(16 marks)

Why transformer is generally rated in KVA and not in kW? Explain factors affecting the efficiency of transformer with proper mathematical justification and graph. [2+6]

Explain the no load and loaded operation of single phase ideal transformer. Prove that net magnetic flux in the core is remain constant in any loaded condition. [2+2+4]

a) What is an auto transformer? State its merits and demerits over a two winding transformer. Derive an expression of cu-saving in auto transformer. [2+6]

How practical transformer is different from ideal one? Explain with phasor diagram the operation of practical transformer when secondary is connected to load. [2+6]

Explain the no-load and loaded operation of an ideal transformer. Prove that the flux in the transformer core remains constant irrespective of the change in load. [8]

Describe different types of losses on the transformer and how the efficiency is calculated? Derive the condition at which the efficiency of transformer will be maximum. [8]

Explain the working principle of a single transformer with necessary diagram and deduce the expression for emf in secondary winding. [8]

... load affects the nature of armature reaction. [8]

Explain, how can we make equivalent circuits referred to primary side and referred to secondary side. What happens, when a power transformer is connected to a d.c. supply of the same voltage ratings? [6+2]

A 10 KVA, 200/400 V, 50 Hz single-phase transformer ...

a) Derive expression giving amount of copper saving in an auto-transformer. [4]

b) Discuss how to conduct open-circuit and short-circuit tests on a single phase transformer. From the test results how the efficiency and voltage regulation of the transformer is determined? [6]

Copper loss is assumed to be negligible in no load test and iron loss is assumed negligible in short circuit test. Explain why it is so. [8]

The following test result ...

How current transformer is different from conventional transformer. Explain how CT is used to measure high currents. Also explain, what happens if the secondary of CT is open when there is high current flowing in primary side. [8]

a) Explain working principle of an auto-transformer. Derive an expression for Cu saving in an auto-transformer. [8]

Explain the operation of transformer with no-load and load. Prove that the magnetic field in a transformer core remains constant at any load.

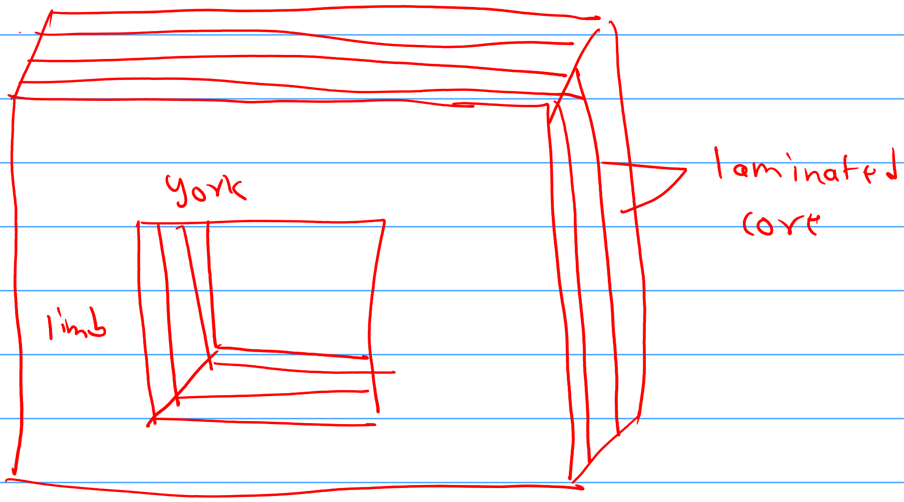
a) Explain the working of an ideal transformer under (i) no-load and (ii) loaded conditions and derive expressions for voltage and current ratios relating to transformer turns ratio. [4+4]

Derive an expression for Cu saving in an auto-transformer.

Explain the no-load and loaded operation of an Ideal transformer. Prove that the net magnetic flux in the core remains constant at any load.

Describe different types of losses on the transformer. Also derive the expression for the maximum efficiency of the transformer. [8]

Transformer



→ Transformer is a static electrical machines which transfers electric power from one circuit to another circuit. while transferring the power from one ckt to another, the voltage level of the 2nd circuit may change w.r.t. the voltage level of the 1st ckt but the frequency of both the ckt remains same.

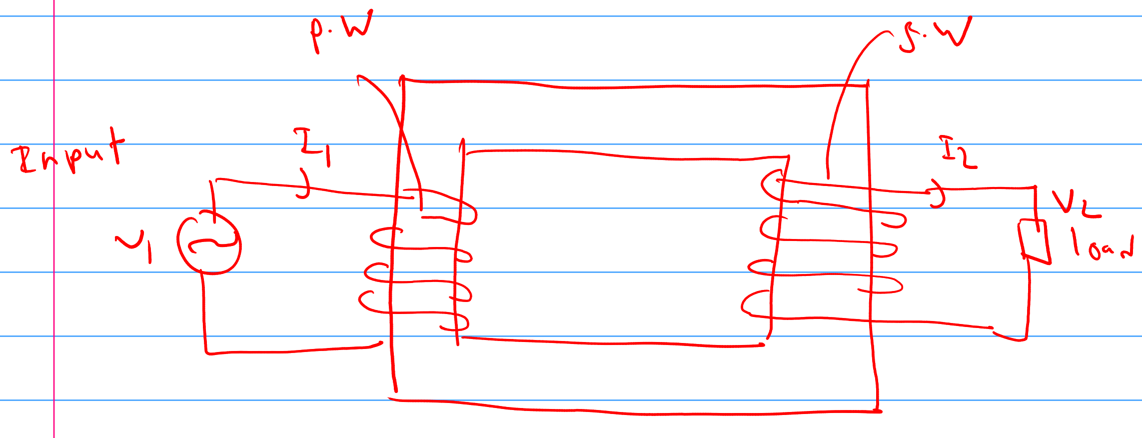
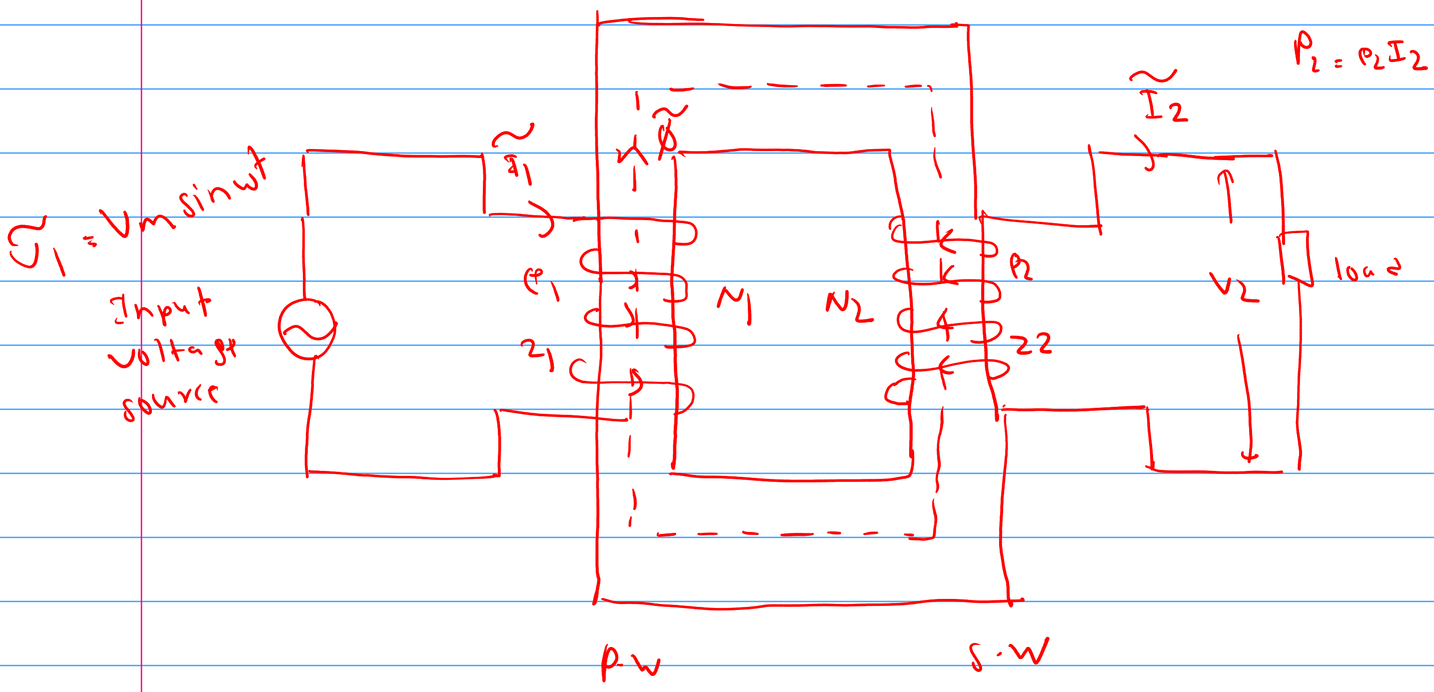


Fig: block diagram:

Working principle and EMF equation of transformer (IOE)

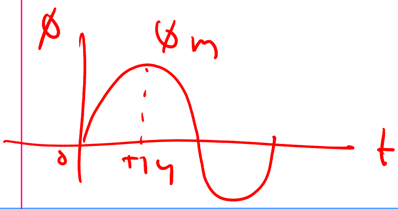


→ When ac voltage $\tilde{V}_1 = V_m \sin\omega t$ is connected across the 1st winding on ac current $\tilde{I}_1$ will flow through 1st winding.

