

TRANSFORMER

Unit-3

Transformer : Transformer is a static device which transfer electrical energy from one circuit to another circuit without changing frequency is known as transformer.

During the transformer electrical energy the voltage level will increase and current level will decrease overall voltage value will be increase decrease and current value increase.

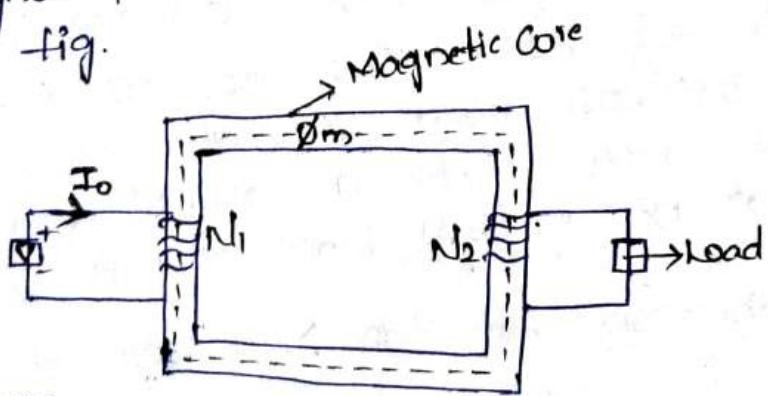
~~construction and working principle of transformer~~ The working principle of transformer is based on mutual induction b/w two couple coils according to electro magnetic induction.

→ According to principle the rate of change of flux with respect to time is equal to induced emf of each coil across "N" turns

$$E = N \frac{d\Phi}{dt}$$

→ & q

→ Signal phase transformer in the circuit shown in fig.



Where

① N_1 = no. of ^{temp} primary winding

② N_2 = no. of ^{temp} secondary winding

③ Φ_m = Magnetic flux

④ V = Supply Voltage (or) Input Voltage

⑤ I = Primary Current

→ Signal phase transformers are consisting of two windings.

- i) Primary winding ii) Secondary winding.

→ The winding with "N₁" no. of terms is called primary winding and winding with "N₂" no. of terms is called secondary winding.

→ The energy transfer from one circuit to another circuit is take place with help of electro magnetic induction.

→ The current flowing in primary winding the magnetic flux will be produced.

→ The primary winding connected to the AC supply which are input voltage is taken.

→ The secondary winding of flux linkage (or)

→ The secondary winding of flux linkage (or) mutual flux the induced emf will be produced.

→ The magnitude frequency completely depends upon secondary winding.

→ The induced emf of secondary winding can be

→ The induced emf of secondary winding can be delivered the power to any load across

→ The induced emf of secondary winding the

→ The induced emf of secondary winding that is induced load will be open circuit that is terminal voltage.

→ Depends upon the connection of winding classification of transformer two types.

i) Core type transformer

ii) Shell type transformer

→ Depending upon Connection of voltage two types.

→ Depending upon Connection of voltage two types.

i) Step up transformer

ii) Step down transformer

- Construction of the signal phase transformer
they are no moving parts.
- Construction of the transformer, divided into Nine parts

1) Radiators

2) Magnetic core

3) Winding

4) Constructive tank

5) Breathers

6) Brushing

7) Transformer oil

8) Container

9) Buchholz relay

Difference b/w step up & step down transformer.

Step-up transformer

i) Secondary terminal voltage is greater than primary terminal voltage

$$V_s > V_p$$

ii) No. of terms in secondary winding greater than no. of terms in primary winding

$$N_s > N_p$$

iii) Secondary current is less than primary current

$$I_s < I_p$$

iv) Step up transformer used in electrical transmission system.

Step-down transformer

i) Secondary terminal voltage is less than primary terminal voltage

$$V_s < V_p$$

ii) No. of terms in secondary winding less than no. of terms in primary winding

$$N_s < N_p$$

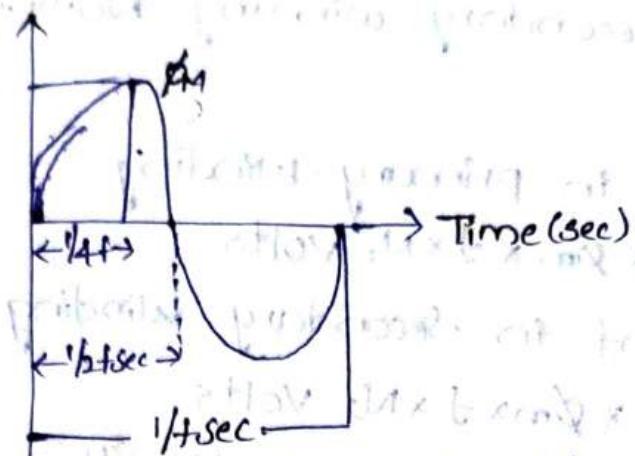
iii) Secondary current greater than primary current

$$I_s > I_p$$

iv) Step up down transformer in electrical distribution system.

E.M.F Equation of Transformer.

Let consider alternating flux by voltage source in sinusoidal wave form shown in fig.



In above wave form in, alternating flux will be in the time period $\frac{1}{4}f$ Sec.

→ By electro magnetic induction

$$E = N \frac{d\phi}{dt}$$

Hence change in flux $d\phi = \phi_M$ (Weber)

$$dt = \frac{1}{4}f \text{ sec}$$

The average induced emf is given as

$$E_{avg} = N \frac{\phi_M}{\frac{1}{4}f}$$

$$\boxed{E_{avg} = 4\phi_M f N \text{ Volts}}$$

Since the flux value is sinusoidal wave form.

→ The formfactor of sinusoidal flux value will be

Constant 1.11

formfactor defined as the ratio RMS value to average value.

$$\boxed{\text{form-factor} = \frac{\text{RMS Value}}{\text{Average value}}}$$

→ The RMS induced emf is given as

$$E_{rms} = \text{form-factor} \times \text{Average value}$$

$$E_{rms} = 1.11 \times \phi_M \times f \times N$$

$$E_{rms} = 4.44 \Phi_m \times f \times N$$

If E_1 and E_2 RMS value of induced emf in Primary and Secondary winding having N_1 and N_2 respectively.

Induced Emf in primary winding

$$E_1 = 4.44 \times \Phi_m \times f \times N_1 \text{ Volts}$$

Induced Emf in secondary winding

$$E_2 = 4.44 \times \Phi_m \times f \times N_2 \text{ Volts}$$

→ Where maximum magnetic flux

$$\Phi_m = \frac{\Phi M}{A} \text{ (Tesla) (or) } \frac{\text{Weber}}{m^2} \text{ boeing unit}$$

$$\Phi M = B \times A$$

Where B = Magnetic flux density. $A = ?$

units : Tesla (or) Weber/m²

A = Area of cross section

Units : m²

Substitute the Φ_m value

$$E_1 = 4.44 \times B \times A \times f \times N_1 \text{ Volts}$$

Similarly

$$E_2 = 4.44 \times B \times A \times f \times N_2 \text{ Volts}$$

Voltage Ratio of Transformer

The Ratio of induced emf in Secondary winding to induced emf in primary winding is known as voltage ratio of transformer.

It is denoted by "K".

$$K = \frac{\text{Induced emf in Secondary winding}}{\text{Induced emf in Primary winding}} = \frac{E_2}{E_1}$$

$$K = \frac{4.44 \times \mu_0 \times f \times N_2}{4.44 \times \mu_0 \times f \times N_1}$$

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

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

- (Q) In a single phase transformer 50Hz has 80 turns in the primary winding 400 turns in secondary winding the area of cross section of the core 200 cm^2 if the primary winding connected to 240 V. Determine
 i) The induced emf in Secondary winding.
 ii) Maximum flux density of the core in primary winding.

Given data

frequency $f = 50 \text{ Hz}$

No. of turns in primary winding (N_1) = 80

No. of turns in Secondary winding (N_2) = 400

No. of turns in Secondary winding (N_2) = 400

Area of cross section $A = 200 \text{ cm}^2$

$$= 200 \times 10^{-4} \text{ m}^2$$

$$= 2 \times 10^{-2} \text{ m}^2$$

Induced emf in primary (E_1) = 240

i) $E_2 = ?$

ii) $B = ?$ in primary

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

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

$$= \frac{400}{80}$$

$$K = 5$$

$$K = \frac{E_2}{E_1} \Rightarrow E_2 = K \times E_1$$

$$= 5 \times 240$$

$$E_2 = 1200 \text{ V}$$

$$E_1 = 4.44 \times B \times A \times f \times N_1$$

$$240 = 4.44 \times B \times 2 \times 10^{-2} \times 50 \times 80$$

$$B = \frac{240}{4.44 \times 2 \times 10^{-2} \times 50 \times 80}$$

$$B = 0.67 \text{ Tesla} \cdot \text{wb/m}^2$$

Result:

- i) $E_2 = 1200 \text{ V}$
- ii) $B = 0.67 \text{ Tesla}$

Q) In a single phase transformer 50Hz, 200-turns in the primary winding and 800 turns in secondary winding, the area of cross section is 24 cm^2 . If the secondary winding connected to 400V, determine the

- i) The induced emf in the primary winding.
- ii) The maximum flux density in secondary winding.

Sol: Given data.

$$\text{frequency } f = 50 \text{ Hz}$$

No. of turns in primary winding (N_1) = 200

No. of turns in secondary winding (N_2) = 800

$$\begin{aligned} \text{Area of cross section } A &= 24 \text{ cm}^2 \\ &= 24 \times 10^{-4} \text{ m}^2 \end{aligned}$$

Induced emf in primary $E_1 = ?$

Induced emf in Secondary $E_2 = 400$

i) $E_1 = ?$

ii) $B = ?$ Secondary.

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$K = \frac{N_2}{N_1} = \frac{800}{200}$$

$$K = 4$$

$$\beta = \frac{E_2}{E_1} \rightarrow E_2 = 100 \times E_1 \\ = 100V$$

$$A = \frac{400}{E_1}$$

$$E_1 = \frac{400}{A}$$

$$E_1 = 100V$$

$$E_2 = 4.44 \times B \times A \times f \times N_2 \\ 400 = 4.44 \times B \times 24 \times 10^{-4} \times 50 \times 800$$

$$B = \frac{400}{4.44 \times 24 \times 10^{-4} \times 50 \times 800}$$

$$B = 0.93 \text{ Tesla} \cdot \text{Wb/m}^2$$

Result:

$$i) E_1 = 100V$$

$$ii) B = 0.93 \text{ Tesla}$$

Q) $\frac{3300}{230}$ V, 50Hz single phase transformer is to be work

at maximum flux density 1.2 Tesla in the core
is 150 cm^2 . calculate the value of primary &
secondary turns.

