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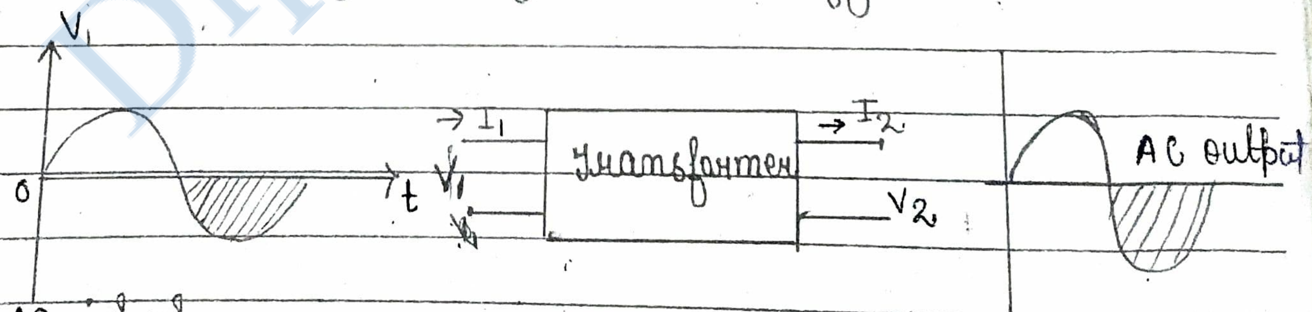
DC Machines And Transformers.

Unit: 3 Single Phase Transformers

Introduction :-

Transformer :- It is a static device (i.e the one which doesnot contain any rotating or moving part) which is used to transfer electrical energy from one AC circuit to another AC circuit, through the medium of magnetic field with increase and decrease in voltage / current but without any change in frequency.

This is shown in figure



voltage level is change but there is no change in frequency.

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

Uses Of Transformer.

→ The electrical energy is generated and transmitted extremely high voltages. The voltage is to be then reduced to a lower value for a domestic and industrial used.

→ This is done by using a transformer. It is possible to reduce the voltage level using a transformer, then the transformer is called step down transformer.

→ ON the other hand we can also used the transformer to increase the voltage level (step up transformer)

→ It is also used to isolate the ckt such transformer (isolating Transformer) (1:1)

→ The power Transmission system using transformer is shown in fig. when the transformer changes the voltage level, it changes the current level also.

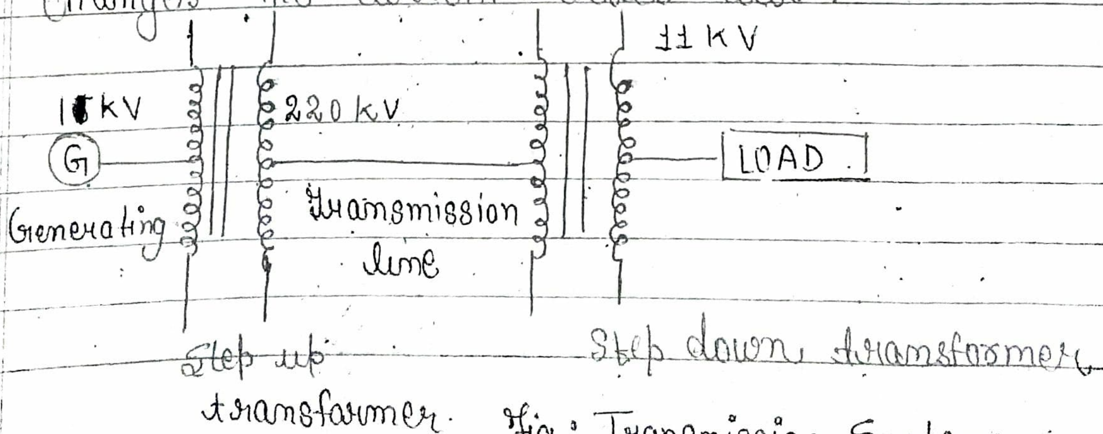

Fig: Transmission System

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Important point Related To Transformer

→ Transformer works on the principle of mutual induction

→ When compared to all other electrical machine transformer efficiency is high, since rotation losses are equal to zero.

→ In the transformer, the winding which is connected to the source is called primary winding and the winding which is connected to the load is called secondary winding

→ The primary and secondary winding are isolated from each other as well as from the iron core, thus there is absolutely no physical connection between a the primary and secondary windings.