→ because of this current $\tilde{I}_1$, the iron core will get magnetized and alternating flux $\tilde{\phi}$ circulates through the iron core.

→ Since the changing flux $\tilde{\phi}$ is linking with the N_2 no of turns emf (e_2) will induce in the secondary winding according to faraday's law of EMI.

→ If the load is connected across the secondary winding current $\tilde{I}_2$ will flow through the load and $P_2 = e_2 I_2$ is the power consumed by the load which was transferred from the primary winding.



emf equation (IOE)

→ According to FLEI, emf e_2 induced in a coil 2 due to ϕ is ÷

→ alternating flux (changing)

$$e_2 = N_2 \frac{d\phi}{dt} \quad \text{— (i)}$$

remember

Here, ϕ changes from 0 to ϕm in $\frac{T}{4}$ seconds

$$\frac{d\phi}{dt} = \frac{\phi m - 0}{\frac{T}{4}} = \frac{4\phi m}{T}$$

So, $$\frac{d\phi}{dt} = \frac{4\phi m}{T} \quad \text{— (ii)}$$

→ avg rate of change of flux

Avg value of emf e_2 is ÷

$$E_2(\text{avg}) = N_2 \frac{d\phi}{dt} = N_2 \frac{4\phi m}{T}$$

$$E_2(\text{avg}) = N_2 4 \phi m f \quad \text{(iii)} \qquad \left(\frac{1}{T} = f\right)$$

For sine wave

$$\text{form factor} = \frac{\text{Rms value}}{\text{avg value}} = 1.11 \quad \text{— (iv)}$$

$$E_2(\text{rms}) = \text{form factor} \times E_2(\text{avg})$$

$$= 1.11 \times N_2 4 \phi m f$$

$$\therefore \boxed{E_2\,(rms) = 4.44\, N_2 f \phi_m} \quad -(iv)$$

since change in flux $\tilde{\phi}$ is also linking with N_1 turns emf E_1 will be induce in p.w

$$\boxed{E_1\,(rms) = 4.44\, N_1 f \phi_m} \quad -(v)$$

Eqn (iv) and (v) are the emf equation of transformer

KVL secondary winding

$$\tilde{E}_2 = \tilde{I}_2 \tilde{Z}_2 + \tilde{V}_2$$

at no load $I_2 = 0$

$$|E_2| = |V_2|$$

KVL primary

$$\tilde{V}_1 = \tilde{I}_1 \tilde{Z}_1 + \tilde{E}_1$$

at no load $I_1 \to$ very small

$$|V_1| = |E_1|$$

Dividing (iv) and (v)

$$\frac{E_2\,(rms)}{E_1\,(rms)} = \frac{4.44 f N_2 \phi_m}{4.44 f N_1 \phi_m}$$

$$\therefore \frac{V_2}{V_1} = \frac{N_2}{N_1} = k \quad \text{(transformer ratio)}$$

$$\boxed{V_2 = kV_1}$$

Case I : $N_2 > N_1$ $(k > 1)$

→ step-up transformer

Case II $N_2 < N_1$ $(k < 1)$

→ Step-down transformer

Case III $N_2 = N_1$ $(k = 1)$

→ isolation transformer.

Ideal Transformer | Real Transformer (IOE)

→ whose winding are purely inductive
→ whose power loss is zero
→ whose magnetic flux leakage is zero
→ whose efficiency is 100 %.

(Operating principle mathi ko is of ideal)

→ The process in which a changing current in one coil induces emf in another coil is called mutual inductance.

No-load and load operation of transformer (IOE)

(i) Operation at no-load

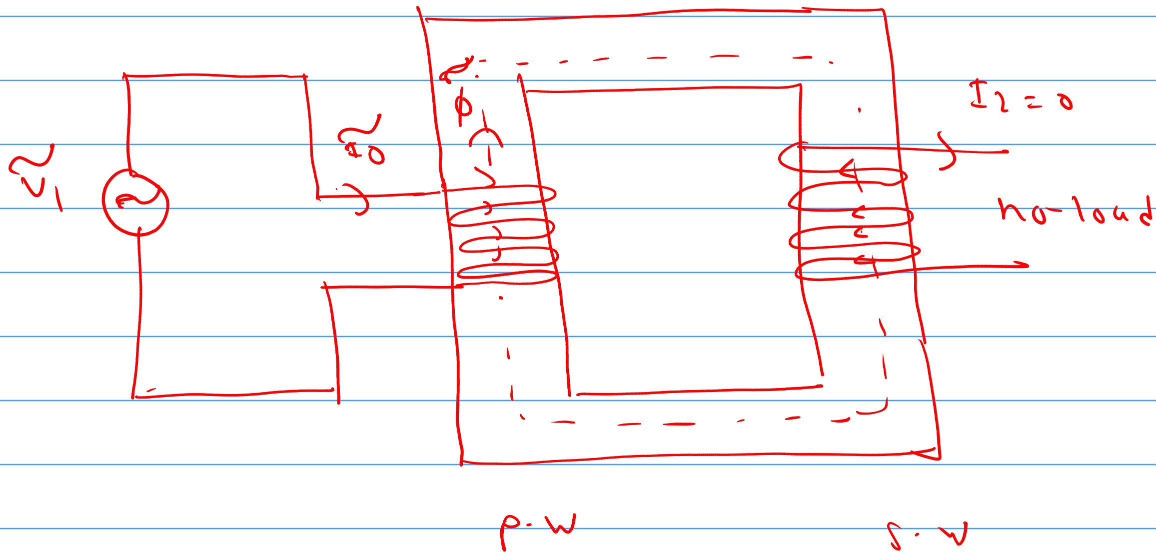


Fig shows a 1ϕ transformer without load in the secondary side. Primary winding is supplied by rated voltage $\tilde{V}_1$.
Here, Secondary current $\tilde{I}_2 = 0$

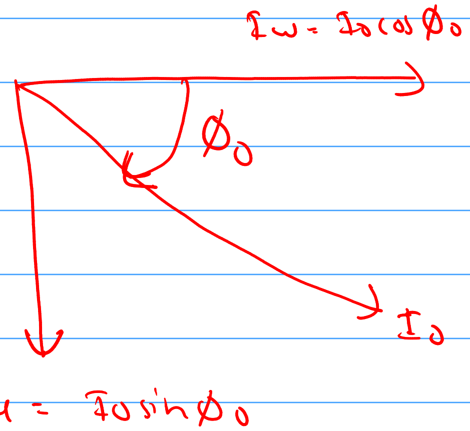
primary winding draws a small amount of current $\tilde{I}_0$.
$\tilde{I}_0$ is known as the no-load current of the transformer.

Volt-Amp consumed by primary winding at no-load
$= V_1 I_0$

This Volt-Amp consumed is extended in following two purposes.

(i) to supply iron loss of transformer
(ii) to maintain magnetic flux in the core.

In ac ckts only 90° lagging current can produce magnetic flux whereas in-phase current produces heat.



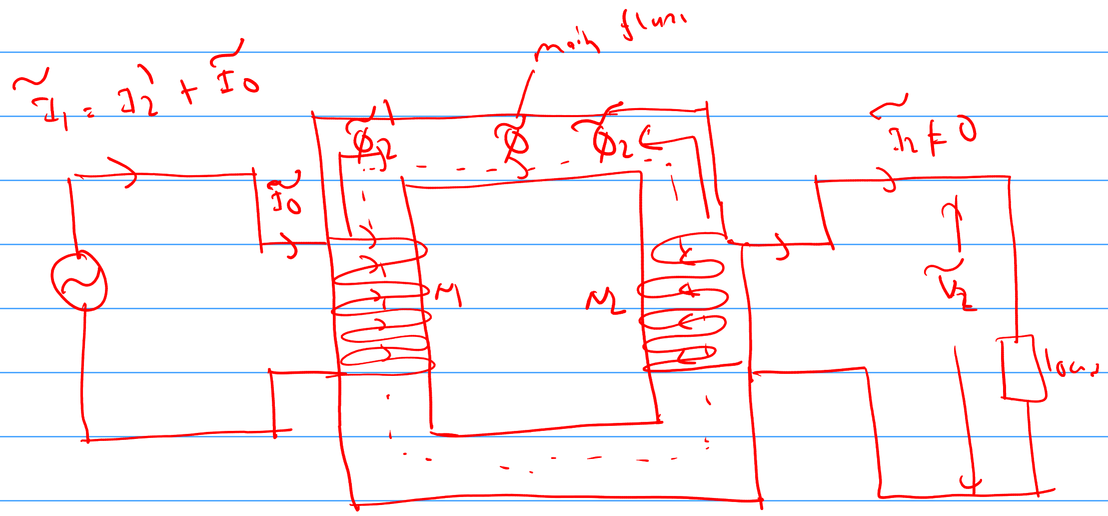
(I_0 lags V_1 due to inductive coil)

$I_w = I_0 \cos\phi_0$ (in phase comp of I_0)
(produces iron loss)

$I_\mu = I_0 \sin\phi_0$ (90° lag comp of I_0)
(produces mag flux in the core)

$$\therefore \boxed{I_0 = \sqrt{(I_w)^2 + (I_\mu)^2}}$$

(ii) Operation with load (20E)



→ when load is added in the secondary winding $\tilde{I}_2$ current flows

→ Hence, 2^{nd} winding produces flux $\tilde{\phi}_2$ in the core which opposes the main flux $\tilde{\phi}$ so it seems that the net magnetic flux in the core decreases but it does not happen because when secondary winding is loaded the primary draws additional current $\tilde{I}_2'$ due to load in secondary to produce a cancelling flux $\tilde{\phi}_2'$. The magnitude of $\tilde{\phi}_2' = \tilde{\phi}_2$ and they cancel each other and net flux in the core remains const and equal to ϕ.

