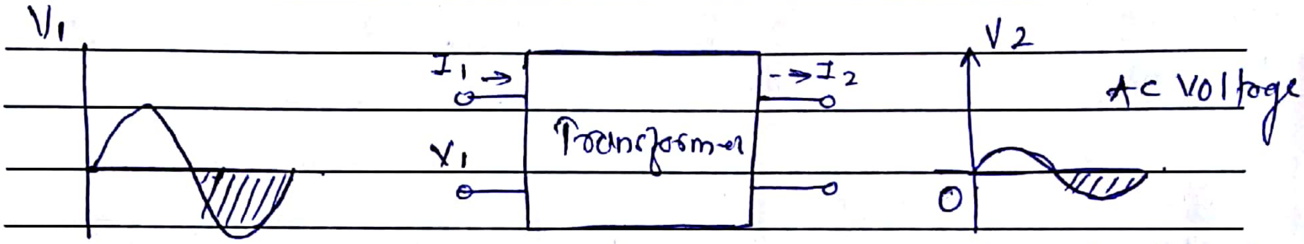
Single phase Transformer:

The transformer is a static device (i.e the one which does not contain any rotating or moving parts) which is used to transfer electrical energy from one ac circuit to another ac circuit. with increases or decreases in voltage / current but without any changes in frequency.



Voltage level has been changed, but there is no change in frequency.

It is important to remember that input to transformer and output from a transformer both are alternating (AC) quantities.

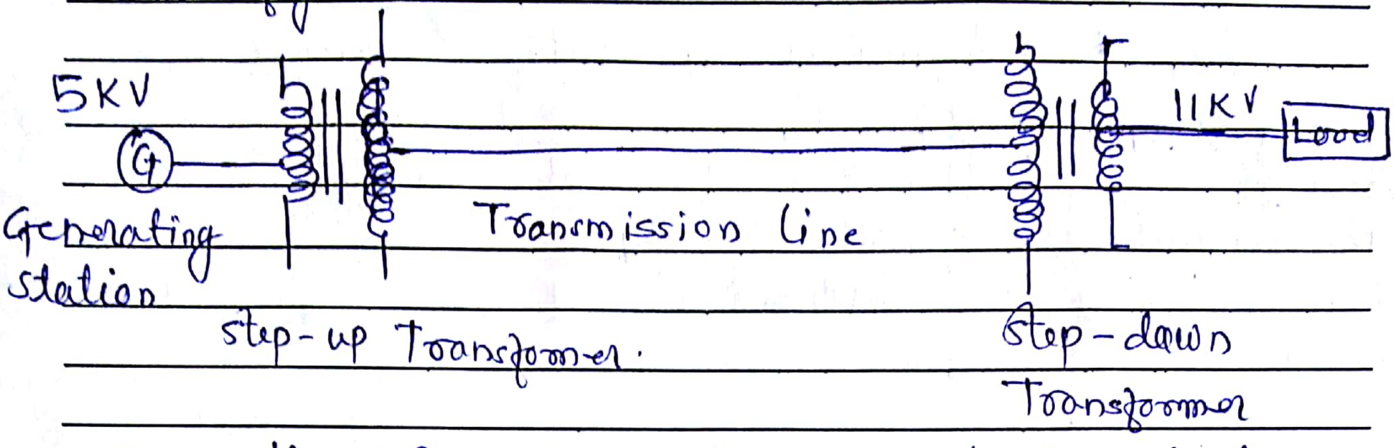
What is the use of transformer.

The electrical energy is generated & transmitted at extremely high voltage. The voltage is to be then reduced to a lower value for its domestic & industrial use.

This is done by using Transformer. thus it is possible to reduce the voltage level using transformer (then the transformer is called as step down transformer)

On the other hand we can also use the transformer to increase the voltage level (step-up transformer)

The power transmission system using transformer is shown fig



When the T/F changes the voltage level, it changes the current level also.

Types of transformer:
Transformer are designed for either single phase or three-phase supply, According they are called as 1 ϕ T/f or 3 ϕ T/f
However the principle of operation for both the types is same.

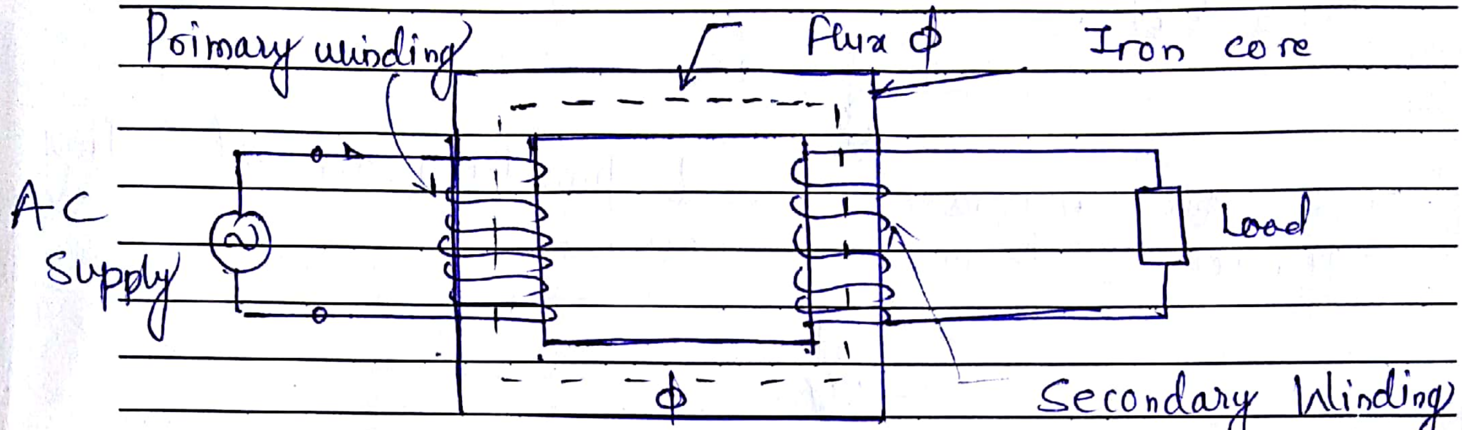
Principle of Operation :-

The construction of 1ϕ T/f is as shown in fig.

It consist of two highly inductive coils (windings) wound on an iron or steel core.

The winding (coils) connected to the ac supply called as primary winding whereas the other one is called as the secondary winding.

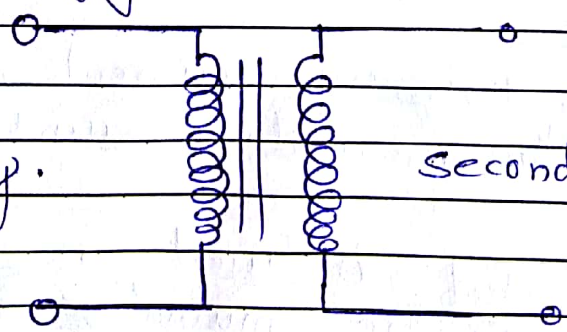
The AC supply is connected to primary winding whereas the load is connected to the secondary winding.



Flux produced due to current flowing through primary winding.

The primary & secondary windings are isolated from each other as well as from the iron core. Thus there is absolutely no physical connection betn the primary winding & secondary winding.

The symbolic representation of the transformer is shown in fig.



Symbol of Transformer.

Subject:

Name of Faculty:

Operating Principle of a T/F.

1. As soon as the primary is connected to the 1-ϕ A.C supply, an AC current starts flowing through it.

↓

2. The A.C primary current produces an alternating fluxes ϕ in the core.

↓

3. Most of this changing flux gets linked with the secondary winding through the core.

↓

4. The varying flux will induce voltage into the secondary winding according to the 'Faraday's laws of electromagnetic Induction.

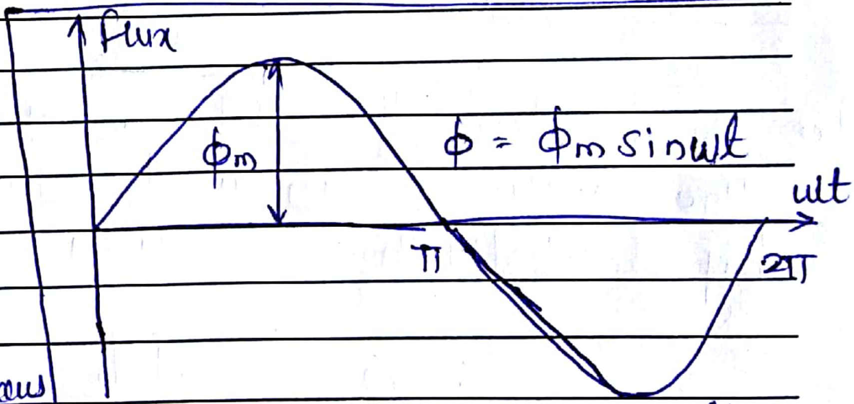
Thus due to primary current, there is an induced Voltage in the secondary winding due to mutual Induction.
Hence the emf induced in the secondary is called as the mutually Induced EMF.

Can the Transformer Operate on D.C?

- The answer is No.
The transformer action does not take place with a direct current of constant magnitude Because with a DC primary current the flux produced in the core is not alternating but it is of constant value.

- As there is no change in the flux linkage with the secondary winding the induced emf in the secondary winding is zero.

EMF Equation of a Transformer.



Variation of the flux with time

let's

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

ϕ = flux in weber.

ϕ_m = Max value of Instantaneous flux

$\omega = 2\pi f$ where 'f' is frequency of the flux waveform

To obtain the induced voltage in T/F. followed the following steps.

Step-1 Write the expression for the Instantaneous flux ϕ

Step-2 - obtain the expression for the induced voltage $e = -N \frac{d\phi}{dt}$

Step-3: Calculate the Maximum value of "e" per turn.

Step-4: Obtain the RMS value of "e" per turn.

Step 5: Multiply "e" per turn by the number of turns N_1 or N_2 to get the expression for E_1 & E_2

Step-1 $\phi = \phi_m \sin\omega t$

ϕ_m = Maximum value of the instantaneous flux

$\omega = 2\pi f$

Step-2 Obtain the Expression for Induced Voltage according to Faradays laws of electromagnetic Induction

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

Step-3 Obtain the Max. value of "e" per turn. The value of induced emf per turn can be obtained by substituting $N = 1$

$$\therefore e = -\frac{d\phi}{dt} \quad ; \quad as\ \phi = \phi_m \sin\omega t$$

$$e = -\frac{d}{dt}[\phi_m \sin\omega t]$$

$$e = [\text{illegible}] \quad -\phi_m \omega \cdot \cos\omega t$$

The Max. value of induced voltage per turn is given by substituting $\cos\omega t = \pm 1$

$$e_{max} = \omega\phi_m = 2\pi f \phi_m \text{ Volts.}$$

* Voltage Transformation Ratio (K)

$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K = \frac{I_1}{I_2}.$$

It is the ratio of secondary emf to primary emf (E_1)
or It is the ratio of primary winding current (I_1) to secondary winding current (I_2)

* Rating of Transformer.

Q. Why the rating of transformer in (Volt - Ampere) or (KVA)

→ Generally the rating of machine should indicate the power supplied by it. But in case of transformer, the output power is not constant.

- It's keeps changing with the load, the output power factor is also a function of load.
- also the losses in transformer is only depend on Voltage & current quantity. ($P_i \propto V$) & ($P_{cu} \propto I^2$)
- Hence the rating of T/F is expressed in terms of Voltage & current.

Rating of transformer :-	=	Primary Voltage × Primary current
or	=	secondary Voltage × secondary current.

as the Voltage & current may (or) may not be in phase, the units of transformer rating are Volt Ampere (VA) or KVA.

$$VA \text{ or } KVA = V_1 \cdot I_1 = V_2 I_2.$$

Hence $\boxed{I_1 = \frac{KVA \times 10^3}{V_1}}$ Amp $\boxed{I_2 = \frac{KVA \times 10^3}{V_2}}$ Amp.

