UNIT-II

TRANSFORMER

- The main advantage of alternating currents over direct currents is that alternating currents can be easily transferable from low voltage to high (or) high voltage to low.
- This alternating voltages can be raised (or) lowered as per the requirements.
- So, it is possible with a static device called Transformer.

TRANSFORMER:

It is a static device which transfers electrical energy from one circuit to another circuit with the desired change in voltage and current, without change in frequency.

Step Up Transformer:

If the transformer receives the Electrical Energy at one voltage and delivers the higher voltage. Then it is called "step up transformer".

step up down Transformer:

If the transformer receives the Electrical Energy at one voltage and delivers the lower. voltage. Then it is called "step down Transformer."

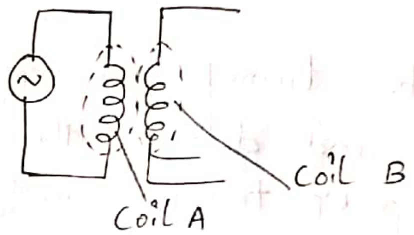
- Transformers require little care & maintenance because of their simple and rugged construction.
- Transformer has no moving parts and the windings are magnetically coupled, there is no Electrical connection.
- The Efficiency of the transformer is high because there are no moving parts & efficiency may vary from 94 to 96% for 5KVA & 97 to 99% for 100mVA.

- Based on this, transformers are used to supply electricity at any desired voltage depending upon the requirements.

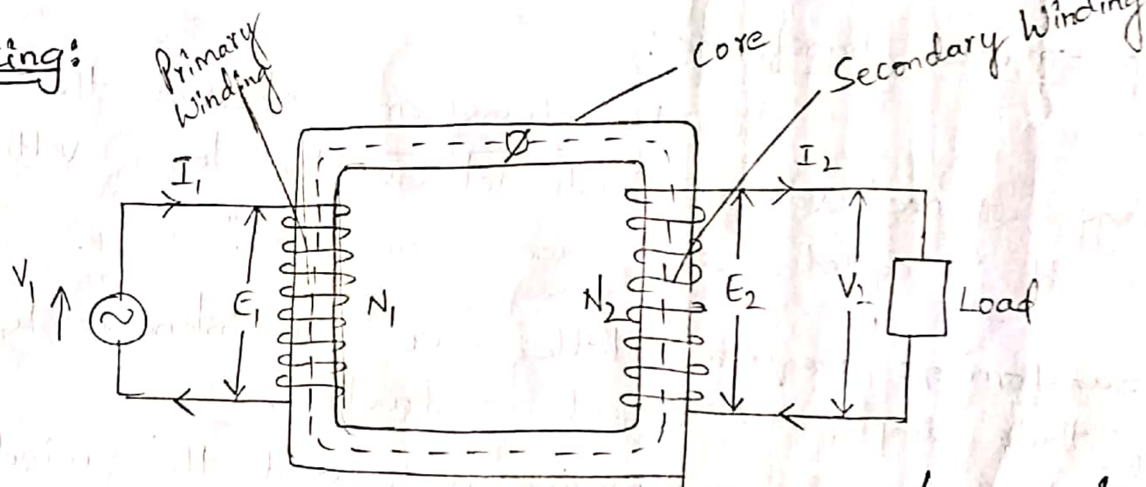
WORKING PRINCIPLE:

Transformer works on the principle of "Mutual Induction".

Mutual Induction:
When an alternating supply is applied to a coil A, then current starts flowing through the coil A and induces Emf (or) flux in the coil A. The flux induced in the coil A links with the coil B. Thus, the flux linking the coil B which is induced by coil A is known as "Mutual Induction".



Working:



Transformer mainly consist of three parts one is primary winding, other winding is secondary winding and another is core.

These two windings are electrically separated but magnetically coupled to each other.

- The winding which is connected to the AC source (2)
is called primary winding.
- The winding which is connected to the load is called secondary winding.
- The primary winding has N_1 number of turns.
- The secondary winding has N_2 number of turns.
- When alternating voltage (V_1) is applied to the primary an alternating flux (ϕ) is set up in the core.
- The flux set up in the primary links the secondary called mutual induction principle.
- According to Faradays law of Electromagnetic Induction the flux linking both the windings induces emf E_1 in the primary and E_2 in the secondary.
- If the load is connected to the secondary, ~~due~~ ~~to~~ the induced emf (E_2) drives a current (I_2) through the load.
- E_1 called primary emf
  E_2 called secondary emf
  N_1 called primary turns
  N_2 called secondary turns
- According to Faradays law of electromagnetic induction

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

Then,

$$E_1 = -N_1 \frac{d\phi}{dt}$$

$$E_2 = -N_2 \frac{d\phi}{dt}$$

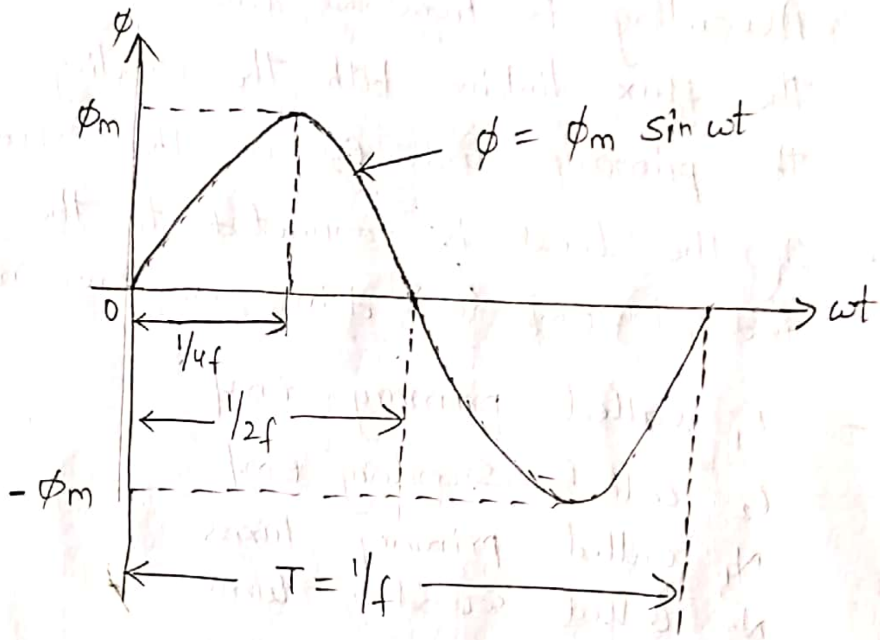
Now,

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

- The magnitudes E_1 & E_2 depends on the number of turns of primary and secondary windings.
- If $N_2 > N_1$, then $E_2 > E_1$ (or) $V_2 > V_1$ it is step up Transformer.
- If $N_2 < N_1$, then $E_2 < E_1$ (or) $V_2 < V_1$ it is step down Transformer.
- If $N_2 = N_1$ then $E_2 = E_1$ it is called Isolation Transformer (1:1)

EMF EQUATION OF TRANSFORMER:

When the primary winding is excited by an alternating voltage V_1, then alternating current circulates and produces an alternating flux (ϕ).



ϕ = Flux

ϕ_m = Maximum Value of flux

f = frequency of the supply voltage

N_1 – Number of primary winding turns

N_2 – Number of secondary winding turns

E_1 – RMS Value of the primary induced emf

E_2 – RMS Value of the secondary induced emf

From, Faradays law of electromagnetic Induction the average emf induced in each turn is proportional to the average rate of change of flux. (3)

Average emf per turn = Average rate of change of flux

Now, $\frac{d\phi}{dt} = \frac{\text{change in flux}}{\text{Time required for change in flux}}$

- For $\frac{1}{4}$ th cycle of the flux, complete cycle gets completed in $\frac{1}{f}$ seconds.
- In $\frac{1}{4}$ th time period, the change in flux is from 0 to ϕ_m

$$\frac{d\phi}{dt} = \frac{\phi_m - 0}{\frac{1}{4f}} = \frac{\phi_m}{\frac{1}{4f}} = \frac{\phi_m}{1} \times \frac{4f}{1} = 4f\phi_m \text{ wb/sec}$$

as dt for $\frac{1}{4}$ th time period is $\frac{1}{4f}$ seconds.

Now, Average emf per turn $= 4f\phi_m$ volts

As ϕ is sinusoidal the emf induced in each turn is

$$\text{form Factor} = \frac{\text{Rms value}}{\text{Average value}}$$

~~Form~~ $= 1.11$

$\therefore$ Rms value $= 1.11 \times$ Average value

$= 1.11 \times 4f\phi_m$

$= 4.44 f\phi_m$

Including the number of turns N_1 & N_2, the emf's Equations are

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

- The primary winding of a 50HZ, 1-ϕ Tfr has 480 turns & is fed from a 6400 V supply. The secondary winding has 20 turns. Find the peak value of flux in the core and the secondary voltage.

Sol: Given Data:

$F = 50HZ$

$N_1 = 480$

$V_1 = 6400$

$N_2 = 20$

$\phi = ?$

$V_2 = ?$

As $E_1 = V_1$

$E_1 = 4.44 f \phi m N_1$

$6400 = 4.44 \times 50 \times \phi_m \times 480$

$$\frac{6400}{4.44 \times 50 \times 480} = \phi m$$

$$\boxed{\phi_m = 60 \text{ mwb}}$$

Now, $E_2 = V_2$

$V_2 = 4.44 f \phi_m N_2$

$= 4.44 \times 50 \times 60 \times 10^{-3} \times 20$

$$\boxed{V_2 = 266.4 V}$$

(or) $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

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

$$\boxed{V_2 = 266.6 V}$$

- A 1-ϕ 2200/250V, 50HZ tfr has a net core area of $36 cm^2$ and maximum flux density of $6 wb/m^2$. calculate the number of turns of primary & secondary.

Sol: Given Data:

$E_1 = 2200 V$

$E_2 = 250 V$

$f = 50HZ$

$A = 36 cm^2$

$B = 6 \, wb/m^2$

$N_1 = ?$

$N_2 = ?$ (4)

As $\phi = B \cdot A$

$\phi_m = B_m \cdot A$

$= 6 \times 36 \times 10^{-4}$

$= 0.0216 \, wb$

$E_1 = 4.44 f \phi_m N_1$

$2200 = 4.44 \times 50 \times 0.0216 \times N_1$

$\boxed{N_1 = 459}$

$E_2 = 4.44 f \phi_m N_2$

$250 = 4.44 \times 50 \times 0.0216 \times N_2$

$\boxed{N_2 = 52}$

CONCEPT OF IDEAL TRANSFORMER:

The transformer is said to be ideal transformer, if it satisfies the following properties:

i, It has No Losses

ii, Its windings have zero resistance

iii, Leakage flux is zero (i.e. 100%) flux produced by primary links with the secondary.

TRANSFORMER RATIOS:

Voltage Ratio:

$E_1 = 4.44 f \phi_m N_1$

$E_2 = 4.44 f \phi_m N_2$

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

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

Current Ratio:

As $V_1 I_1 = V_2 I_2$

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

The currents are in the inverse ratio.

