 \cos\phi + W_0 + n^2 W_{sc}} \times 100$$

⇒ Regulation Calculation is determined as before

$$\% R = \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100$$

referred to pri. side

$$\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$$

referred to sec. side

I_1, I_2 are rated current at full load & V_1, V_2 are rated voltage.

If load is in fraction then

$$I_1 = n (I_1)_{FL}$$

$$I_2 = n (I_2)_{F.L.}$$

Q. A 250 kVA, 1φ T/F has 98.135% efficiency at full load & p.f. is .8 lagging. The efficiency, at half load & p.f. is .8 lagging, is 97.751%. Calculate Iron loss & Cu loss.

Soln.- Total output power at full load (Real Power) $= 250 \times 10^3 \times .8$
$= 200 \times 10^3$ watt

For Full load

$$\eta\% = \frac{\text{Output Power}}{\text{Input Power}}$$

$$\text{Input Power} = \frac{200 \times 10^3}{.98135}$$

$$\therefore \text{total loss} = \text{Input} - \text{Output} = \frac{200 \times 10^3}{.98135} - 200 \times 10^3$$
$$= 3800.88\,W$$

$$\therefore \Rightarrow \boxed{P_i + P_{cu} = 3800.88} \longrightarrow (1)$$

similarly, Total output power at half ~~full~~ load (Real power) $= n \times 200 \times 10^3$
For half load
$$= .5 \times 200 \times 10^3$$
$$= 100 \times 10^3 \text{ watt}$$

$$\text{Input power} = \frac{100 \times 10^3}{\eta \text{ at half load}} = \frac{100 \times 10^3}{.97751}$$

$$\text{Total losses} = \text{Input} - \text{Output} = \frac{100 \times 10^3}{.97751} - 100 \times 10^3$$

$$\boxed{P_i + n^2 P_{cu} = 2300.74\,W}$$

$$\boxed{P_i + (.5)^2 P_{cu} = 2300.74} \longrightarrow (2)$$

solve (1) & (2)

&

$P_i = 2000.18$ watts

$P_{cu} = 1800.69$ watt

Q:- A 5KVA, 500/200 V, 50Hz, 1φ T/F give the following readings.

O.C. Test :- 500V, 1A, 50W (L.V. side),

S.C. Test :- 25V, 10A, 60W (L.V. side shorted)

Determine → (i) η at full load & lagging p.f.

(ii) η at 60% of full load & leading p.f

(iii) % Voltage Regulation on full load & leading p.f.

(iv) Draw equivalent circuit referred to pri. side with all elements.

Soln:- From O.C. Test

(Iron losses) no. load.

$I_1 = I_0 = 1A$, $W_0 = 50W$

$V_0 = 500V$

$\Rightarrow \cos\phi_0 = \dfrac{W_0}{V_0 I_0} = \dfrac{50}{500\times 1} = .1$

$\Rightarrow I_c = I_0 \cos\phi_0 = 1\times .1$

$\boxed{I_c = .1}$

$\Rightarrow I_m = I_0 \sin\phi_0 = 1\times .9949$

$\boxed{I_m = .9949}$

$\Rightarrow \boxed{P_i = W_0 = 50W}$

From S.C. Test

[Cu (f.L.) losses)

$V_{sc} = 25V$, I_{sc} (rated) $= 10A$

$\boxed{W_{sc} = 60W = P_{cu}(f.L)}$

$Z_{1e} = \dfrac{V_{sc}}{I_{sc}} = \dfrac{25}{10} = 2.5\Omega$

$\boxed{Z_{1e} = 2.5\Omega}$

$R_{1e} = \dfrac{W_{sc}}{I_{sc}^2} = \dfrac{60}{(10)^2}$

$\boxed{R_{1e} = .6\Omega}$

$X_{1e} = \sqrt{(2.5)^2 - (.6)^2}$

$\boxed{X_{1e} = 2.4269}\ \Omega$

$\boxed{(I_1)_{F.L} = I_{sc} = 10A}$

or $I_1(F.L) = \dfrac{VA\ rating}{V} = \dfrac{5\times 10^3}{500} = 10A$

(i) $\eta\% = \dfrac{(VA\ rating)\cos\phi_2}{\left[(VA)_{rating}\cos\phi_2 + P_i + P_{cu}(F.L)\right]}\times 100$