If rating is specified in MVA, then the multiplying factor will be 10^6 rather than 10^3

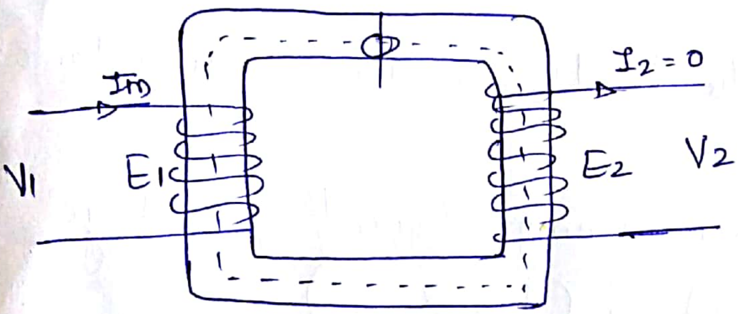
Ideal Transformer

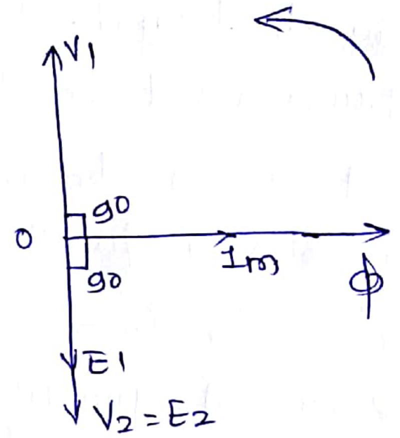
An Ideal T/F is one that has

1. No winding Resistances $(R_1 \& R_2) = 0$
2. No leakage flux ie the same flux links both the winding $(X_1 \& X_2) = 0$
3. No Iron losses $P_i = 0$ (eddy current loss & hysteresis loss) $= 0$

* Also as Ideal transformer (With No load) $I_2 = 0$

$\boxed{V_1 = E_1}$ & $\boxed{V_2 = E_2}$ ∴ No Vtg drops as $(R_1 \& R_2) = 0$





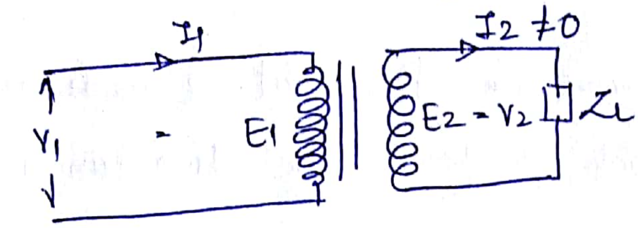
Consider an Ideal T/F on No load; i.e secondary is open circuited

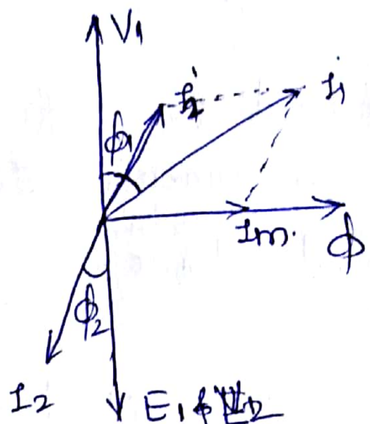
1. under such condⁿ; the primary is simply a coil of pure inductance
2. When alternating Voltage V_1 is applied to the primary winding; it draws small magnetizing current I_m. Which lags behind the V_1 by 90°.
3. This alternating current (I_m) produces an alternating flux (ϕ) which proportional to and in phase with it.
4. The alternating flux ϕ links both the winding & induces emf E_1 in the primary winding & EMF E_2 in secondary
5. The primary emf (E_1) is at every instant; equal to & in phase opposition to V_1 (Lenz's law)

(6) Both emf (E_1 & E_2) lags behind flux (ϕ) by 90°

(7) Note E_1 & E_2 are in phase - but ($E_1 = V_1$) & 180° out of phase with it

* Ideal transformer with load ($I_2 \neq 0$)





For lagging load

$I_W = 0$ as there is no P_i

Practical Transformer

The major difference betn the ideal & practical T/F is that we have to take into account various 'losses'. Some of losses taking place in the practical T/F are as follows

(1) Hysteresis loss
(2) Eddy current loss
(3) Iron Losses
(4) copper losses taking place in

When the practical T/F is on No load, the secondary current will be zero, Hence the copper loss in the secondary winding is zero

However a small primary current does flow under the No load condition. Due to the small primary resistance, a small primary copper loss take place even at No load.

The primary current under No load condition has to supply the iron losses (hysteresis loss & Eddy current loss) & small primary copper loss.

The primary current under the No load condition is denoted by I_0.

The (I_0) No load current has two component current.

① To magnetize the core i.e to produce the flux ϕ (I_m)

② To supply for the total losses under No load condition. (I_w)

The No load primary current I_0, can be thought of made up of two components I_m & I_w which perform the two function mentioned above.

No load Primary current I_0

- Magnetizing component (I_m) current.
  - This component magnetizes the core ie; produces flux
- Active component (I_w) current
  - This component supplies the total losses at No load.

* Magnetizing component (I_m)

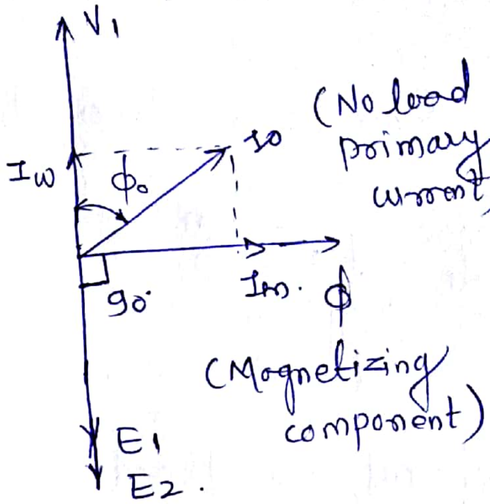
- This is the purely reactive component of No load current I_0. It magnetizes the core & produces flux in the core.
- This component is at 90° with respect to E_1 as shown in phasor diagram.
- This component (I_m) is also called as Wattless component

* Active Component current (I_w)

- The active component (I_w) is the component of No load current I_0; Its job is to supply the total loss under No load condⁿ
- It is therefore called as the power component (or) core loss component of I_0; It is at 90° with respect to the magnetizing current I_m as shown in fig.

Phasor Diagram of Practical Transformer on (No Load)

* The two component I_m & I_w are 90° phase shifted with respect to each other & I_0 is the resultant of the two.



Hence the total No load current I_0 is the phasor addition of I_w & I_m.

$\therefore \vec{I_0} = \vec{I_w} + \vec{I_m}$

$$\boxed{I_0 = \sqrt{I_m^2 + I_w^2}} \text{ Amp.}$$

In the practical T/F; the No load current I_0 does not have 90° phase shift with respect to V_1, but now it lags V_1 by an angle ϕ_0 which is smaller than 90°

No load Power factor = $\cos\phi_0$

From the phasor diagram; $I_m = I_0 \sin\phi_0$ (I_m lags V_1 by 90°)

$\therefore$ core loss component $I_w = I_0 \cos\phi_0$ (I_w in phase with V_1)

The Magnitude of No load primary current

$$\boxed{I_0 = \sqrt{I_w^2 + I_m^2}}$$

& No load power factor angle ϕ_0 is given by $\phi_0 = \tan^{-1}[I_m/I_w]$

The total power input on No load is denoted by $P_i = V_1 I_0 \cos\phi_0$

but $I_w = I_0 \cos\phi_0$

Hence $P_i = \text{Iron loss} = V_1 I_w$

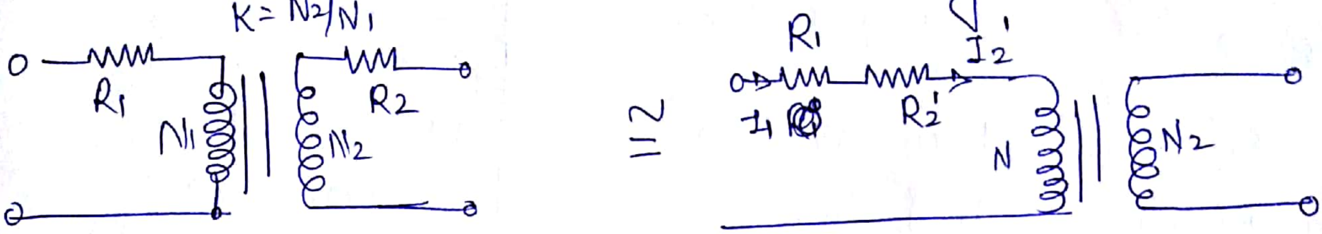
The value of No load primary current I_0 is very small, of the order of 3 to 5% of the rated full load current.

P_i represent the core loss or Iron loss

$W_0 = P_i = \text{Iron Loss} = V_1 I_w$ or $V_1 I_0 \cos\phi_0$.

* Before going to learn Practical T/F (on Load) first we are going to see some basics. *

— Resistance Transferred to Primary side. ($R_1 \leftarrow R_2$)



Without Transferred

With transfer of Resistance from secondary to primary.

Q Why Transferred method are going to be used?
• Just to make all calculation easier.

$R_2' = ?$

as $P_{cu} = I_1^2 R_1 + I_2^2 R_2$ — ①

$I_1 = I_2'$

$P_{cu} = I_1^2 R_1 + I_2'^2 R_2'$ — ②

$P_{cu} = I_1^2 (R_1 + R_2')$ — ③.

$P_{cu} \;\; I_1^2 (R_{1T})$

$\therefore R_{1T} = R_1 + \frac{R_2}{K^2}$

by eqn ① & ②.

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

$\frac{I_2^2}{I_2'^2} R_2 = R_2' \quad \therefore (I_1 = I_2')$ from transfer ckt.

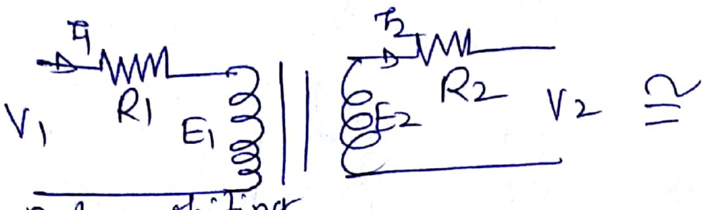
$R_2' = R_2 \left(\frac{I_2}{I_1}\right)^2$ as $\left(K = \frac{I_1}{I_2}\right)$; $\frac{1}{K} = \frac{I_2}{I_1}$

$R_2' = \frac{R_2}{K^2}$ Similarly.

$X_2' = \frac{X_2}{K^2}$ secondary Reactance reffered to primary side

$Z_2' = \frac{Z_2}{K^2}$ secondary Impedance reffered to primary side

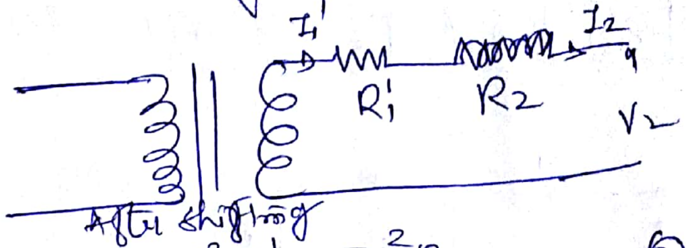
Resistance Transferred to secondary side (R_1 R_2)



Before shifting

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2 \quad \text{--- (1)}$$

≅



After shifting

$$P_{cu} = I_1'^2 R_1' + I_2^2 R_2 \quad \text{--- (2)}$$

$$P_{cu} = I_2^2 (R_1' + R_2)$$

$$\boxed{P_{cu} = I_2^2 (R_{2T})}$$

Total Resistance of T/F. reffered to secondary side

$$\boxed{R_{2T} = (R_1' + R_2)}$$

$$\boxed{R_1 K^2 + R_2 = R_{2T}}$$

From (1) & (2)

$$I_1^2 R_1 + \cancel{I_2^2 R_2} = I_1'^2 R_1' + \cancel{I_2^2 R_2}$$

$$\left(\frac{I_1^2}{I_2^2}\right) R_1 = R_1' \quad \text{as } \frac{I_1}{I_2} = K$$

$$\boxed{R_1' = R_1 \cdot K^2}$$

similarly.

$$\boxed{X_1' = X_1 K^2}$$

$$\boxed{Z_1' = Z_1 K^2}$$

Formulaes.