Proof: (IOE)

$$\phi_2 = \frac{mmf}{Rel} = \frac{N_2 I_2}{Rel} \quad \text{—(i)}$$

$$\phi_2' = \frac{mmf}{Rel} = \frac{N_1 I_2'}{Rel} \quad \text{—(ii)}$$

Same core

For ideal transformer no power loss

i.e $P_2 = P_1$

or $V_2 I_2 = V_1 I_1$.

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

we know

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \rightarrow \text{from transformer ratio}$$

Q_1

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}}$$

Sol

$$\frac{N_2}{N_1} = \frac{I_1}{I_2}$$

or $\boxed{N_2 I_2 = N_1 I_1}$ amp-turn balance

$$N_2 I_2 = N_1 \left(I_0 + I_2' \right) \qquad (I_0 \to \text{small})$$

$$N_2 I_2 = N_1 I_2'$$

Sol

$$\phi_2' = \frac{N_1 I_2'}{R_{eq}} = \frac{N_2 I_2}{R_{eq}} = \phi_2$$

$$\therefore \quad |\tilde{\phi}_2'| = |\tilde{\phi}_2|$$

$\tilde{\phi}_2$ and $\tilde{\phi}_2'$ are equal in magnitude and always oppose each other and cancels out completely.

Hence, the net magnetic flux in the core of the transformer is always constant irrespective of the load

Imp proof :

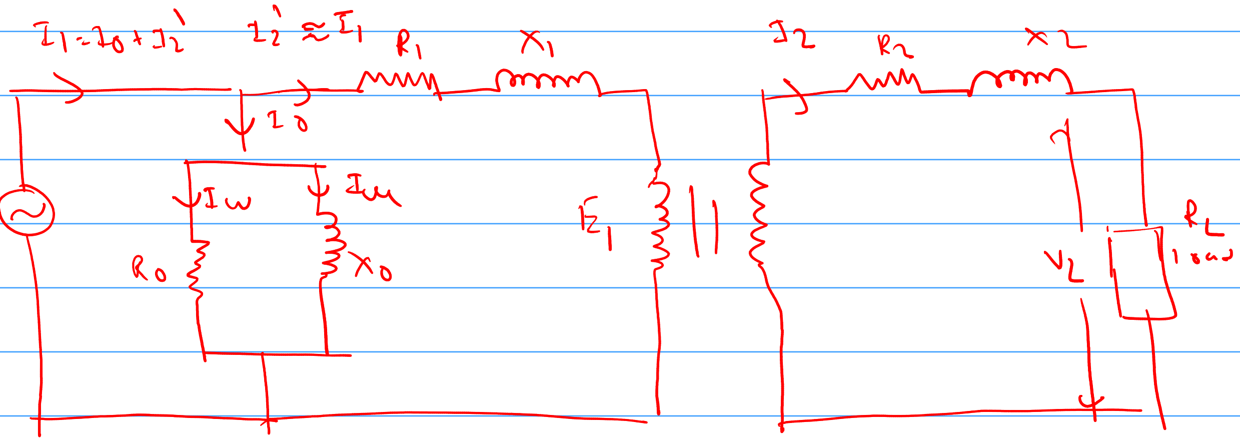
I_2' → additional current in primary side due to added load in secondary side

I_0 → no load current

I_μ → magnetic flux (reactance)

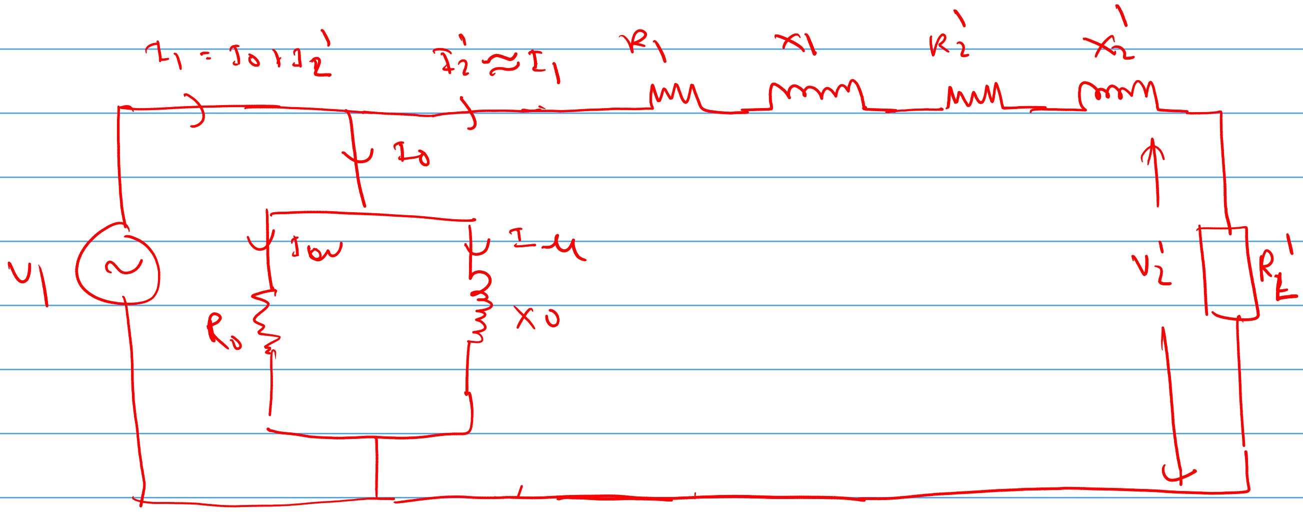
I_w → iron loss (resistance)

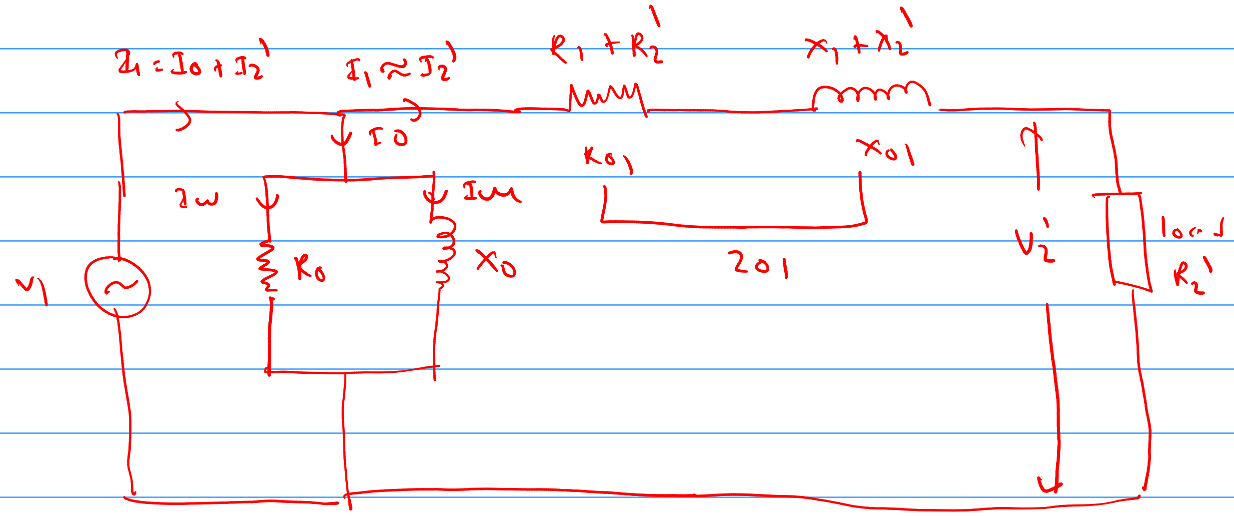
Equivalent ckt of a Transformer



(i) equivalent ckt of a transformer referred to primary side

(sab lai primary ma leuna)