$= \dfrac{5\times 10^3 \times .8}{5\times 10^3\times .8 + 50 + 60}\times 100$

$= 97.32\%$

(ii) $\%\eta = \dfrac{n\,(VA)_{rating}\cos\phi_2}{n\,(VA)_{rating} + P_i + n^2 P_{cu}}\times 100 = \dfrac{.6\times 5\times 10^3\times .8}{.6\times 5\times 10^3 + 50 + (.6)^2\times 6}$

$= 97.103\%$

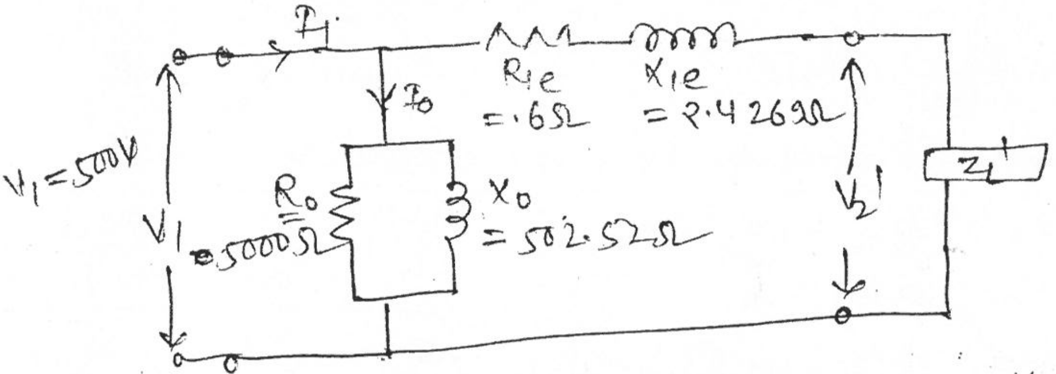
(iii) $\% R = ?$ leading

$$\% R = \frac{(I_1)_{FL} R_{1e} \cos\phi_2 - (I_{1FL}) X_{1e} \sin\phi_2}{V_1} \times 100$$

$$= \frac{10 \times .6 \times .8 - 10 \times 2.4269 \times .6}{500} \times 100$$

$$= -1.95\%$$

(iv) Equivalant circuit referred to pri. side



$$R_0 = \frac{V_1}{I_c} = \frac{500}{.1} = 5000\Omega \quad , \quad X_0 = \frac{V_1}{I_m} = \frac{500}{.9949} = 502.52\ \Omega$$

3n:- In no-load test 1-ϕ T/F , the following data were obtained:—

Pri. voltage : 200V, Sec. voltage : 110V .

Pri. current : ·5A , Power input : 30W , Resistance (pri.) = ·6Ω

Find:— (i) Turn ratio (ii) I_m magnetizing ~~current~~ component of no-load current

(iii) Iron loss (iv) I_w Iron loss component of no-load current

Soln:- (i) $\text{Turn ratio} = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{200}{110} = 2$

(ii) $I_m = I_0 \sin\phi_0$

$= .5 \times .962$

$= .48A$

& $W_0 = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \frac{30}{200 \times .5} = .273$

$\sin\phi_0 = .962$

(iv) $I_w = I_0 \cos\phi_0$.