(1) $I_1 = \dfrac{KVA \times 10^3}{V_1}$

(2) $I_2 = \dfrac{KVA \times 10^3}{V_2}$.

(3) $E_1 = 4.44 f \phi N_1$

(4) $E_2 = 4.44 f \phi N_2$

(5) $\boxed{B_m = \dfrac{\phi m}{A_i}}$ Flux density $\dfrac{Wb}{m^2}$

ϕ_m = flux — weber

A_i = Net Iron area m^2

(6) Iron loss $P_i = V_1 I_0 \cos\phi$

$P_i = V_1 I_w$

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

$I_m = I_0 \sin\phi_0$

$I_w = I_0 \cos\phi_0$.

(7) $\boxed{R_2' = R_2 / K^2}$; $\boxed{X_2' = \dfrac{X_2}{K^2}}$; $\boxed{Z_2' = \dfrac{Z_2}{K^2}}$

(8) $\boxed{R_1' = R_1 K^2}$; $\boxed{X_1' = X_1 K^2}$; $\boxed{Z_1' = K^2 Z_1}$

(9) $K = \dfrac{V_2}{V_1} = \dfrac{E_2}{E_1} = \dfrac{N_2}{N_1} = \dfrac{I_1}{I_2}$

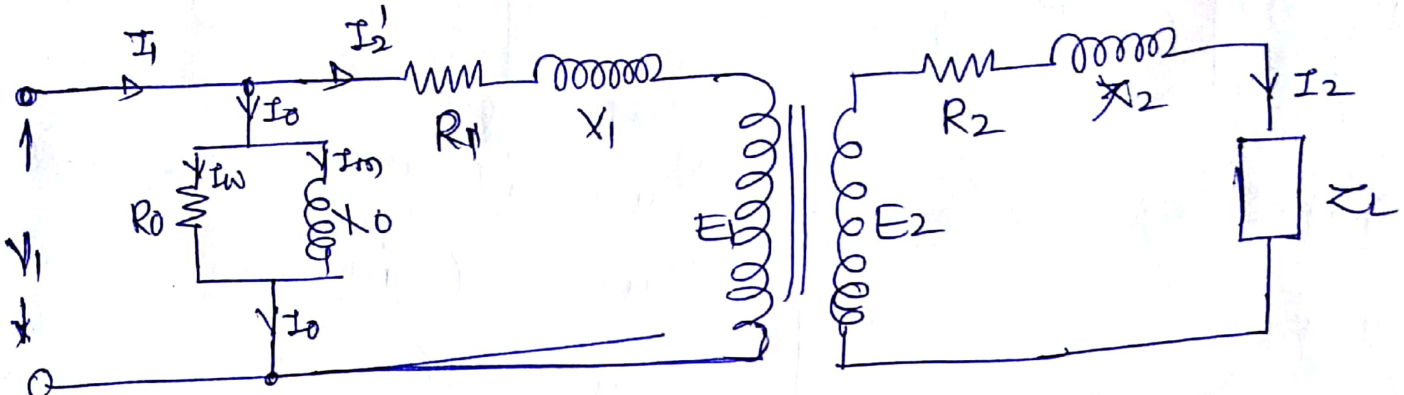
(10) $R_{1T} = (R_1 + R_2')$ ∴ $R_2' = R_2 / K^2$

(11) $R_{2T} = (R_1' + R_2)$ ∴ $\boxed{R_1' = R_1 K^2}$

V = IR

Scanned by CamScanner

Practical Transformer (ON Load) $I_2 \neq 0$



$\therefore$ $\boxed{\bar{I}_1 = \bar{I}_0 + \bar{I}_2'}$

$\therefore$ $\boxed{\bar{I}_0 = \bar{I}_w + \bar{I}_m}$

fig ①

By shifting secondary winding to primary side.

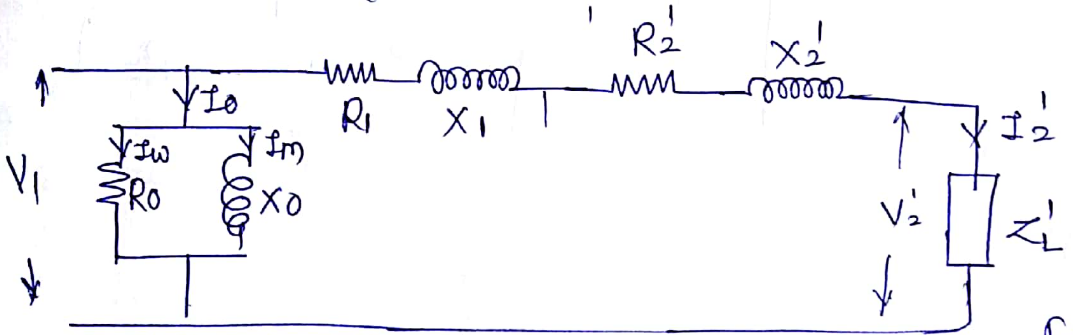


fig ②

$$R_{1T} = (R_1 + R_2') = (R_1 + R_2/K^2)$$
$$X_{1T} = (X_1 + X_2') = (X_1 + X_2/K^2)$$

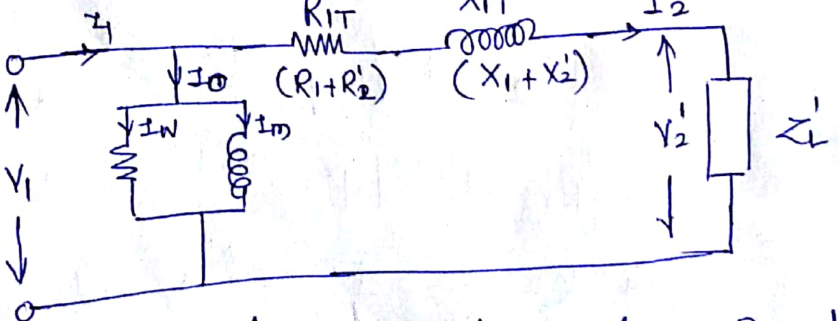
$$Z_{1T} = \sqrt{(R_{1T})^2 + (X_{1T})^2}$$

Similarly

$\boxed{I_2' = I_2 K}$

$\boxed{V_2' = \frac{V_2}{K}}$

$\boxed{Z_L' = \frac{Z_L}{K^2}}$



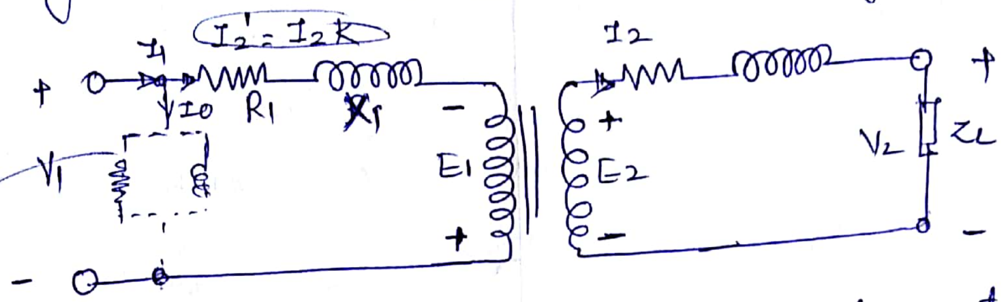
Equivalent circuit of T/F. reffered to primary side.

The practical transformer having leakage reactance(X) & Resistance R. This are the actual condn that exist in T/F.

There is Vtg drop in R_1 & X_1 so that primary emf E_1 is less than the applied Vtg [($E < V_1$) due to Vtg drop in R_1 & X_1]

Similarly, there is Vtg drop in R_2 & X_2 so that secondary terminal Vtg is less than EMF(E_2) ($E_2 > V_2$) due to R_2 & X_2

* **Voltage drop in T/F** *: from fig ①.

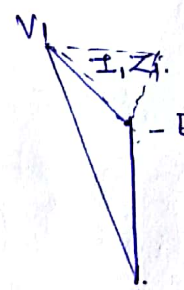


Neglect as small current for Vtg eqn

From primary winding (V_1) according to KVL

$$-V_1 + I_1 Z_1 - E_1 = 0$$

$$\boxed{V_1 = -E_1 + I_1 Z_1} = \boxed{V_1 = -E_1 + I_1(R_1 + jX_1)}$$

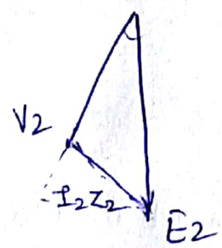


Similarly from secondary winding (V_2)

$$-E_2 + I_2 Z_2 + V_2 = 0.$$

$$V_2 = E_2 - I_2 Z_2$$

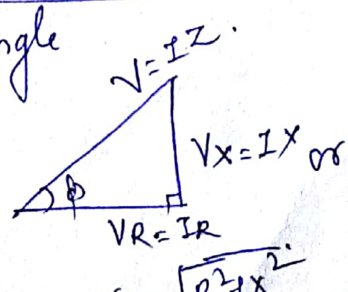
$$\boxed{V_2 = E_2 - I_2(R_2 + jX_2)}$$



Basics:

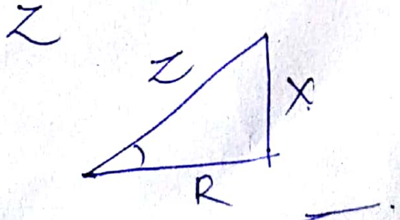
as from Vtg triangle

V =



or $V = \sqrt{R^2 + X^2}$

Z



$Z = \sqrt{R^2 + X^2}$

From vtg eqn V_1 & V_2.

$V_1 = -E_1 + I_1 Z_1$ ($V_1 > E_1$) due to drop in R_1 & X_1

$V_2 = E_2 - I_2 Z_2$ ($V_2 < E_2$) due to drop in R_2; X_2

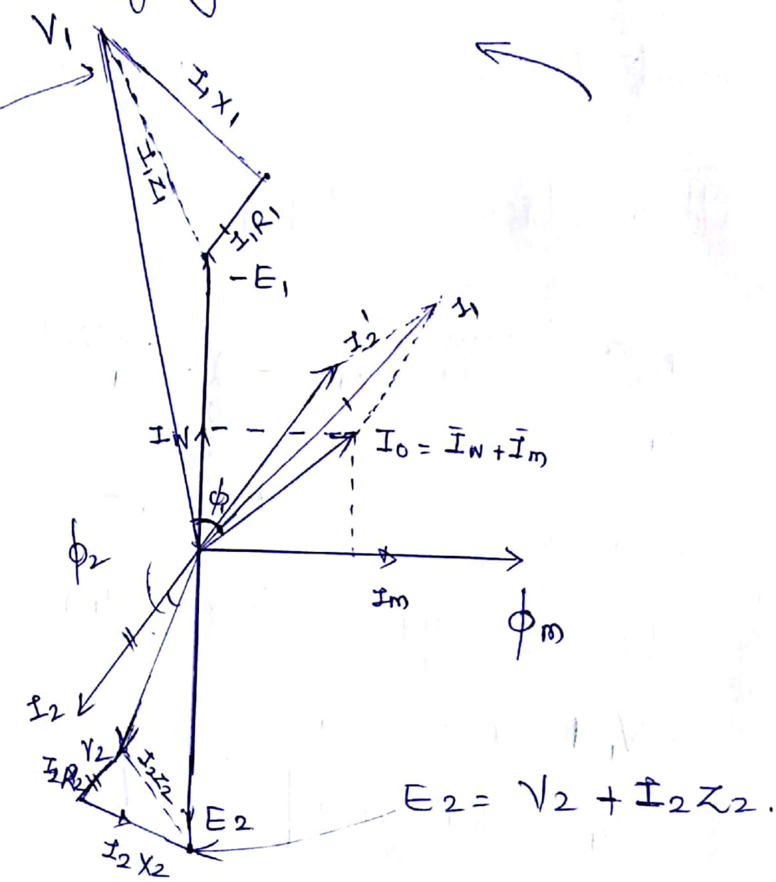
Phasor diagram for lagging load.