Sol: Given data

frequency $f = 50\text{Hz}$, induced emf in primary winding (E_1) = 3300

Induced emf in secondary winding (E_2) = 50

Induced emf in cross section $A = 150 \text{ cm}^2$

$$= 150 \times 10^{-4} \text{ m}^2 \\ = 15 \times 10^{-3} \text{ m}^2$$

Maximum flux density (Φ_m) = 1.2 Tesla.

$$E_1 = ?$$

$$E_2 = ?$$

$V_P = \text{constant}$ across the bar

$\phi = \text{constant}$ across the coil

$E = \text{constant}$ across the coil

$$K = \frac{E_1}{E_2}$$

$$= \frac{230}{3300}$$

$$K = 0.06$$

$$E_1 = 4.44 \times 8 \times A \times f \times N_1$$

$$3300 = 4.44 \times 1.2 \times 150 \times 10^4 \times 50 \times N_1$$

$$N_1 = \frac{3300}{4.44 \times 1.2 \times 150 \times 10^4 \times 50}$$

$$N_1 = 826$$

$$K = \frac{E_2}{E_1}$$

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

$$N_2 = K \times N_1$$

$$N_2 = 0.06 \times 826$$

$$N_2 = 57$$

Q) 6300/210 V, 50Hz in single phase transformer has for turns induced emf 9V and the maximum flux density 1.2 W/m². find the number of high voltage and low voltage turns and area of cross section of the core.

Sol: Given data

$$E_1 = 6300 \text{ V}$$

$$E_2 = 210 \text{ V}$$

$$f = 50 \text{ Hz}$$

$$B = 1.2 \text{ Wb/m}^2$$

Induced emf per each turn = 9V

i) High voltage then $N_1 = ?$

ii) Low voltage then $N_2 = ?$

iii) $A = ?$

High voltage - Then $N_1 = \frac{\text{Primary Voltage } (E_1)}{\text{Induced emf each turn}}$

$$= \frac{6300}{9}$$

$$\boxed{N_1 = 700}$$

If $N_2 = \frac{\text{Secondary Voltage } (E_2)}{\text{Induced emf each turn}}$

$$N_2 = \frac{210}{9}$$

$$= 23.3$$

$$\boxed{N_2 = 23}$$

$$E_1 = 4.44 \times B \times f \times A \times N_1$$

$$6300 = 4.44 \times 1.2 \times 1 \times 50 \times 700$$

$$A = \frac{6300}{4.44 \times 1.2 \times 50 \times 700}$$

$$\boxed{A = 0.03 \text{ m}^2}$$

Q) 25 KVA (power) Single phase transformer has 250 turns in the primary and 40 turns in secondary winding. The primary winding is connected to 1500V and 50Hz. Calculate the

i) Secondary induced emf

ii) Primary and secondary current

iii) Maximum flux of the core

Sol: Given data

Rating of transformer = 25 KVA

No. of turns in primary $N_1 = 250$

No. of turns in secondary $N_2 = 40$

$$E_1 = 1500 \text{ V}$$

$$f = 50 \text{ Hz}$$

i) $E_2 = ?$

ii) $I_1 = ? \quad I_2 = ?$

iii) $\Phi_M = ?$

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

$$\text{i) } K = \frac{N_2}{N_1} = \frac{40}{250}$$

$$K = 0.16$$

$$K = \frac{E_2}{E_1} \Rightarrow E_2 = K \times E_1 \\ = 0.16 \times 1500$$

$$E_2 = 240 \text{ V}$$

$$\text{ii) } \frac{\text{I}_1}{\text{I}_2} = \frac{\text{KVA rating}}{\text{Primary voltage}}$$

$$\frac{\text{I}_1}{\text{I}_2} = \frac{25 \times 10^3}{1500}$$

$$\boxed{\text{I}_1 = 16.66 \text{ A}}$$

$$\frac{0.16}{P} = 14$$

$$E \cdot B =$$

$$EB = 14$$

$$\frac{V \cdot I}{P} = P \times 8 \times \pi \times \mu \times A = 14$$

$$\frac{P}{0.08 \times 14} = \frac{P}{0.08 \times 14} = 0.083$$

$$\frac{\text{I}_1}{\text{I}_2} = \frac{P}{0.083} = A$$

$$16.66 \cdot 0 = A$$

$$K = \frac{\text{I}_1}{\text{I}_2}$$

$$\text{iii) } \frac{\text{I}_2}{\text{I}_1} = \frac{\text{I}_1}{K} \Rightarrow \frac{16.66}{0.16}$$

$$\boxed{\text{I}_2 = 104.12 \text{ A}}$$

$$\text{iv) } \emptyset_m = ?$$

$$E_1 = 4.44 \times \emptyset_m \times f \times N_1$$

$$1500 = 4.44 \times \emptyset_m \times 50 \times 250$$

$$\emptyset_m = \frac{1500}{4.44 \times 50 \times 250}$$

$$\boxed{\emptyset_m = 0.02 \text{ wb}}$$

$$V_{0.02} = 12$$

$$I_{H0.2} = 1$$

Differences between Ideal and Practical Transformer.

Ideal

i) Ideal transformer has no losses.

ii) The applied voltage in primary winding is equal to induced emf voltage in primary winding.

$$E_1 = V_1$$

iii) The winding resistance of the transformer is equal to zero.

iv) The induced emf in secondary voltage is equal to load voltage.

v) There is no voltage drop in type of transformer.

vi) There is no leakage reactance.

vii) There is no magnetic flux exist.

viii) To develop the flux in the core there is no current required in this type of transformer.

ix) The total flux in primary winding links with secondary winding.

Practical

i) Practical transformer including iron copper and Iron losses.

ii) The applied voltage in primary winding is not equal to induced emf voltage in primary winding.

$$E_1 \neq V_1$$

iii) The winding resistance of the transformer is equal to definite value.

iv) The induced emf in secondary voltage is not equal to load voltage.

v) There is voltage drop exist.

vi) There is leakage reactance exist.

vii) There is magnetic flux exist.

viii) To develop the flux in the core ^{magnetizing} current is required in this type of transformer.

ix) The total flux in primary winding don't link with secondary winding.

Losses of Transformer

The losses of transformer are classified into two types.

- Copper losses
- Iron/core losses

i) Copper losses: The copper losses occurs the winding resistance of the transformer appears has heat result in increasing temperature.

If I_1, I_2 primary and secondary current
 R_1, R_2 Primary and Secondary resistance

respectively.

The copper losses in primary winding $I_1^2 R_1$
 The copper losses in secondary winding $I_2^2 R_2$
 The copper losses of the transformer is given as $I_1^2 R_1 + I_2^2 R_2$

ii) Iron/core losses; The iron losses occurs alternating flux and also classified into two types.

- Hysteresis losses
- Eddy current losses

i) Hysteresis losses:

The hysteresis losses occurs due to continuous magnetization and demagnetization every cycle of alternating flux.

→ The hysteresis losses appears on the resulting in increasing in temperature.

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The hysteresis losses can't be eliminated however the can be minimize which passes low hysteresis coefficient.

The hysteresis losses is given as

$$\text{Phys} = K_{\text{hys}} B_M^x V f$$

units: watts

Where K_{hys} = Constant

B_M^x = Maximum flux density

V = Volume of the magnetic core

f = frequency

x = The value is varies from 1.2 to 1.6

Eddy current losses:

The Eddy current losses occurs alternating flux to the core the induced emf on passing through circulating current is known as eddy current losses.

This type of losses depending upon length of the resistance.

The eddy current losses reduced by using thickness of lamination to the core material

also can't be eliminated.

This type of losses also effective resistance

By using lamination the current value will be increased as to eddy current will be decreased.

The eddy current losses is given as

$$P_{\text{eddy}} = \frac{K_{\text{eddy}} B_M^2 f^2 t^2}{\rho}$$

Where ρ = Resistivity of the material

t = thickness of the lamination of the core

K_{eff} = Constant

Efficiency of Transformer.

efficiency of transformer it is defined as the ratio of output power to input power is known as Efficiency.

→ The outpower is less than input power due to losses in transformer.

The mathematical efficiency is given as

$$\eta = \frac{\text{output power}}{\text{Input power}}$$

$$\% \eta = \frac{\text{output power}}{\text{Input power}} \times 100$$

Based on the above equation the efficiency of transformer is given as

$$\text{outpower} = \text{Input power} - (\text{Total losses})$$

$$\text{outpower} = I/P - (P_{\text{iron}} + P_{\text{cu}})$$

$$I/P = \text{output power} + (P_{\text{iron}} + P_{\text{cu}})$$

$$\eta = \frac{\text{Input power} - (P_{\text{iron}} + P_{\text{cu}})}{\text{Input power}}$$

$$\therefore \eta = \frac{\text{Input power} - (P_{\text{iron}} + P_{\text{cu}})}{\text{Input power}} \times 100$$

Voltage regulation:

It is defined as the ratio of difference between Secondary terminal voltage no load and Secondary terminal voltage full load to Secondary terminal no load. It is known as voltage regulation.

The voltage regulation is known as

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

where

E_2 = Secondary terminal voltage no load

V_2 = Secondary terminal voltage full load.

Condition for Maximum efficiency.