$= .5 \times .273 = .365A$

(iii) Cu loss $= I_0^2 R_1 = (.5)^2 \times .6 = .15W$

Iron loss $= 30 - .15 = 29.85W$

Q :- A 10KVA, 200/400V, 50Hz 1φ-T/F give the following test results:

O.C. Test :- 200V, 1.3A, 120W, on L.V. side

S.C. Test :- 22V, 30A, 200W, on H.V side

Calculate :- (i) I_m, I_w, (ii) R_o, X_o, (iii) % R at .8 pf leading under supply F.L.

Soln :-

O.C. Test: LV side (pri. side)

$V_1 = 200V$, $I_o = 1.3A$, $W_o = 120W$

S.C. Test: H.V. side (sec side)

$I_{sc} = 30A$ (sec current)

$I_2(FL) = \frac{10 \times 10^3}{400} = 25A$

(i) $I_m = I_o \sin\phi_o$ —— ①

$I_w = I_o \cos\phi_o$ —— ②

$W_o = V_1 I_o \cos\phi_o$

$\cos\phi_o = \frac{120}{200 \times 1.3} = .462$

from eqn ② $I_w = 1.3 \times .462 = .6A$

from eqn ① $I_m = 1.3 \times .886 = 1.15A$

Ans.

(ii) $R_o = \frac{V_1}{I_w} = \frac{200}{.6} = 333\Omega$

$X_o = \frac{V_1}{I_m} = \frac{200}{1.15} = 174\Omega$

(iii) $Z_{02e} = \frac{22}{30} = .733\Omega$ $\left(\frac{V_{sc}}{I_{sc}}\right)$

$R_{02e} = \frac{W_{sc}}{I_{sc}^2} = \frac{200}{(30)^2} = .222$ Ans.

$X_{02e} = \sqrt{(.733)^2 - (.222)^2} = .698\Omega$ Ans.

FL on H.V. side = we know = 25A = I_2 fl

% R referred to sec side at leading pf $= I_2[R_{2e}\cos\phi_2 - X_{2e}\sin\phi_2] / V_2 \times 100$

$= 25[.222 \times .8 - .698 \times .6] / 400 \times 100$

$= -1.5\%$ Ans.

Q^n:- A 10 KVA, 200/400 V, 50 Hz, 1-φ T/F gave the following test results:-

O.C test : 200V, 1.3A, 120W — on L.V. side

S.C test : 22V, 30A, 200W — on H.V. side

Calculate : ① efficiency and sec. terminal voltage when supplying full load at ·8 leading power factor.

② Calculate the load at unity p.f corresponding to max. efficiency.

Solⁿ:- ① We calculate $\% \eta = \frac{output}{input} \times 100$

For leading p.f. & Voltage drop V_2

$V_2 = I_{2e}[R_{2e}\cos\phi_2 - X_{2e}\sin\phi_2]$

Input = output + losses

then output power (F.L) $= 10 \times 10^3 \cos\phi$ (Watt)

$= 10 \times 10^3 \times .8 = 8\,KW$

→ We'll find cu loss, Iron loss

O.C. test gives Iron loss = 120W = ·12 KW = P_i

S.C test gives cu loss but not full load $W_{sc} = 200W$

$I_{2\,FL} = \frac{10 \times 10^3}{400} = 25A$ $\qquad I_{sc} = 30$

$\frac{I_{FL_2}}{I_{sc}} = n = \frac{25}{30} = \frac{5}{6}$

Full load cu loss $P_{cu_{FL}} = n^2 P_{sc} = \left(5/6\right)^2 \times 200$

$= 140W = .14\,KW$

$(\text{Total Losses})_{F.L} = P_i + P_{cu_{F.L}} = .12 + .14 = .26$

$\eta\% = \frac{output}{output + losses} = \frac{8}{8 + .26} \times 100 = 96.85\%$

Voltage drop $= I_2[R_{2e}\cos\phi - X_{2e}\sin\phi] = -6V$ | means voltage rise due to leading p.f.