★ The symbolic representation of the transformer as shown in figure.

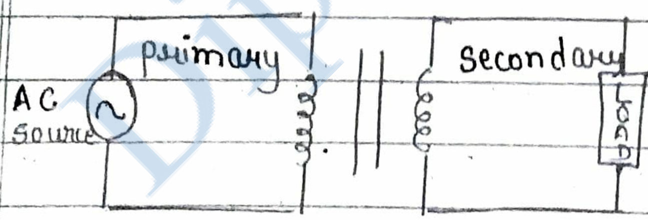

Fig : Symbol of Transformer

★ Faraday's Law

1'st Law :- When conductor cuts a magnetic lines of force an emf is induced in the conductor.

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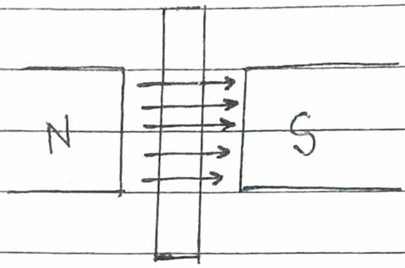
2nd Law :- The emf induced in a conductor is directly proportional to the rate of change of flux.

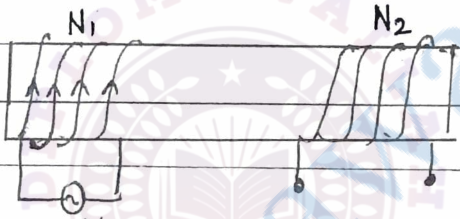


(i) e

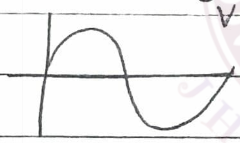
(ii) $e \propto \frac{d\phi}{dt} \Rightarrow \boxed{e = -N\frac{d\phi}{dt}}$

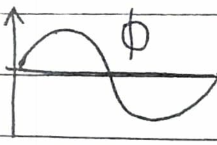
where e = dynamically induced emf

example - Generator



{ 2 conductor = 1 turn
no. of turn = coil }





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

↑ Lenz's Law

V, I, ϕ, e

opposes

where -ve sign indicates induce voltage opposes it causes of existence due to Lenz's law

$e_1 \propto \frac{d\phi}{dt}$

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

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$$e_1 = -N_1 \frac{d\phi}{di} \cdot \frac{di}{dt} \qquad \therefore L_1 = \frac{N_1\phi}{i}$$