Volt Ampere Rating:

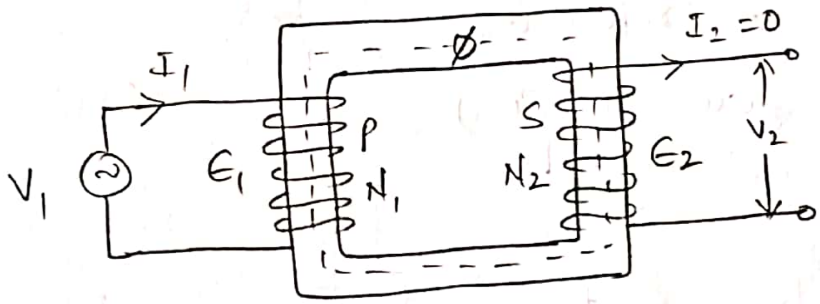
$$\text{KVA rating of a transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

Full load currents:

$$I_1 \text{ full load} = \frac{\text{KVA rating} \times 1000}{V_1}$$

$$I_2 \text{ full load} = \frac{\text{KVA rating} \times 1000}{V_2}$$

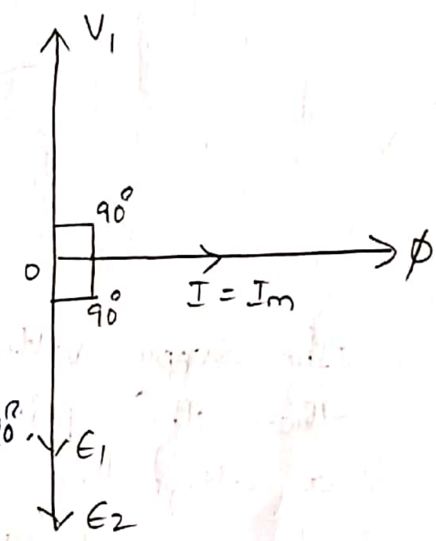
IDEAL TRANSFORMER ON NO LOAD



(No load)

- The Supply voltage V_1 is applied to the primary then the primary draws a current I_1 and produces a alternating flux in the core.
- The current in the secondary will be zero as it on No load.
- As the flux magnetising the core, it is called as magnetising current (I_m)
- As the transformer is ideal the winding resistance is zero.
- So, the winding is purely inductive in nature due to this I_m will be very small and lags V_1 by 90°.
- I_m produces a alternating flux (ϕ) which is in phase with I_m.

- The flux links both the windings and induces emf's E_1 and E_2 in the primary & secondary.
- So, according to Lenz's law the induced emf opposes the cause (voltage)
- E_1 is antiphase with V_1
- E_2 also opposes V_1
- Hence E_1 & E_2 are in phase & antiphase with V_1.
- From the phasor diagram it is clear that flux (ϕ) is taken as reference.



- As the magnetising current (I_m) produces flux (ϕ) it is in phase with flux (ϕ).
- V_1 leads by 90° because the winding is purely inductive.
- Current (I) lags the voltage by 90°.
- As the power input to the transformer is $V_1 I_1 \cos\theta$
  $V_1 I_m \cos 90$
  (ie., zero)
- Because of No Load the output power is zero hence input power is also zero.
- So, the powerfactor for ideal Transformer is zero lagging.

Practical Transformer On No Load

- When the transformer is considering practically there will be a presence of core losses (i.e. Eddy current Loss & Hysteresis Loss).
  - So to reduce these losses care should be taken while designing.
  - i, Silicon steel has to be used to reduce Hysteresis Loss.
  - ii, Core should be laminated to reduce Eddy current loss.
- As it is practical primary winding has some resistance due to this there will be presence of small copper loss.
- So, the primary current on No load has to supply iron losses and small amount of copper loss.
- No load primary current (I_0) has two components:
  - i, I_m – Magnetising component of No load current required to produce the flux. (Wattless Component)
  - ii, I_c / I_w – Active (or) working component supplies losses on No load condition called power component (or) Wattful component (or) core loss component.

$$I_0 = I_m + I_w$$

- Due to winding resistance, I_0 is no longer at 90° with respect to supply voltage V_1.
- But it lags V_1 by angle ϕ_0 which is less than 90°

Thus $\cos\phi_0$ – No Load p.f

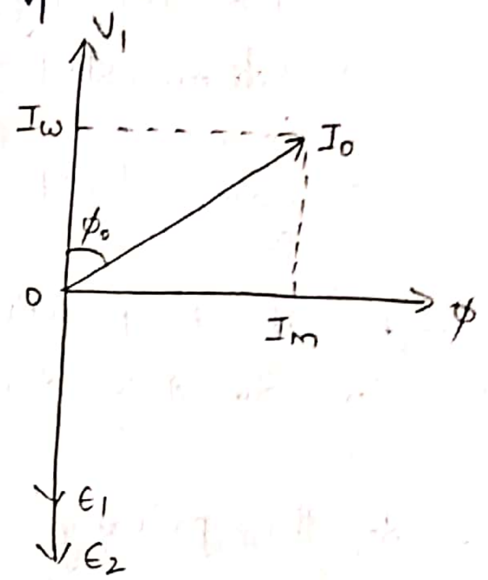
- Two Components are
  - $\rightarrow$ $I_m = I_0 \sin\phi_0$

    I_m lags V_1 by $90°$
  - $\rightarrow$ $I_w = I_0 \cos\phi_0$

    I_w is in phase with V_1

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

ϕ_0 – No load p.f angle



- Total power input on No load is given by

$$W_0 = V_1 I_0 \cos\phi_0$$

$$W_0 = V_1 I_w$$

- No load p.f $\cos\phi_0 = \frac{I_w}{I_0}$

$$\sin\phi_0 = \frac{I_m}{I_w}$$

Problem: A transformer takes a current of 0.6A and absorbs 64W when primary is connected to its normal supply of 200V, 50HZ, the secondary being on open circuit. Find the magnetising and iron loss currents,

Sol: $I_0 = 0.6A$

$W_0 = 64W$

$V_1 = 200V$

$f = 50HZ$

$I_m = ?$

$I_w = ?$

No Load power $W_0 = V_1 I_0 \cos\phi_0$

$$\frac{W_0}{V_1} = I_0 \cos\phi_0$$

$I_w = I_0 \cos\phi_0$

$$I_w = \frac{W_0}{V_1} = \frac{64}{200} = 0.32A$$

No load current $I_0 = \sqrt{I_m^2 + I_w^2}$

$\therefore$ Magnetising Current $I_m = \sqrt{I_0^2 - I_w^2}$

$$= \sqrt{(0.6)^2 - (0.32)^2}$$

$$\boxed{I_m = 0.507A}$$

→ The No load current of a transformer is 4A at 0.25 pf when supplied at 250V, 50Hz. The number of turns on the primary winding is 200. Calculate the

i, Rms value of the flux in the core.

ii, Core loss & iii, Magnetising current

Sol:

$I_0 = 4A$

$\cos\phi_0 = 0.25$

$V_1 = 250V$

$f = 50HZ$

$N_1 = 200$

i, $V_1 = 4.44 f \phi_m N_1$

$250 = 4.44 \times 50 \times \phi_m \times 200$

$$\phi_m = 250 / 4.44 \times 50 \times 200$$

$$\phi_m = 5.63 \text{ m wb}$$

$$\phi(\text{Rms}) = \phi m/\sqrt{2} = \frac{5.63}{\sqrt{2}} = 3.98 \text{ m wb}$$

ii, Core loss (or) No power input :
W

$$W_0 = V_1 I_0 \cos\phi_0$$

$$W_0 = 250 \times 4 \times \cos(0.25)$$

$$W_0 = 250 \text{ W}$$

iii, $I_m = I_0 \sin\phi_0$

$$= 4 \times 0.968$$

$$= 3.873 \text{ A}$$

(Practical Tfr on ON Load)

→ A 1-ϕ transformer with a ratio of 440/110V takes the no-load current of 5A at 0.2 p.f lagging. If the secondary supplies a current of 120A at a p.f 0.8 lagging. Find the current taken by the primary.

Sol: 1-ϕ Tfr

$V_1 = 440\text{V}$

$V_2 = 110\text{V}$

$I_0 = 5\text{A}$

$\cos\phi_0 = 0.2$ lag

$I_2 = 120\text{ A}$

$\cos\phi_2 = 0.8$ lag

$I_1 = ?$

$$K = \frac{V_2}{V_1} = \frac{110}{440} = \frac{1}{4}$$

$$I_2' = K \cdot I_2 = \frac{1}{4} \times 120 = 30\text{A}$$

$\cos\phi_0 = 0.2 \Rightarrow \phi_0 = \cos^{-1}(0.2) \Rightarrow \phi_0 = 78.46^\circ$

$\cos\phi_2 = 0.8 \Rightarrow \phi_2 = \cos^{-1}(0.8) \Rightarrow \phi_2 = 36.87^\circ$

$$\theta = 78.46 - 36.87 = 41.59^\circ$$

$$I_1 = \sqrt{(I_0)^2 + (I_2')^2 + 2 I_0 I_2' \cos\theta}$$

$$= \sqrt{(5)^2 + (30)^2 + 2 \times 5 \times 30 \cos(41.59)}$$

$$I_1 = 33.9 A$$

- The voltage on the secondary of a 1-ϕ t/f is 200V when supplying a load of 8kW at a p.f of 0.8 lag. The secondary resistance is 0.04Ω & secondary leakage reactance is 0.8Ω. Calculate the induced emf in the secondary.

Sol:

$V_2 = 200V$

$P_2 = 8kW = 8 \times 10^3 W$

$\cos\phi_2 = 0.8$ lag

$R_2 = 0.04\Omega$

$X_2 = 0.8\Omega$

$E_2 = ?$

$$V_2 = E_2 - I_2 Z_2$$

$$V_2 = E_2 - I_2 (R_2 + jX_2)$$

$$E_2 = V_2 + I_2 (R_2 + jX_2)$$

As $P = V \cdot I \cos\phi$

$$I_2 = \frac{P_2}{V_2 \cos\phi_2} = \frac{8 \times 10^3}{200 \times 0.8} = 50 A$$

power factor angle $\cos\phi_2 = 0.8$

$$\phi_2 = \cos^{-1}(0.8)$$

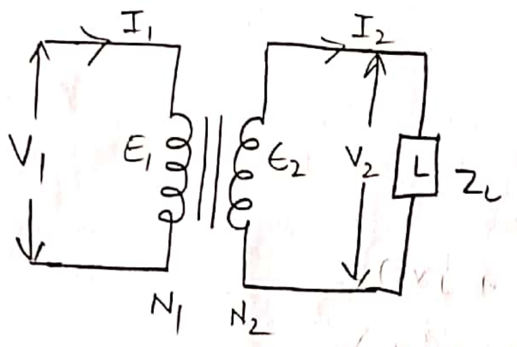
$$\phi_2 = 36.9^\circ$$

$$I_2 = 50 \angle -36.9^\circ$$

$$Z_2 = R_2 + jX_2$$
$$= 0.04 + j0.08$$
$$= 0.8 \angle 87.14^\circ$$

$$E_2 = V_2 + I_2 Z_2$$
$$= 200\angle 0^\circ + 50\angle -36.9^\circ \times 0.8\angle 87.14^\circ$$
$$= 200\angle 0^\circ + 40\angle 50.24^\circ$$
$$= (200 + j0) + (25.58 + j30.75)$$
$$= 225.58 + j30.75$$
$$E_2 = 227.67 \angle 7.8^\circ \text{ volts}$$

IDEAL TRANSFORMER on ON LOAD



When the load is connected to secondary side emf E_2 causes current I_2 to flow through the load.

$$I_2 = \frac{E_2}{Z_L} = \frac{V_2}{Z_L}$$

- The angle at which I_2 leads (or) lags V_2/E_2 depends upon the resistance and reactance of the load
- As we are considering inductive load, so the current I_2 lags behind V_2 by ϕ_2.