sec. voltage = 400 + 6 = 406V

(ii) KVA for max. efficiency $= F.L\,KVA \sqrt{\frac{P_i}{P_{cu\,F.L}}}$

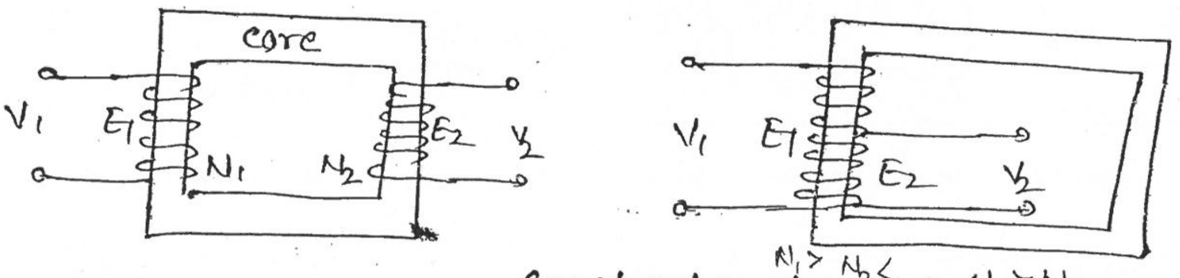
$= 10\sqrt{\frac{120}{140}} = 9.25\,KVA$

Load at unity p.f = 9.25 × 1 = 9.25 KW

Auto Transformer :-

* It's a special type of T/F which has only one winding only, wound over a closed magnetic circuit of low permeability i.e. Auto T/F is a single winding T/F of an iron core and a part of winding is common to both primary and secondary circuit.

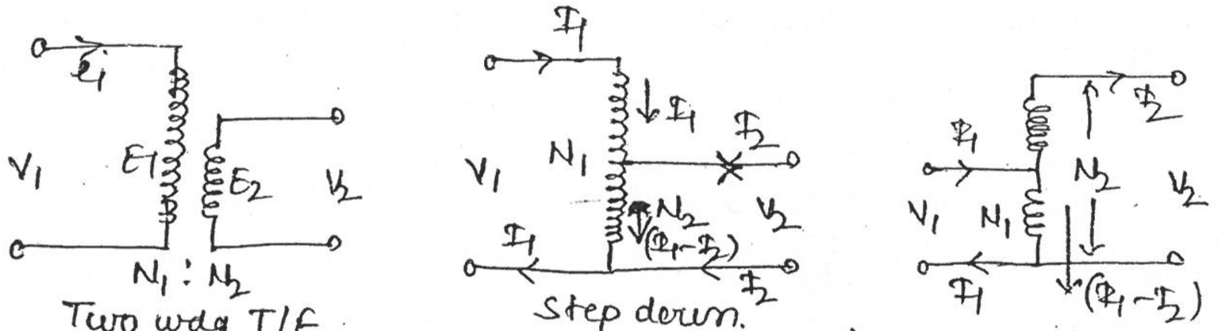
*



a) Two-winding transformer

Constructional View

b) Auto transformer



Two wdg T/F

Step down.

Auto T/F

Step Up

* Operating principle and construction of an auto T/F is same, but in 2-wdg T/F, pri. wdg are completely insulated to sec. wdg & magnetically coupled with a common core.

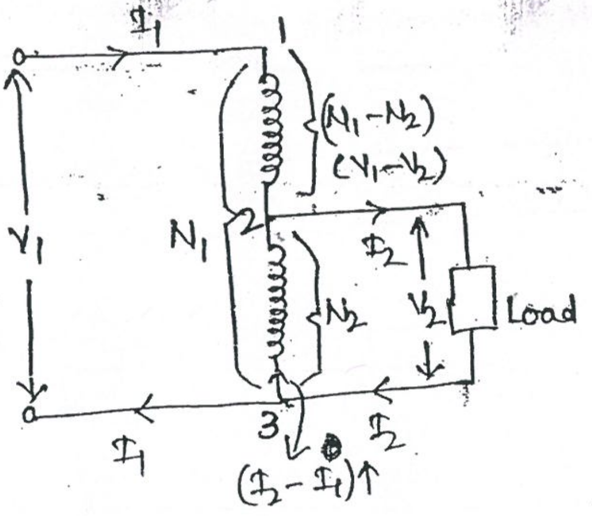
While, in auto T/F pri. & sec. wdg are inter-related to each other.