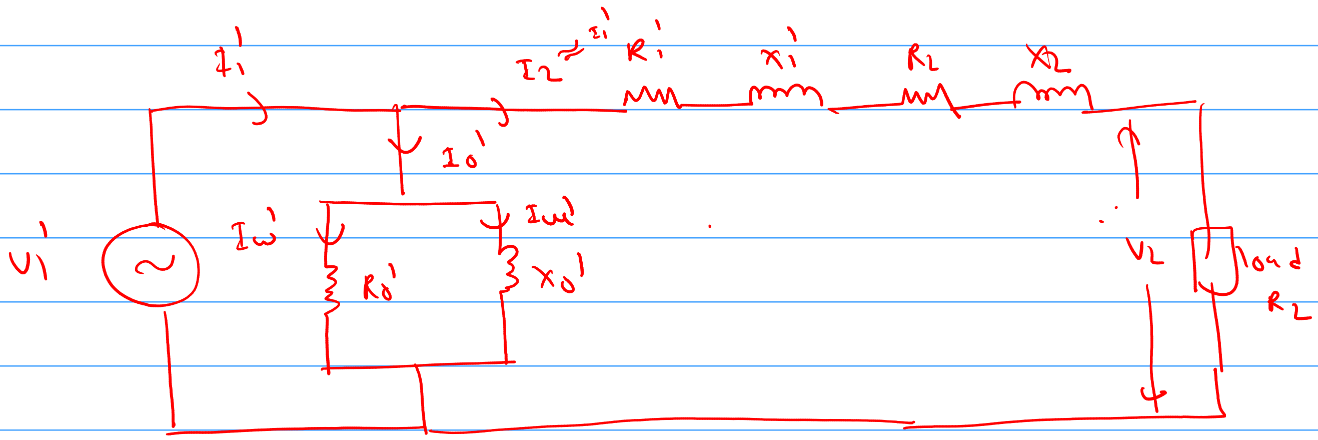
$$Z_{01} = R_{01} + jX_{01}$$

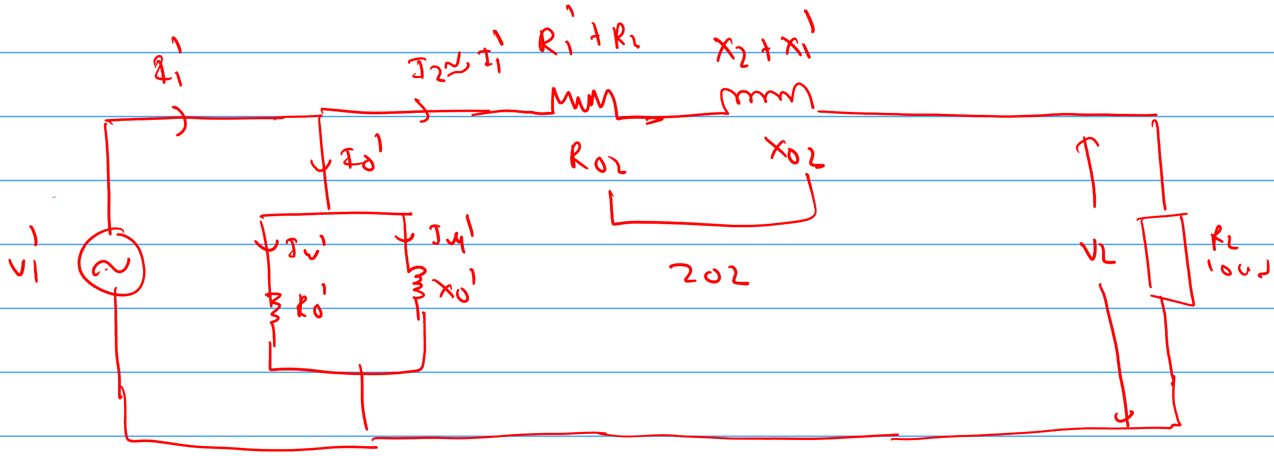
$$= \sqrt{R_{01}^2 + X_{01}^2}$$

$\therefore$ $\boxed{R_2' = \frac{1}{K^2} R_2}$ $\boxed{X_2' = \frac{X_2}{K^2}}$ $\boxed{R_L' = \frac{R_L}{K^2}}$

secondary to primary convert

(ii) Equivalent ckt referred to secondary side





$$Z_{02} = R_{02} + jX_{02}$$

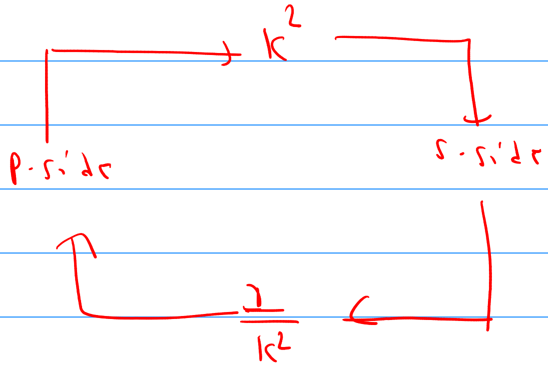
$$= \sqrt{R_{02}^2 + X_{02}^2}$$

$\therefore$ $\boxed{R_1' = k^2 R_1}$ $\boxed{X_1' = k^2 X_1}$ $\boxed{V_1' = kV_1}$

$\boxed{I_1' = \frac{I_1}{k}}$

Conclusion:

(i) R and X



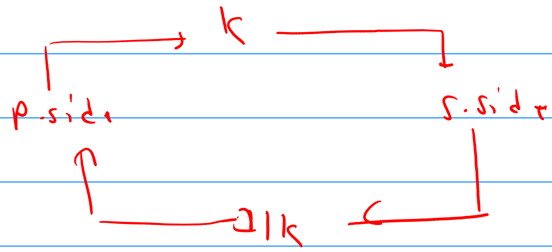
(p-s)

$R_1' = k^2 R_1$

$R_2' = \frac{R_2}{k^2}$

(s-p)

(ii) V



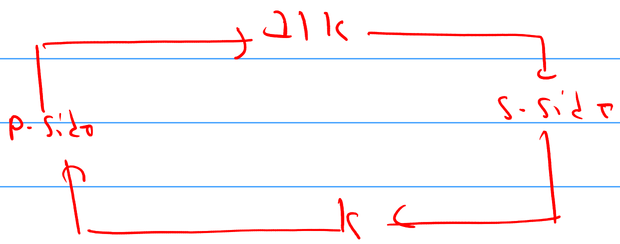
(p-s)

$V_1' = kV_1$

s-p

$V_2' = \frac{V_2}{k}$

③ I



p-s

$I_1' = \frac{I_1}{k}$

s-p

$I_2' = I_2 k$

Capacity of the transformer (IOE)

→ defined as the max output in V-A that a transformer can deliver to the load continuously without producing excessive heating and exceeding specified voltage regulation.

→ The role of the transformer is only to transform the power. Voltage in primary and secondary are always fixed.

→ The design engineer of transformer does not know what types of load will be connected across the transformer in the future.

→ Resistive load → Active power, kW

→ Inductive load / capacitive → Reactive power, KVAR

→ When the system draw both active and reactive power, we call it apparent power. $\left(\sqrt{(kW)^2 + (kVAR)^2}\right)$ → KVA

→ Why we rate transformer in kVA? (IOE)

→ If a transformer were rated in kW, it would imply a fixed power factor, but different loads have different p.f.

resistive load → 1 p.f, inductive → 0.8 p.f

$$p.f = \frac{kW \text{ — active}}{kVA \rightarrow \text{apparent}}$$

→ A 100 kVA transformer can supply 100 kVA at any power factor, but the actual usable power (kW) depends on load.

→ If a load has low power factor (pf: 0.8), the transformer still supplies the same kVA, but the kW output is reduce

resistive load

→ 100 kVA at p.f = 1.0 = 100 kW

→ 100 kVA at p.f 0.8 = 80 kW

inductive load

(kW = p.f × kVA)

→ different industries use different loads so the pf varies so transformer are rated in kVA to ensure that they can handle any load condition.

→ The same 100kVA transformer supplies different kW values depending on load's p.f

→ If transformer in rated in kW, it would be misleading because it can't guarantee a fixed kW output.

Eg:- 100 kW transformer, p.f = 0.8 then,

$$\text{required kVA} = \frac{kW}{p.f} = \frac{100}{0.8} = 125 \text{ kVA}$$

But our transfer is only 100kVA, so it would fail

→ thus, kVA rating ensures the transformer works safely under all power factor conditions.

Transformer testing (Imp) (Theory + Numericals)

① No-load Test / open-ckt test

Objectives

→ to determine the core loss (iron loss)

→ determine the no-load current (I_0) and branch parameter R_0 and X_0 and no load p.f.

L.V | H.V
11 kV | 22 kV

Steps

① open H.V side

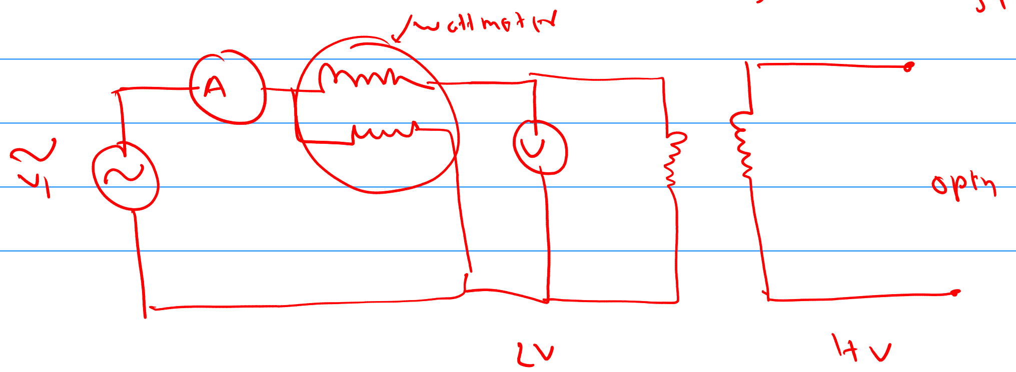
② supply L.V side with normal rated voltage

③ ammeter, voltmeter and wattmeter are connected in LV side

④ test is done without load on the transformer

⑤ voltmeter measures LV side voltage, ammeter no load current (I_0), wattmeter no-load power (core loss / iron)

① Step-up transformer (LV – HV) (exam ma show step-up)