↳ self inductance

$$\boxed{e_1 = -L_1 \frac{di}{dt}}$$

↑ Self induced emf

Similarly,

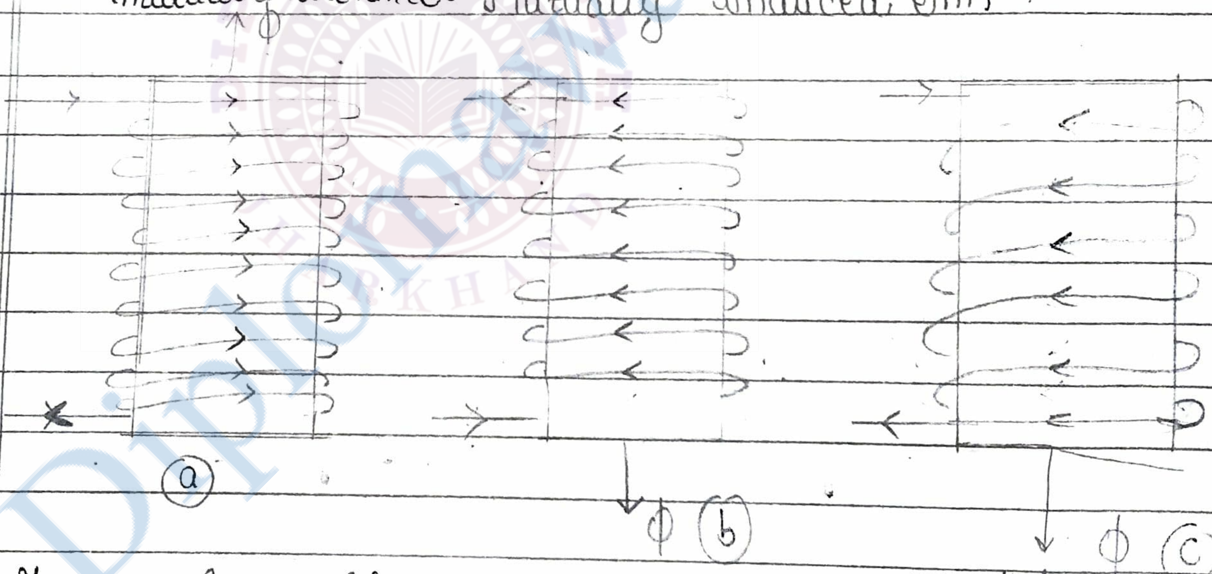
$$e_2 \propto \frac{d\phi}{dt}$$

$$e_2 = -N_2 \frac{d\phi}{dt}$$

$$e_2 = -N_2 \frac{d\phi}{di} \cdot \frac{di}{dt}$$

$$\therefore \left[M = \frac{N\phi}{i} \right] \Rightarrow \boxed{e_2 = -M\frac{di}{dt}}$$

mutual inductance — Mutually induced emf



★ From above diagram we can conclude that direction of flux depends on that

a) Direction of current

b) Sense of the winding or arrangement of the winding.

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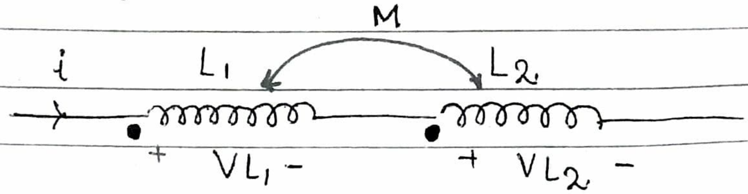
★ Based on the direction of flux coupled circuits are classified as :-

i) +ve magnetic coupled circuit

ii) -ve magnetic coupled circuit



$$L_{eq} = L_1 + L_2 + 2M$$

Proof:

$$V = V_{L_1} + V_{L_2}$$

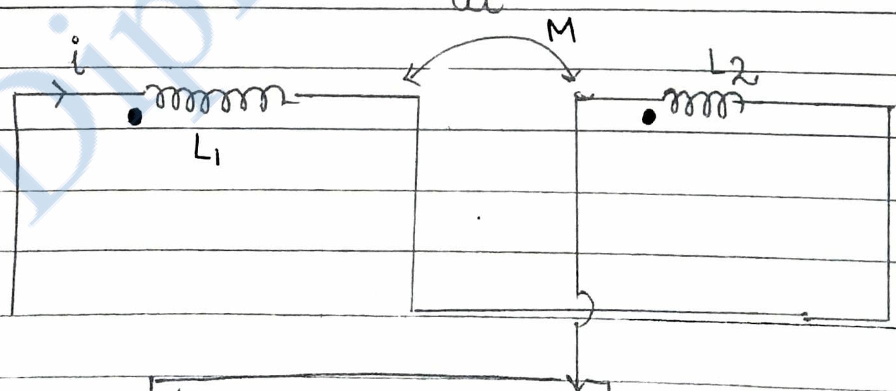
$$V_{L_1} = L_1 \frac{di}{dt} + M \frac{di}{dt}$$