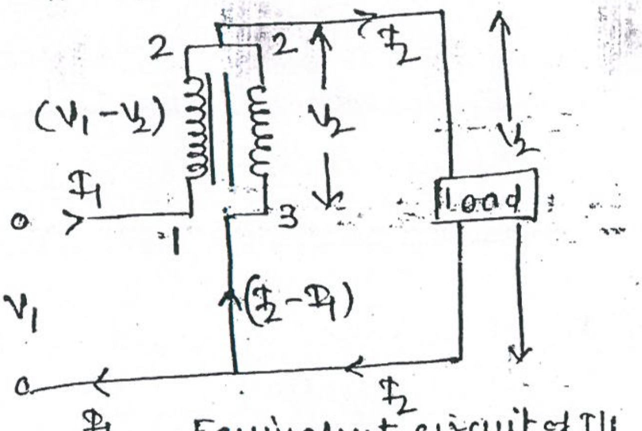
* Neglect the losses, leakage reactance & I_m then for Ideal T/F,

$$\boxed{\text{Transformation Ratio } K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}}$$

> Theory of Auto-transformer :-

→ Assume an Ideal step-down T/F on load





Equivalent circuit of T/F

$$\frac{V_2}{V_1-V_2} = \frac{N_2}{N_1-N_2}$$

$$(V_1-V_2)I_1 = (I_2-I_1)V_2$$

$$\Rightarrow V_1I_1 - V_2I_1 = I_2V_2 - I_1V_2$$

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

$$\Rightarrow V_2(N_1-N_2) = N_2(V_1-V_2)$$

$$\Rightarrow V_2N_1 - V_2N_2 = N_2V_1 - N_2V_2$$

$$\Rightarrow \boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1} = K}$$

> Copper Saving :-

* Weight of Cu required in wdg ∝ current × turns

→ 2-winding T/F : $W_{cu\,2w} \propto (I_1N_1 + I_2N_2)$

→ Auto 1-wdg T/F : W

for section 1-2 $\propto I_1(N_1-N_2)$

for section 2-3 $\propto (I_2-I_1)N_2$

⇒ Total $W_{cu\,auto\,T/F} \propto$

$$I_1(N_1-N_2) + N_2(I_2-I_1)$$

$$= I_1N_1 - I_1N_2 + N_2I_2 - I_1N_2$$

$$= I_1N_1 + I_2N_2 - 2I_1N_2$$

*Now Ratio ↦

$$\frac{\text{Weight of Cu in auto T/F } (W_a)}{\text{Weight of Cu in 2-wdg T/F } (W_o)} = \frac{I_1N_1 + I_2N_2 - 2I_1N_2}{(I_1N_1 + I_2N_2)}$$

$$= 1 - \frac{2I_1N_2}{(I_1N_1+I_2N_2)} = 1 - \frac{\cancel{2}I_1N_2}{\cancel{2}I_1N_1} \qquad \{\because I_1N_1 = I_2N_2$$

$$= 1 - \frac{N_2}{N_1} = 1 - K$$

$$\frac{W_a}{W_o} = (1-K) \Rightarrow \boxed{W_a = (1-K)W_o}$$

* Saving in Cu = Copper used in 2wdg T/F − Copper used in auto T/F $= W_o - W_a$

$= W_o - (1-K)W_o = KW_o$

$\boxed{\text{Saving in Cu} = K \times \text{wdg of Cu in 2wdg T/F}}$

> **Output**:- In Auto T/F, pri. & sec. are connected magnetically & electrically.