$I_1 = \bar{I}_2' + \bar{I}_0$

$I_0 = I_m + I_w$

$V_1 = -E_1 + I_1 Z_1$

$V_2 = E_2 - I_2 Z_2$



Load power factor $= \cos\phi_2$

Primary p. factor $= \cos\phi_1$

I/P power to T/F $P_1 = V_1 I_1 \cos\phi_1$

O/P power to T/F $P_2 = V_2 I_2 \cos\phi_2$

Practical T/F for usual case of Inductive load both E_1 & E_2 lags mutual flux ϕ by 90°.

Phasor diagram of T/F lag load

* $I_2' = K I_2$ & opposite to I_2.

* The phasor sum of I_2' & I_0 gives primary current $I_1 = \bar{I}_2' + \bar{I}_0$

Note ~~I_0 opposes ϕ_1~~ ∴

Losses in Transformer.

In Ideal T/F losses are zero, but in practical T/F there are fallowing losses taking places.

Losses in T/F

- (variable) copper Loss $(P_{cu}) \propto I^2$
  - $P_{cu} = I^2 R$
- constant Iron Loss $(P_i) \propto V$
  - $P_i = V_1 I_0 \cos\phi_0$.
  - Hysteresis Loss
  - Eddy current loss

① Copper Loss :- The total power loss taking place in the winding resistances of a T/F is known as the copper loss.

copper loss = power loss in prim winding + Power loss in sec winding

$$\boxed{P_{cu} = I_1^2 R_1 + I_2^2 R_2}$$ or $P_{cu} = I_1^2 R_{1T}$ or $P_{cu} = I_2^2 R_{2T}$

The copper loss is also called as <u>variable loss</u> as they are dependent on the square of load current.

The Relation betn copper loss at full load & that at Half Load is as fallow.

$$P_{cu(HL)} = \left(\frac{1}{2}\right)^2 P_{cu(FL)}$$

$\therefore P_{cu(HL)}$ = Pcu at Half Load

$P_{cu(FL)}$ = Pcu at Full Load

$$P_{cu(HL)} = \frac{P_{cu\,FL}}{4}$$

The to reduce the copper loss ; it is essential to reduce R_1 & R_2. by using good quality of conducting material

* Generally short circuit test are carried out to determine the copper losses $\therefore$ $\boxed{W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}}$

Iron Loss :- $P_i = V_1 I_0 \cos\phi_0$ $\propto F$

Iron Loss P_i is the power loss taking place in the core of the T/F.

It is equal to the sum of two components called as hysteresis loss & eddy current loss.

$$P_i = \text{Hysteresis Loss} + \text{Eddy current loss}$$

① Hysteresis Losses :-

We have already discussed the hysteresis loss taking place in the magnetic material.

The area enclosed by the hysteresis loop of a material represent the hysteresis loss.

$$\text{Hysteresis Loss} = K_H \cdot B_m^{1.67} \cdot f \cdot V \quad \text{Watt}$$

B_m = Magnetic flux density f = frequency , V = Vol^m of core

Thus the hysteresis loss is frequency dependent loss.

② **Eddy current Loss :-**

* Due to the time varying flux, there is some induced emf in the Transformer core.

This induced emf causes some current to flow through the core body.

These current are known as the eddy currents.

$$\text{Eddy current loss} = (\text{Eddy current})^2 \times r$$

↑ r = resistance of core

The eddy current losses are minimized by using laminated core.

$$\text{Eddy current Loss} = K_E B_m^2 F^2 T^2$$

↑ T = thickness of core

The Iron loss is denoted by P_i; It is the sum of Hysteresis loss & eddy current loss.
Which does not depend on the load condⁿ. (It's constant)

Hence P_i at No load & any load = constant $\propto V$

$$P_i = V_1 \underbrace{I_0 \cos\phi}_{I_W} = I_W \cdot V_1$$

But Copper loss is a variable loss and its depend on the square of current $(I)^2$

$P_{cu} = I_1^2 R_{1T}$ $\therefore P_{cu} \propto I_1^2$ ← Full load Primary current

Full load Primary current $= I_1$
Half load primary current $= \frac{I_1}{2}$.

Hence P_{cu} is load dependent loss.

at Full load $P_{cu} = [\text{Full load current}]^2 \times [R_{1T}]$

$$\boxed{P_{cu(FL)} = I_1^2 \cdot R_{1T}}$$ or ~~[struck out]~~

at Half load $P_{cu(HL)} = [\text{Half load current}]^2 \times [R_{1T}]$

$$P_{cu(HL)} = \left[\frac{I_1}{2}\right]^2 \times R_{1T}$$

$$P_{cu(HL)} = \frac{I_1^2 R_{1T}}{4} = \frac{P_{cu(FL)}}{4}$$

From above eqⁿ it is clear that for Half load the Copper loss becomes $\frac{1}{4}$.

* Efficiency of Transformer.

Efficiency of T/F (η) = $\dfrac{\text{Output Power}}{\text{Input power}} = \dfrac{V_2 I_2 \cos\phi_2}{V_1 I_1 \cos\phi_1}$

or $\dfrac{\text{Output Power}}{\text{~~Input~~ output power} - \text{Losses}} = \dfrac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + [P_i + P_{cu}]}$

The output power at full load = $V_2 I_2 \cos\phi_2$.

KVA – rating of T/F (Full load) $(KVA \cos\phi_2) \times 1000$ Watt.

Hence the η at full load

$$\eta_{FL} = \frac{[(KVA)_{FL} \cdot \cos\phi_2 \times 10^3]}{[(KVA)_{FL} \cos\phi_2 \times 10^3] + [P_L]}$$

P_L → Total loss $P_i + P_{cu}$

$$\eta_{FL} = \frac{KVA \cdot \cos\phi_2 \cdot \times 10^3}{[KVA \cos\phi_2 \times 10^3] + [P_i + P_{cuFL}]}$$

P_i ↑ constant, P_{cuFL} ↑ variable

Similarly η at Half load ; the rating become Half, current also

$$(KVA)_{HL} = \frac{(KVA)}{2} = [0.5\,KVA]$$

$$\eta_{HL} = \frac{(KVA)_{HL} \cdot \cos\phi_2 \times 10^3}{[(KVA)_{HL} \cos\phi_2 \times 10^3] + [(P_i) + P_{cuHL}]}$$

$$P_{cuHL} = (0.5)^2 P_{cuFL} = \left(\frac{1}{2}\right)^2 P_{cuFL} = \frac{P_{cuFL}}{4}$$

$$\eta_{HL\ 50\%} = \frac{0.5\,KVA \times \cos\phi_2 \times 10^3}{[0.5\,KVA \times \cos\phi_2] + [P_i + (0.5)^2 P_{cuFL}]}$$

$$\eta_{HL\ x\%\,load} = \frac{(x)\,KVA \times \cos\phi_2 \times 10^3}{[(x)\,KVA \times \cos\phi_2] + [P_i + (0.5)^2 P_{cu(FL)}]}$$

Generalized Formula.

Condition for Max Efficiency

$$\eta = \frac{V_2 I_2 \cos\phi_2 \times 10^3}{V_2 I_2 \cos\phi_2 \times 10^3 + I_2^2 R_2 + P_i}$$

Divide the numerator & denominator by I_2 we get

$$\eta = \frac{V_2 \cos\phi_2 \times 10^3}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_2}$$

To get Max η_{max} when the derivative of denominator with respect to I_2 is min

$$\frac{d}{dI_2}\left[V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_2\right] = 0$$

$$0 - \frac{P_i}{I_2^2} + R_2 = 0$$

$$\frac{P_i}{I_2^2} = R_2$$

$$P_i = R_2 I_2^2 \quad ; \quad \boxed{P_i = I_2^2 R_2}$$

Iron losses = Copper losses

Hence efficiency of transformer will be Max when Cu losses are equal to constant loss (Iron loss

load current I_2 corresponding to Maximum efficiency

$$\boxed{I_2 = \sqrt{\frac{P_i}{R_2}}}$$

* Output KVA corresponding to Max efficiency:

P_{cu} = copper loss at full load KVA.

P_i = Iron loss.

x = fraction of full load KVA at which η is max

Total $P_{cu} = x^2 P_{cu}$

$$x^2 P_{cu} = P_i$$

$$x = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{\text{Iron Loss}}{\text{Copper Loss F.L}}}$$

∴ output KVA corresponding to max efficiency.

$$(KVA)_{max} = x \cdot \text{full load KVA} = x \cdot KVA.$$

$$\boxed{(KVA)_{max} = KVA \times \sqrt{P_i / P_{cu}}}$$

It may be noted that the value of KVA at which the efficiency is maximum is independent of P.f of the load.

ed

Voltage Regulation :- The Vtg regulation of T/f is the arithmetic difference (not phasor difference) betn the no-load secondary voltage (V_{2NL}) & secondary load voltage V_{2FL} on load expressed as percentage of No load voltage

(

$$\%\text{age Vtg Reg}^n = \frac{V_{2NL} - V_{2FL}}{V_{2NL}} \times 100$$

(V_{2FL} — Full load Vtg; V_{2NL} — No load Vtg.)

ary

$$V_{2NL} - V_{2FL} = I_2 R_{2T} \cos\phi_2 \pm I_2 X_{2T} \sin\phi_2$$

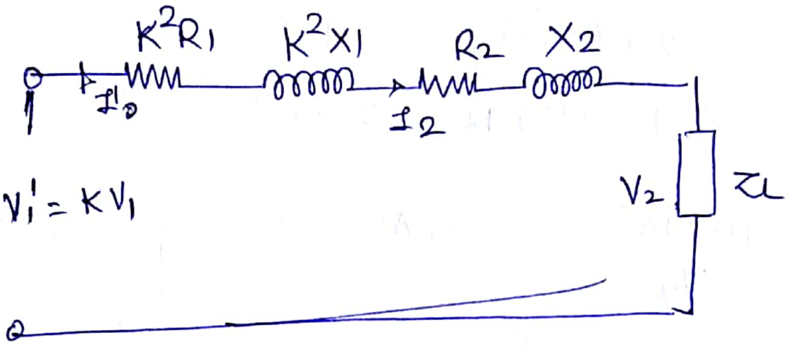
– sign for leading

+ sign for lagging

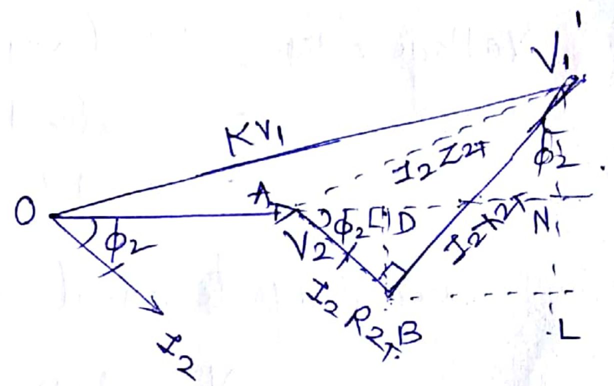
It may be noted that %age of Voltage Regulation of T/F will be same whether primary or secondary side is considered.

$$\%age\ Vtg\ regulation = \frac{I_1 R_{1T} \cos\phi_1 \pm I_1 X_1 \sin\phi_1}{V_{1NL}}$$

Lets see



Approximate Vtg drop in secondary



$AN = AD + DN$

$= [I_2 R_{2T} \cos\phi_2] \pm [I_2 X_{2T} \sin\phi_2]$

Note If the circuit referred to to primary, then it can be easily established that.