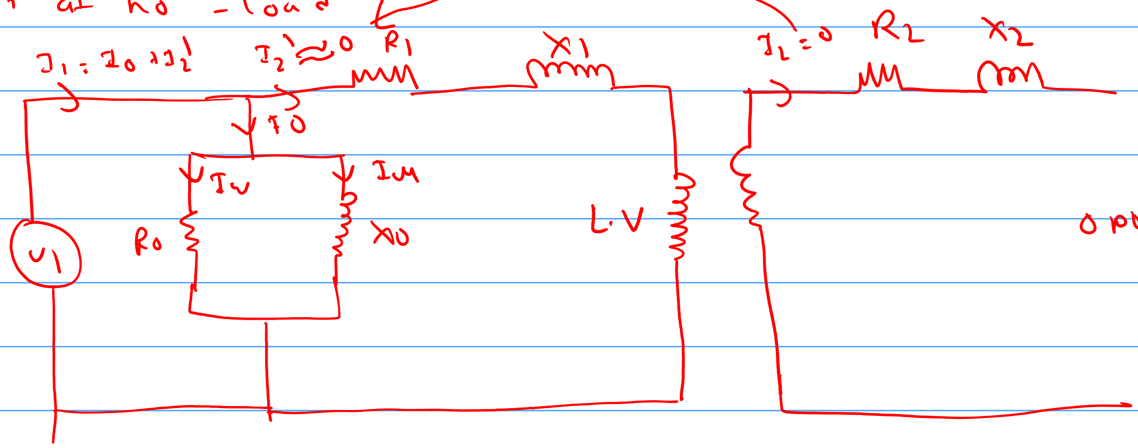
normal rated voltage is supplied to LV winding

Ammeter reading $= I_0 =$ no-load current

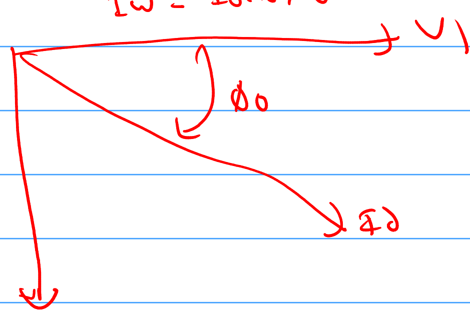
voltmeter reading $= V = V_1$

wattmeter reading $= W_0 =$ Iron loss

Eq^n ckt at no-load



$I_w = I_0 \cos\phi_0$ (iron loss)



I_μ
$= I_0 \sin\phi_0$
(magnetic flux)

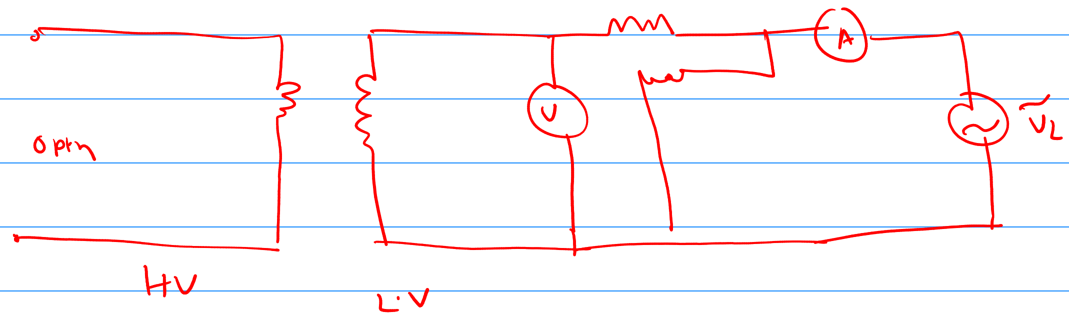
$$\boxed{W_0 = V_1 \times I_w}$$

$$= V_1 \times I_0 \cos\phi_0$$

$$\therefore \boxed{\phi_0 = \cos^{-1}\left[\frac{W_0}{V_1 \times I_0}\right]}$$

$\therefore$ $\boxed{I_w = I_0 \cos\phi_0}$ $\boxed{I_\mu = I_0 \sin\phi_0}$ $\boxed{R_0 = \frac{V_1}{I_w}}$ $\boxed{X_0 = \frac{V_1}{I_\mu}}$

② Step-down transformer (HV − LV)



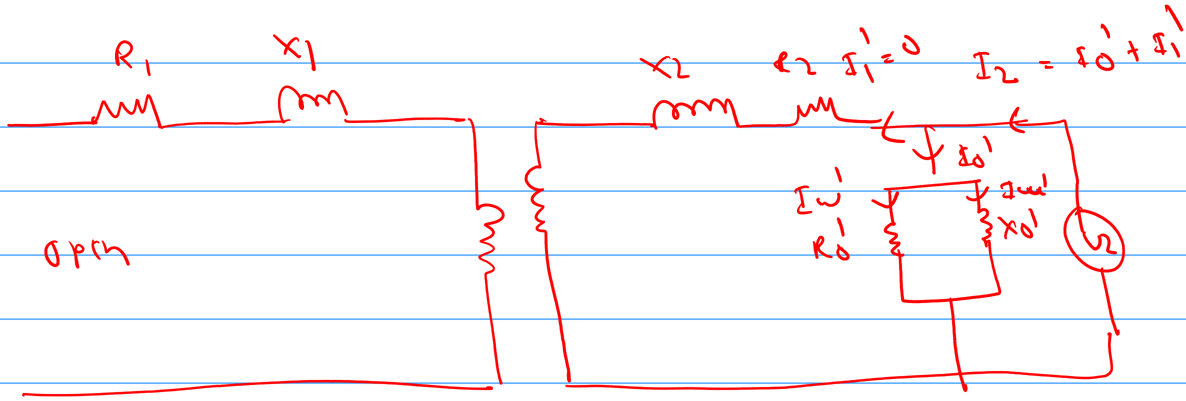
V_2 is supplied at L.V

ammeter reading = I_0 = no-load current

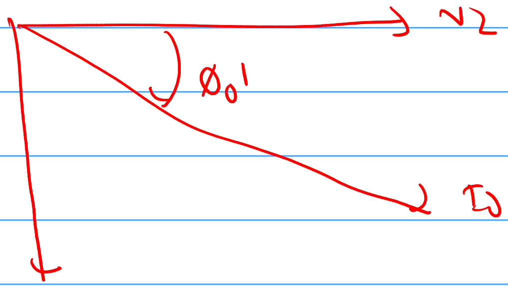
voltmeter reading (V) = V_2

wattmeter reading (W_0) = Iron loss

eqn ckt



$I_w' = I_0' \cos \phi_0'$



$I_\mu' = I_0' \sin \phi_0'$

$$\boxed{W_0 = V_2 \times I_w'}$$

$$W_0 = V_2 \times I_0' \cos\phi_0'$$

$$\boxed{\therefore \phi_0' = \cos^{-1}\left[\frac{W_0}{V_2 \times I_0'}\right]}$$

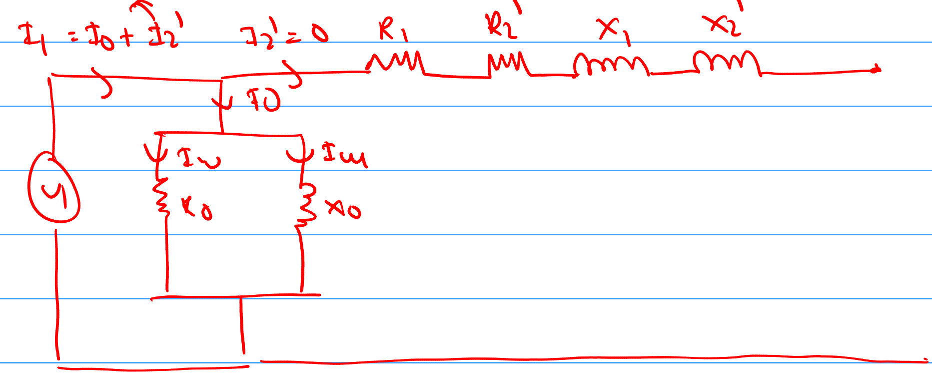
$$\boxed{I_w' = I_0' \cos\phi_0'} \quad \boxed{I_\mu' = I_0' \sin\phi_0'} \quad \boxed{R_0' = \frac{V_2}{I_w'}}$$

$$\boxed{X_0' = \frac{V_2}{I_\mu'}}$$

Original value, $R_0' = K^2 R_0$ $\quad \therefore$ $\boxed{R_0 = \frac{R_0'}{K^2} \quad X_0 = \frac{X_0'}{K^2}}$