Magnetically connected ⟶ Transformer action

Electrically connected ⟶ conductively (Directly source to load)

Output Apparent Power $= V_2 I_2$

Inductively Apparent Power transferred $= V_2(I_2 - I_1)$

$= V_2 I_2 (1 - I_1/I_2) = V_2 I_2 (1-K)$

or $V_1 I_1 (1-K)$

* Power transferred inductively = Input × (1−K)
* Power transferred conductively = Input − Input (1−K)

= K Input. or K × output

> Note:- Advantage of auto T/F decreases as ratio of transformation increases. Therefore, an auto T/F has more advantageous at relative transformation ratio (near to 1).

> Comparison b/w 2wdg T/F & auto T/F.

S.N.	Parameter	2wdg T/F	Auto T/F
1	Winding	Pri. & sec.	A part of wdg is common.
2	Movable contact	Not	Yes
3	Types	Step-Up & Step-Down.	Step-UP & Step-Down.
4	Copper saving	None	Yes
5	Size	Large	Small
6	Cost	high	low
7	Efficiency	Low	high.
8	Regulation	Poor	Better.
9	Application	Power supply, Welding, Isolation, Main T/F.	Variac, starting of ac motor, dimmerstat
10	Maintenance cost	Low	High

- I.M. Induction Machine
- M/c - Machine

> Summery of Auto T/F

	Advantages	Disadvantages	Applications
1	Higher efficiency [Losses Reduced]	(1) No isolation b/w pri. & sec. wdg. Dangerous for H.V. application.	(1) Starting for I.M & Syn. M/c by using tapping
2	Better Voltage Regulation (Resistance Reduced)	(2) If common part of the wdg lost → O.Circuited then T/F action lost. Pri. voltage appear across the sec. → S.C. then large current will appear to sec. side.	(2) Used as balance coil to give 3-wire neutral.
3	Small size & weight	(3) High maintenance due to movable parts	(3) Used as boosters in ac feeders.
4	Easy Transportation		(4) Variac for lab.
5	Less Cu required		(5) Biggest Application - Regulating T/F
6	Low cost		(6) As dimmerstat in cinema hall to reduce the intensity of bulb
7	Required small exciting current.		

Q^n:- An auto T/F supplies a load of 2.5KW at 110V & at a power factor of unity. If the primary applied voltage is 220V. Calculate Power supplied to load-
(i) Inductively (ii) conductively. [Neglect losses]

Soln:-
$$K = \frac{110}{220} = .5$$

Neglect losses, then output = Input

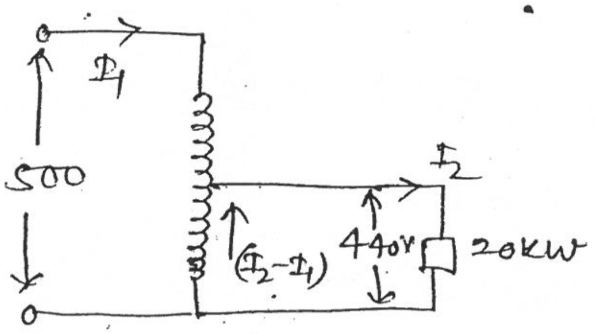
(i) Power T/F^ed inductively = input × (1−K)
$= 2.5 \times (1 - .5) = 1.25KW$

(ii) Power Transfered conductively = K × input = .5×2.5
$= 1.25KW$

* Q^n:- An auto T/F is used to transformer form 500V to 440V. The load is ~~5~~ 20 kW at unity power factor. Neglecting losses and magnetizing current, find the currents in various part of wdg.