$$V_{L_2} = L_2 \frac{di}{dt} + M \frac{di}{dt}$$

$$V = (L_1 + M) \frac{di}{dt} + (L_2 + M) \frac{di}{dt}$$

$$V = (L_1 + L_2 + 2M) \frac{di}{dt}$$

$$V = L_{eq} \frac{di}{dt}$$



$$L_{eq} = L_1 + L_2 - 2M$$

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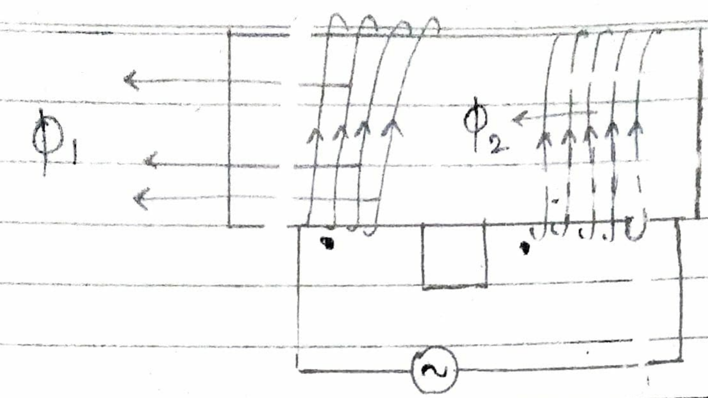
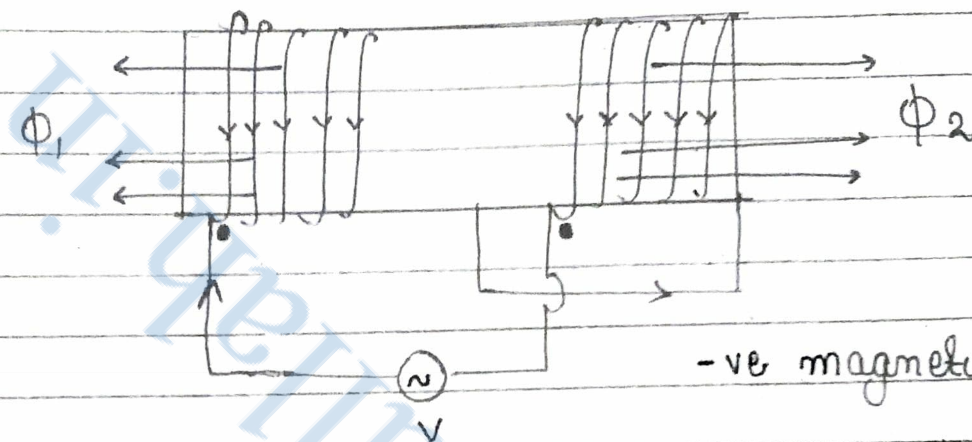


+ve magnetic coupling



-ve magnetic coupling

★ <u>+ve magnetic coupling</u> :- When current is entering either both dotted terminals ~~also~~ or current is leaving at both dotted terminals, then the coupling is called as +ve magnetic coupling.

★ <u>-ve magnetic coupling</u> :- When current is entering at one dotted terminals and leaving at other doted terminals, then it is called as -ve magnetic coupling.

Classification Of Transformers.

1. Based On level of voltage

a) Step up transformer
b) Step down transformer

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2. Based On Construction
a) Core type   New (Berry Berry Transformer)
b) Shell type

3. Based on Number of winding
a) Single winding transformer (Auto transformer)
b) Two winding transformer
c) Three winding transformer

4. Based on Number of phases
a) Single phase transformer
b) Three phase transformer

5. Based on power system application
a) Distribution transformer
b) Power transformer

6. Based on Measurement application
a) Current transformer
b) Potential transformer

7. Based on operating frequency
a) Power frequency transformer
b) audio frequency transformer

8. Based on electronics and other application
a) Impedence matching transformer
b) Isolation transformer (1:1 transformer)
c) pulse transformer

9. Based on Nature of cooling

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a) Natural cooled transformer
b) Forced cooled transformer

Step Up And Step down Transformer

→ A transformer in which the output (secondary voltage is greater than its input (primary) voltage is called a step up transformer

i.e $E_1 < E_2$ or $E_2 > E_1$

$N_1 < N_2$

→ A transformer in which the output (secondary voltage is less than its input (primary) voltage is called a step down transformer.

i.e $E_1 > E_2$ or $N_1 > N_2$

V.V.I

EMF equation Of the transformer

Let, the flux at any instant be $\phi = \phi_m \sin \omega t$
where ϕ_m = max^m flux or peak up value of Flux
ω = angular frequency in radian/second.
$\omega = 2\pi f$
and f = The supply frequency in Hz
The instantaneous emf induced in a coil of N - turns is given by Faradays law of electromagnetic induction.