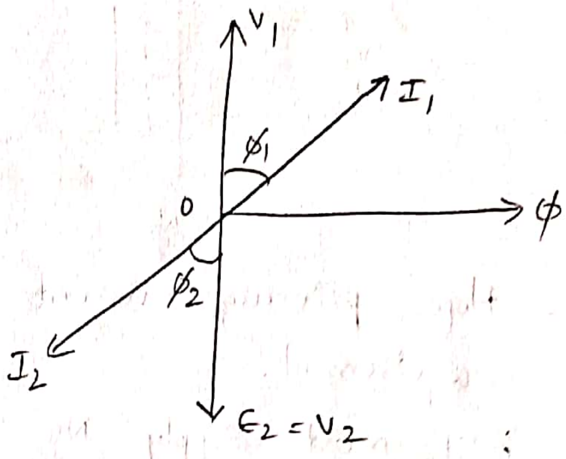
- As the primary current sets up $N_1 I_1$
- As the secondary current sets up $N_2 I_2$
- So, the current I_2 sets up an mmf $N_2 I_2$ which produces a flux in the opposite direction to the flux (ϕ) setup in primary by the I_m(magnetising current)

- $N_1 I_1 = N_2 I_2$

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

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

$$I_1 = k \cdot I_2$$



- Then $\phi_1 = \phi_2$

$$\cos\phi_1 = \cos\phi_2$$

$$V_1 I_1 \cos\phi_1 = V_2 I_2 \cos\phi_2$$

- There are no losses in ideal transformer
- Then input primary power = Output secondary power.

PRACTICAL TRANSFORMER ON ON LOAD:

As we are considering the transformer On ON load Condition. It has practically that to on ON load Condition. It has the following two cases:

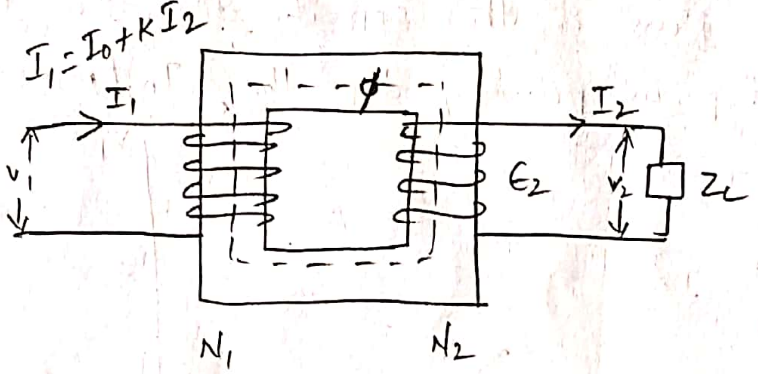
i, No winding resistance & leakage flux
ii, Winding resistance & Leakage flux

i, No winding resistance and Leakage flux

- Assuming resistance and leakage reactances of the windings are negligible.

- As $V_2 \simeq E_2$ and $V_1 \simeq E_1$

- Considering Inductive load I_2 lags V_2 by ϕ_2.



- Here primary current (I_1) should meet two requirements.

i, I_1 must supply No load current (I_0) & should meet the iron losses in the transformer & provides the flux.

ii, I_1 should meet (or) supply a current I_2' to counteract the demagnetising effect of secondary current I_2.

The magnitude of I_2' is

$$N_1 I_2' = N_2 I_2$$

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

$$I_2' = k \cdot I_2$$

As $I_2' = k \cdot I_2$

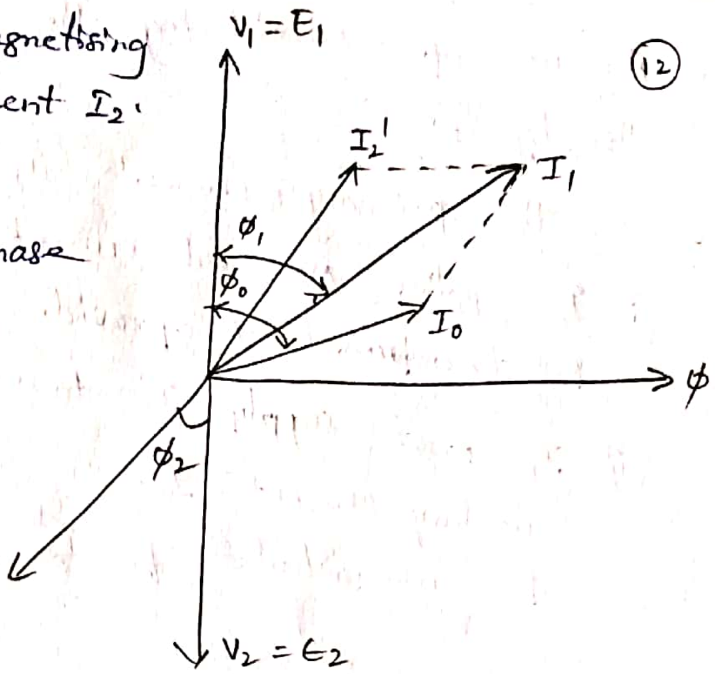
$$I_1 = I_0 + k \cdot I_2$$

$$I_1 = I_0 + I_2'$$

- From the phasor diagram it is clear that both emf E_1 & E_2 lags behind the flux (ϕ) by 90°.

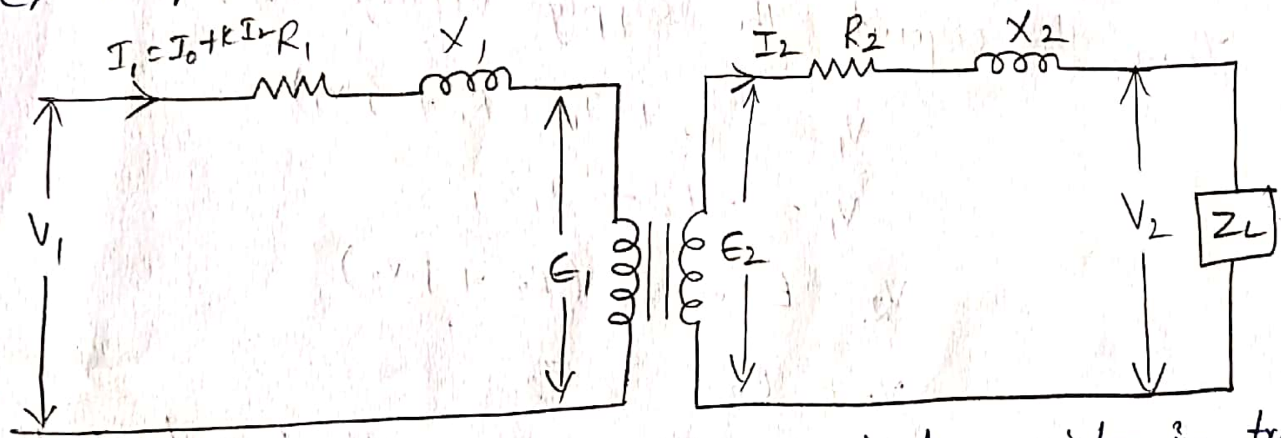
(12)

- I_2' represents the demagnetising effect of secondary current I_2.
- As $I_2' = k \cdot I_2$
- So, I_2' is in anti-phase with I_2.
- $I_1 = I_0 + I_2'$
- Assume $k = 1$
- Then the primary phasors are equal to secondary phasors



- Now primary power factor $= \cos\phi_1$
  Secondary power factor $= \cos\phi_2$
  Primary input power $= V_1 I_1 \cos\phi_1$
  Secondary output power $= V_2 I_2 \cos\phi_2$

ii) Transformer with resistance and leakage reactance:



These are actual conditions which exist in transformer, the primary

- Due to voltage drop in R_1 and X_1 the emf E_1 is less than V_1 $(E_1 < V_1)$
- Similarly, the voltage drop in R_2 and X_2 the secondary emf $(E_2 > V_2)$. (or) $V_2 < E_2$

- As we are considering the inductive load, I_2 lags V_2 by ϕ_2.
- So, the primary current (I_1) must meet 2 requirements.

i, I_1 supplies No load current (I_0) to meet iron losses in transformer & provide the flux in the core.

ii, I_1 must supply I_2' to demagnetise the Effect of secondary current I_2.

The magnitude of I_2' is

$$N_1 I_1 = N_2 I_2$$

$$N_1 I_2' = N_2 I_2$$

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

$$I_2' = k \cdot I_2$$

- Total primary current $I_1 = I_0 + I_2'$

$$I_1 = I_0 + k \cdot I_2$$

- From the circuit the supply voltage (V_1)

$$V_1 = -E_1 + I_1 (R_1 + j X_1)$$

$$V_1 = -E_1 + I_1 Z_1$$

$$V_2 = E_2 - I_2 (R_2 + j X_2)$$

$$V_2 = E_2 - I_2 Z_2$$

- Now, from the phasor diagram it is clear that as the load is inductive.
- Then E_1 & E_2 lags the flux (ϕ) by $90°$.
- $I_2' = k \cdot I_2$

- I_2' is in antiphase to I_2

- Total primary current
$$I_1 = I_0 + I_2'$$

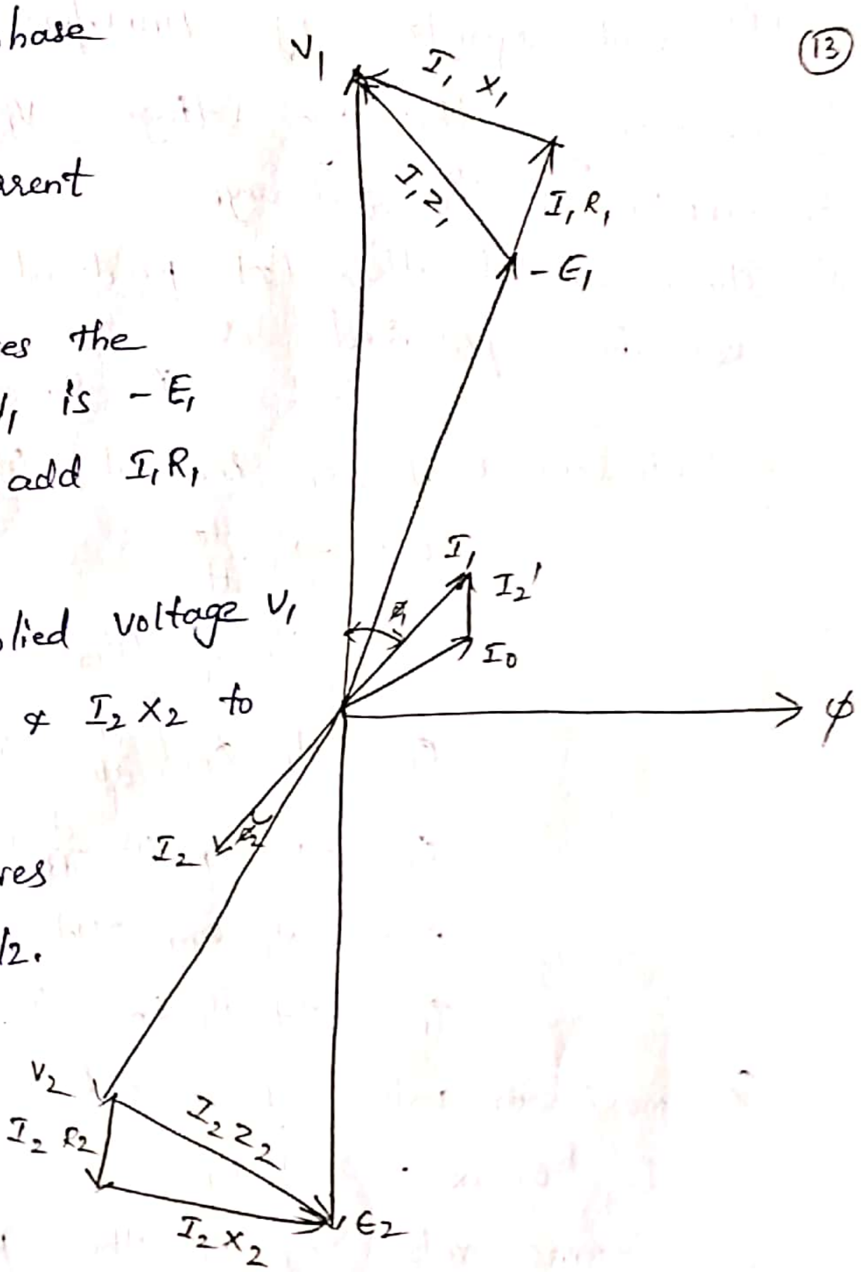
- As the emf opposes the applied voltage V_1 is $-E_1$

- So, we need to add I_1R_1 I_1X_1 to $-E_1$

- To get the applied voltage V_1

- Similarly, I_2R_2 & I_2X_2 to E_2

- To get (or) gives the voltage V_2.