The efficiency of transformer said to be maximum when it is copper losses to iron losses.

$$P_{Cu} = P_{Iron}$$

The copper losses in Secondary winding = $I_2^2 R_2$

We know that,

$$P_{Iron} = P_{Hyst} + P_{Eddy}$$

Let consider Input power = $VI_2 \cos \phi$

The efficiency of transformer is given as

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$\text{Output} = \text{Input power} - (\text{Total losses}) (P_{Cu} + P_{Iron})$$

$$VI_2 \cos \phi - (I_2^2 R_2 + P_{Iron})$$

$$\text{Output} = VI_2 \cos \phi - I_2^2 R_2 - P_{Iron}$$

$$\eta = \frac{VI_2 \cos \phi - I_2^2 R_2 - P_{Iron}}{VI_2 \cos \phi}$$

$$\eta = 1 - \frac{I_2^2 R_2}{VI_2 \cos \phi} - \frac{P_{Iron}}{VI_2 \cos \phi}$$

$$\eta = 1 - \frac{I_2^2 R_2}{VI_2 \cos \phi} - \frac{P_{Iron}}{VI_2 \cos \phi}$$

diff w.r.t I_2

$$\left(\because d\left(\frac{1}{x}\right)\right)$$

$$I_2 A_2 - I_2 L = \frac{1}{R_2^2}$$

$$\frac{d\sigma}{dI_2} = 0 - \frac{(1)R_2}{V\cos\phi} + \frac{P_{iron}}{VI_2^2 \cos\phi}$$

$$\frac{d\sigma}{dI_2} = -\frac{R_2}{V\cos\phi} + \frac{P_{iron}}{VI_2^2 \cos\phi}$$

The maximum efficiency of transformer equivalent to zero

$$\frac{d\sigma}{dI_2} = 0$$

$$\frac{-R_2}{V\cos\phi} + \frac{P_{iron}}{VI_2^2 \cos\phi} = 0$$

$$\frac{P_{iron}}{VI_2^2 \cos\phi} = \frac{R_2}{V\cos\phi}$$

$$\frac{P_{iron}}{I_2^2} = R_2$$

$$P_{iron} = I_2^2 R_2$$

Hence the verification is proved

$$I_2^2 = \frac{P_{iron}}{R_2} \Rightarrow I_2 = \sqrt{\frac{P_{iron}}{R_2}}$$

Q) The no load current of transformer is 10Amp at the power factor of 0.25 lagging power factor when connected through 400V & 50Hz apply calculate the magnetisation current component of no load current, iron losses and the maximum value of flux if the core consider primary winding terms has 500 turns.

Given data:

$$\text{load current } I_0 = 10A = I_1$$

$\cos \phi = 0.25$

$f = 50 \text{ Hz}$

$V_1 = 400 \text{ V}$

No of turns $N_1 = 500$

i) $I_M = ?$

ii) Iron losses

iii) $\Phi_m = ?$

i) $I_M = I_0 \sin \phi$

$\cos \phi = 0.25$

$\phi = \cos^{-1}(0.25)$

$\phi = 75.52^\circ$

$I_m = 10 \times \sin(75.52)$

$I_m = 9.68 \text{ A}$

ii) Iron losses no load current $= V_1 I_m \cos \phi$
 $= 400 \times 10 \times 0.25$

$P_{iron} = 1000 \text{ W}$

iii) $E_1 = 4.44 \times \Phi_m \times f \times N_1$

$400 = 4.44 \times \Phi_m \times 50 \times 500$

$\Phi_m = \frac{400}{4.44 \times 50 \times 500}$

$\Phi_m = 3.603 \times 10^{-3} \text{ Wb}$

$\Phi_m = \frac{3.603}{1000} = 0.0036 \text{ Wb}$

$\boxed{\Phi_m = 0.0036 \text{ Wb}}$

The no load current of transformer is 20 Amp at the power factor of 0.8 lagging when connected through 600V & 50Hz supply calculate the magnetization current component of no load current, iron losses and mass density of flux density of core consider primary winding turns has 400 area of cross section 100 cm^2 gives data

load current $I_0 = 20 \text{ A} = I_1$

$\cos \phi = 0.8$

$f = 50 \text{ Hz}$

$V_1 = 600 \text{ V}$

No. of turns $N_1 = 400$

$$\text{Area of cross section} = 20 \times 10^{-2} \text{ m}^2$$

$$= 20 \times 10^{-3} \text{ m}^2$$

$$= 2 \times 10^{-3} \text{ m}^2$$

i) $I_m = ?$

ii) Iron losses

iii) $B = ?$

$$I_m = I_o \sin \phi$$

$$\cos \phi = 0.8$$

$$\phi = \cos^{-1} 0.8$$

$$\phi = 0.643$$

$$I_m = 20 \times \sin(0.643)$$

$$I_m = 11.94 \text{ A}$$

$$\text{ii) Iron losses no load current} = V_1 I_1 \cos \phi$$

$$= 600 \times 20 \times 0.8 = 00.$$

$$P_{\text{iron}} = 9600 \text{ W}$$

$$F_1 = 4.44 \times B_M \times A \times f \times N_1$$

$$600 = 4.44 \times 8M \times 20 \times 10^4 \times 50 \times 400$$

$$B_M = \frac{600}{4.44 \times 20 \times 10^4 \times 50 \times 400}$$

$$B_M = 3.878 \text{ mW/m}^2 \text{ (or) Tesla}$$

Q) 50 KVA, 6,600/220 Volts step down transformer of total resistance in Secondary winding 0.0211 ohms. calculate of full load copper and efficiency of transformer full load. If the iron losses is equal to copper losses at unity power factor of this load.

Given data

$$\text{KVA rating} = 50 \text{ KVA}$$

$$= 50 \times 10^3 \text{ A}$$

$$\text{Primary voltage} = 6600 \text{ V}$$

$$\text{Secondary voltage} = 220 \text{ V}$$

$$\text{Total resistance in Secondary } R_2 = 0.021 \Omega$$

$$\cos \phi = 1$$

$$I_2 = ?$$

$$\text{i) } P_{cu} = ?$$

$$\text{ii) } \eta = ?$$

$$\text{full load Secondary current } I_2 = \frac{\text{KVA rating}}{\text{Secondary voltage}}$$

$$= \frac{50 \times 10^3}{220}$$

$$= 227.27 \text{ A}$$

$$\text{The copper losses in Secondary} = I_2^2 \times R_2$$

$$= (227.27)^2 \times 0.021$$

$$W_{Cu} = P_{Cu} = 1089.84 \text{ W}$$

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

$$\text{output power} = (\text{Desired load})^2 \times VI \cos \phi$$

$$= 1 \times 50 \times 10^3 \times 1$$

$$\text{O/P Power} = 50,000$$

$$\text{Input power} = \text{output power} + \text{Total losses}$$

$$\text{Total losses} = P_{iron} + P_{cu}$$

$$P_{iron} + P_{cu}$$

$$\text{Total losses} = 2 \times P_{cu}$$

$$\text{The copper losses in full load} = (\text{Desired load})^2 \times P_{cu}$$

$$(1)^2 \times 1089.84$$

$$\text{The full load cu losses} = 1089.84 \text{ W}$$

$$\text{Total losses} = 2 \times P_{cu}$$

$$= 2 \times 1089.84$$

$$= 2179.68 \text{ W}$$

$$\% \eta = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$\% \eta = \frac{50,000}{50,000 + 217968} \times 100$$

$$\boxed{\% \eta = 95.82 \%}$$

- * * *
- Q) A single phase transformer, 15 KVA has iron losses 200W and ^{full load} copper losses 300W. Determine the efficiency of transformer

- i) full load, unity power factor (UPF)
- ii) 3/4 load UPF
- iii) 1/2 load 0.8 power factor

Given data

$$\text{KVA rating} = 15 \text{ KVA} = 15 \times 10^3 \text{ VA}$$

$$\text{Iron losses (Piron)} = 200 \text{ W}$$

$$\text{full load copper losses (Pcu)} = 300 \text{ W}$$

calculate efficiency

- i) full load UPF
- ii) 3/4 load, UPF
- iii) 1/2 load, 0.8 PF
- iv) $\eta = \frac{\text{output power}}{\text{Input power}}$

$$\text{output power} = (\text{desired load}) \times VI \cos \phi$$

$$= (1) \times 15 \times 10^3$$

$$= 15000 \text{ W}$$

$$\text{Input power} = \text{output power} + \text{Total losses}$$

$$\text{Total losses} = \text{Piron} + \text{Pcu}$$

$$= 200 + 300$$

$$\text{Total losses} = 500 \text{ W}$$

$$\% \eta = \frac{15000}{15500} \times 100$$

$$\therefore \eta = 96.7\%$$

Output power = Desired load $\times V I \cos \phi$
 $= (3/4) \times 15 \times 10^3 \times 1$
 $= 11250 \text{ W}$

I/P = O/P power + Total losses

Copper losses in 3/4 load $P_{cu} = (\text{Desired load})^2 \times P_{cu}$
 $= (3/4)^2 \times 300$
 $P_{cu} (3/4) = 168.75 \text{ W}$

Total losses = $P_{iron} + P_{cu} 3/4$
 $= 200 + 168.75$
 $= 368.75 \text{ W}$

$$\therefore \eta = \frac{\text{O/P Put Power}}{\text{I/P Put Power}} \times 100$$

$$\therefore \eta = \frac{11250}{11618.7} \times 100$$

$$\therefore \eta = 96.8\%$$

Output power = (desired power) $\sqrt{V I \cos \phi}$
 $= (1/2) \times 15 \times 10^3 \times 0.8$
 $= 6000$

I/P = O/P + total losses

Copper losses in 1/2 load $P_{cu} = P(\text{Desired load})^2 \times P_{cu}$
 $= (\frac{1}{2})^2 \times 300$
 $= \frac{1}{4} \times 300$

$$P_{cu} = 750$$

Total losses = $P_{cu} (1/2) + P_{iron}$

$$= 75 + 200$$

$$= 275$$

$$I/P = 6000 + 275$$

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$\therefore \eta = \frac{6000}{6275} \times 100$$

$$\therefore \eta = 95.61$$

Q) A single phase transformer working at UPR efficiency 95% at both half load and full load and rating of transformer 1.5 KVA determine the efficiency of 60% full load.