The induced emf is

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

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

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$$e = -N \frac{d}{dt}(\phi_m \sin\omega t)$$

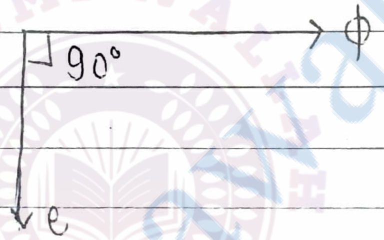
$$= -N \phi_m \cos\omega t \times \omega$$

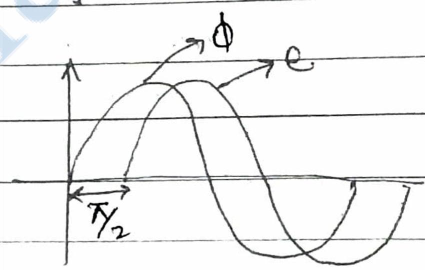
$$\boxed{e = N\phi_m \omega \sin(\omega t - \pi/2)} \quad \text{—— (1)}$$

The induced emf e is maximum when $\sin(\omega t - \pi/2) = 1$, Therefore, the maximum value of the induced emf e is $E_{max} = N\phi_m\omega$

Therefore eq^n (1) written as,

$$\boxed{e = E_{max} \sin(\omega t - \pi/2)} \quad \text{—— (2)}$$





★ For sin wave for RMS value of the emf is given by

$$E_{rms} = \frac{e_{max}}{\sqrt{2}}$$

$$= \frac{N\phi_m\omega}{\sqrt{2}}$$

$$= \frac{2\pi F N\phi_m}{\sqrt{2}}$$

$$\boxed{E_{rms} = 4.44\, fN\phi_m}$$

$$\boxed{E = 4.44\, fN\phi_m} \quad \text{—— (3)}$$

This is the required emf equation of a transformer.

★ A transformer is a constant flux machine.

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* The emf induced in each winding of the transformer can be calculated from its emf equation. Let the subscript '1' and '2' are used for primary and secondary winding respectively then the emf equation for primary winding is $4.44 f N_1 \phi_m$ volts.

Subscript '1'

$$\boxed{E_1 = 4.44 f N_1 \phi_m} \quad \text{Volts}$$

Similarly the emf equation of secondary winding is $E_2 = 4.44 f N_2 \phi_m$

If 'B_m' is the maximum value of the flux density in the magnetic circuit in Tesla (wb/m^2), A is the cross-sectional area in m^2, then $\phi_m = B_m \cdot A$ $\quad \left(B_m = \frac{\phi_m}{A} \right)$

The emf equation of a transformer becomes

$$\boxed{E_1 = 4.44 f N_1 B_m A \quad \text{volts}}$$

$$\boxed{E_2 = 4.44 f N_2 B_m A \quad \text{volts}}$$

Voltage Ratio and Turn Ratio

Since, we know that emf equation primary winding is

$$E_1 = 4.44 f N_1 \phi_m$$

$$\boxed{\frac{E_1}{N_1} = 4.44 f \phi_m} \quad \text{— (1)}$$

Similarly, the emf eq^n of secondary winding is

$E_2 = 4.44 F N_2 \phi_m$

$$\frac{E_2}{N_2} = 4.44 F \phi_m \quad \text{——— ii)}$$

Now from eq^n (i) and (ii) we get

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} \quad \text{——— (3)}$$

The ratio $\frac{E_1}{N_1}$ and $\frac{E_2}{N_2}$ is called emf per turns.

Now, from eq^n (3) we get

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

or

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

The ratio $\frac{E_2}{E_1}$ is called induced emf ratio

and the ratio $\frac{N_2}{N_1}$ is called turn ratio.

→ The induced emf ratio and turn ratio is called transformation ratio

i.e $\frac{E_2}{E_1} = \frac{N_2}{N_1} = k$ This constant k is also known as voltage transformation ratio

★ → In practical transformer there is very small difference between the terminal voltage & induced emf i.e $V_1 \simeq E_1$ & $V_2 \simeq E_2$

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

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Working Principle Of Transformer