- Load power factor $= \cos\phi_2$
- Primary power factor $= \cos\phi_1$
- Input power to transformer $(P_1) = V_1 I_1 \cos\phi_1$
- Output power of transformer $(P_2) = V_2 I_2 \cos\phi_2$

(or) EMF Equation of Transformer

Considering alternating voltage V_1 of frequency 'f' is applied to the primary.

So, the sinusoidal flux (ϕ) produced by the primary can be represented as

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

Instantaneous Emf e_1 induced in the primary

$$e_1 = -N_1 \frac{d\phi}{dt}$$

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

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

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

$$e_1 = -N_1 \phi_m 2\pi f \cos \omega t$$

$$e_1 = 2\pi f N_1 \phi_m \sin(\omega t - 90^\circ)$$

So, maximum value of induced emf in the primary is $E_{max} = 2\pi f N_1 \phi_m$

The rms value E_1 of the primary emf is

$$E_1 = \frac{E_{max}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$= \frac{\sqrt{2} \times \cancel{\sqrt{2}}\, \pi f N_1 \phi_m}{\cancel{\sqrt{2}}}$$

$$= 1.414 \times 3.14 f N_1 \phi_m$$

$$\boxed{E_1 = 4.44 f N_1 \phi_m}$$

Similarly $E_2 = 4.44 f N_2 \phi_m$

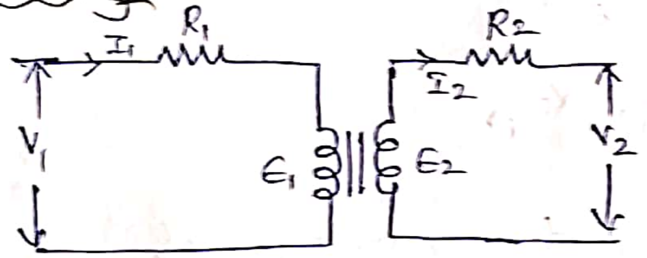
TRANSFORMER PARAMETERS:

i, Winding Resistance
ii, Leakage Reactance
iii, Impedance

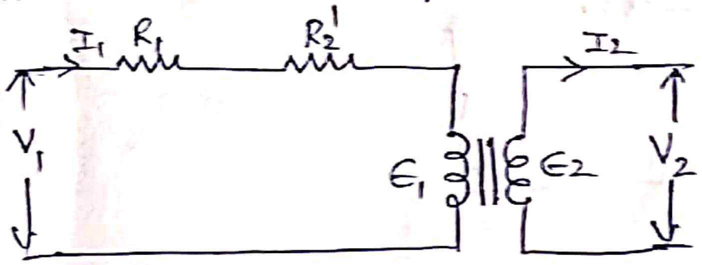
So, Resistance & reactance when referred to primary it should be divided by K^2.

So, Resistance & reactance when referred to secondary it should be multiplied with K^2.

i, Winding Resistance:



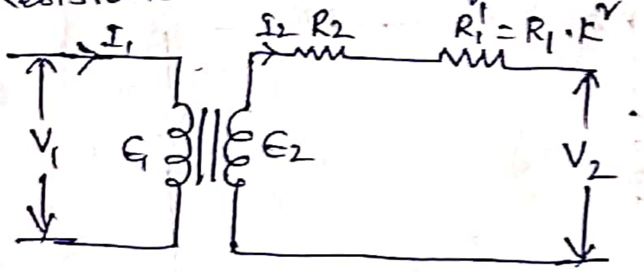
⇒ Resistance when referred to primary side



$$R_2' = R_2/K^2$$

$$\therefore R_{01} = R_1 + R_2' = R_1 + R_2/K^2$$

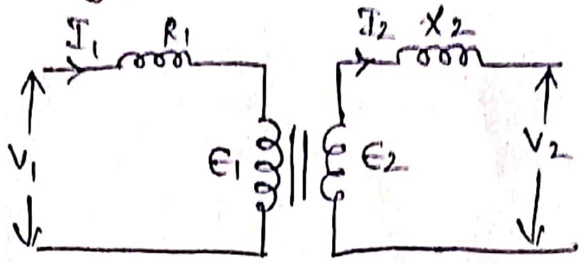
⇒ Resistance when referred to secondary side



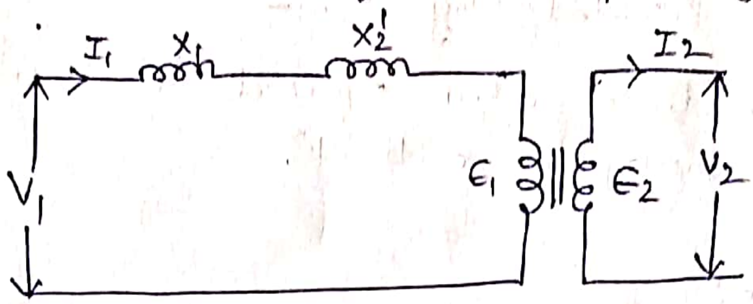
$$R_1' = R_1 \cdot K^2$$

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

ii, Leakage Reactance :



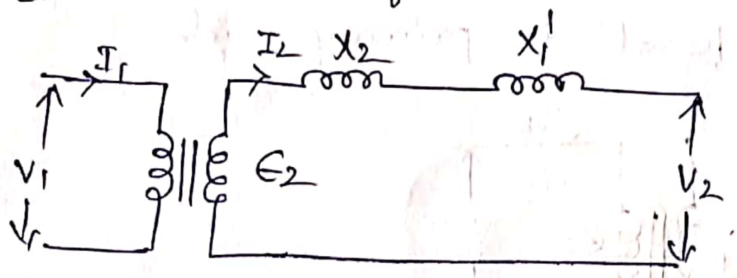
⇒ Reactance when referred to primary side



$$X_2' = X_2/K^2$$

$$\therefore X_{01} = X_1 + X_2' = X_1 + X_2/K^2$$

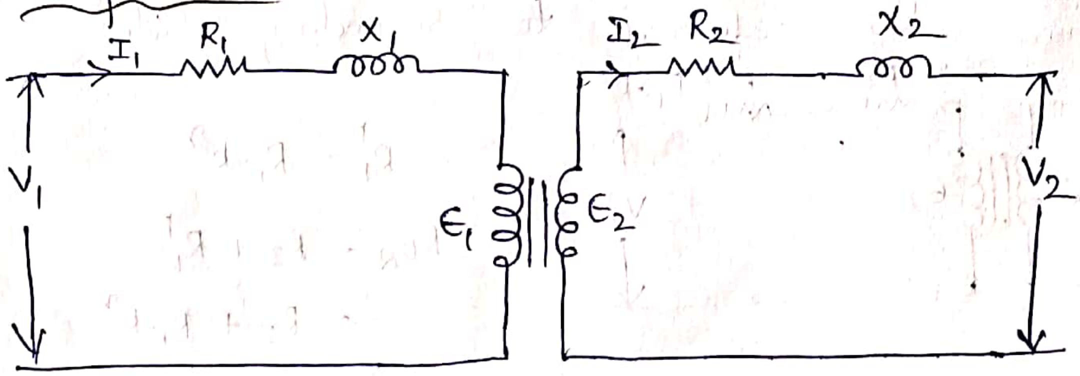
⇒ Reactance when referred to secondary side



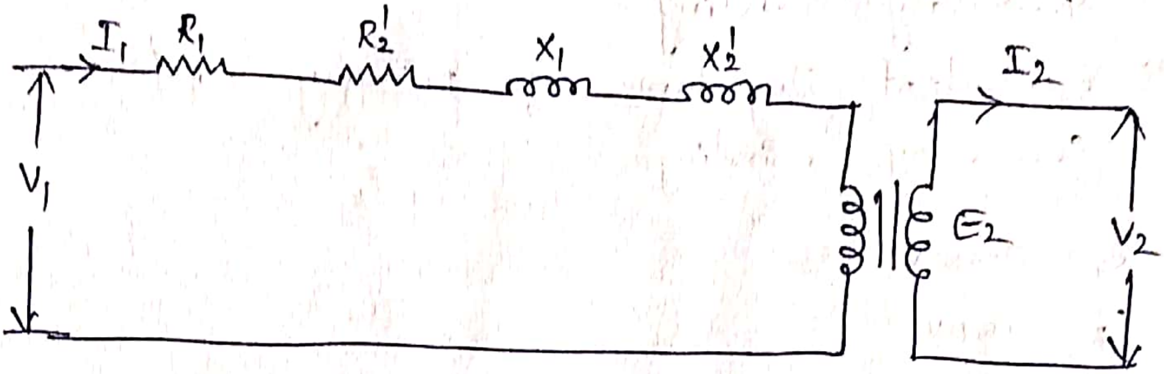
$$X_1' = X_1 \cdot K^2$$

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

iii, Impedance :



Impedance when referred to primary Side

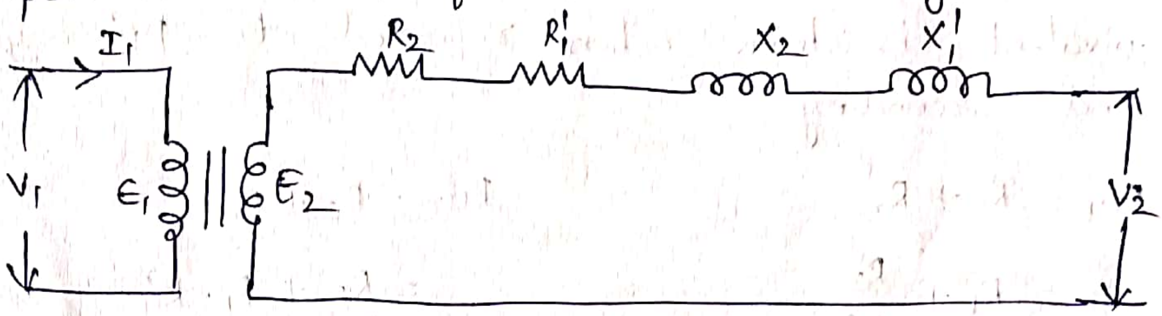


$$R_{01} = R_1 + R_2'$$

$$X_{01} = X_1 + X_2'$$

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

Impedance when referred to secondary side



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

$$X_{02} = X_2 + X_1'$$

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

(P) A 50KVA 3000/150V, 50HZ Transformer has a High voltage winding resistance of $0.25\,\Omega$ & a leakage reactance of $0.55\,\Omega$. The Low voltage winding resistance is $0.03\,\Omega$ and the leakage reactance is $0.022\,\Omega$. Calculate i, Equivalent Resistance Referred to primary & Secondary winding

ii. Equivalent Reactance of primary and secondary winding
iii. Equivalent Impedance of primary and Secondary winding.