eqn ckt referred to primary and secondary

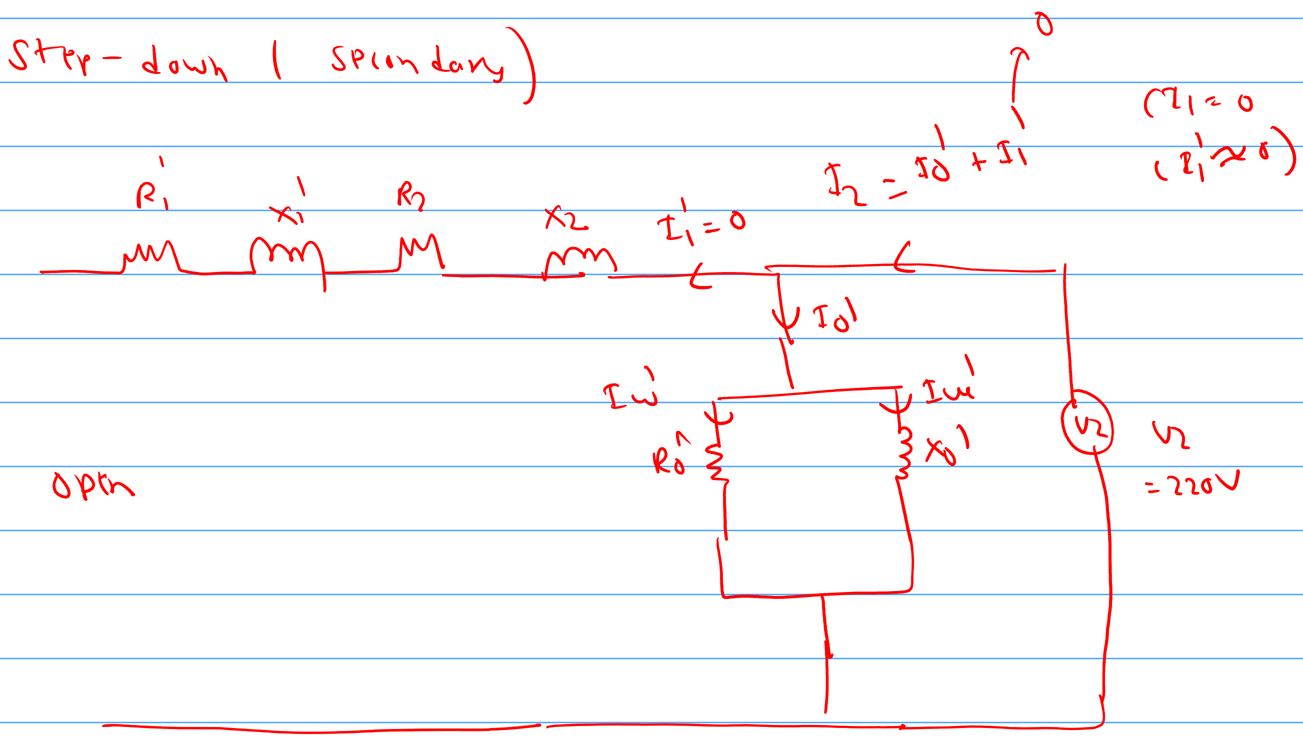
step-up (primary side)



$\left(\begin{matrix} P_2 = 0 \\ I_2' \approx 0 \end{matrix} \right)$

open

Step-down (secondary)



② **Short-ckt Test (SCT)**

→ gives the copper loss at the transformer at full load and series parameters of the transformer. (R_{01}, X_{01} or R_{02}, X_{02})

Producedure

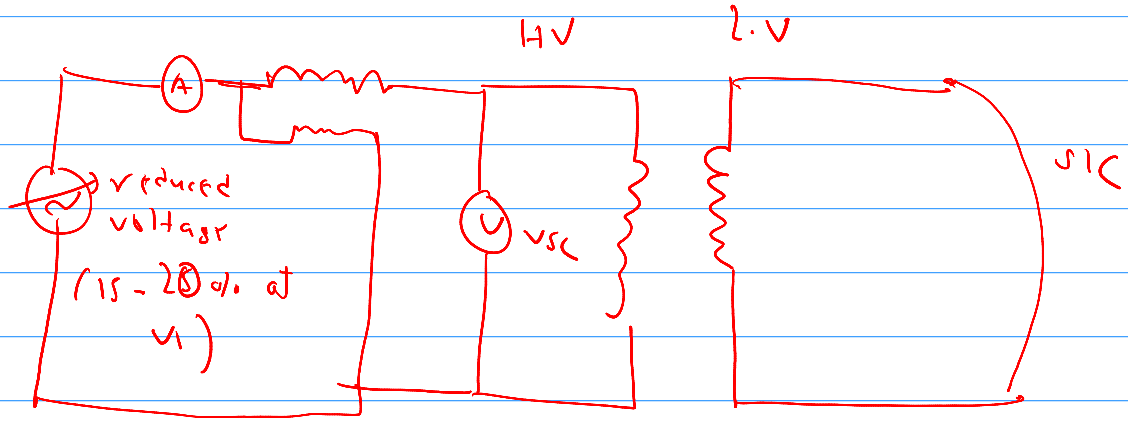
→ LV side of transformer is short circuited by thik wire and HV side is supplied by reduced voltage.

→ ammeter, voltmeter and watt meter are connected in HV side

→ Increase applied voltage slowly from zero untill ammeter reads full load current.

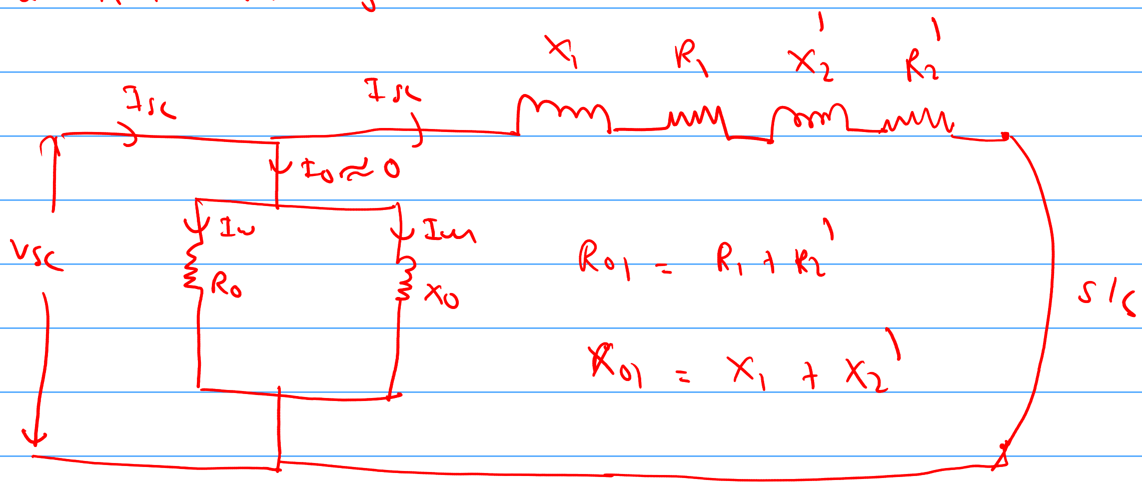
✓ exam ma explain this :

① Step down transformer (HV - LV)



Vsc = Voltmeter reading = reduced voltage (15 - 20% of normal rated Voltage)

Isc = ammeter reading



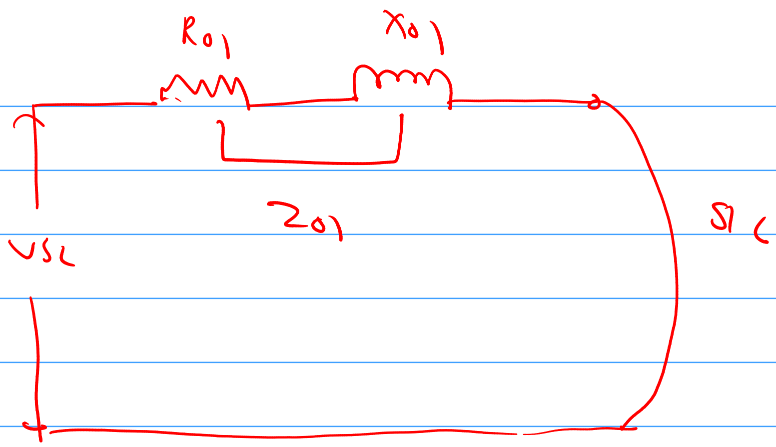
$R_{01} = R_1 + R_2'$

$X_{01} = X_1 + X_2'$

Since $|R_0|$ and $|X_0|$ >> $|R_{01}|$ and $|X_{01}|$

negligible current flows through R_0 and X_0 at reduced voltage. So there is no iron - loss.

(Why iron loss is negligible in S/C test ?)



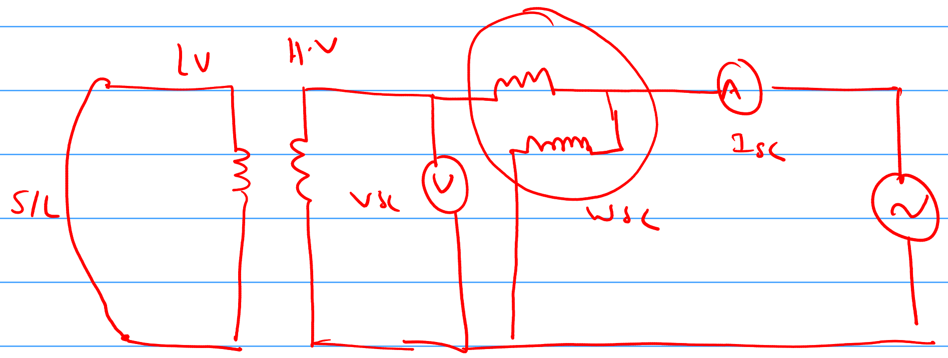
W_{sc} → copper loss only due to resistance (cu-loss)

$$\boxed{W_{sc} = I_{sc}^2 \times R_{01}} \quad \therefore \quad \boxed{R_{01} = \frac{W_{sc}}{(I_{sc})^2}}$$

$$\boxed{Z_{01} = \frac{V_{sc}}{I_{sc}}}$$

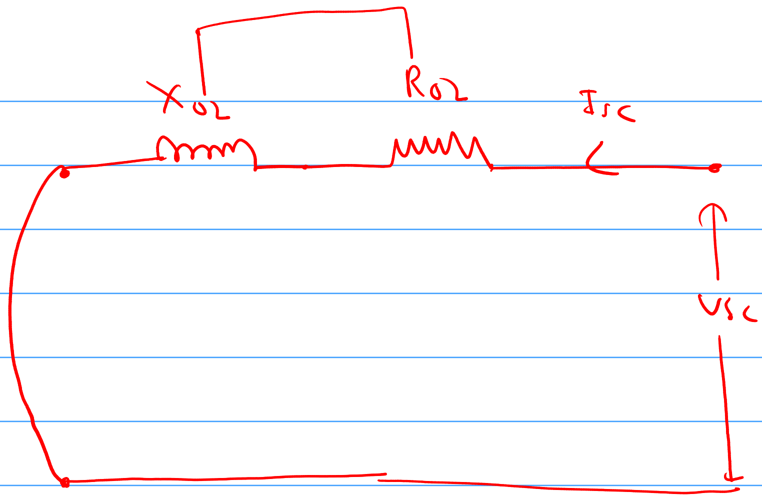
$$\therefore \boxed{X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}}$$