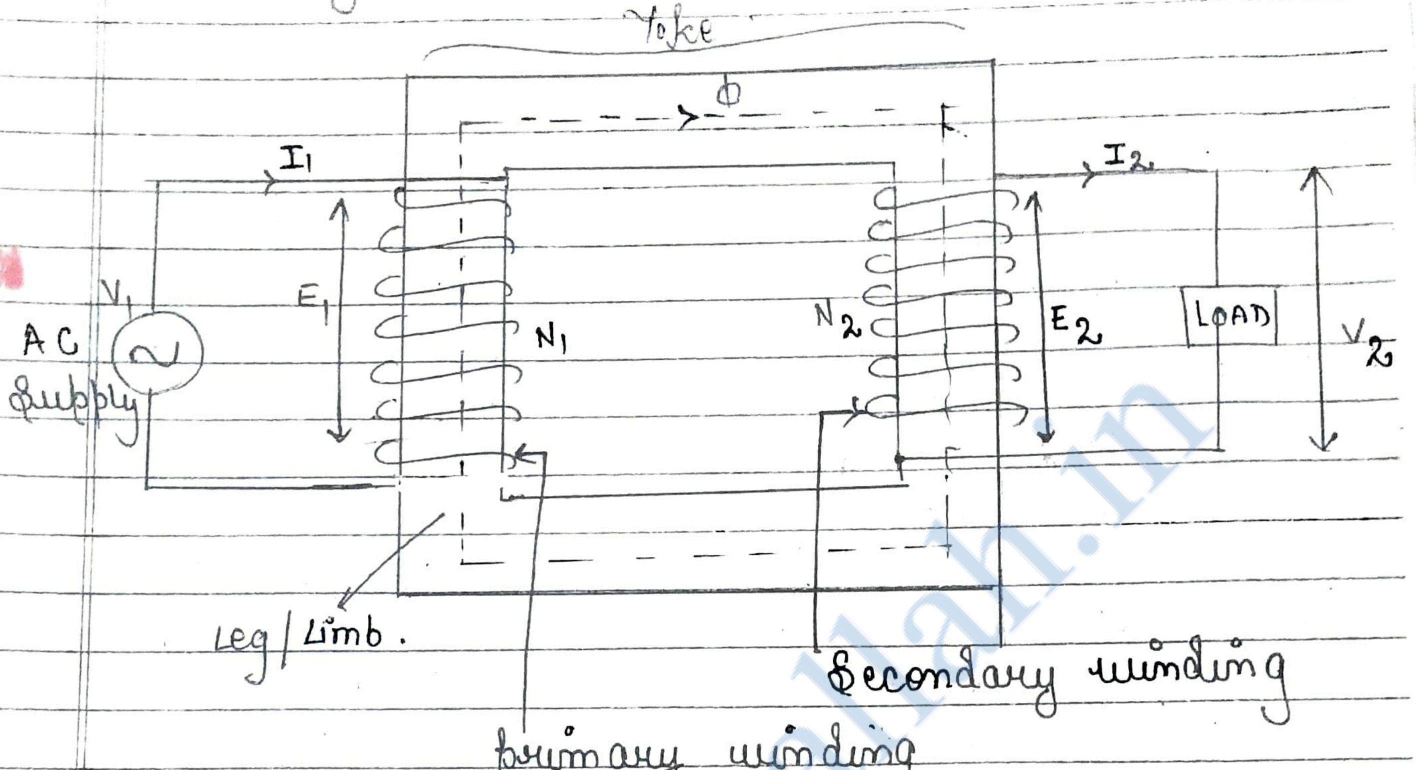

Fig : Basic Transformer

Simple arrangement of two winding transformer is shown

★ A single phase transformer consist of primar and secondary windings put on a magnetic core. Magnetic core is used to confined flux to a definite path. The magnetic core is a stack of thin silicon steel laminations (CRGO) steel (cold rolled grained oriented steel). The lamination reduces eddy current losses and silicon steel reduces hysteresis losses.

Note: Due to conductivity of material = eddy current loss
Due to magnetising and demagnetising = hystersis losses
Due to winding of a transformer. = copper losses

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Let us consider that two coils namely one (1) and (2) two wound on a simple magnetic circuit as shown in the above fig.

Let N_1 and N_2 be the no. of turns of the primary and secondary winding respt.

When an alternating voltage V_1 is applied to the primary winding and alternating current flows in it. This alternating current produces an alternating flux 'ϕ', in the magnetic circuit. This alternating flux links both the windings. The mean path of this flux is shown in the figure by dotted lines. This alternating flux 'ϕ' links the turn 'N_1' of coil 1 and induces in them alternating voltage 'E_1' by self induction. This emf E_1 is known as primary induced emf.

Thus, all the flux ϕ produce in coil 1 also links the turn N_2 of the coil 2 and induces in them voltages E_2 by mutual induction. This induce EMF E_2 in the secondary causes a secondary current I_2. The induce emf E_2 is known as secondary induce emf.