Sol: $E_1 = 3000V$

$E_2 = 150V$

$R_1 = 0.25\Omega$

$X_1 = 0.55\Omega$

$R_2 = 0.03\Omega$

$X_2 = 0.022\Omega$

$$k = E_2/E_1 = V_2/V_1 = \frac{15\cancel{0}}{300\cancel{0}} = 0.05$$

i. Equivalent Resistance when referred to primary and secondary

$$R_{01} = R_1 + R_2'$$
$$= R_1 + \frac{R_2}{k^2}$$
$$= 0.25 + \frac{0.03}{(0.05)^2}$$
$$\boxed{R_{01} = 12.25\ \Omega}$$

$$R_{02} = R_2 + R_1'$$
$$= R_2 + R_1 \cdot k^2$$
$$= 0.03 + 0.25 \times (0.05)^2$$
$$\boxed{R_{02} = 0.03\ \Omega}$$

ii. Equivalent Reactance when referred to primary and Secondary

$$X_{01} = X_1 + X_2'$$
$$= X_1 + X_2/k^2$$
$$= 0.55 + \frac{0.022}{(0.05)^2}$$
$$\boxed{X_{01} = 9.35\ \Omega}$$

$$X_{02} = X_2 + X_1'$$
$$= X_2 + X_1 \cdot k^2$$
$$= 0.022 + 0.55 \times (0.05)^2$$
$$\boxed{X_{02} = 0.023\ \Omega}$$

CamScanner

iii, Equivalent Impedance when referred to primary and Secondary,

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

$$= \sqrt{(12.25)^2 + (9.35)^2}$$

$$\boxed{Z_{01} = 15.41\,\Omega}$$

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

$$= \sqrt{(0.03)^2 + (0.023)^2}$$

$$\boxed{Z_{02} = 0.037\,\Omega}$$

⇒ **LOSSES IN A TRANSFORMER :-**

There are two types of losses

i, Iron (or) core loss

ii, Copper loss

- This losses appear in the form of heat due to this efficiency of transformer will be reduced.
- As the iron loss consists of Hysteresis and Eddy current loss which occur due to alternating flux;

Hysteresis loss $P_h = \eta\, B_{max}^{1.6}\, f\, V$ watts

Eddy current loss $P_e = K\, B_{max}^2\, f^2\, t^2\, V$ watt

- Iron losses are same at all loads.
- Hysteresis Loss can be reduced by using steel of high silicon.
- Eddy current loss can be reduced by using core of thin Laminations.
- So, these two losses can be determined by open circuit Test.

ii. Copper loss:

These losses occurs in primary winding and secondary winding due to ohmic resistance.

- Total copper loss = $I_1^2 R_1 + I_2^2 R_2$
- It is clear that copper losses vary as the square of load current (I_L)
- This loss can be determined by Short Circuit Test

∴ Total losses in transformer = Iron loss + Copper loss

$= W_i + W_{cu}$

$=$ Constant losses + Variable losses

⇒ EFFICIENCY OF TRANSFORMER:

Generally, Efficiency $= \dfrac{\text{output}}{\text{Input}}$

Transformer efficiency $(\eta) = \dfrac{\text{output power}}{\text{Input power}}$

$$\eta = \frac{\text{output power}}{\text{output power + Total losses}}$$

As, $P = VI\cos\phi$

Considering the Output $= V_2 I_2 \cos\phi_2$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + W_i + W_{cu}}$$

For any load 'x' is the Variable of Full load

$$= \frac{x \, V_2 I_2 \cos\phi_2}{x \, V_2 I_2 \cos\phi_2 + W_i + x^2 W_{cu}}$$

$\{As \; W_{cu} = I_2^2 R_{02}\}$

$$= \frac{x \, V_2 I_2 \cos\phi_2}{x \, V_2 I_2 \cos\phi_2 + W_i + x^2 I_2^2 R_{02}}$$

⇒ **CONDITION FOR MAXIMUM EFFICIENCY:**

Output Power $= V_2 I_2 \cos\phi_2$

Copper losses $= I_2^2 R_{02} \, (W_{cu})$

Iron losses $= W_i$

Total Losses = copper losses + Iron losses

$= I_2^2 . R_{02} + W_i$

$$\text{Efficiency } (\eta) = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02}}$$

Now, divide the Numerator and Denominator by 'I_2'.

$$\eta = \frac{\dfrac{V_2 I_2 \cos\phi_2}{I_2}}{\dfrac{V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02}}{I_2}}$$

$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{W_i}{I_2} + I_2 R_{o2}}$$

For, the Efficiency to be maximum the denominator should be minimum.

Then, differentiate the denominator with 'I_2' and Equate it to zero.

$$\frac{d}{dI_2}\left(V_2 \cos\phi_2 + \frac{W_i}{I_2} + I_2 R_{o2}\right) = 0$$

$$\frac{d}{dI_2}(V_2 \cos\phi_2) + \frac{d}{dI_2}\left(\frac{W_i}{I_2}\right) + \frac{d}{dI_2}(I_2 R_{o2}) = 0$$

$$\cancel{V_2 \cos} \cdot 0 + W_i \frac{d}{dI_2}\left(\frac{1}{I_2}\right) + R_{o2} \frac{d}{dI_2}(I_2) = 0$$

$$0 + W_i\left(\frac{-1}{I_2^2}\right) + R_{o2}(1) = 0$$

$$0 - \frac{W_i}{I_2^2} + R_{o2} = 0$$

$$R_{o2} = \frac{W_i}{I_2^2}$$

$$I_2^2 R_{o2} = W_i$$

$$\boxed{\text{Copper losses} = \text{Iron losses}}$$

Variable losses = Constant losses.

(P) In a 50 KVA transformer the iron loss is 500W and F.L cu loss is 800W. Find the Efficiency at Full load and Half load at 0.8 power factor lagging

Sol: Given Data:

50KVA

Iron loss $(W_i) = 500W$

Full load copper loss $(W_{cu}) = 800W$

η at F.L = ?

η at H.L = ?

$\left\{ \because \cos\phi = \frac{KW}{KVA} \right\}$

Now, Full load at 0.8 pf

Full load output $= KVA \times \cos\phi$

$= 50 \times 0.8$

$= 40 \; KW$

Total Full load losses $= 500 + 800 = 1300 \; W = 1.3 \; KW$

Full load Input $= 40 + 1.3 = 41.3 \; KW$

Full load $\eta = \frac{\text{output}}{\text{output} + \text{losses}}$

$= \frac{40}{41.3} \times 100$

$= 96.8\%$

Now, Half load at 0.8 pf

Half load output $= \left(\frac{50}{2}\right) \times 0.8 = 20 \; KW$

Total Half load losses $= \frac{\text{Total full load losses}}{2}$

Total H.L losses $= 500 + (1/2)^2 \times 800 = 0.7 \; KW = \frac{1.3}{2}$

$= 0.65\ kW$

Half Load η at Input $= 20 + 0.65$
$= 20.65\ kW$

Half Load Efficiency $(\eta) = \frac{20}{20.65} \times 100$

20.7

$= 96.8\%$ / 96.6%

→ A 40 KVA transformer has iron loss of 450W & full copper loss of 850W. If the power factor of the load is 0.8 lag. Calculate i) Full load η

ii) Load at which maximum η occurs

iii) Maximum η

Sol: i) Full load Efficiency η:

Full load Output $= KVA \times \cos\phi$
$= 40 \times 0.8$
$= 32\ kW$

Full load losses $= 450 + 850$
$= 1.3\ kW$

Full load Input $= 32 + 1.3 = 33.3\ kW$

$$F.L\ \eta = \frac{32}{33.3} \times 100 = 96.1\%$$

ii) Load at which maximum η occurs:

$$= F.L\ KVA \sqrt{\frac{\text{Iron loss}}{\text{F.L copper loss}}}$$

$$= 40 \sqrt{\frac{450}{850}}$$

$= 29.1\ kVA$

Corresponding output in kW $= kVA \times \cos\phi$

$= 29.1 \times 0.8$

$= 23.3\ kW$

iii) Maximum Efficiency (η):

copper loss = Iron loss

Iron loss $= 450 \times 2 = 900W = 0.9\ kW$

As copper loss = Iron loss

$\therefore 0.9\ kW$

Total losses $= 0.9\ kW$

Input = Output + losses

$= 23.3 + 0.9$

$= 24.2\ kW$

$$\text{Maximum } \eta = \frac{23.3}{24.2} \times 100 = 96.2\%$$

REGULATION OF A TRANSFORMER:

VOLTAGE REGULATION: Voltage Regulation of a transformer is defined as the change in secondary terminal voltage from No load to Full Load and is usually expressed as No load voltage

$$\text{Voltage Regulation} = \frac{\text{No Load voltage} - \text{Full load voltage}}{\text{No Load Voltage}}$$

When the transformer is loaded with continuous supply voltage, the terminal voltage of the transformer varies. The variation of voltage depends on the load and its power factor.

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

E_2 – Secondary terminal voltage at No Load

V_2 – Secondary terminal voltage at full load

If, the voltage regulation considering the primary terminal voltage of the transformer is expressed as

$$\% \text{ Voltage Regulation} = \frac{V_1 - E_1}{V_1} \times 100$$

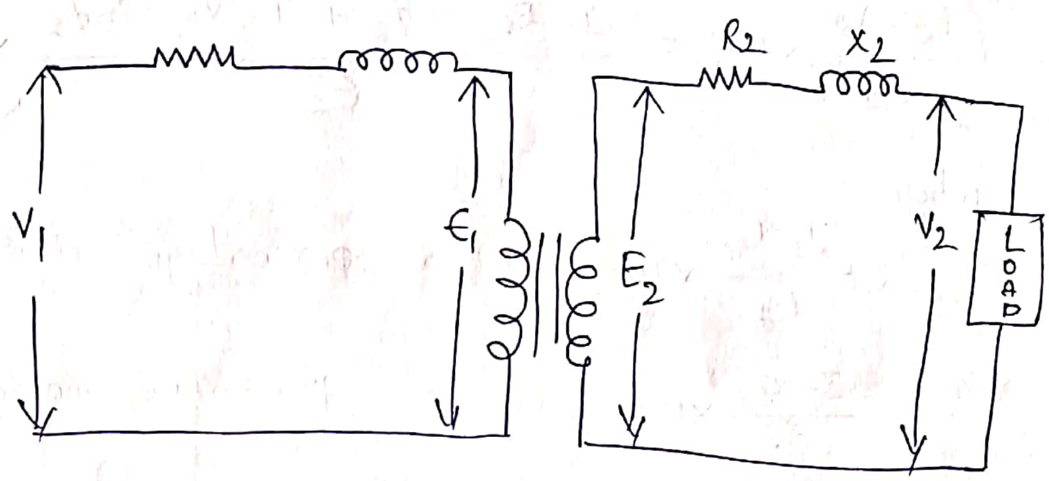
Ex:

If the secondary terminals of the transformer are open circuited (or) No Load is connected to the secondary terminals, the no-load current flows through it.

If the No load current flows through the secondary terminals of the transformer, the voltage drops across the resistive and reactive load becomes zero.

So, the voltage across the primary side of the transformer is Negligible

Now, if the transformer is fully loaded i.e., the load is connected to their secondary terminal, the voltage drops appears across it. The value of the voltage regulation should always be less for the better performance of the transformer.



From this figure,

- The primary voltage of the transformer is always greater than the Emf induces on the primary side.

$V_1 > E_1$

- The secondary terminal voltage at No load is always greater than the voltage at full load condition. $E_2 > V_2$.

So, the Equations are as follows:

$$V_1 = I_1 R_1 \cos\phi_1 + I_1 X_1 \sin\phi_1 + E_1$$

$$E_2 = I_2 R_2 \cos\phi_2 + I_2 X_2 \sin\phi_2 + V_2$$

The approximate expression for the No load secondary voltage for the different types of load is.

→ For Inductive Load:

$$E_2 = I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2 + V_2$$

(OR)

$$E_2 - V_2 = I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2$$

(OR)

$$\frac{E_2 - V_2}{E_2} \times 100 = \frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2}{E_2} \times 100$$

where,

$\frac{I_2 R_{02}}{E_2} \times 100$ is a percentage resistance drop

$\frac{I_2 X_{02}}{E_2} \times 100$ is a percentage reactance drop

→ **For Capacitive Loads**

$$E_2 = I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2 + V_2$$

(OR)

$$E_2 - V_2 = I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2$$

(OR)

$$\frac{E_2 - V_2}{E_2} \times 100 = \frac{I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2}{E_2} \times 100$$

CONSTRUCTION OF TRANSFORMER:

The constructional details of a transformer consists of core, windings, Tank, Bushings, Breather, Buchholz Relay and Transformer Oil, Radiators.