Given data

The efficiency of full load = 95% = 0.95

The efficiency of half load = 95% = 0.95

KVA rating of transformer = $1.5 \text{ KVA} = 1.5 \times 10^3 \text{ VA}$

$$\cos \phi = 1$$

i) 60% full load efficiency

$$\eta = \frac{\text{output power}}{\text{input power}}$$

$$\text{output power} = (\text{Desired load}) \times \sqrt{2} \cos \phi$$

$$= (1) \times 1.5 \times 10^3 \times 1$$

$$\text{output power} = 1500 \text{ W}$$

$$\text{Input power} = \frac{\text{output power}}{\text{efficiency}}$$

$$\text{I/p power} = \frac{1500}{0.95}$$

$$\boxed{\text{I/p power} = 1578.94 \text{ W}}$$

$$\text{I/p power} = \text{outpower} + (P_{\text{iron}} + P_c)$$

$$P_i + P_c = \text{Input} - \text{outpower}$$

$$= 1578.74 - 1500$$

$$P_i + P_c = 78.94 \quad \textcircled{1}$$

$$\eta = \frac{\text{outpower}}{\text{input power}}$$

$$\text{output power} = (\text{Desired load}) \times \sqrt{2} \cos \phi$$

$$= (1/2) \times 1.5 \times 10^3 \times 1$$

$$\boxed{\text{output power} = 750 \text{ W}}$$

$$\text{Input} = \frac{\text{Output Power}}{\text{efficiency}}$$

$$\text{Input power} = \frac{750}{0.95}$$

$$\boxed{\text{Input power} = 789.47}$$

$$\text{Total losses} = P_i + P_c$$

$$\begin{aligned} P_{\text{out}} &= (\text{Desired load})^2 \times P_{\text{cu}} \\ &= \left(\frac{1}{2}\right)^2 \times P_{\text{cu}} \end{aligned}$$

$$P_{\text{cu}} = \frac{P_c}{4}$$

$$\text{Input power} = \text{o/p power} + \text{Total losses}$$

$$P_i + \frac{P_c}{4} = \text{I/p} - \text{o/p}$$

$$\frac{4P_i + P_c}{4} = 789.47 - 750$$

$$\frac{4P_i + P_c}{4} = 39.47$$

$$4P_i + P_c = 157.88 \quad \text{--- (2)}$$

Solving (1) & (2)

$$P_i + P_d = 78.94$$

$$\frac{4P_i + P_c}{4} = 157.88$$

$$-3P_i = -78.94$$

$$P_i = \frac{-78.94}{-3} = 26.31$$

$$\boxed{P_i = 26.31 \text{ W}}$$

P_i sub in eq (1)

$$26.31 + P_c = 78.94$$

$$P_c = 78.94 - 26.31$$

$$\boxed{P_c = 52.63 \text{ W}}$$

$$\% \eta = \frac{\text{o/p power}}{\text{i/p power}} \times 100$$

$$\begin{aligned} \text{o/p power} &= (\text{Desired load}) \times \sqrt{1 - \cos \theta} \\ &= (0.6) \times 1.5 \times 10^3 \times 1 = 1800 \text{ W} \end{aligned}$$

$$\boxed{\text{o/p power} = 900 \text{ W}}$$

Input = output power + ($P_i + P_c$)

$$\text{P}_{\text{out},i} = (\text{Desired load})^2 \times \text{P}_{\text{in}} \\ = (0.6)^2 \times 52.63$$

$$P_c = 18.94 \text{ W}$$

$$I/P = 900 + (26.31 + 18.94)$$

$$I/P \text{ power} = 945.25 \text{ W}$$

$$\% \eta = \frac{900}{945.25} \times 100$$

$$\% \eta = 95.21$$

- Q) A single phase transformer working at 0.8 Power factor the efficiency of 96.8%. At both half and full load the KVA rating of transformer 150 KVA determine the efficiency at 75% full load.

Given

The efficiency of full load = 96.8 = 0.968

The efficiency of half load = 96.8 = 0.968

KVA rating of transformer = 150 KVA

$$= 150 \times 10^3 \text{ VA} \\ = 150000 \text{ VA}$$

$$\cos\phi = 0.8$$

i) 75% of full load efficiency

$$\eta = \frac{\text{output power}}{\text{input power}}$$

$$\text{Output power} = (\text{Desired load}) \times \sqrt{2} \cos\phi \\ = (1) \times 150000 \times 0.8$$

$$\text{Output power} = 120000 \text{ W}$$

$$\text{Input power} = \frac{\text{Output power}}{\text{efficiency}}$$

$$\text{I/P} = \frac{120000}{0.968}$$

$$\boxed{\text{I/P power} = 123966.9}$$

$$\text{I/P power} = \text{O/P power} + (\text{Pout} + \text{Piron})$$

$$\text{Pout} + \text{Piron} = \text{I/P} - \text{O/P}$$

$$\text{Pout} + \text{Piron} = 123966.9 - 120000$$

$$\boxed{\text{Pout} + \text{Piron} = 3966.94} \quad \textcircled{1}$$

75% of half load of

$$\eta = \frac{\text{output power}}{\text{Input power}}$$

$$\begin{aligned} \text{output power} &= (\text{desired load}) \times \sqrt{3} \cos \theta \\ &= (1/2) \times 150000 \times 0.8 \\ &= 60000 \end{aligned}$$

$$\begin{aligned} \text{Input power} &= \frac{\text{output power}}{\text{efficiency}} = \frac{60000}{0.75} \\ &= \frac{60000}{0.968} \end{aligned}$$

$$\boxed{\text{I/P} = 61983.47}$$

$$\text{I/P} = \text{outpower} + (\text{Pout} + \text{Piron})$$

$$\text{Pout} + \text{Piron} = \text{Input power} - \text{output power}$$

$$\text{Pout} + \text{Piron} = 61983.47 - 60000$$

$$\text{Pout} + \text{Piron} = 1983.47$$

$$\text{Losses in copper} = (\text{desired load})^2 \times \text{Pcu}$$

$$= \left(\frac{1}{2}\right)^2 \times \text{Pcu}$$

$$= \frac{\text{Pcu}}{4} = \frac{(13.6 \times 0.009 \times 10)}{4} = 0.009 \text{ kW} = 9 \text{ W}$$

$$\text{Piron} + \frac{\text{Pcu}}{4} = 1983.47$$

$$\frac{4\text{P}_i + \text{P}_{cu}}{4} = 1983.47$$

$$4P_i + P_{cu} = 4 \times 1983.47$$

$$4P_i + P_{cu} = 7933.88 \quad \text{--- (2)}$$

Solving eq (1) & (2)

$$P_{ir} + P_{cu} = 3966.94$$

$$\underline{4P_{ir} + P_{cu} = 7933.88}$$

$$\cancel{+3P_{iron}} = -3966.94$$

$$P_{iron} = \frac{3966.94}{3}$$

$$P_{iron} = 1322.31$$

P_{iron} Sub in (1)

$$P_{iron} + P_{cu} = 3966.94$$

$$1322.31 + P_{cu} = 3966.94$$

$$P_{cu} = 3966.94 - 1322.31$$

$$P_{cu} = 2644.63$$

$$\therefore \eta = \frac{\text{output power}}{\text{input power}} \times 100$$

$$O/P = (\text{Desired power}) \sqrt{1 \cos \phi}$$

$$= (0.75) \times 150000 \times 0.8$$

$$O/P \text{ power} = 90000 \text{ W}$$

$$\text{Input} = \text{Output power} + (P_i + P_c)$$

$$P_{cu}(75\%) = (\text{Desired load})^2 \times P_{cu}$$

$$= (0.75)^2 \times 2644.63$$

$$P_{cu} = 1487.60$$

$$I/P = 90000 + (1487.60 + 1322.31)$$

$$I/P = 92809.91$$

$$\therefore \eta = \frac{90000}{92809.91} \times 100$$

$$\therefore \eta = 96.9\%$$

Auto transformer

Auto transformer consisting of only one winding in a single winding serve the purpose of primary as well as secondary winding.

The principle operation of Auto transformer

→ The same as the two winding transformer but only one difference i.e. primary winding & secondary winding which are not electrically separated.

→ The voltage ratio (turns) $\frac{\text{auto}}{\text{transformer}}$ is equal to unity

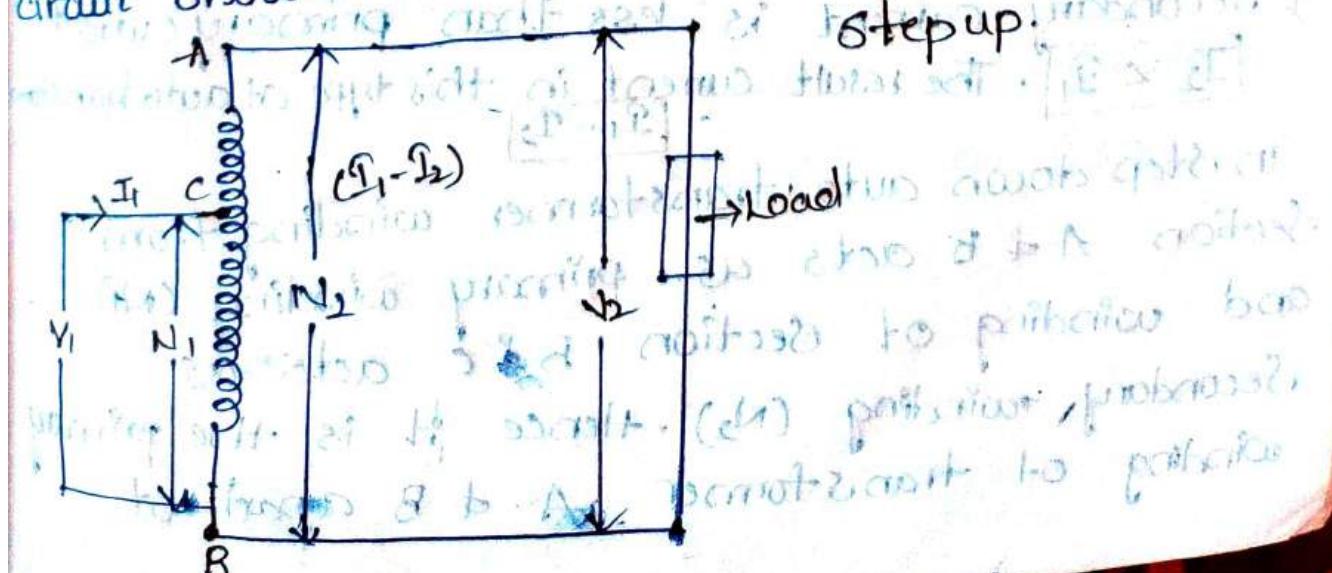
→ The classification of auto transformer in two types.