(6) Step-up transformer (LV - HV)



reduced voltage V_2 (15-20% of normal rated voltage V_2)

Z_{02}



eqn ckt referred to secondary side

$V_{sc} = I_{sc} \times Z_{02}$

Cu-loss

$\therefore \boxed{Z_{02} = \frac{V_{sc}}{I_{sc}}}$ $\boxed{W_{sc} = I_{sc}^2 \times R_{02}}$

→ only due to resistance

$\boxed{R_{02} = \frac{W_{sc}}{I_{sc}^2}}$ $\boxed{X_{02} = \sqrt{Z_{02}^2 - R_{02}^2}}$

For primary side

$\boxed{R_{01} = \frac{R_{02}}{k^2}}$ $\boxed{X_{01} = \frac{X_{02}}{k^2}}$

Voltage regulation

$$V.R = \frac{V_{02} - V_{f2}}{V_{f2}}$$

$V_{02} \rightarrow$ secondary voltage at no-load

$V_{f2} \rightarrow$ secondary voltage at full load

voltage drop at full load is very small $\rightarrow$ good VR

" " " " " " " is very large $\rightarrow$ bad VR

Losses in a transformer (IOE)

① Iron loss (Core loss) $\rightarrow$ constant

$\rightarrow$ Occurs in transformer core due to alternating magnetic field.

$\rightarrow$ hysteresis loss, eddy current loss

② Copper loss $\rightarrow$ depends on load

$\rightarrow$ Occurs in windings of the transformer due to the electrical resistance of the copper coils.

$$P_{copper} = I^2 R$$

$\rightarrow$ can occur in both windings.

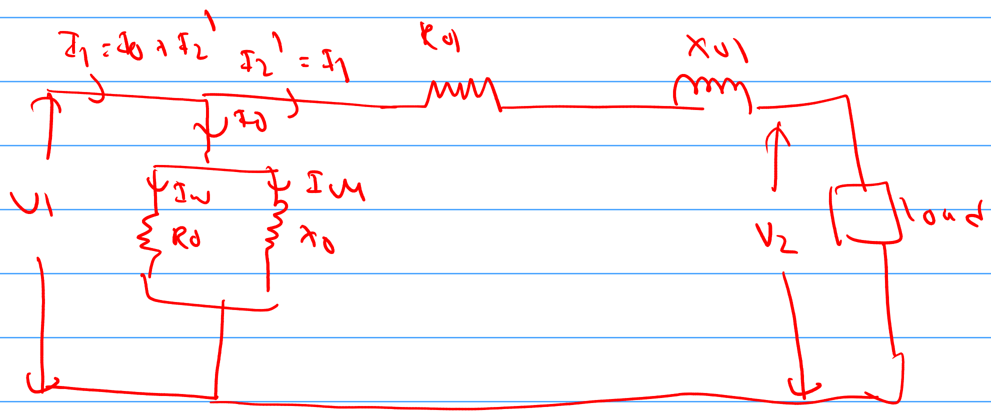
(without load $\rightarrow$ iron loss only
with load $\rightarrow$ iron + cu-loss)

Efficiency and condition for max efficiency of transformer (IOE)

$$\boxed{\eta = \frac{P_{out}}{P_{in}}}$$ at no-load, $P_{out} = 0$, $\eta = 0$

When some load is added in secondary side, $\eta \neq 0$

→ When the load on transformer increases, η of the transformer goes on increasing. However there is a limit on increasing the η. After certain load the efficiency of the transformer decreases.



P_{out} = P_{input} − losses
= P_{in} − Iron loss − Copper loss ← resistance
$= V_1 I_1 \cos\phi_1 - W_0 - (I_1)^2 \times R_{01}$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_1 I_1 \cos\phi_1 - W_0 - I_1^2 R_{01}}{V_1 I_1 \cos\phi_1}$$

$$\eta = 1 - \frac{W_0}{V_1 I_1 \cos\phi_1} - \frac{I_1 R_{01}}{V_1 \cos\phi_1}$$

η will be max when

$$\frac{d\eta}{dI_1} = 0$$

or $$0 - \frac{W_0}{V_1 \cos\phi_1} \frac{d(1/I_1)}{dI_1} - \frac{R_{01}}{V_1 \cos\phi_1} \frac{d(I_1)}{dI_1} = 0$$

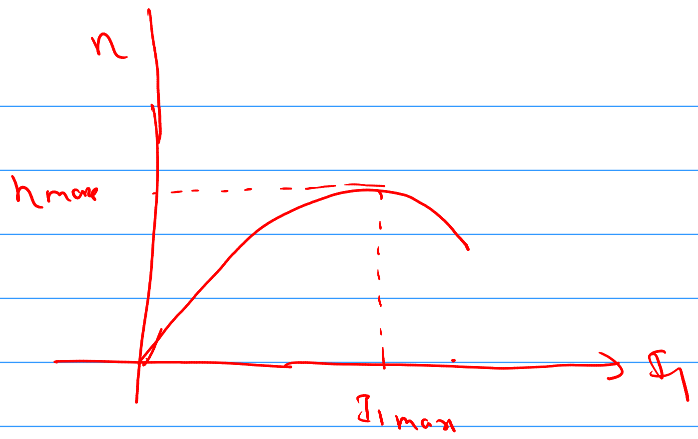
or $$-\frac{W_0}{V_1 \cos\phi_1} \cdot (-I_1^{-2}) - \frac{R_{01}}{V_1 \cos\phi_1} = 0$$

or $$\frac{W_0}{I_1^2 V_1 \cos\phi_1} = \frac{R_{01}}{V_1 \cos\phi_1}$$

or $$\boxed{W_0 = R_{01} \times I_1^2}$$

$$\boxed{\text{iron loss } (W_0) = R_{01} \times I_1^2 \cancel{\phi} = \text{Cu-loss}}$$

When iron loss = Cu-loss, η of the transfor will be max.



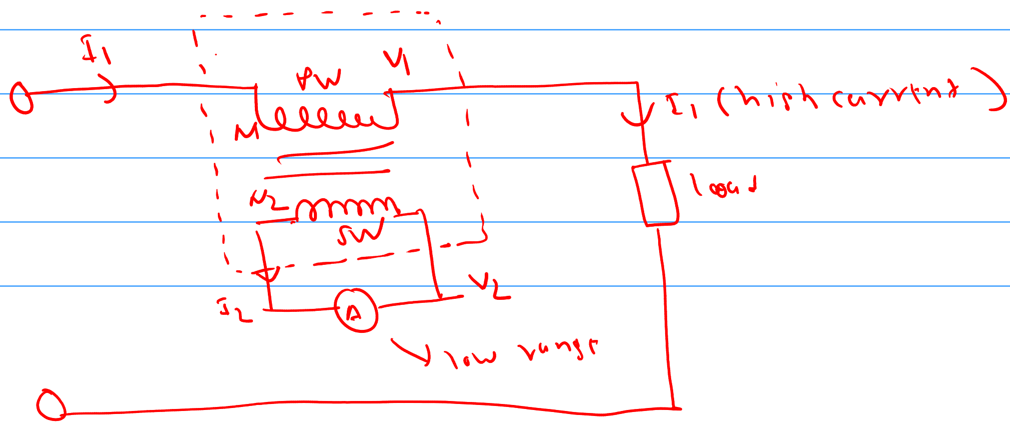
$\therefore I_1 \, max = \sqrt{\dfrac{W_0}{R_{01}}}$

$\eta_{\text{all day}} = \dfrac{\text{o/p power in kWh}}{\text{i/p power in kWh}}$ for 24 hrs

Current Transformer (IOE)

→ It is used to measure high amp load current low range ammeter.

→ The primary winding of the CT is connected in series with the load whose current is to be measured. ammeter is connected across the SW.



→ CT will step dow high current I_1 to low current I_2

AT balance → This way high amp current can be measured by using low range ammeter with help of CT.

$$N_1 I_1 = N_2 I_2$$

$$I_1 = \left(\frac{N_2}{N_1}\right) I_2$$

$$\therefore I_1 = k I_2$$

I_1 measured with help of I_2.

Why SW of a CT never be kept open without Ammeter?