CORE:

The core of a transformer is made of silicon steel (or) sheet steel with 4% silicon.

This silicon steel material has low hysteresis loss and high permeability.

The core is laminated to reduce the Eddy current loss. Overall the iron (or) Core losses are reduced.

The thickness of the lamination is 0.35mm for 60HZ operation and 5mm for 25 HZ operation.

0.25mm to 0.5mm for 50 HZ operation

WINDINGS:

The transformer has two windings one is primary winding and the other is secondary winding.

- The winding which receives the Electrical Energy is called primary winding.
- The winding which delivers the Electrical Energy is called secondary winding.
- These windings are made of High Grade copper, because they carry high currents. by stranded conductor
- For carrying high currents, stranded conductors are used.
- The function of the windings is to carry the current and produce the flux for the necessary functioning.

CONSERVATOR TANK:

When a transformer is oil-filled and self-cooled the oil in the tank is subjected to heat and expand naturally due to variations in the load current.

- The conservator tanks provides the oil to settle down by expanding under Heavy Loads.
- Without, conservator tank very high pressures will be developed inside which could lead to the bursting of the Tank.

BUSHINGS:

The purpose of bushings is to provide proper insulation for the output leads to be taken out from the transformer tank.

- Two types of Bushings:
  i, Porcelain type used for voltage ratings upto 33kV.
  ii, Condenser type and Oil-Filled type used for voltage rating higher than 33kV.

BREATHER:

Transformer oil should not be exposed directly to the atmosphere because it may absorb moisture & dust from the environment & may loose it Electrical properties in a very short time.

To avoid this dust & moisture breather is provided. → to the conservator Tank. This breather completely prevents the moisture and dust coming in contact with the oil in the conservator Tank.

BUCHHOLZ RELAY:

It is a safety gas operated relay connected to transformer. When the fault gets developed inside the transformer, the gases are released.

This Relay is operated with these gases and trips the circuit breaker to protect the device.

METHODS OF COOLING TRANSFORMER:

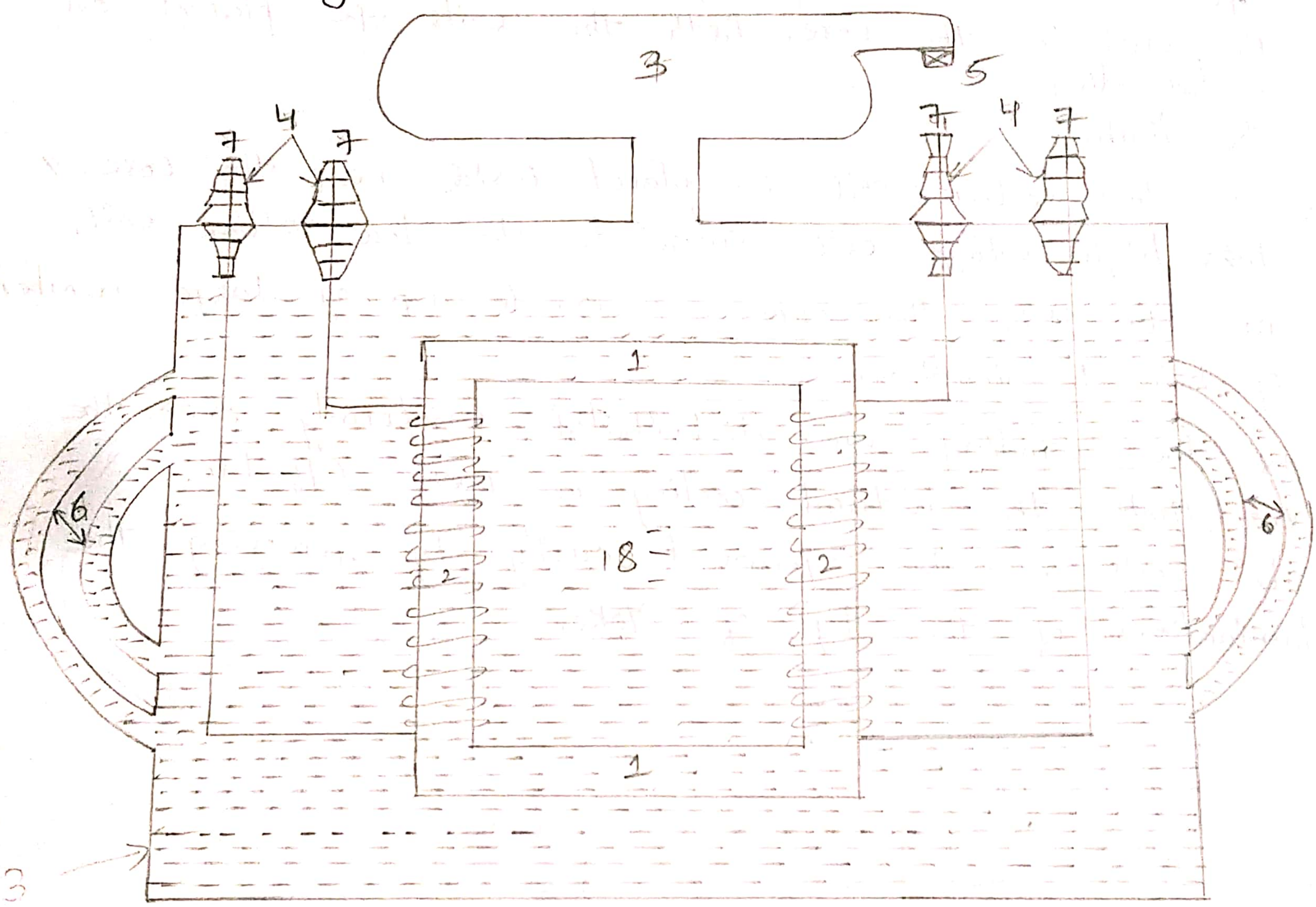
(a) Natural Radiation : Used for transformer having low voltage output ratings (i.e. upto 500V & 5KVA)

(b) Oil Filled and Self cooled : Used for large sized transformers with ratings upto 132kV and 1000MVA.

(c) Forced cooling with Air-Blast : Used for machines with ratings higher than 33kV and 100MVA

RADIATORS:

Radiators are not only to increase the surface area but also provide the path for circulation of the cooling fluid (i.e., Transformer Oil)



1 – core
2 – Windings
3 – Conservator Tank
4 – Bushings
5 – Breather
6 – Radiators
7 – Winding Leads (Input & Output)
8 – Transformer Oil

AUTO TRANSFORMER:

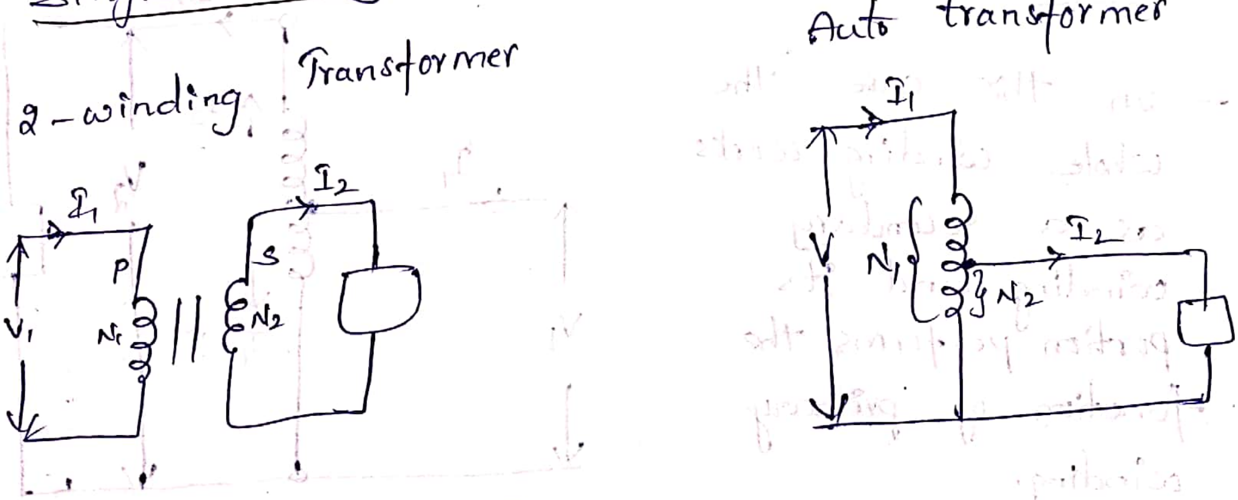
It is a transformer in which a part of the winding is common to both primary and secondary circuits.

In this transformer the primary and secondary are not electrically isolated from each other as same as the two (2) winding transformer.

The working of such type of transformer is similar to a 2-winding transformer.

Because of one winding, it uses less copper and hence, is cheaper. & Used where transformation ratio differs little from unity.

- Auto transformer is called as one-winding (or) single winding transformer.



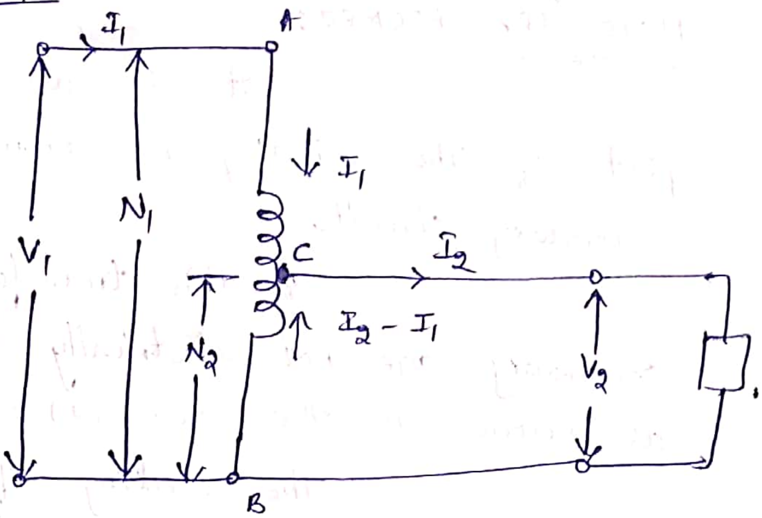
TYPES OF AUTO-TRANSFORMER:

An auto-transformer may be step-down (or) step-up the voltage.

i, Step-down Transformer
ii, Step-Up Transformer

→ **Step - down Auto - Transformer:**

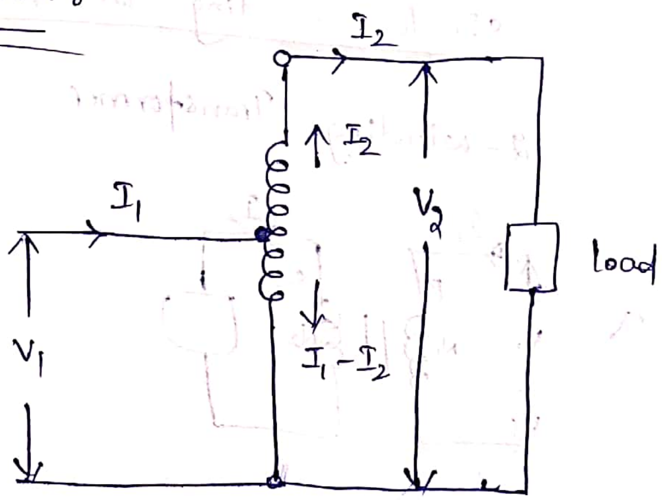
- In this case, the complete winding acts as primary winding while the tapped section of this winding works as secondary winding.