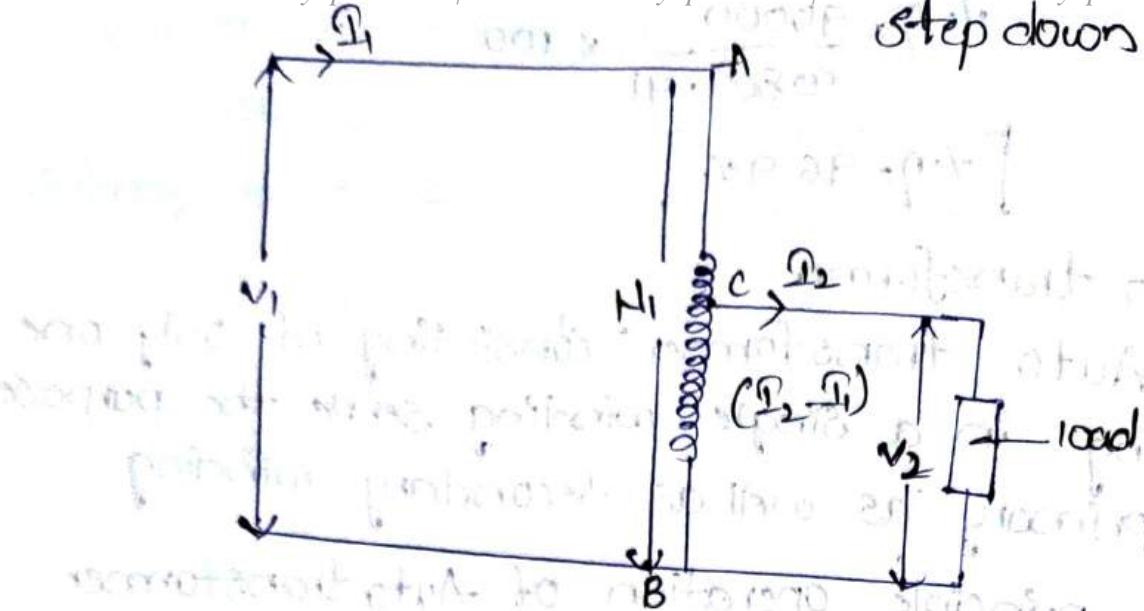
i) step up auto transformer on input to load

ii) step down auto transformer in the

→ Step up & step down auto transformer

Circuit shown in fig.





→ In step up of auto transformer winding from Section A & B acts as secondary winding (N_2) and winding of section B & C acts as primary winding (N_1). Hence it is secondary winding A & B a part of primary winding B & C.

→ If it satisfies step condition of auto transformer are

- i) The no. of turns in Secondary is greater than no. of turns in Primary $\boxed{N_2 > N_1}$
- ii) Secondary Voltage is greater than primary Voltage $\boxed{V_2 > V_1}$
- iii) Secondary current is less than primary current $\boxed{I_2 < I_1}$. The result current in this type of auto transformer $\therefore \boxed{I_1 - I_2}$

In Step down auto transformer winding from Section A & B acts as primary winding (N_1) and winding of section B & C acts as secondary winding (N_2). Hence it is the primary winding of transformer A & B apart of

secondary winding B & C

- If it is satisfies the conditions step down auto transformer are
- The no. of turns in primary is greater than no. of turns in Secondary $N_1 > N_2$
- i) Secondary primary voltage is greater than secondary terminal voltage $V_1 > V_2$
- ii) Primary current is less than secondary current $I_1 < I_2$

Advantages

- i) Low cost
- ii) More efficiency
- iii) Voltage regulation is more.
- iv) Voltage variation is possible

Disadvantages

- The auto transformer mainly due to direct electrically supply from low voltage to high voltage

Applications

- i) It is used in starting of induction motor.
- ii) It is used in continuous varies supply
- iii) It is used in inter connecting transformer

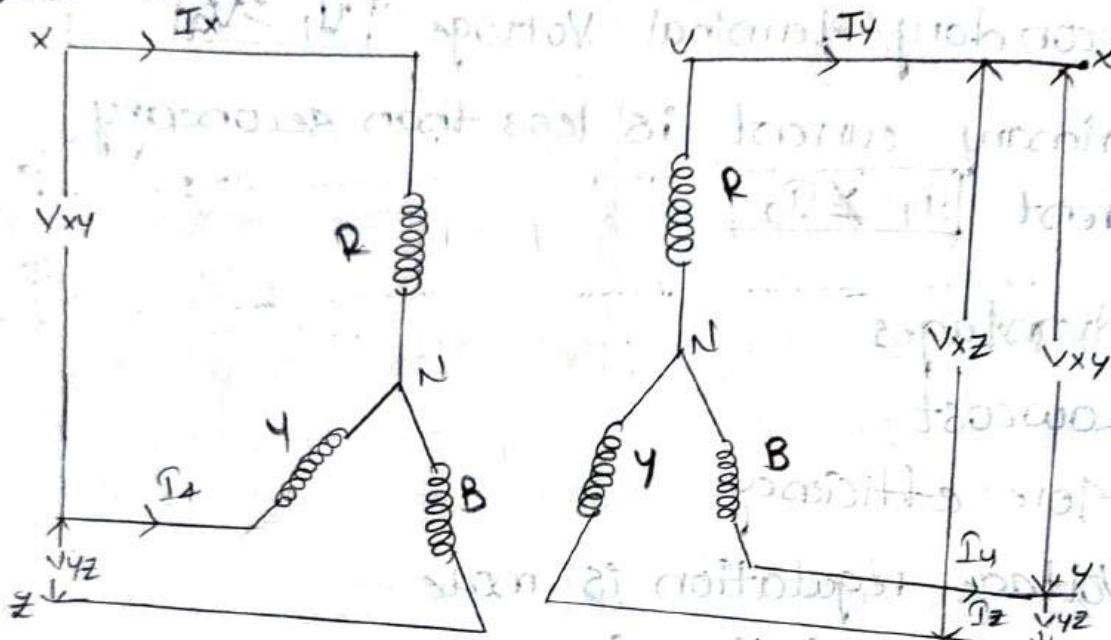
130 KVA Supply.

300 KVA

Three phase Connections of transformer.

- i) Star to star connection
- ii) Delta to Delta connection
- iii) Star to Delta connection
- iv) Delta to star connection.

i) Star to star connection.



Primary line Voltage = V_L

Primary phase Voltage = $\frac{V_L}{\sqrt{3}}$

Primary phase current = I_L

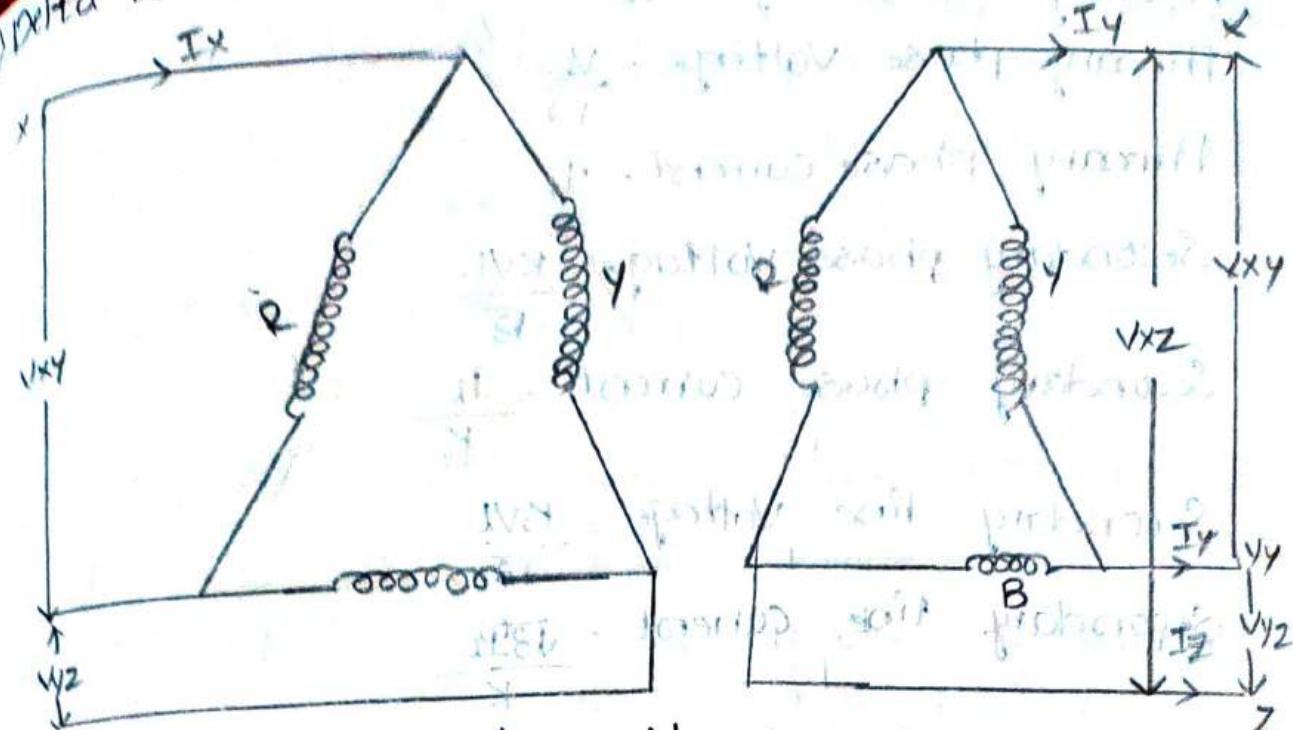
Secondary phase voltage = $\frac{K V_L}{\sqrt{3}}$