Approximate Vtg drop $= [I_1 R_{1T} \cos\phi_1 \pm I_1 X_{1T} \sin\phi_1]$

+ for lagging
– for Leading

$$\%age\ Vtg\ Regulation = \frac{I_1 R_{1T} \cos\phi_1 \pm I_1 X_1 \sin\phi_1}{V_1} \times 100$$

$$= \frac{I_2 R_{2T} \cos\phi_2 \pm I_2 X_2 \sin\phi_2}{V_2} \times 100$$

Q. A 10KVA, 2000/400V 1ϕ T/F has following data.
$R_1 = 5\Omega$, $X_1 = 12\Omega$; $R_2 = 0.2\Omega$ $X_2 = 0.48\Omega$.
Determine the secondary terminal Vtg at full load 0.8 p.f lagging when the primary supply Voltage is 2000V.

Soln:-

$K = 400/2000 = 1/5$.

$R_{2T} = R_2 + K^2 R_1 = 0.2 + (1/5)^2 5 = 0.4\Omega$

$X_{2T} = X_2 + K^2 X_1 = 0.48 + (1/5)^2 12 = 0.96\Omega$.

F.L. current $I_2 = \dfrac{10 \times 10^3}{V_2} = 25A$.

$\cos\phi_2 = 0.8$ $\sin\phi_2 = 0.6$.

Voltage drop $= I_2(R_{2T}\cos\phi_2 + X_{2T}\sin\phi_2)$

$= 25(0.4 \times 0.8 + 0.6 \times 0.96)$

$= 22.4V$

∴ secondary terminal Voltage $V_2 = E_2 - (I_2 Z_2)$ (Vtg drop).

$V_2 = 400 - 22.4$

$V_2 = 377.6V$

Q The prim & sec winding of 40KVA, 6600/250 V 1ϕ T/F have $R_1 = 10\Omega$ & $R_2 = 0.02\Omega$ respectively. $X_{1T} = 35\Omega$; Calculate %age Vtg Regn of T/F when supplying full load current at 0.8 lag.

Soln:- %age Vtg Regn $= \dfrac{I_1 R_{1T}\cos\phi_1 + I_1 X_{1T}\sin\phi_1}{V_1} \times 100 = ?$

① $R_{1T} = R_1 + \dfrac{R_2}{K^2}$; $K = \dfrac{250}{6600}$

$R_{1T} = 10 + 0.02\left(\dfrac{6600}{250}\right)^2$

$R_{1T} = 23.93\Omega$

② $X_{1T} = 35\Omega$ given.

③ $\cos\phi_1 = 0.8$

④ $\sin\phi_1 = 0.6$

⑤ $I_1 = \dfrac{KVA \times 10^3}{V_1} = 6.06A$.

Hence.

%age Vtg Regn $= \dfrac{6.06[23.93 \times 0.8 + 35 \times 0.6] \times 100}{6600}$

%age Vtg Regn $= 3.7\%$

Q Cal. % Voltage regulation of T/F in which the % Resistance drop is 1% & percentage reactance drop is 5% when the p.f is
(i) 0.8 lagging (ii) unity (iii) 0.8 leading

Soln :- % Vtg Regn = $\frac{I_2 R_{2T}\cos\phi_2 \pm I_2 X_{2T}\sin\phi_2}{V_2} \times 100$

$= \left[\frac{I_2 R_{2T}}{V_2}\cos\phi_2 \pm \frac{I_2 X_{2T}}{V_2}\sin\phi_2\right]\times 100$

$= [V_r \cdot \cos\phi_2 \pm V_x \sin\phi_2] \times 100$

$\therefore V_r = \frac{I_2 R_{2T}}{V_2} \times 100 \Rightarrow$ Percentage resistive drop

$V_x = \frac{I_2 X_{2T}}{V_2} \times 100 =$ Percentage reactive drop.

(i) When $\cos\phi_2 = 0.8$ lag ; Regn $= V_r\cos\phi_2 + V_x\sin\phi_2$
$= 1\times 0.8 + 5\times 0.6 = 3.8\%$

(ii) When $\cos\phi_2 = 1$ %Regn $= 1\times 1 + 5\times 0 = 1\%$

(iii) When $\cos\phi_2 = 0.8$ lead %Regn $= 1\times 0.8 - 5\times 0.6 = 2.2\%$

Q a 80KVA, 2000/200 V, 50HZ 1ϕ T/F has impedance drop of 8% & resistance drop of 4%. Calculate the % Vtg regn of T/F at F.L load at 0.8 p.f lag

% Z drop = $\frac{I_2 Z_{2T}}{V_2}\times 100 = 8 = \frac{I_2 Z_{2T}}{V_2}\times 100$ | $I_2 = \frac{80\times 10^3}{200} =$

$I_2 Z_{2T} = \frac{8\times 200}{100} = 16\,V$

% R drop = $\frac{I_2 R_{2T}}{V_2}\times 100 = 4 = \frac{I_2 R_{2T}}{200}\times 100$

$I_2 R_{2T} = \frac{4\times 200}{100} = 8\,V.$

$I_2 X_{2T} = \sqrt{(I_2 Z_{2T})^2 - (I_2 R_{2T})^2} = \sqrt{16^2 - 8^2} = 13.86\,V$

% Vtg Regn = $\frac{I_2 R_{2T}\cos\phi_2 + I_2 X_{2T}\sin\phi_2}{V_2}\times 100$

$= \frac{8\times 0.8 + 13.86\times 0.6}{200} = 7.35\%$

~~Q~~ ~~oct8502P~~

Q The prim & sec winding of 40KVA, 6600/250V 1φ T/F ~~transferred~~ $R_1 = 10$, $R_2 = 0.2\ \Omega$ respectively, $X_{1T} = 35\ \Omega$, Cal (i) V_1 required to circulate full load current when the secondary is S.C (ii) the full load regn at 0.8 P.f lagging. Neglect the No load current.

Soln:- $K = 250/6600$

i) The Resistance of secondary winding referred to primary is

$$R_2' = R_2/K^2 = \frac{0.2}{(25/660)^2} = 13.9\ \Omega$$

$R_{1T} = R_1 + R_2' = 23.9\ \Omega$
$X_{1T} = 35\ \Omega$ given.

If the secondary is S.C, the Z of load reflected in primary is zero

∴ total impedance of T/F referred to primary.

$$Z_{1T} = R_{1T} + X_{1T} = (23.9 + j35) = 42.24\ \Omega$$

Full load current $I_1 = \frac{40 \times 10^3}{6600} = 6.06\ A$

∴ primary Vtg required to circulate full-load current is

$$V_{sc} = I_1 \times Z_{1T} = 6.06 \times 42.24 = 256\ V$$

ii) Voltage drop $= I_1 (R_{1T} \cos\phi_1 + X_{1T} \sin\phi_1)$

$= 6.06 (23.9 \times 0.8 + 35 \times 0.6) = 243\ V$

$$\%\ Vtg\ Reg^n = \frac{243}{6600} \times 100 = 3.7\%$$

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Transformer Test

The circuit * constants, efficiency & Voltage regulation of T/F can be determine by two simple test.

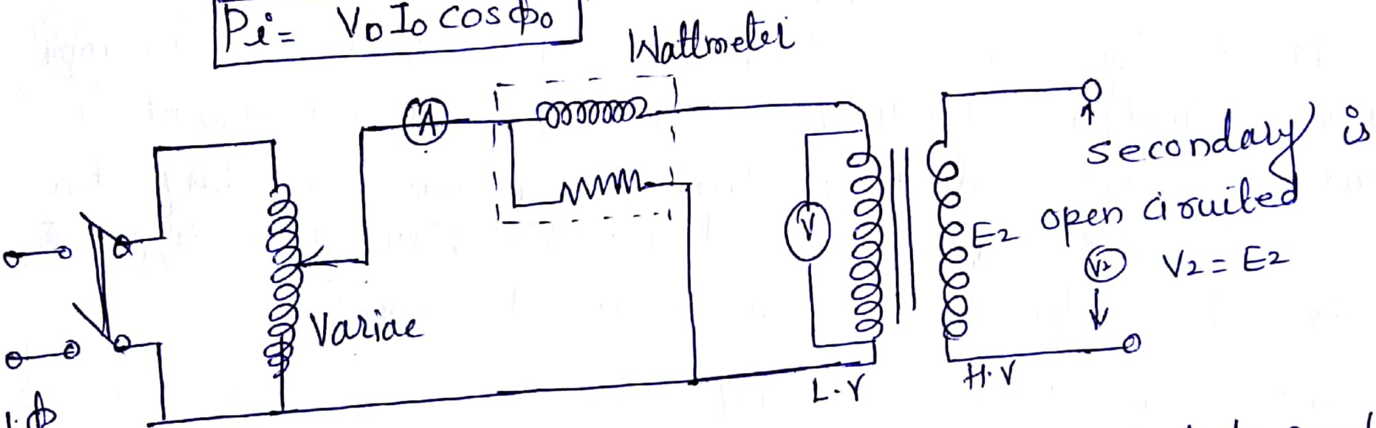
1. Open circuit Test = (Iron loss) $P_i = V_1 I_0 \cos\phi_0$ (No load Test)
2. Short circuit Test = $P_{cu} = V_{sc} I_{sc} \cos\phi_{sc}$

* These test are very convenient as they provide the required information without actually loading the T/F.
* Further; the power required to carry out these test is very small as compared with full load output of the T/F.

OPEN CIRCUIT TEST (No load test)

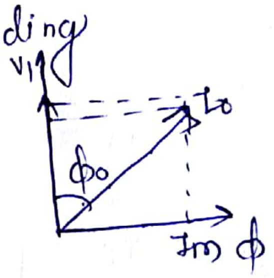
From this test Iron Losses P_i of T/F can be determined.

$$\boxed{P_i = V_0 I_0 \cos\phi_0}$$



generally low Voltage side of T/F is connected to supply side

1. at No load cond^n (O.C) $I_2 = 0$, $\boxed{E_2 = V_2}$
2. but small current is flowing through primary winding
3. ie No load current $\vec{I_0} = \vec{I_m} + \vec{I_w}$



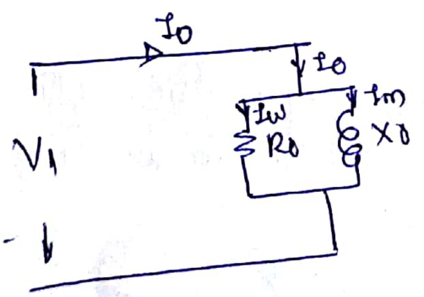
4. Wattmeter indicates No load losses at this cond^n =

$$W_0 = P_i = V_0 I_0 \cos\phi_0$$

$V_0 = V_1$ = No load Vtg

I_0 = No load current

$\cos\phi_0$ = N.L P.F.