- The current in section CB is vector difference of I_2 and I_1.
- But as the two currents are in phase opposition the resultant current is $(I_2 - I_1)$ where I_2 is greater than I_1.

→ **Step- Up Auto Transformer:**

- In this case the whole winding works as a secondary winding and its portion performs the function of primary winding.



- The current in section CB is vector difference of I_1 and I_2.
- But as the two currents are in phase opposition, the resultant current is $(I_1 - I_2)$ where I_2 is less than I_1.

TRANSFORMATION RATIO :

By neglecting the losses, the leakage reactance and magnetising current, the transformation ratio of an auto-transformer can be obtained as:

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

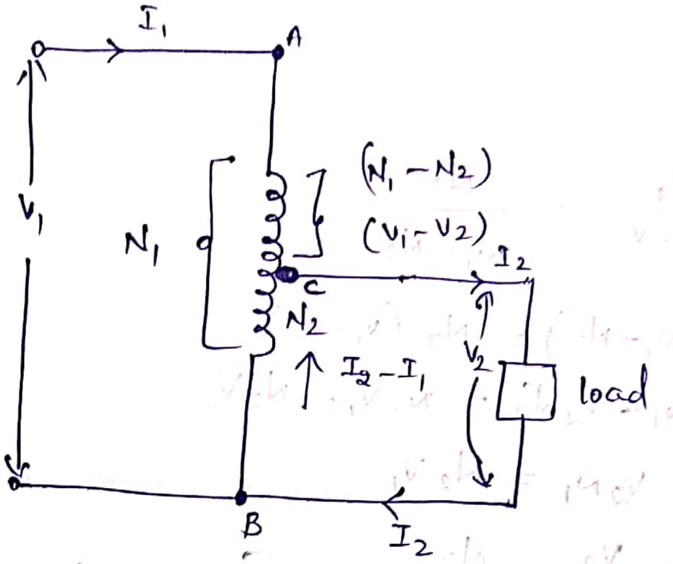


Fig. (a) step down Auto Transformer ON Load

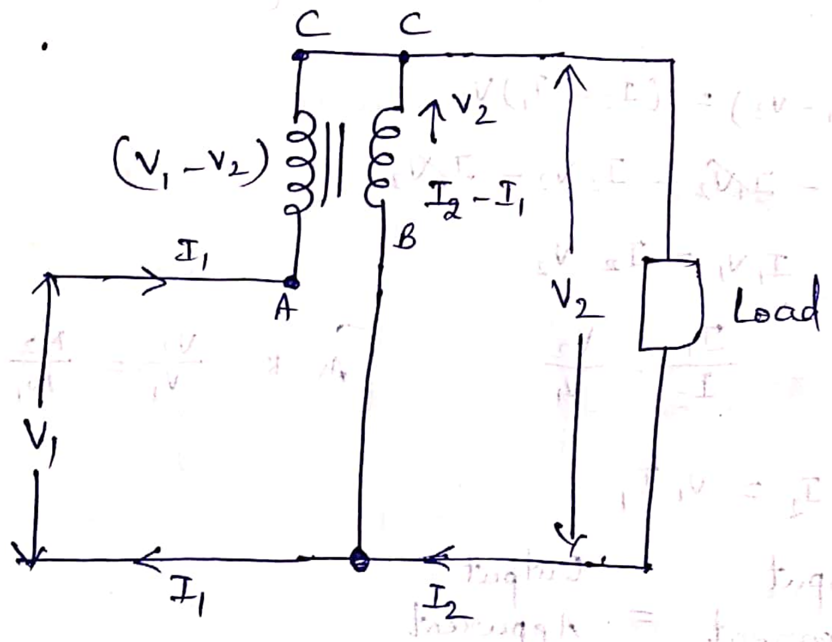


Fig (b)... Equivalent Circuit of an Auto Transformer

In fig (a), the winding A-B having 'N_1' turns is the primary winding while winding B-C having 'N_2' turns is is the secondary winding. The inputs current is I_1 while the output (or) load current is I_2.

- The portion A-C has $N_1 - N_2$ turns and voltage across this portion of the winding is $V_1 - V_2$.
- The current through the common portion of the winding is $I_2 - I_1$.

→ From fig (b).,

We have

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

$$\boxed{\frac{\text{Output Voltage}}{\text{Total voltage}} = \frac{\text{o/p turns}}{\text{Total turns}}}$$

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

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

$$V_2 N_1 = N_2 V_1$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \qquad \left[\text{As } K = \frac{V_2}{V_1} = \frac{N_2}{N_1}\right]$$

Also,

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

$$I_1 V_1 - \cancel{I_1 V_2} = I_2 V_2 - \cancel{I_1 V_2}$$

$$I_1 V_1 = I_2 V_2$$

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} \qquad \left[\text{As } K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}\right]$$

Since, $V_2 I_2 = V_1 I_1$

Input Apparent Power = Output Apparent Power

$$\left\{\because V_1 I_1 = V_2 I_2\right\}$$

Then, Output Apparent power $= V_2 I_2$

Apparent power transferred inductively $= V_2 (I_2 - I_1)$

$= (V_2 I_2 - I_2 k)$

$V_2 I_2 - V_2 I_1$

$V_2 I_2 - V_2 I_2 K$

$V_2 I_2 (1-K)$

$$\left[\because \frac{I_1}{I_2} = k \quad I_1 = k \cdot I_2 \right]$$

$= V_2 I_2 (1-k)$

$= V_1 I_1 (1-k)$

$\therefore$ Power transferred inductively $=$ Input $\times (1-k)$

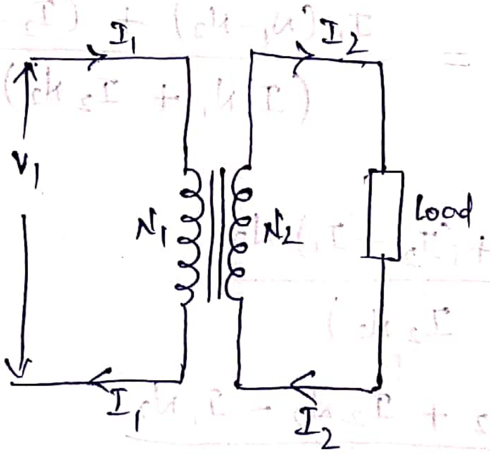
Power transferred Conductively $=$ Input $-$ Input $\times (1-k)$

$= \cancel{\text{Input}} - \cancel{\text{Input}} + k \cdot \text{Input}$

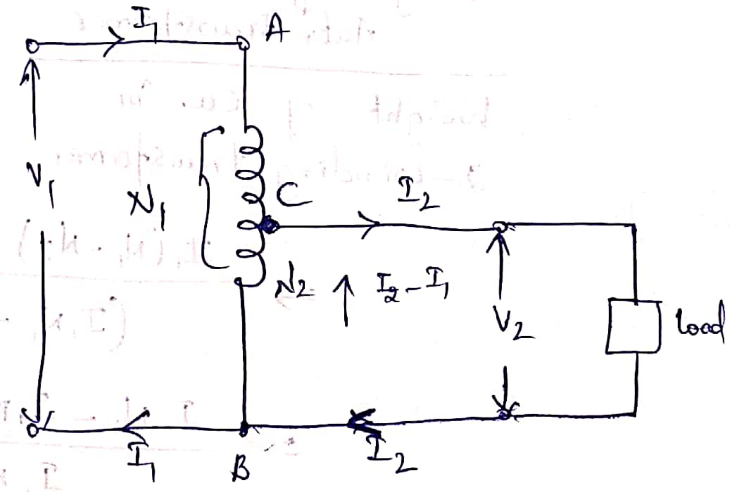
$= k \times \text{Input}$

** ⇒ COPPER SAVING IN AN AUTO TRANSFORMER:

For the same output and voltage transformation ratio $k = \frac{N_2}{N_1}$ an auto transformer requires less copper than an ordinary 2-winding transformer.



2-winding Transformer



Auto-Transformer

The length of copper required in a winding is proportional to the number of turns and the area of cross-section of the winding wire is proportional to the current rating

Therefore, weight of copper required in a winding is proportional to current × turns

i.e., wt. of cu required in a winding ∝ current × turns

2-winding transformer:

Weight of cu. required in a winding ∝ $(I_1 N_1 + I_2 N_2)$

Auto-transformer:

Weight of cu. required in A-C Section ∝ $I_1 (N_1 - N_2)$

Weight of cu. required in section C-B ∝ $(I_2 - I_1) N_2$

Total weight of cu. required ∝ $I_1 (N_1 - N_2) + (I_2 - I_1) N_2$

$$\frac{\text{Weight of cu. in Auto transformer}}{\text{Weight of cu. in 2-winding transformer}} = \frac{I_1 (N_1 - N_2) + (I_2 - I_1) N_2}{(I_1 N_1 + I_2 N_2)}$$

$$\Rightarrow \frac{I_1 (N_1 - N_2) + (I_2 - I_1) N_2}{(I_1 N_1 + I_2 N_2)}$$

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

$$= \frac{I_1 N_1 + I_2 N_2 - 2 I_1 N_2}{I_1 N_1 + I_2 N_2}$$

$$= \frac{\cancel{I_1 N_1 + I_2 N_2}}{\cancel{I_1 N_1 + I_2 N_2}} - \frac{2 I_1 N_2}{I_1 N_1 + I_2 N_2}$$

$$= 1 - \frac{2 I_1 N_2}{I_1 N_1 + I_2 N_2} \qquad (\because I_1 N_1 = I_2 N_2)$$

$$= 1 - \frac{2 I_1 N_2}{I_1 N_1 + I_1 N_1}$$

$$= 1 - \frac{\cancel{2} \cancel{I_1} N_2}{\cancel{2} \cancel{I_1} N_1}$$

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

$$= 1 - K$$

$\therefore$ Weight of cu in Auto Transformer $= (1-K) \times$ Weight of cu. in 2-winding Transformer

(or)

$$W_{auto} = (1-K) \times W_{2\text{-}wdg}$$

$\therefore$ Saving in Copper (Cu) $= W_{2\text{-}wdg} - W_{auto}$

$$= W_{2\text{-}wdg} - (1-K) \times W_{2\text{-}wdg}$$

$$= \cancel{W_{2\text{-}wdg}} - \cancel{W_{2\text{-}wdg}} \times K\,(W_{2\text{-}wdg})$$

$$= K \times W_{2\text{-}wdg}$$

[OR]

Saving in Cu $= K \times$ Weight of copper (cu) in 2-winding transformer.

Suppose, if $K = 0.1$, the saving of cu is 10%
if $K = 0.9$, the saving of cu is 90%

Therefore, the value of K of auto-transformer is nearer to 1.

Problem: An auto-transformer supplies a load of 3 kW at 115V at a unity power factor. If the applied primary voltage is 230V, Calculate:

i, Transformation ratio

ii, Secondary Current

iii, Primary Current

iv, Number of turns in the secondary, if total number of turns is 500.

v, Power Transferred

vi, Power Conducted directly from the supply mains to the load.

Sol: Given Data:

$V_1 = 230\,V$

$V_2 = 115\,V$

Power factor $(\cos\phi) = 1$

$P = 3\,kW = 3 \times 1000\,W.$

i, Transformation Ratio $(K) = \frac{V_2}{V_1} = \frac{115}{230} = 0.5$

ii, Secondary Current (I_2):

As $P = V_2 I_2 \cos\phi$

$$I_2 = \frac{P}{V_2 \cos\phi} = \frac{3 \times 1000}{115 \times 1}$$

$I_2 = 26.08\ A$

iii, Primary current: $I_1 = k \cdot I_2$

iv, $k = \frac{N_2}{N_1}$

$\Rightarrow N_2 = k \cdot N_1 = 0.5 \times 500 = 250$

v, Power transformed (or) Power transferred inductively

$= \text{Input} \times (1-k)$

$= 3 \times (1-0.5)$

$= 1.5\ kW$

vi, Power transferred Conductively $= \text{Input} \times k$

$= 3 \times 0.5$

$= 1.5\ kW$

Q The primary and secondary voltages of an auto-transformer are 500V and 400V respectively., show with the help of diagram, the current distribution in the winding when the Secondary current is 100A and calculate the economy of cu in this case.