Soln:- Step-UP auto T/F.

$$I_2 = \frac{20 \times 10^3}{440V}$$
$$= 45.45 \text{ Amp}$$



$$V_1 I_1 = V_2 I_2$$
$$I_1 = \frac{440}{500} \times 45.45 = 40A$$

$$(I_2 - I_1) = 45.45 - 40 = 5.45A$$

Q^n:- An auto T/F supplies a load of 5kW at 125V unity p.f & pri. voltage is 250V, determine-
(i) Transformer ratio $K = \frac{125}{250} = .5$
(ii) Sec. current $I_2 V_2 \cos\phi_2 = W_2 \Rightarrow I_2 = \frac{5 \times 10^3}{125 \times 1} = 40A$
(iii) Pri. current $I_1 = K I_2 = .5 \times 40 = 20A$
(iv) Power delevered inductively = $(1-K)\, I/P = (1-.5)\times 5 = 2.5KW$
(v) Power " conductively = K I/P

Characteristic of D.C. Compound motor :-

Compound Motor is capable of large power (torque) at ... is like series and ... on light or no condition.

Differential Compound motor

* This motor is not capable to generate large torque at low speeds, basically here speeds increases as load increases.

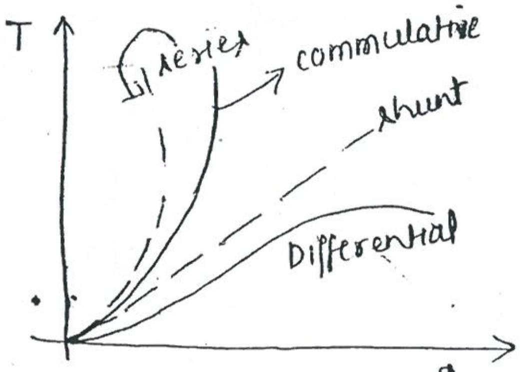
* Shunt field produce definite ... and series field help the ...unt field to increase the total flux level.

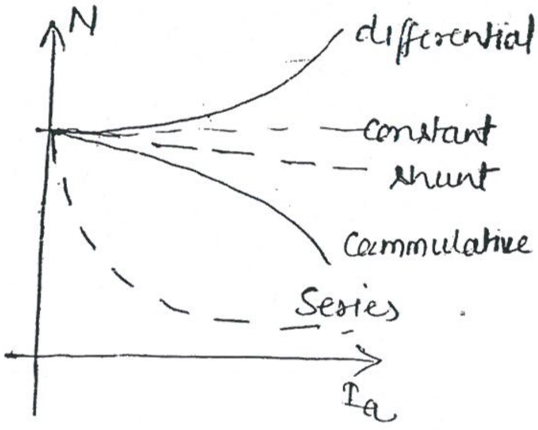
Actually exact shape of below characteristic depends upon shunt & series field wdg contribution.

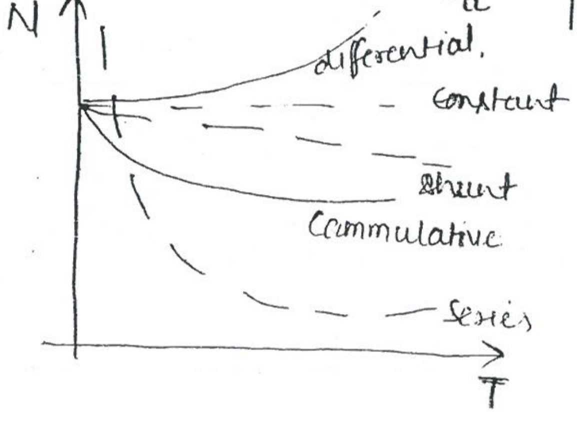
* Which wdg dominant, characteristics turns the corresponding ~~wdg~~ (series / shunt) machine ckticks.

* Two fluxes (shunt & series field wdg) opposes each other, then the resultant flux decreases as load increase, & i.e m/c runs at higher speed as load increase, which will dangerous at ~~high speed~~ full load. so this type of m/c practically is not used.