$$\cos\phi_0 = \frac{P_i}{V_1 I_0}.$$

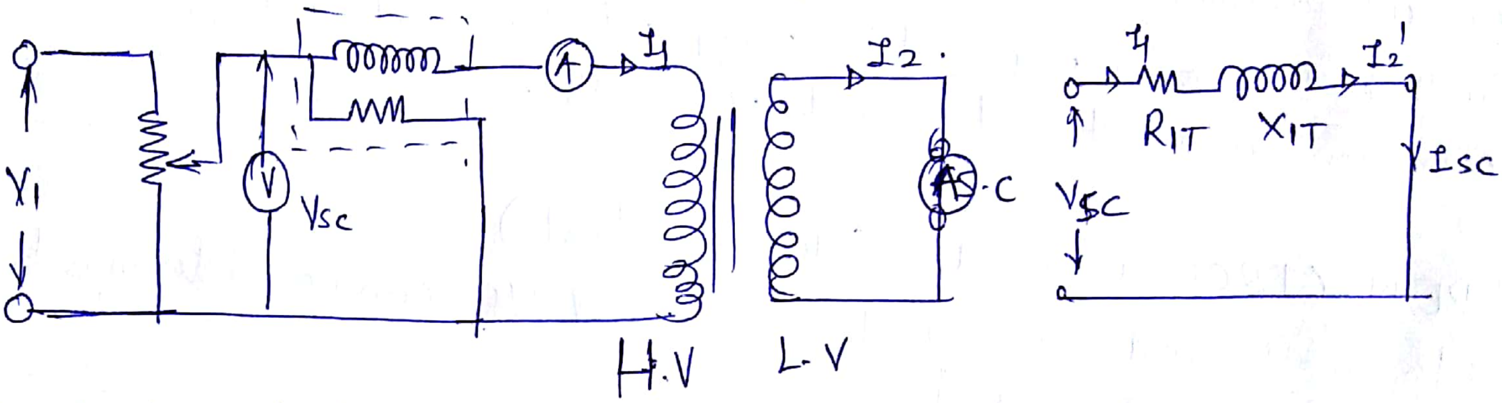
$I_W = I_0 \cos\phi_0$; $I_m = I_0 \sin\phi_0$

$R_0 = \dfrac{V_1}{I_W}$ & $X_0 = \dfrac{V_1}{I_m}$.

Thus open circuit test enables us to determine iron losses & parameter R_0 & X_0 of T/F.

SHORT CIRCUIT TEST (to det. Pcu loss) = $V_{sc} I_{sc} \cos\phi_{sc}$

① generally H.V side is connected to supply side
② In this method L.V side is short circuited by Ammeter.
③ From this test copper loss of T/F can be determined



④ The variable low Vtg is applied to the HV side & the low input Vtg is gradually raised till at voltage Vsc; full load current I_1 flows in primary winding, then I_2 in the secondary also has full load current, i.e full load current is flowing through T/F at this condn wattmeter will shows full load copper loss.

F.L Cu loss P_{cu} = Wattmeter reading = W_{sc}
Applied Vtg = Voltmeter reading = V_{sc}
FL prim current = Ammeter reading = $I_{sc} = I_1$

$$P_{cu} = I_{sc}^2 R_{1T} \text{ or }$$

$$Z_{1T} = \frac{V_{sc}}{I_{sc}}$$

$$X_{1T} = \sqrt{Z_{1T}^2 - R_{1T}^2}$$

$$\cos\phi_{sc} = \frac{P_{cu}}{V_{sc} I_{sc}}.$$

Note the s.c test will gives full load Cu loss only if the applied Vtg Vsc is such so as to circulate full load current in the winding.

Advantages of T/F test.

① The power required to carry out these test is very small

② These test are enable us to determine the efficiency & Voltage regulation.

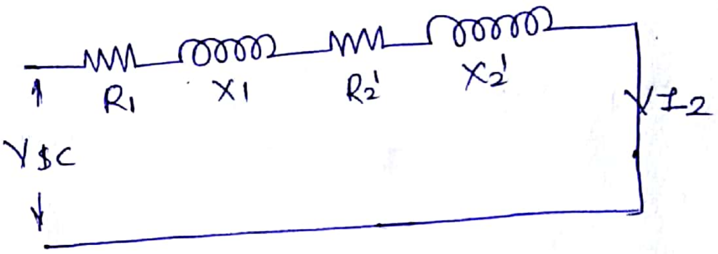
③ Also enable to R_{1T} & X_{1T} & Z_{1T}

Q 1 ϕ 50H T/F has full load secondary current 500A; the primary current being one-fifth of this value. The T/F has following parameters.

$R_1 = 0.6\Omega$ $R_2 = 0.03$ $X_1 = 2\Omega$ $X_2 = 0.06\Omega$

If the secondary is short circuited. find the primary Vtg required to circulate F.L current. Neglect the N.L current, what is the power factor on short circuit?

⇒ given data $F = 50Hz$ $I_2 = 500A$, $I_1 = 100A$ as (one-fifth to I_2)



$R_{1T} = R_1 + R_2'$
$= R_1 + R_2/k^2$

$R_{1T} = 1.35\Omega$

$X_{1T} = 3.5\Omega$, $Z_{1T} = 3.75\Omega$

Primary Voltage required to circulate full load current.

$V_{sc} = I_{sc} \cdot Z_{sc} = I_{sc} \cdot Z_{1T} = I_1 Z_{1T} = 100 \times 3.75$

$V_{sc} = 375V$

Short circuited p.f

$\cos\phi_{sc} = \frac{R_{0T}'}{Z_{1T}} = \frac{1.35}{3.75} = 0.36$ lag

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Q In a No-load test of 1ϕ T/F the following test data
primary Voltage : 220V ; secondary Vtg 110V
primary current : 0.5A Power Input = 30W.
(i) Find the turns ratio (ii) the magnetizing component of no-load current (iii) the iron-loss component of no-load current (iv) Iron loss, The resistance of primary winding is 0.6Ω

Soln (i) Turn ratio $\frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{V_1}{V_2} = 2$

(ii) ~~Iron Loss~~; $P_i = V_1 I_0 \cos\phi_0$.

$$\cos\phi_0 = \frac{P_i}{V_1 I_0} = \frac{30}{200 \times 0.5} = 0.273$$

$$\sin\phi_0 = 0.962.$$

Magnetizing current $I_m = I_0 \sin\phi_0 = 0.48$ Amp.
Active comp. current. $I_w = I_0 \cos\phi_0 = 0.1365$ Amp

(iv) Primary copper loss $= I_0^2 R_1 = 0.5^2 \times 0.6 = 0.15$ W.
Iron loss = $30 - 0.15 = 29.85$ W.

Q; 10 KVA, 200/400 V, 50 Hz 1ϕ T/F gave the following data

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

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

Cal. ① The Magnetizing current & component corresponding to core loss at normal frequency & Voltage,

(ii) the magnetizing-branch impedances & (iii) % Vtg Regn. when supply full load at 0.8 p.f leading.

Soln:- Given data

$V_0 = V_1 = 200\,V$ $\quad V_{sc} = 22\,V$

$I_0 = 1.3\,A$ $\quad I_{sc} = I = 30\,A$

$P_i = 120\,W$ $\quad P_{cu} = 200\,W$

(i) No-load p.f $\cos\phi_0 = \frac{P_i}{V_1 I_0} = \frac{120}{200\times1.3} = 0.462$

Magnetizing current $I_m = I_0 \sin\phi_0 = 1.3\times0.866 = 1.15A$

Active component current $I_W = I_0\cos\phi_0 = 1.3\times0.462 = 0.6A$

(ii) $R_0 = \frac{V_1}{I_W} = \frac{200}{0.6} = 333\,\Omega$

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

(iii) Total Impedance referred to H.V side

$Z_{2T} = \frac{V_{sc}}{I_{sc}} = \frac{22}{30} = 0.733\,\Omega$

$R_{2T} = \frac{W_{sc}}{I_{sc}^2} = \frac{200}{(30)^2} = 0.22\,\Omega$

$X_{2T} = \sqrt{Z_{2T}^2 - R_{2T}^2} = 0.698\,\Omega$.

(iii) $I_2 = \frac{10\times10^3}{400} = 25\,A$. (Leading p.f)

Approximate Voltage drop $= I_2(R_{2T}\cos\phi_2 - X_{2T}\sin\phi_2)$
$= -6\,V$

% age Vtg Regn $= \left[-6/400\right]\times100 = -1.5\%$.

Q A 200 KVA, 2000/440 V, 50 Hz 1 ϕ T/F.

O.C	2000 V	1.8 A	1.75 KW	on H.V side
S.C	13 V	300 A	1 KW	on L.V side – (see) – data R_2

obtain the equivalent circuit as referred to H.V side.

soln:- Here $X_{1T} = ?$ $R_{1T} = ?$ $Z_T = ?$

Component of No-load current corresponding to core loss.

$$I_W = \frac{P_i}{V_1} = \frac{1.75 \times 10^3}{2000} = 0.875\,A.$$

Magnetizing current $I_m = \sqrt{I_0^2 - I_W^2} = 1.57\,A.$

$$R_0 = \frac{V_1}{I_W} = 2286\,\Omega \quad ; \quad X_0 = \frac{V_1}{I_m} = \frac{2000}{1.57} = 1274\,\Omega$$

Total impedance referred to L.V side (secondary) is

$$Z_{2T} = V_{sc}/I_{sc} = 13/300 = 0.0433\,\Omega.$$

$$R_{2T} = \frac{W_{sc}}{I_{sc}^2} = 0.011\,\Omega$$

$$X_{2T} = \sqrt{Z_{2T}^2 - R_{2T}^2} = 0.042\,\Omega.$$

Total resistance & reactance referred to H.V side (primary) is

$$R_{1T} = \frac{R_{2T}}{K^2} = \frac{0.011}{(440/2000)^2} = 0.227\,\Omega$$

$$X_{1T} = \frac{X_{2T}}{K^2} = 0.868\,\Omega.$$

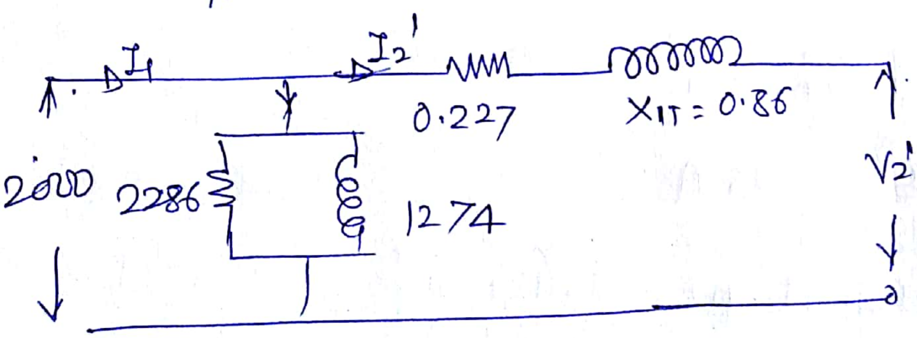


Fig. shows the required equivalent circuit as referred to H.V side (primary side) (32).

A 4 KVA, 200/400 V, 50 Hz 1ϕ T/F.

N.L — 200 V ; 0.7 A, 60 W. (Low vtg data)

S.C — 9 V 6 A 21.6 W. (High vtg data) sec − R_2

cal ① $I_m = ?$ $I_w = ?$ ② η_{FL} at $\cos\phi = 1$; ③ V_2 (1, ±0.8, cosϕ)

Soln

① from o.c test.

$\cos\phi_0 = \frac{P_i}{V_1 I_0} = 0.43$

$I_m = I_0 \sin\phi_0 = 0.63$

$I_{w0} = I_0 \cos\phi_0 = 0.3$

$\therefore \sin\phi_0 = 0.9$

$\therefore \cos\phi = 1$

② η_{FL} at unity Power factor.

$\eta_{FL} = \frac{[KVA \times 10^3]}{[KVA \times 10^3] + P_i + P_{cuFL}}$

copper loss at 6A on 400 V side = 21.6 W

F.L sec current $I_2 = \frac{4 \times 10^3}{400} = 10 A$

Hence cu losses corresponding to F.L current.

$P_{cuFL} = 21.6 \times [10/6]^2 = 60 W$.