Sol: Given Data:

$V_1 = 500V$

$V_2 = 400V$

$I_2 = 100A$

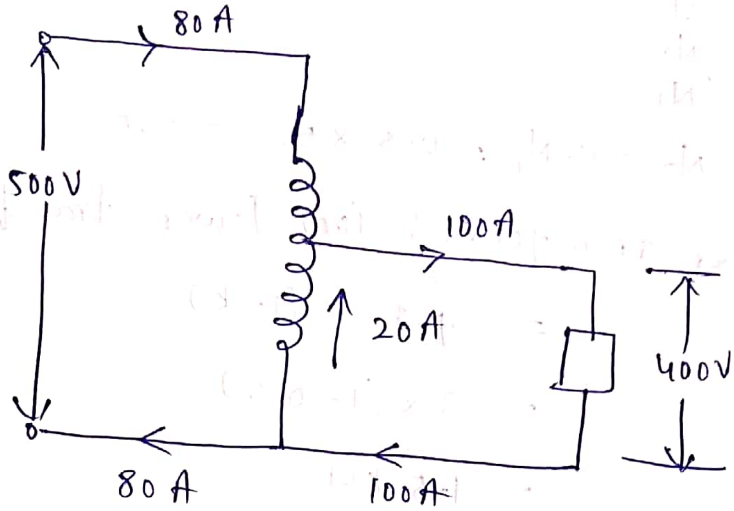
Transformation Ratio $(k) = \frac{V_2}{V_1} = \frac{400}{500} = 0.8$

$I_1 = k \cdot I_2$

$= 0.8 \times 100$

$= 80\ A$

Current distribution in figure:



Saving in copper $= K \times W_{2\text{-wdg}}$

$= 0.8 \times W_{2\text{-wdg}}$

$\therefore$ Percentage saving $= 0.8 \times 100$

$= 80$

Advantages:

- Requires less copper.
- High Efficiency
- Cost & Size are less
- Better Voltage regulation
- Smooth & continuous

Disadvantages:

- Two windings are not separated electrically, due to this a severe shock may be effect on low voltage side
- Use of Auto transformer is more Economical, when K is nearer to 1.

Applications:

- Used for starting of I.M
- Used where continuous supply variable
- Used as interconnecting transformers in 132 kV / 330 kV systems.

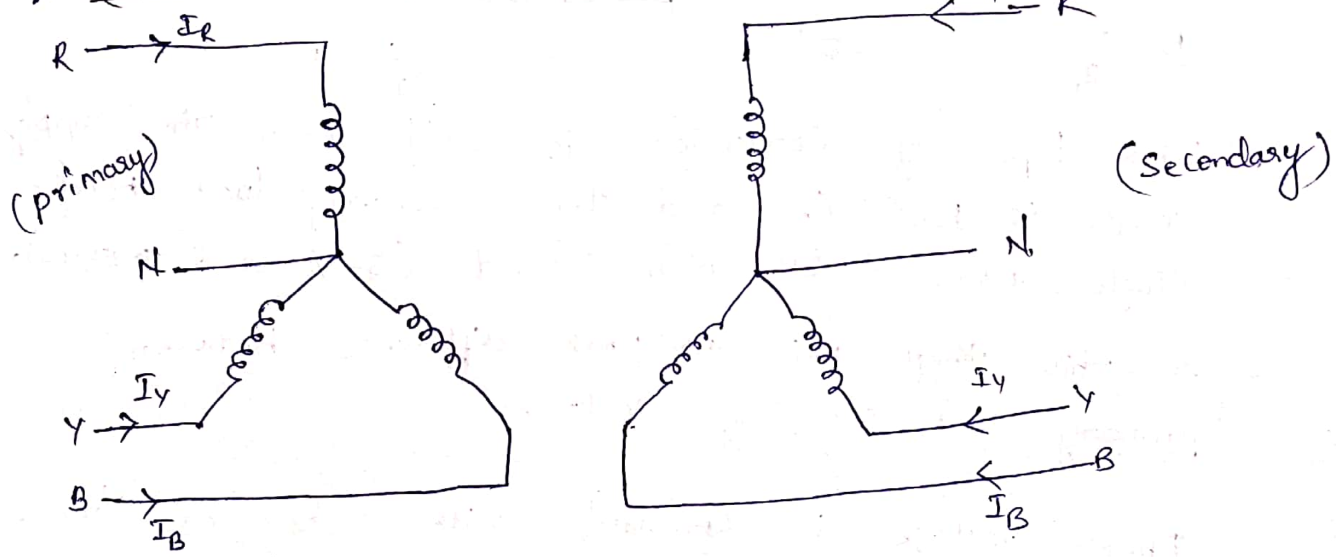
THREE PHASE TRANSFORMER CONNECTIONS:

1. Star to Star Connection (Y – Y)
   Small High Voltage Transformer

2. Delta to Delta Connection (Δ – Δ)
   Large High Voltage Transformer

3. Star to Delta Connection (Y – Δ)
4. Delta to Star Connection (Δ – Y)

⇒ (Y – Y)



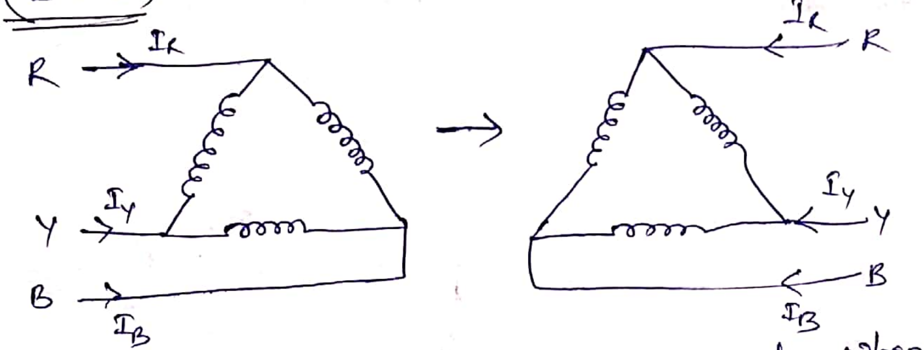
phase voltage $(V_{ph}) = \frac{V_L}{\sqrt{3}}$

$\Rightarrow V_L = \sqrt{3}\, V_{ph}$

- It is a three phase (3-ϕ) 4 wire System
- Current flowing through both primary and secondary windings are equal to the line and load.

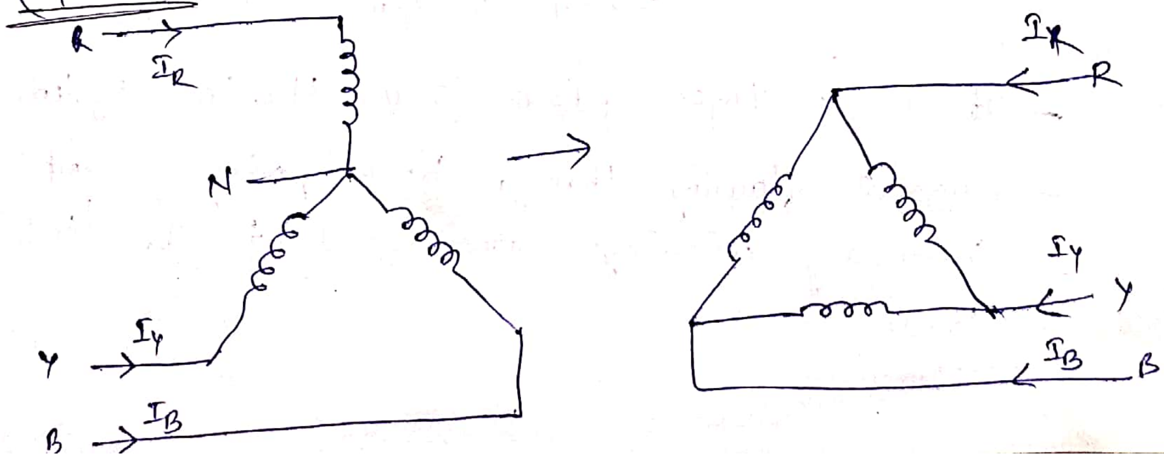
- There is no phase difference between primary and secondary winding.
- Neutral is available, it is well suited as 3-ϕ 4-wire system.
- Such a Connection can be preferred when the load is unbalanced to make the system balanced.

⇒ **($\Delta - \Delta$)**



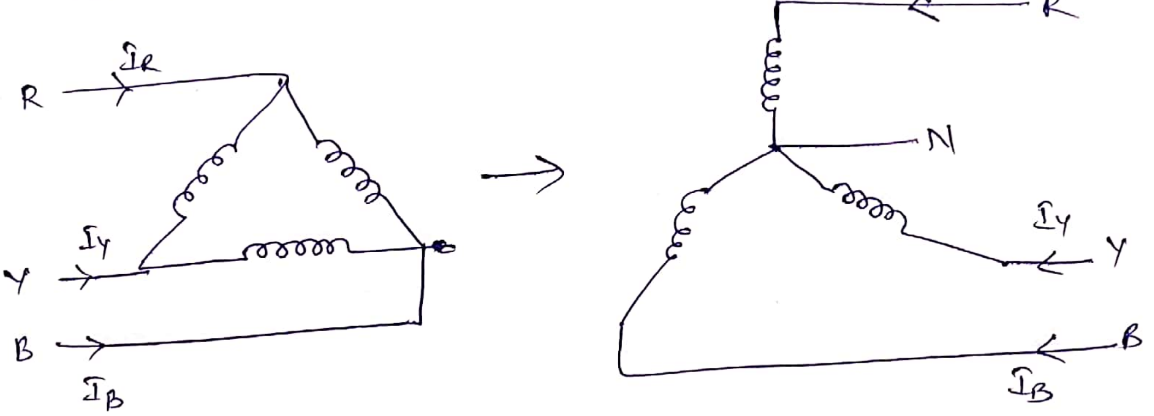
- This type of Connection is used when the supply source is Delta (Δ) and the secondary load need single voltage with high current (3-ϕ load motors).
- In this, there exist no phase difference between primary and secondary voltage.
- Phase voltage is constant with unbalanced load.

→ **(Y – Δ)**



- Neutral point on the primary are high voltage side can be grounded which is desirable in most of the cases.
- There exist 30° phase difference between primary and secondary winding
- Primary voltage coil 58% insulation requirements for high voltage winding.

⇒ (Δ - Y)



- Sending End is high voltage terminal.
- Primary and secondary voltage phase difference is possible.
- It is not possible for parallel connection.
- It requires less space to install higher efficiency.
- Some loads such as industrial & commercial.

Formulas:

Load current at maximum efficiency

$$I_{2m} = I_{2FL}\sqrt{\frac{P_i \text{ (Iron losses) (or) } W_i}{P_{cu} \text{ (copper losses) (or) } W_{cu}}}$$

KVA applied at maximum efficiency (η_{max})

$$KVA\ \eta_{max} = KVA \text{ rating} \sqrt{\frac{P_i}{P_{cu}}}$$

$$\eta_{max} = \frac{KVA\ \eta_{max} \cos\phi}{KVA\ \eta_{max} + 2W_i} \times 100$$

$$\left\{ \begin{array}{l} W_i \text{ (or) } P_i = \text{Iron loss} \\ W_{cu} \text{ (or) } P_{cu} = \text{Copper loss} \end{array} \right\}$$