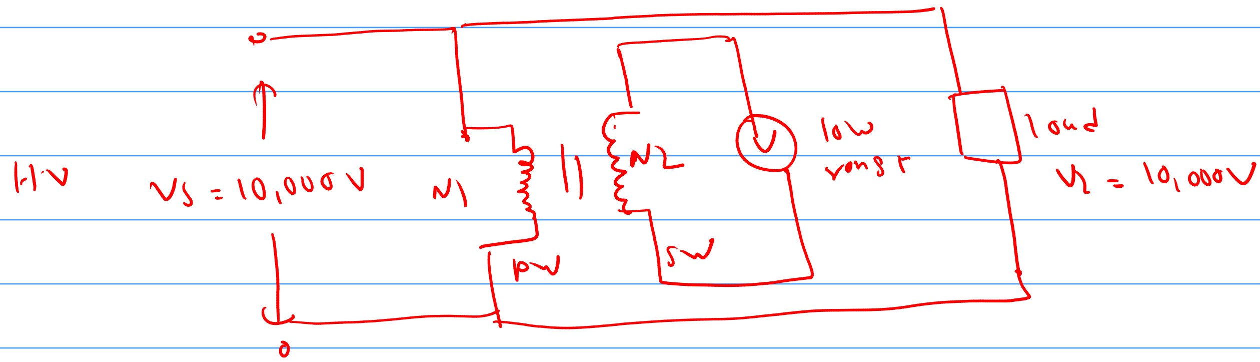
→ If done so $I_2 = 0$, then I_1 is not going to decrease. This (I_1) high current will produce large magnetic flux in the core and there will be no opposing flux to cancel these large flux due to I_1.

→ So net mag flux in the core will be very high. eddy and hysteresis loss in the coil will be very high and iron core will get heated which may damage the winding of CT.

→ If we want to remove the ammeter for some purposes, the SW shall be S/C by a thick wire so that I_2 continues to flow and producing opposite flux.

Potential transformer (PT)

→ designed to measure high voltage using a low range voltmeter.



→ PW of PT is dealing with high voltage so it is made up of thin wires of many turns.

→ PT steps down high voltage to very low voltage, so, S.W of PT is made of thick wire with less turns.

→ The voltmeter (low range) is connected across the SW

→ The voltage ratio $\frac{V_2}{V_1}$ is given by the manufacturer

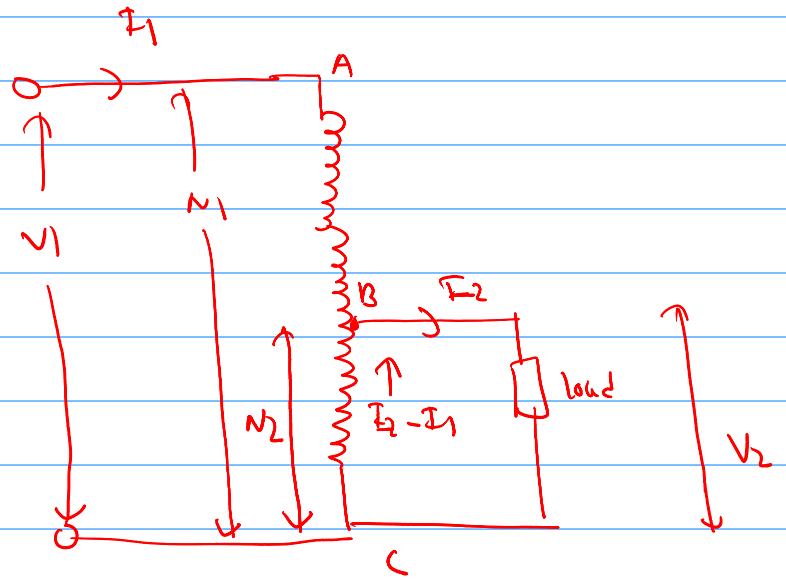
$$\frac{V_2}{V_1} = \text{turn ratio}$$

$$V_1 = \frac{V_2}{\text{turn ratio } (k)}$$

In this way PT is used to measure high voltage using low range voltmeter.

Auto transformer (IOE)

→ This is a a transformer having only one winding acting as primary as well as secondary winding.



→ Unlike conventional two-winding transformer where two windings are electrically isolated, the common winding reduces the amount of copper needed leading to materials savings.

→ The fig shows a step-down auto transformer (H.V - L.V)

→ To operate in step up swap the position of load and voltage source.

→ AC = HV winding, AB = series winding
BC = LV winding

$|V_2| < |V_1|$

N_1 → turns in AC
N_2 → turns in BC
$N_1 - N_2$ turns in AB

$I_2 \rightarrow$ current drawn by load
$I_1 \rightarrow$ current drawn from supply

$\rightarrow$ current in section BC $= I_2 - I_1$ ($\uparrow$)

Cu-saving :

weight of Cu $\propto NI$

weight of Cu in AB section $\propto (N_1 - N_2) I_1$
weight of Cu in BC section $\propto N_2 (I_2 - I_1)$

Total weight of Cu in auto transformer

$$W_{auto} \propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1) \quad \text{— (i)}$$

weight of Cu used in two winding transformer

$$W_{TW} \propto N_1 I_1 + N_2 I_2 \quad \text{— (ii)}$$

Dividing (i) by (ii)

$$\frac{W_{auto}}{W_{TW}} = \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

or $$\frac{W_{auto}}{W_{TW}} = \frac{N_1 I_1 + N_2 I_2 - N_2 I_1 - N_2 I_1}{N_1 I_1 + N_2 I_2}$$

or $$\frac{W_{auto}}{W_{TW}} = 1 - \frac{2N_2 I_1}{N_1 I_1 + N_2 I_2}$$

or $$\frac{W_{auto}}{W_{TW}} = 1 - \frac{\frac{2N_2 I_1}{N_1 I_1}}{\frac{N_1 I_1}{N_1 I_1} + \frac{N_2 I_2}{N_1 I_1}}$$ Dividing by $N_1 I_1$

or $$\frac{W_{auto}}{W_{TW}} = 1 - \frac{2\left(\frac{N_2}{N_1}\right)}{1 + \left(\frac{N_2}{N_1}\frac{I_2}{I_1}\right)}$$

We know, $N_1 I_1 = N_2 I_2$ (at balance)

$$\frac{N_1}{N_2} = \frac{I_2}{I_1}$$

So $$\frac{W_{auto}}{W_{TW}} = 1 - \frac{2\left(\frac{N_2}{N_1}\right)}{1 + \frac{N_2}{N_1} \times \frac{N_1}{N_2}} = 1 - \frac{2\left(\frac{N_2}{N_1}\right)}{2}$$

$$\therefore \frac{W_{auto}}{W_{TW}} = 1 - \frac{N_2}{N_1}$$

We know, $\frac{N_2}{N_1} = k$ (transformer ratio)

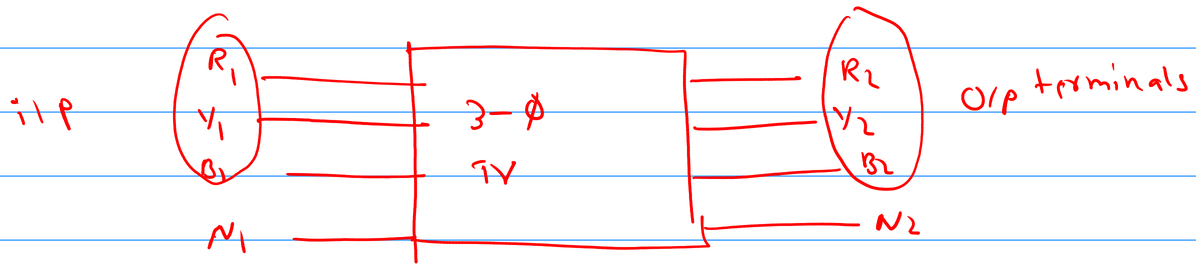
$$\therefore \boxed{\frac{W_{auto}}{W_{TW}} = 1-k}$$

$$k \approx 1$$

The weight of Cu used in auto will be very less compared to two winding transformer which is economical.

Three phase transformer

→ It is a transformer which step up or down 3ϕ voltage.



Two ways to obtain 3ϕ operation

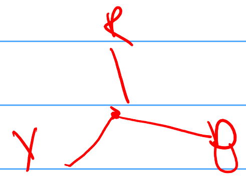
(i) use 3 1ϕ transformer
(ii) use 1 3ϕ transformer

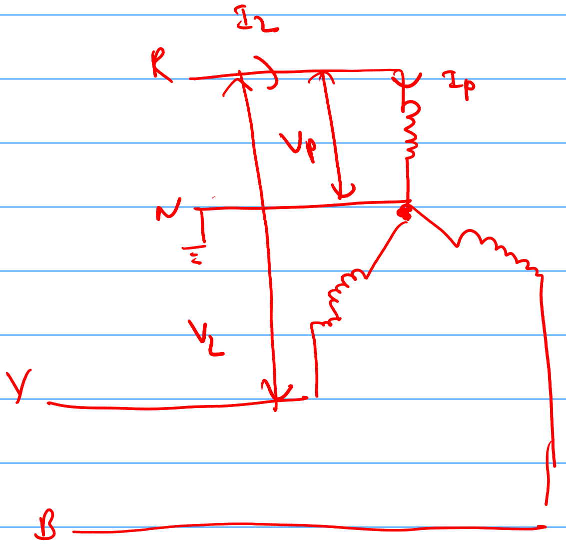
→ Single unit of 3ϕ transformer is very large compared to a single phase unit so transportation is difficult.

→ Using 3 separate 1ϕ is more expensive, less efficient and occupies more space.

Connections

① (Y) Star connection (λ)





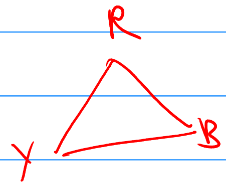
voltage between any lines = line voltage

voltage between line and neutral = phase voltage

line bata flow hune current → line current

winding bata bagne current → phase current

$\boxed{V_p = \frac{V_L}{\sqrt{3}}}$ $\boxed{I_p = I_L}$



② Δ connection (delta)

$$\boxed{I_p = \frac{I_L}{\sqrt{3}} \qquad V_p = V_L}$$