If the coil 2 is connected to the load, then an alternating current will flow through it and energy will be delivered to the load. Thus electrical energy is transfered form Coil-1 to coil-2 by a common magnetic circuit. Since there is no relative

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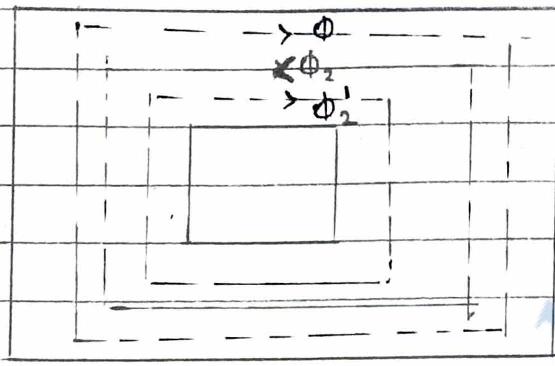
ratio between the coils, the frequency of the induced voltage in the coil - 2 is exactly the same as the frequency of the applied voltage to coil 1



ϕ, E_2, I_2, ϕ_2 opposes

$\phi_N = \phi - \phi_2$

$\phi = \frac{MMF}{S}$

$N_1 I_2 = N_2 I$

$\phi_2' = \phi_2$

$\phi_2, \phi_N \downarrow, E_1 \downarrow, I_2, \phi_2$

$\phi_N = \phi - \phi_2 + \phi_2$

$$\boxed{\phi_N = \phi}$$

Note :- In the transformer from no load to full load flux is constant. Hence transformer is also called constant flux machine.

Operating Principle Of a Transformer

→ As shown as the primary winding is connected to the single phase AC supply an AC current starts flowing through it

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→ The AC primary current produces an alternating flux ϕ in the core.

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

→ The varying flux will induced voltage into the secondary winding according to the Faraday's law of electromagnetic induction.

Current Transformation Ratio

In an ideal transformer the loses are negligible so the volt-ampere input to the primary and volt-ampere output from secondary can be approximately equated, i.e

$$\text{output VA} = \text{Input V.A}$$

$$V_2 I_2 = V_1 I_1$$

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

Since

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

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

$$\boxed{I_1 = k I_2}$$

$$\boxed{I_2 = \frac{I_1}{k}}$$

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Thus, currents are inversely proportional to the respective turns.

Ideal Transformer. ★

⇒ For a better understanding and easier explanation of a practical transformer certain idealizing assumptions are made which are closed approximations for a practical Transform. A transformer having these ideal properties is hypothetical (have no real existence) and is refered to as an ideal transformer.

→ The idealizing assumptions made are as follows :—

1. The losses are zero (No iron loss, no copper loss)

2. The primary and secondary winding resistance are zero.

3 - The leakage flux is zero. Therefore all the flux produce by the primary winding is coupled to the secondary winding.

4. A small current is required to developed flux inside the core. This happens because the permeability of the core is very large (infinite)

5. The external voltage applied to the primary V_1 is same as the primary induced voltage E_1. This is because the primary winding resistance is zero

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and so there is no voltage drop across it
i.e. $E_1 = V_1$

6) Similarly the voltage induced in the secondary winding E_2 will be equal to the load voltage V_2 because the secondary resistance is zero

7) The transformation ratio of an ideal transformer is given by

$$k = \frac{E_2}{E_1} = \frac{V_2}{V_1}$$

8. Efficiency of an ideal transformer is 100% ∴ This is because there are no losses taking place.

9. The voltage regulation is 0% that means the secondary voltage will remain constant irrespective of the load current.

Q:- Can the transformer operates on DC?
Ans No. A transformer cannot operate on DC supply and never be connected to a DC source. If a rated DC voltage is applied to the primary of a transformer, the flux produce in the transformer core will not vary but remain constant in magnitude and therefore no emf will be induced in the secondary winding.