Secondary phase current = $\frac{I_L}{K}$

Secondary line current = $K I_L$

Secondary line current = $\frac{I_L}{K}$

Delta to Delta connection



Primary line voltage = V_L

Primary phase voltage = V_L

Primary phase current = $\frac{I_L}{\sqrt{3}}$

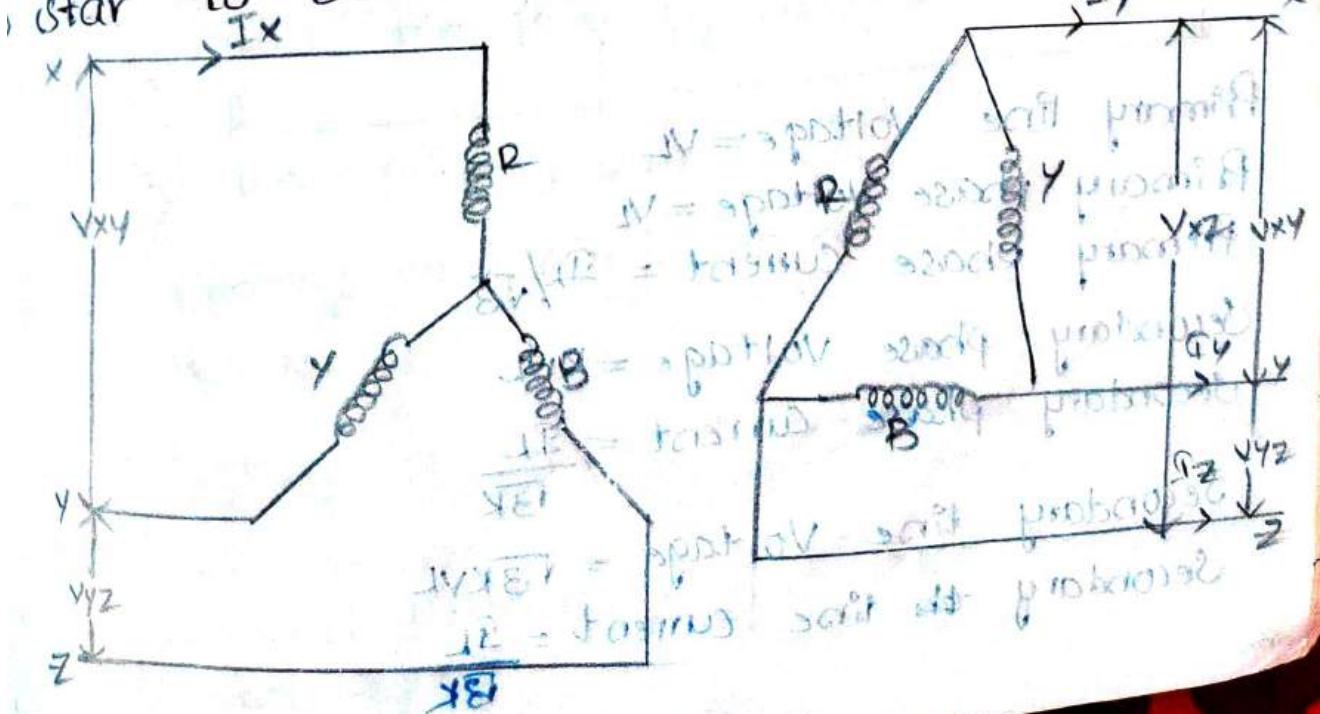
Secondary phase voltage = $K V_L$

Secondary phase current = $\frac{S_L}{\sqrt{3}K}$

Secondary line voltage = $K V_L$

Secondary line current = $\frac{I_L}{K}$

Star to Delta connection.



Primary line voltage = V_L

Primary phase voltage = $\frac{V_L}{\sqrt{3}}$

Primary phase current = I_L

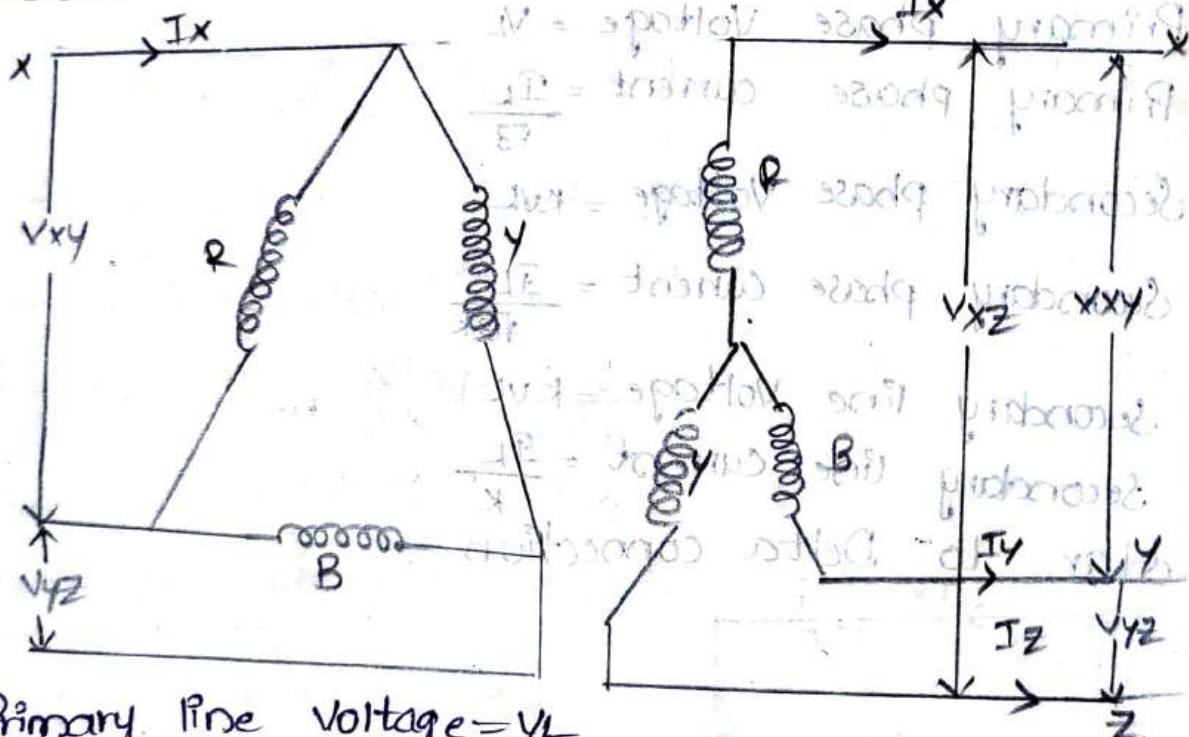
Secondary phase voltage = $\frac{K V_L}{B}$

Secondary phase current = $\frac{I_L}{K}$

Secondary line voltage = $\frac{K V_L}{\sqrt{3}}$

Secondary line current = $\frac{\sqrt{3} I_L}{K}$

iv) Delta to Delta connection.



Primary line voltage = V_L

Primary phase voltage = V_L

Primary phase current = $I_L/\sqrt{3}$

Secondary phase voltage = $K V_L$

Secondary phase current = $\frac{I_L}{\sqrt{3} K}$

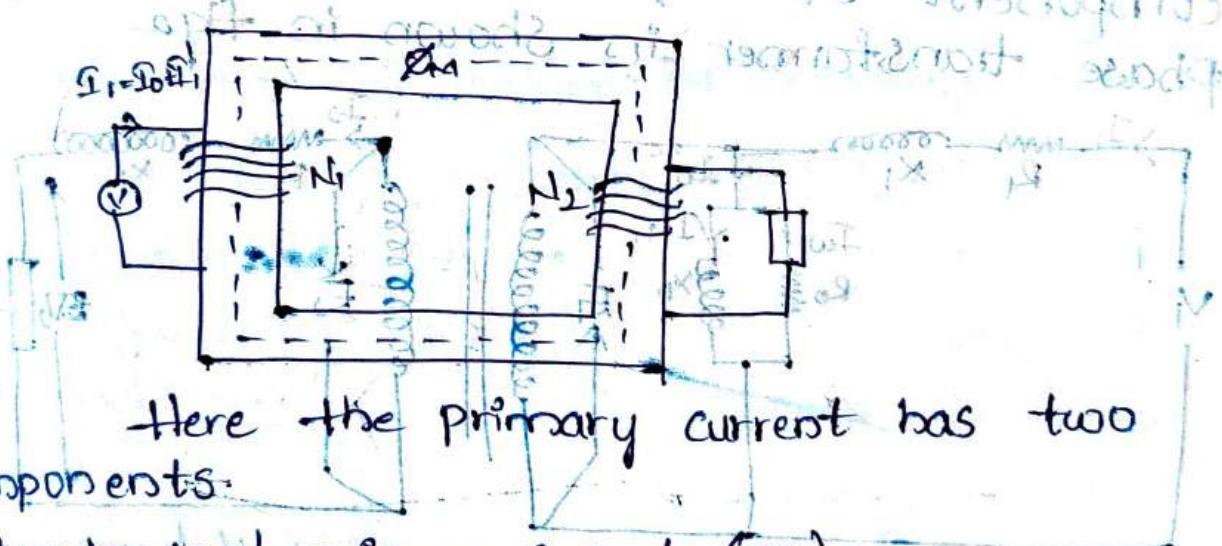
Secondary line voltage = $\sqrt{3} K V_L$

Secondary line current = $\frac{I_L}{\sqrt{3} K}$

Type of connection	Primary Side			Secondary Side				Line current
	Line voltage	Phase voltage	Phase current	Phase voltage	Phase current	Line voltage		
Star to Star (Y)	V_L	$\frac{V_L}{\sqrt{3}}$	I_L	$\frac{KVL}{\sqrt{3}}$	$\frac{I_L}{K}$	KVL	$\frac{I_L}{K}$	
Delta to Delta (Δ)	V_L	V_L	$\frac{I_L}{\sqrt{3}}$	KVL	$\frac{I_L}{\sqrt{3}K}$	KVL	$\frac{I_L}{K}$	
Star to Delta (Δ) (Y)	V_L	$\frac{V_L}{\sqrt{3}}$	I_L	$\frac{KVL}{\sqrt{3}}$	$\frac{I_L}{K}$	$\frac{KVL}{\sqrt{3}}$		$\frac{\sqrt{3}I_L}{K}$
Delta to Star (Δ) (Y)	V_L	V_L	$\frac{I_L}{\sqrt{3}}$	KVL	$\frac{I_L}{\sqrt{3}K}$	$\frac{\sqrt{3}KVL}{\sqrt{3}}$		$\frac{I_L}{\sqrt{3}K}$

Equivalent circuit of single phase transformer.

The equivalent circuit of single phase transformer is shown in figure below.



Here the primary current has two components:

- 1) No-load primary current (I_0)
- 2) Primary equivalent current refer to Secondary (I')
- The purpose of I' to balance the secondary current.
- The no load primary current also sub-divided into two types.