$N \propto \frac{(V - I_a R_a)}{\downarrow \phi}$







- 10KVA, 200/400V, 50Hz 1φ - T/F give the following test result

O.C :- 200V, 1.3A, 120W, on L.V. side

S.C test :- 22V, 30A, 200W, on H.V side

Calculate :- (i) I_m, I_w, (ii) R_0, X_0, (iii) % R at .8 pf leade under supply F.L.

1- O.C. Test: LV side (pri. side)

$V_1 = 200V$, $I_0 = 1.3A$, $W_0 = 120W$

S.C Test: H.V side (sec side)

$I_{sc} = 30A$ (sec current)

$I_2(FL) = \frac{10 \times 10^3}{400} = 25A$

(i) $I_m = I_0 \sin\phi_0$ — (1)

$I_w = I_0 \cos\phi_0$ — (2)

$W_0 = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \frac{120}{200 \times 1.3} = .462$

from eqn (2) $I_w = 1.3 \times .462 = .6A$

from eqn (1) $I_m = 1.3 \times .886 = 1.15A$

(ii) $R_0 = \frac{V_1}{I_w} = \frac{200}{.6} = 333\Omega$

$X_0 = \frac{V_1}{I_m} = \frac{200}{1.15} = 174\Omega$

(iii) $Z_{02e} = \frac{22}{30} = .733\Omega \left(\frac{V_{sc}}{I_{sc}}\right)$

$R_{02e} = \frac{W_{sc}}{I_{sc}^2} = \frac{200}{(30)^2} = .222$

$X_{02e} = \sqrt{(.733)^2 - (.222)^2} = .698\Omega$

FL on H.V. side = we know = 25A = I_2 fl

% R referred to sec. side at leading p.f. $= I_2[R_{2e}\cos\phi_2 - X_{2e}\sin\phi_2] / V_2 \times 100$

$= 25[.222 \times .8 - .698 \times .6] / 400 \times 100$

$= -1.5\%$

Q^n:- A 10 KVA, 200/400 V, 50 Hz, 1-ϕ T/F gave the following test results:-

O.C test : 200V, 1.3A, 120W — on L.V. side

S.C test : 22V, 30A, 200W — on H.V. side

Calculate : ① efficiency and sec. terminal voltage when supplying full load at .8 leading power factor.

② Calculate the load at unity p.f corresponding to max. efficiency.

Soln:- ① We calculate $\%\eta = \frac{\text{output}}{\text{input}} \times 100$

For leading p.f. & Voltage drop V_2

$V_2 = I_{2e}[R_{2e}\cos\phi_2 - X_{2e}\sin\phi$

Input = output + losses

then output power (F.L) = $10 \times 10^3 \cos\phi$ (watt)

$= 10 \times 10^3 \times .8 = 8\,kW$

→ We'll find cu loss, Iron loss

O.C. test gives Iron loss = 120W = .12 kW = P_i

S.C test gives cu loss but not full load $W_{sc} = 200W$

$I_{2fl} = \frac{10 \times 10^3}{400} = 25A$ $\qquad I_{sc} = 30$

$\frac{I_{fl_2}}{I_{sc}} = n = \frac{25}{30} = \frac{5}{6}$

Full load cu loss $P_{cu_{FL}} = n^2 P_{sc} = (5/6)^2 \times 200$

$= 140W = .14\,kW$

$(\text{Total Losses})_{F.L} = P_i + P_{cu_{F.L}} = .12 + .14 = .26$

$\eta\,\% = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{8}{8 + .26} \times 100 = 96.85\%$

Voltage drop $= I_2[R_{2e}\cos\phi - X_{2e}\sin\phi] = -6V$ | means voltage rise due to leading p.f.

sec. voltage = 400 + 6 = 406V

(ii) KVA for max. efficiency $= \text{F.L KVA}\sqrt{\frac{P_i'}{P_{cu\,FL}}}$

$= 10\sqrt{\frac{120}{140}} = 9.25\,KVA$

Load at unity p.f = $9.25 \times 1 = 9.25\,kW$