Total losses $= P_i + P_{cuFL} = 60 + 60 = 120 W$

$\eta_{FL} = \frac{[4 \times 10^3 \times 1]}{[4 \times 10^3 \times 1] + [120]} \times 100 = 97.1\%$.

③ from s.c test (H.V side), we have

$Z_{2T} = \frac{V_{sc}}{I_{sc}} = 9/6 = 1.5\,\Omega$; $R_{2T} = Z_{2T}\cos\phi_{sc} = 0.6\,\Omega$

$\cos\phi_{sc} = \frac{P_{cu}}{V_{sc} I_{sc}} = 0.4$; $X_{2T} = Z_{2T}\sin\phi_{sc} = 1.37\,\Omega$

Voltage drop in secondary $= I_2(R_{2T}\cos\phi_2 \pm X_{2T}\sin\phi_2)$

① for unity p.f $= I_2 R_{2T} \cdot 1 + 0 = 6 V$.

Hence Load Voltage $= 400 - 6 = 394 V$.

~~[struck-out line]~~

(ii) At p.f 0.8 lagg ($\cos\phi_2 = 0.8$) $= I_2(R_{2T}\cos\phi + X_{2T}\sin\phi)$

$= 10(0.6\times0.8 + 1.37\times0.6)$

$= 13V.$

Load Voltage (V_2) $= 400 - 13 = 387V.$

(iii) At p.f 0.8 leading Vtg drop $= I_2(R_{2T}\cos\phi_2 - X_{2T}\sin\phi_2)$

$= 10(0.6\times0.8 - 1.37\times0.6)$

$= -3.4V$

Load Voltage V_2 $= 400 - (-3.4) = 403.4V.$

Q A, 100KVA, 6600/330V, 50HZ. 1ϕ T/f took 10A, of 436 W at 100V, in a s.c test. the figures referring to the high Vtg side Calculate the Vtg to be applied to the high Vtg side on F.L Load at 0.8 p.f when the secondary load Vtg is 330V.

from s.c test

$$Z_{1T} = \frac{V_{sc}}{I_{sc}} = \frac{100}{10} = 10\Omega.$$

$$\cos\phi_{sc} = \frac{P_{cu}}{V_{sc} I_{sc}} = \frac{436}{100\times10} = 0.436;\ \sin\phi_{sc} = 0.9$$

$R_{1T} = Z_{01}\cos\phi_0 = 4.36\Omega$

$X_{1T} = Z_{1T}\sin\phi_0 = 9\Omega$

$$I_1 = \frac{100\times10^3}{6600} = 15.15A.$$

F.L Load Vtg drop in primary when p.f $\cos\phi_2 = 0.8$

$= I_1(R_{1T}\cos\phi_1 + X_{1T}\sin\phi_1)$

$= 134V.$

Voltage to be applied to the H.V side (primary)

$= 6600 + 134 = 6734V.$

Q The ~~copies~~ corrected instrument reading obtained from s.c & o.c test on 10KVA, 450/120 V, 50HZ T/F

O.C Test :- $V_0 = 120V$, $I_0 = 4.2 A$, $W = 80 W$ at low Vtg side.
S.C Test - 9.65 V, $I_{sc} = 22.4$, $W_{sc} = 120 W$ at H.V side

Calculate (i) the equivalent circuit (simplified) constant.
(ii) efficiency & voltage regulation for full-load at 0.8 p.f log.
(iii) efficiency for half-load & 0.8 p.f logging.

Soln:- In o.c test the primary is open & secondary draw no-load current of 4.2 A. Now $K = 120/450 = 4/15$.

(i) No load current $(I_0) = K \times 4.2 = 1.12 A$.

Primary core-loss component $I_w = \frac{W_{all}}{V_0} = \frac{80}{450} = 0.178 A$.

$I_m = \sqrt{I_0^2 - I_w^2} = 1.1 A$.

$R_0 = \frac{450}{I_w} = 2530 \Omega$; $X_0 = \frac{450}{I_m} = 409 \Omega$.

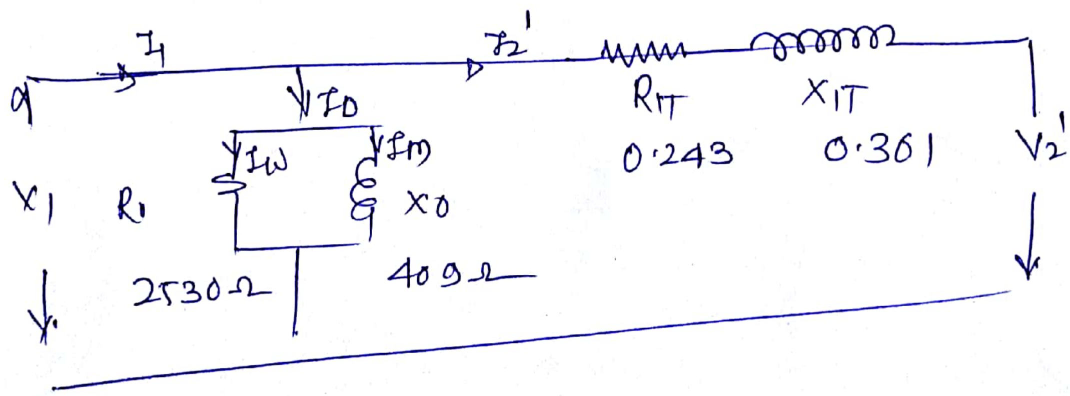
In s.c test secondary (120v side) is s.c & instruments are placed in primary

$Z_{1T} = \frac{V_{sc}}{I_{sc}} = 0.435 \Omega$.

$R_{1T} = \frac{W_{sc}}{I_{sc}^2} = 0.243 \Omega$.

$X_{1T} = \sqrt{Z_{1T}^2 - R_{1T}^2} = 0.361 \Omega$

Thus the required four parameter of the equivalent ckt.



(ii) F.L primary current $I_1 = \frac{10\times10^3}{V_1} = 22.A$

F.L Vtg drop in primary $= I_1 (R_{1T} \cos\phi_1 + X_{1T} \sin\phi_1)$

$= 9.2 V.$

F.L Vtg Regn $= \frac{9.2}{450} \times 100 = 2.04\%$

It is clear that s.c test is conducted for full load.
therefore s.c test gives F.L Cu losses (120 W)

Total F.L losses $= 80 + 120 = 200 W.$

F.L output $= (10\times10^3)\times \cos\phi = 8000 W.$

F.L $\eta = \frac{8000}{8000 + (200)} = 97.57\%$

(iii) Cu loss at half load $= \left(\frac{1}{2}\right)^2 P_{cu_{FL}}$

$= \frac{120}{4} = 30 W.$

output at Half load $= 8000/2 = 4000 W$

Half load Efficiency $= \frac{4000}{4000 + 110} = 97.34\%$

Q A 20 KVA 1φ, 50 Hz, 2200/200 V T/F gives following data:

O.C test – 2200 V applied to primary, power taken 220 W

S.C test – power required to circulate F.L current is S.C secondary 240 W

Cal. η_{FL} & η_{HL} at p.f 0.8 lag.

$V_1 = V_0 = 2200$ V.

$P_i = 220$ W

$P_{cu} = 240$ W

$$\eta_{FL} = \frac{(KVA \times \cos\phi)}{(KVA \cos\phi \times 10^3) + P_i + P_{cu}}$$

(i)

At full load 0.8 p.f lag

$$\eta_{FL} = \frac{KVA \cdot \cos\phi \times 10^3}{[KVA \cos\phi \times 10^3] + P_i + P_{cuFL}}$$

$$= \frac{[20 \times 10^3 \times 0.8]}{[20 \times 10^3 \times 0.8] + [220 + 240]} = 97.21\%$$

(ii)

$$\eta_{HL} = \frac{x(KVA \cdot \cos\phi) \times 10^3}{[x\, KVA \cos\phi] + P_i + x^2 P_{cuFL}}$$

~~Fract~~ fraction

x ~~...~~ % 50%

$x = 0.5$

$$= \frac{0.5(20 \times 10^3 \times 0.8)}{[(0.5(20 \times 10^3 \times 0.8)] + 220 + (0.5)^2 \times 240} = 96.63\%$$

Q 1φ 10 KVA, 500/250 V T/F has the following constant.

Resistance: Primary 0.2 Ω; secondary 0.5 Ω

Reactance: Primary 0.4 Ω; secondary = 0.1 Ω

Resistance of equivalent exciting circuit referred to prim:

$R_0 = 1500$ Ω.

$X_0 = 750$ (X of equivalent exciting ckt referred to primary)

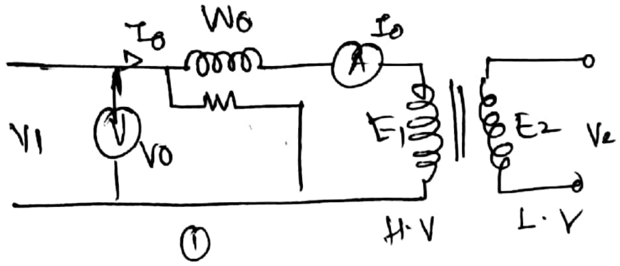
What would be the reading of the instruments when the T/F is connected for the open circuit & short circuit test.

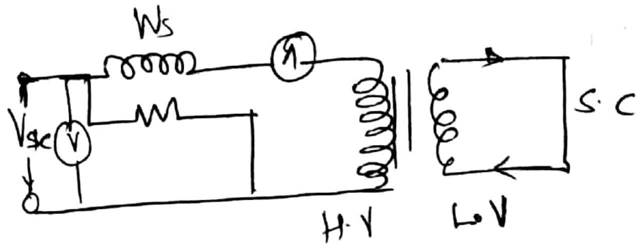
shows the connection of the T/F for open circuit test.

$I_W = \frac{V_1}{R_0} = \frac{500}{1500} = 1/3\,A$, $I_m = \frac{V_1}{X_0} = 2/3\,Amp.$

No load primary input $= V_1 I_W = 500 \times 1/3 = 167\,W.$

Therefore reading of ammeter, Voltmeter & Wattmeter would be 0.75A, 500V, 167 W





Show the connection of the T/F for s.c test. Here the secondary (ie L.V) is short circuited so that all instruments are placed in primary, for the T/F $K = 250/500 = 1/2$.

$R_{1T} = R_1 + R_2' = 2.2\,\Omega$

$X_{1T} = X_1 + X_2' = 0.8\,\Omega$

$Z_{1T} = 2.34$

Full load primary current $I_1 = \frac{10 \times 10^3}{500} = 20\,A.$

$V_{sc} = I_1 Z_{1T} = 46.8\,V$

Power absorbed $= I_1^2 R_{1T} = (20)^2 \times 2.2 = 880\,W.$

therefore, (A), (V), (W) reading resp.
20A 46.8 880 W.

University asked Q

① The following results were obtained from test 30KVA, $\frac{3000V}{110V}$

1ϕ T/F O.C Test (HV side): 3000V ; 0.5A ; 350W
S.C Test (HV side) 150V ; 10A 500W.

Caln efficiency & Regulation of T/F. (S-16) 7M

① FL at 0.8 Pf lag ② ½ FL at UPF. (W-15) 7M.

Simple

② Obtain the equivalent ckt of a 200/400V, 50HZ 1ϕ T/F

306 O.C Test - 200V, 0.7A ; 70W - L.V side
S.C Test - 15V ; 10A ; 85W - HV side

Calculate the secondary Voltage when delivering 5KW at 0.8 P.f lag, the primary Voltage being 200V. (W-16) 8M. (W-17)

$R_0 =$

(S-17) 8M.

③ 3ϕ, 50KVA, 2200V/500V, 50HZ Δ/Y TF
O.C Test (L.V side) 500V ; 3A ; 500W
S.C Test (HV side) : 250V ; IfL 900W

Circuit.