⇒ Working component of no load current (I_w)

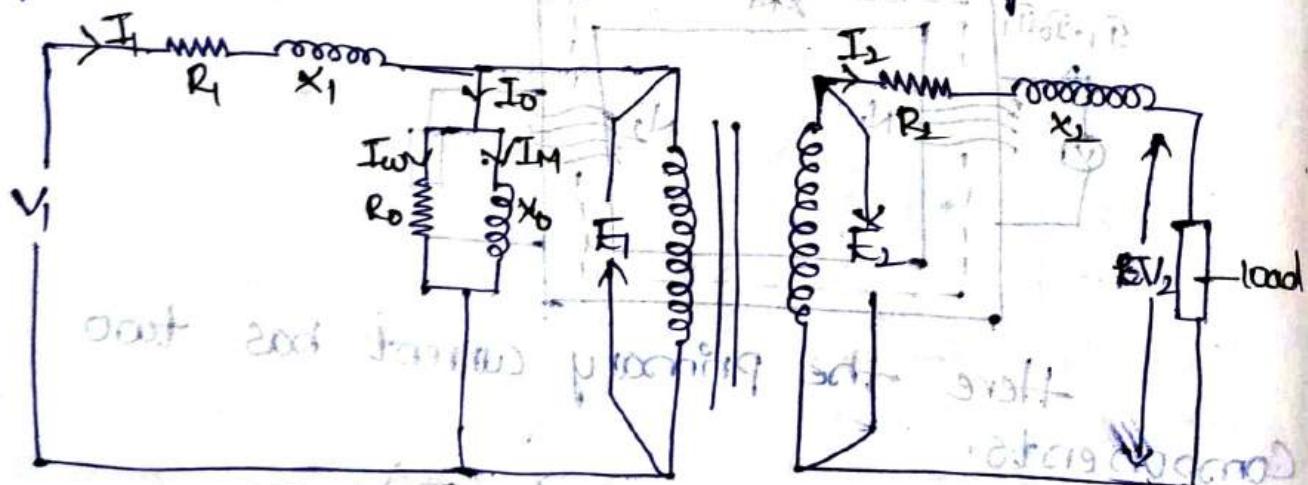
(or) Active component of no load current

ii) Magnetisation component of no load current (I_m) (or) Reactive component of no load current.

→ The working component of no load current which produces the Iron/core losses. Hence it is represented as equivalent resistance (R_o)

→ The magnetisation component of no load current which produce the magnetic flux & generate the induced emf. Hence it is represented as equivalent reactance (X_o)

→ To combination of Active & Reactive component of equivalent circuit of single phase transformer is shown in fig.



Equivalent Circuit of 1-to-1 transformer

→ The equivalent circuit of single phase transformer refer to primary side

Let consider Secondary Values transferred to Primary side in equivalent circuit of transformer

The equivalent circuit of transformer completely depends upon voltage ratio of transformer

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

E'_1 = The primary equivalent of secondary induced emf $k = \frac{E_2}{E_1}$

$$E'_1 \Rightarrow E_1 = E'_1 k$$

V'_1 = The primary equivalent of secondary terminal voltage $V'_1 \Rightarrow V_1 = \frac{V_2}{k}$

I'_2 = The primary equivalent of secondary current $I'_2 \Rightarrow I_1 = I'_2 k$

R'_2 = The primary equivalent of secondary resistance

The copper losses of each winding of

transformer

$$\Omega_1^2 R_1 = \Omega_2^2 R_2 \Rightarrow [R'_2 = R_1]$$

$$\Omega_1^2 R_2 = \Omega_2^2 R_1$$

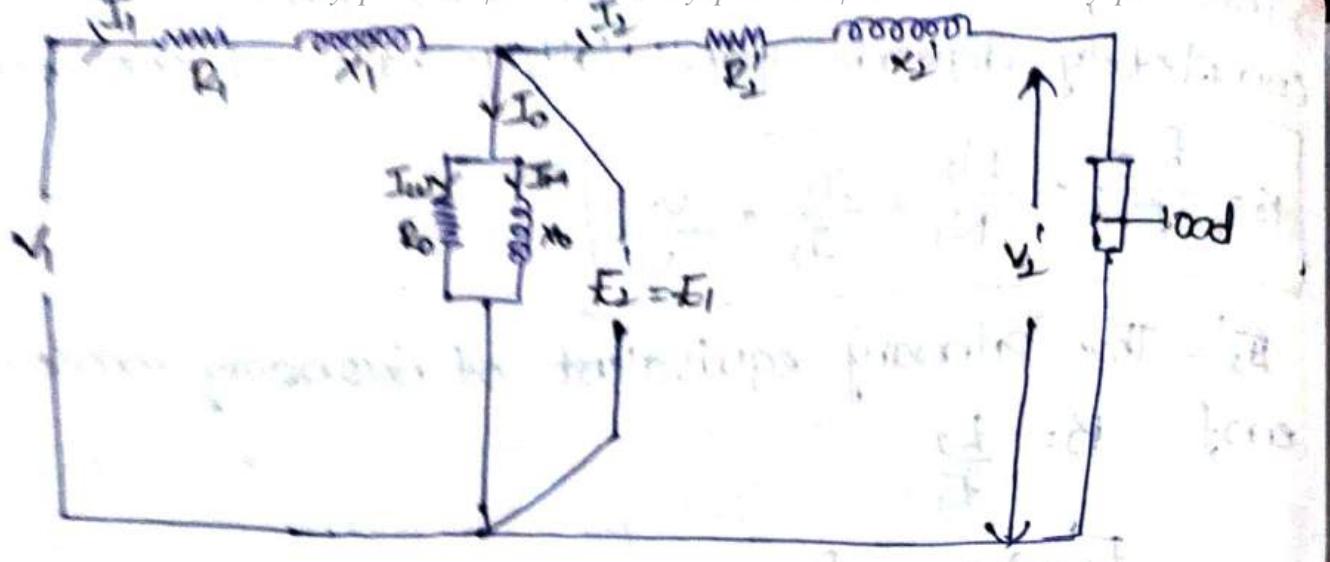
$$R'_2 = \frac{\Omega_2^2}{\Omega_1^2} \times R_2$$

$$R'_2 = \frac{R_2}{k^2}$$

X'_2 = The primary equivalent of second reactance

$$X'_2 = \frac{X_2}{k^2}$$

The equivalent circuit of single phase transformer referred to primary side is the circuit shown in fig 3



The equivalent resistance of transformer
primary side is given as $R_{01} = R_1 + R'_2$

$$R_{01} = R_1 + \frac{R_2}{K^2}$$

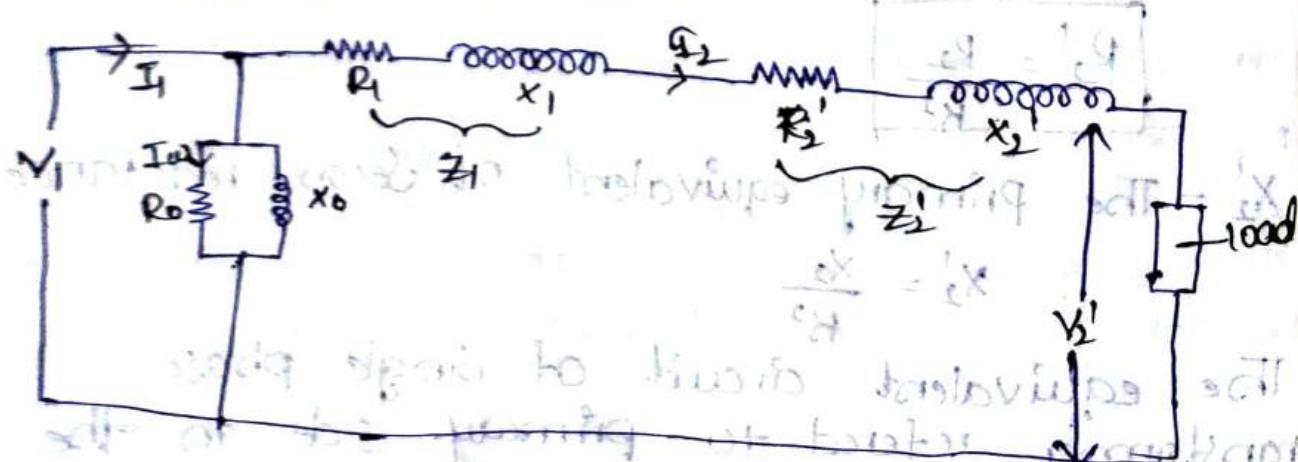
The equivalent reactance of transformer in Primary side is given as $X_{01} = X_1 + X'_2$

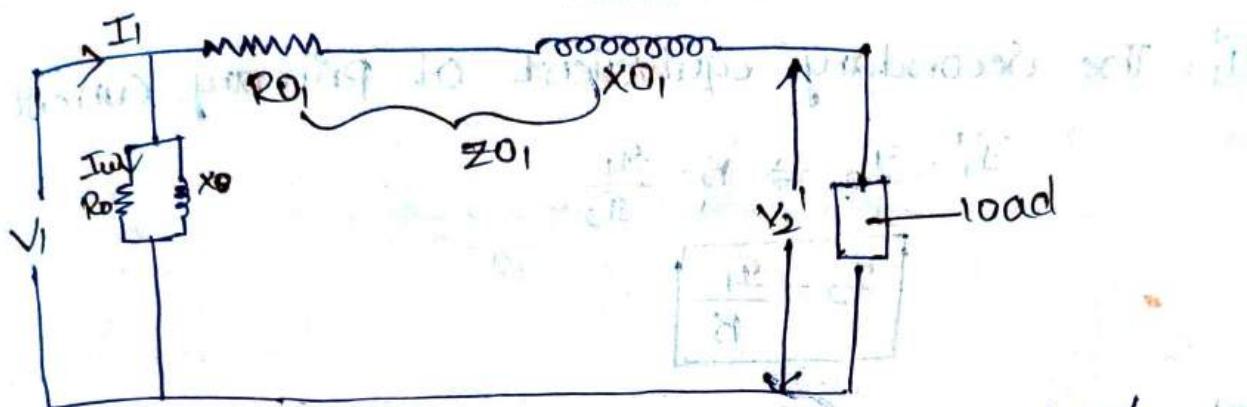
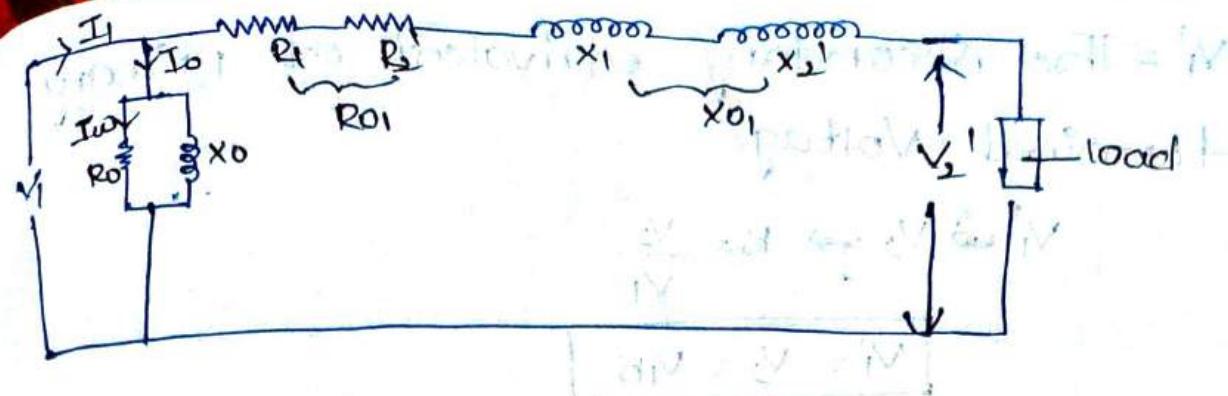
$$X_{01} = X_1 + \frac{X_2}{K^2}$$

The combination of equivalent resistance and equivalent reactance is known as equivalent impedance. It is denoted by Z'

$$Z' = R + jX_L$$

\downarrow
Resistance terminal \downarrow
Reactance terminal





The total impedance of equivalent circuit of single phase transformer in primary sides given as

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

equivalent circuit of single phase transformer refer to the secondary side.

The voltage ratio of single phase transformer is given as

$$K = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{\Phi_1}{\Phi_2}$$

Let consider transfer to primary values to secondary

Φ_1 = secondary equivalent of primary induced emf $E_1 = E_2 \Rightarrow K = \frac{E_2}{E_1}$

$$E_2 = E_1 K$$

$$E'_1 = E_2 = E_1 K$$

V_1' = The Secondary equivalent of primary terminal Voltage

$$V_1' = V_2 \Rightarrow K = \frac{V_2}{V_1}$$

$$V_1' = V_2 = V_1 K$$

I_1' = The Secondary equivalent of primary Current

$$I_1' = I_2 \Rightarrow K = \frac{I_1}{I_2}$$

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

R_1' = The Secondary equivalent of primary Resistance.

The Copper losses of single phase transformer in respective winding is given as $I_1^2 R_1 = I_2^2 R_2$

$$\therefore I_1^2 R_1 = I_2^2 R_2$$

$$\therefore R_1' = R_2$$

$$I_1^2 R_1 = I_2^2 R_1$$

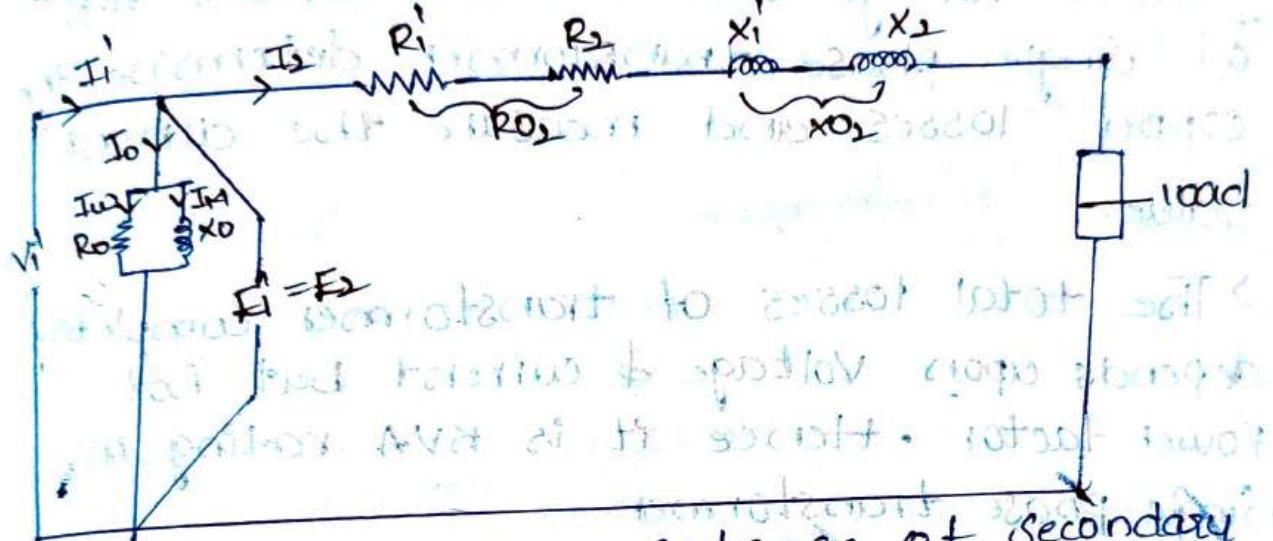
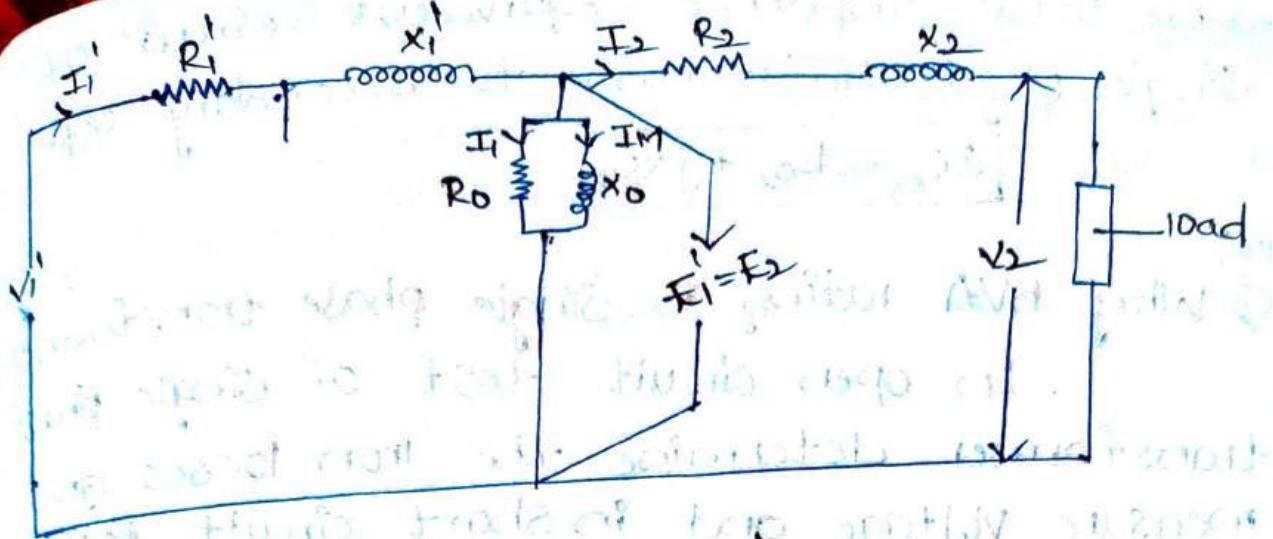
$$R_1' = \frac{I_1^2}{I_2^2} \times R_1$$

$$R_1' = R_1 K^2$$

X_1' = The Secondary equivalent of primary reactance is given as

$$X_1' = X_1 K^2$$

The equivalent circuit of single phase transformer refer to Secondary side in the circuit shown in fig.



The equivalent resistance of secondary side

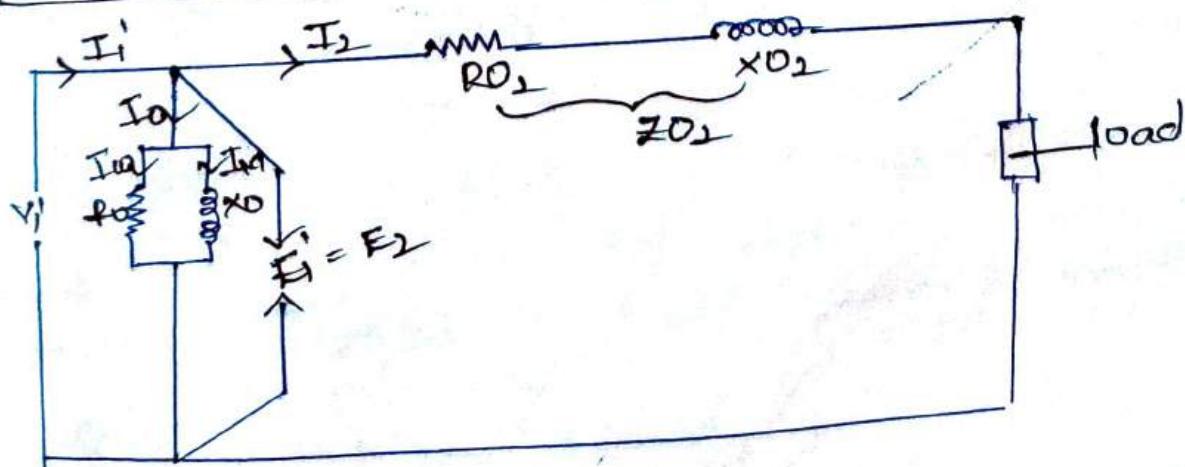
$$R_{02} = R_1' + R_2$$

$$R_{02} = R_1 K^2 + R_2$$

The total equivalent reactance of secondary side is given

$$\text{as } X_{02} = X_1 + X_2$$

$$X_{02} = X_1 K^2 + X_2$$



→ The total impedance equivalent circuit of single phase transformer to secondary side

$$Z_2 = R_2 + jX_2$$

Imp

Q Why KVA rating in single phase transformer?
 In open circuit test of single phase transformer determine the iron losses and measure voltage and in short circuit test of single phase transformer determine the copper losses and measure the current value.

→ The total losses of transformer completely depends upon voltage & current but not power factor hence it is KVA rating in single phase transformer.

$$9 + j0 = 09$$

$$9 + j8.19 = 09$$

$$j8.19 = 8.19$$