① Parameter of shunt branch of equivalent circuit.
② Regulation & Efficiency of T/F at full load 0.8 P.f lagging.
③ Maximum efficiency & load at which it occurs at unity P.f.

④ A-4KVA, 200/400V, 50HZ 1ϕT/F gave the follⁿ data (S-18) 7M

302 No Load (L.V) 200V, 0.7A 60W
S.C (H.V) 9V 6A 21.6W.

① The magnetizing current & the component of iron loss current at normal f & V.

② The secondary terminal Voltage & regulation of T/F at 0.8 leading P.f.

All day Efficiency

We have already defined the power efficiency of the T/F.

$$\eta = \frac{P_{out}}{P_{in}}$$

But for the distribution T/F, the power efficiency does not gives the true idea about the transformer performance.

- Hence the special type of Efficiency called as energy efficiency or all day Efficiency

$$\% \text{ All day } \eta = \frac{\text{Output energy in KWh per day}}{\text{Input energy in KWh per day}} \times 100$$

$$= \frac{\text{Output Energy in KWh per day}}{[\text{Output Energy}] + \text{Energy spent per day for total losses}} \times 100$$

Q. The total full load loss of 150 KVA T/F is 4.5 KW which is divided equally betn iron & copper loss. The T/F is loaded as follows during the 24 Hrs of a day. Cal. the all day η

No. of Hrs	Loading
3 Hrs	Full load
4 Hrs	Half Load
17 Hrs	No Load

Soln Calculate the total Loss.

P_{cu} at F.L = 4.5/2 = 2.25 KW

P_{cu} at H.L = 2.25/4 = 0.5625 KW

Total copper loss in day = (2.25 × 3) + (0.5625 × 3) = 9 KWh

total Iron loss in day = 2.25 KW × 24 = 54 KWh.

Total Loss per day = 9 KWh + 54 KWh = 63 KWh.

assume $\cos\phi = 1$

FL (KW) = KVA × $\cos\phi$ = 150 KW this for 3 Hrs (150 × 3) = 450 kWh

HL (KW) = (KVA/2) × $\cos\phi$ = 75 KW this for 4 Hrs. (75 × 4) 300 KWh

output of T/F per day = (150 KW × 3 Hr) + (75 KW × 4 Hrs) = 750 KWh

$$\eta = \frac{\text{O/P KWh}}{\text{O/P + Losses}} = \frac{750 \text{ KWh}}{750 \text{ KWh} + 63 \text{ KWh}} \times 100 = 92.25\%.$$

University Q. on all day η.

1) A 20KVA T/F has max. η of 98% when the delevering three fourth full load at UPF; if during the day, the T/F is loaded as fallows. (S-17) 7 Marks

12 Hrs — No Load
6 Hrs — 12 KW @ 0.8 P.f
6 Hrs — 20 KW UPF.

Calculate the All day efficiency of the T/F.

2) 50KVA T/F has efficiency of 98% on full load at 0.8 p.f & 98.5% on Half load at 0.9 p.f. Determine all day of this T/F for fallowing load cycle (8M) (W-16)

6 Hrs — 5KW at p.f 0.6
12 Hrs — 40KW at p.f 0.8
6 Hrs — 30KW at p.f 0.85.

Q3) 40 KVA distribution T/F has iron loss of 500W & Full load copper loss of 500W; the T/F supplying a lighting load (unity p.f) The load cycle is as under (S-18) — 8M.

F.L for 4 Hrs
H.L for 8 Hrs.
N.L for 12 Hrs

Cal.
1) Efficiency of T/F at Half load (Same as) — 3M
2) ALL DAY η of T/F — 5M

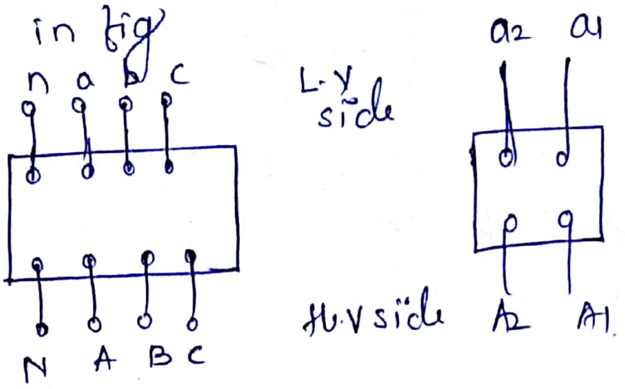
Solⁿ:-

Iron Loss = 500W = 0.5KW
Cu FL Loss = 500 W = 0.5 KW
Cu loss at H.L = 500/4 = 125 W
Iron loss for 24Hrs = (500 × 24) = 12KWh
Cu loss in 24 Hrs = [(0.5 × 4) + (0.125 × 8)] = 3 KWh
Total loss in 24 = 12 + 3 = 15KWh.
Output in 24 Hrs = (40×4) + (40 × 1/2 × 8) = 320 KWh

All day η = $\frac{320}{335} \times 100$ = 95.52%

Polarity Test :-

The H.V & L.V terminals of 1φ & 3φ T/F should be always be marked in fig



For a 3φ T/F, viewed from H.V side the arrangement of both sets of terminals shall be in alphabetical order from left to right.

If neutral is provided; it should be on the extreme left end

In case of 1φ T/F. the terminal subscript numbers should be arranged in descending order from left to right.

capital letters are used to indicate H.V winding; small letters are used to indicate L.V winding.

The identical suffixes on H.V & L.V side represent identical polarity i.e at any instant in a cycle if A_1 is +ve then a_1 must be +ve and at the same instant A_2 & a_2 both must be -ve,

To find polarity correctly, following test are performed

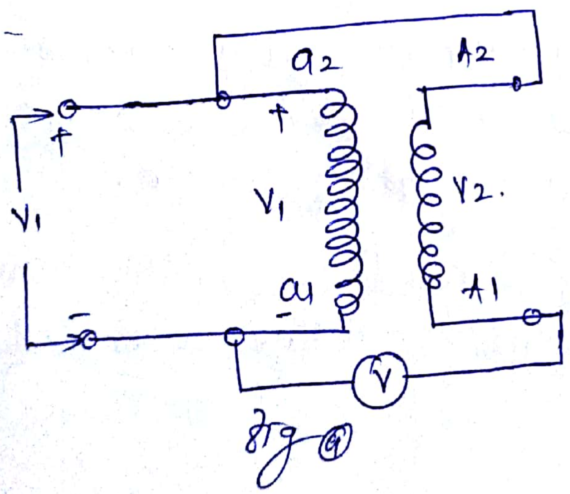
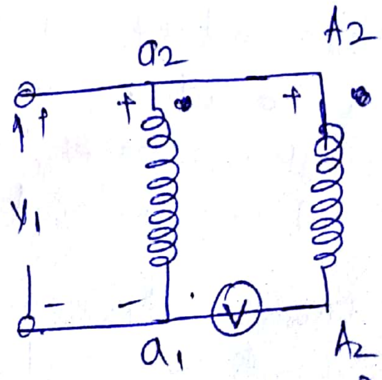


fig (a)

Two winding are connected in series across the voltmeter



$V = V_1 - V_2$

fig (b)

correct polarity

The set up for the polarity test is shown in fig. It shows that the two windings are connected in series & voltmeter is connected across their series connection. The equivalent ckt of this connection is shown in fig (b)

If the polarities of winding voltages are as shown fig (b) then the voltmeter reading is

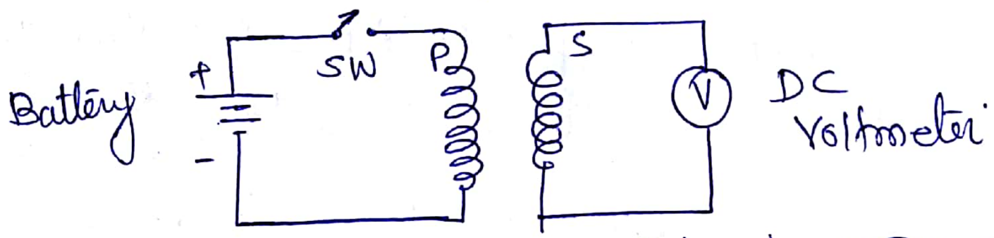
$$V = V_1 - V_2$$

And if the voltmeter reads $(V_1 + V_2)$ then the polarity marking of one of the winding should be interchanged.

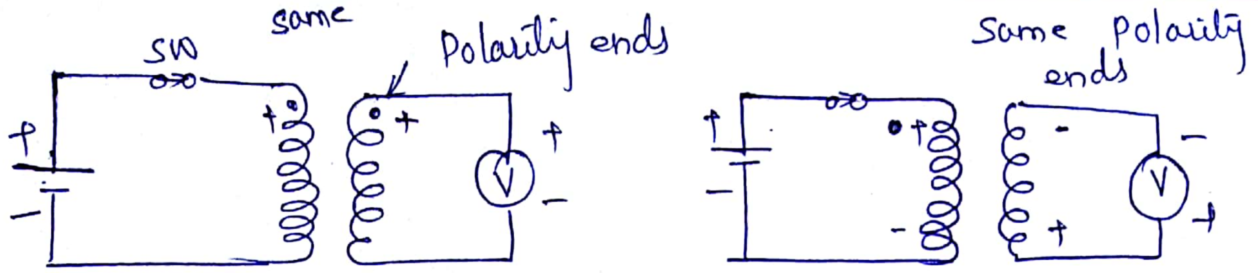
In this way be polarity of the two windings of T/F are identified

Methods II for polarity test

- The earlier method of polarity testing is not very useful for the field testing of T/F.
- so a simpler method of polarity testing is used. this method uses a dc battery, a switch and dc voltmeter of the set up for this polarity test is as shown.



- A battery and series switch is connected on the primary side of the T/F & DC Voltmeter is connected across the secondary winding.
- As we close the switch, the primary current increases the flux linkages of both the winding This will increase the flux linkages of both the windings of the T/F. so emf are induced in both the windings.
- The positive polarity of this induced emf in the primary winding is at the end to which the battery is connected as shown

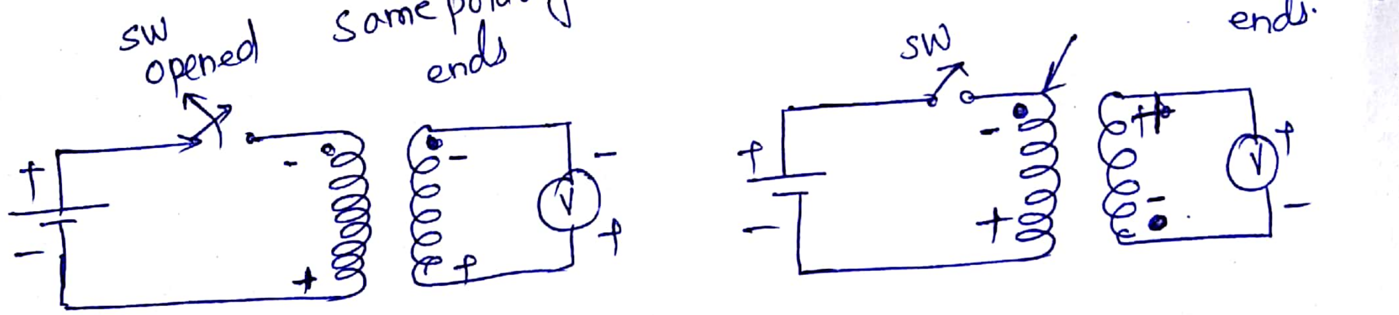


(a) (b)

The end of secondary winding which acquires the same positive polarity is determined by the polarity of secondary voltage as indicated by the voltmeter. as shown in fig (a) & (b)

When the switch is opened; primary current is interrupted & a negative voltage will appear across the primary as shown in fig (c).

- and the similar polarity of on the secondary side is the end which becomes negative as shown (c) & (d)



(c) Fig. (d)