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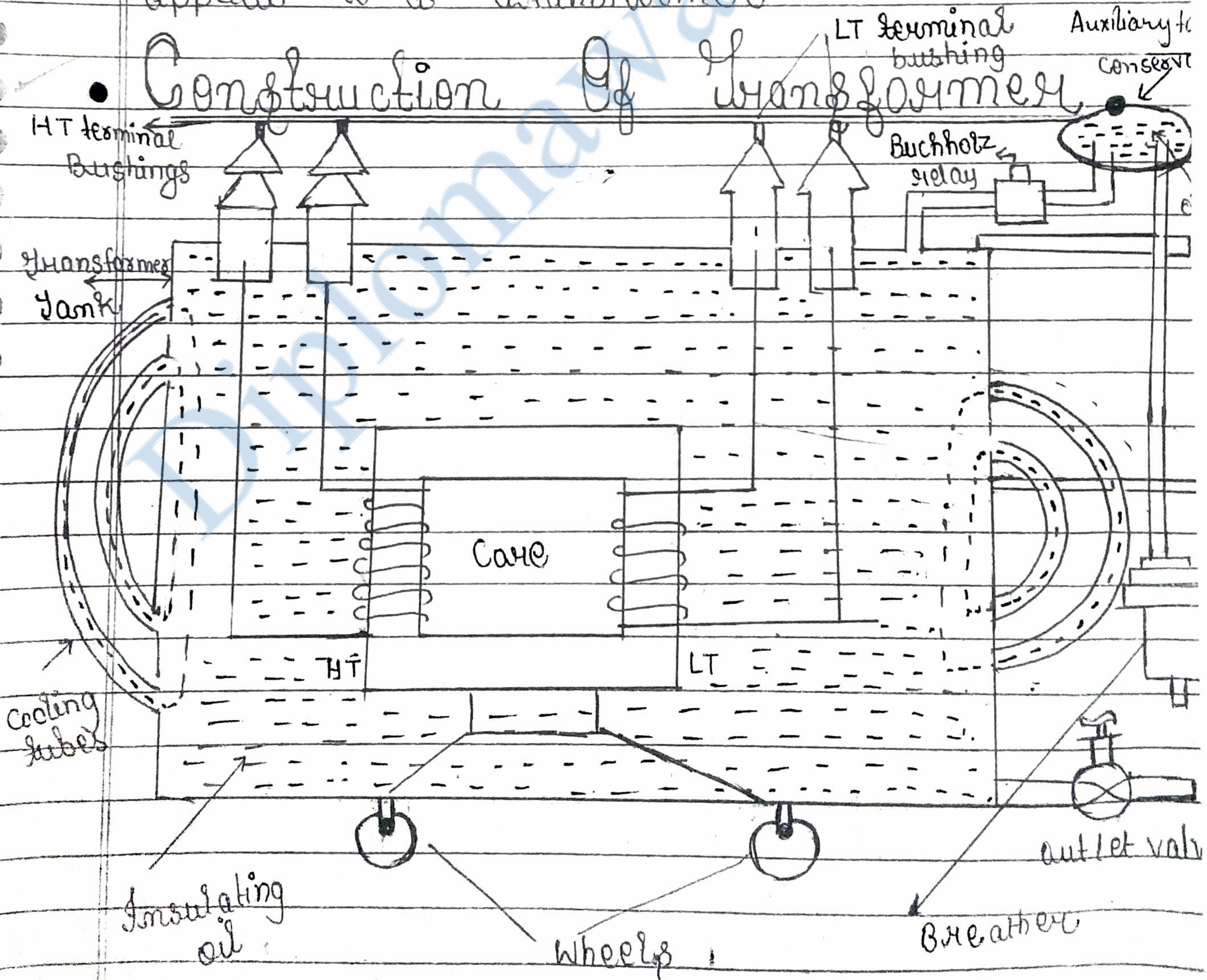
except at the moment of switching 'ON'.

Thus, the transformer is not capable of raising or lowering the DC voltage. Also there will be no self-induced emf in the primary winding which is only possible with varying flux linkage, to oppose the applied voltage and since the resistance of primary winding is quite low. Therefore, a heavy current will flow from the primary winding which may result in the burning out of the primary winding.

This is the reason that the DC is never applied to a transformer.

• Construction Of Transformer



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⇒ The transformer is very simple in construction. It mainly consist of

1. Magnetic circuit
2. Electric circuit
3. Dielectric (or insulation)
4. Tank and other accessories
   - a) Terminal bushing
   - b) Buchholz relay
   - c) Conservator tank
   - d) Breather
   - e) Temperature gauge
   - f) oil gauge
   - g) cooling tube (radiator)

1. Magnetic Circuit

⇒ The basic function of the magnetic circuit is to provide a flux path. This circuit consist of (a) limb (or core) / Limb
b) Yoke

On the basics of magnetic circuit transformer are distinguished

i) Core type transformer
ii) Shell type transformer

★ Core type transformer And shell type

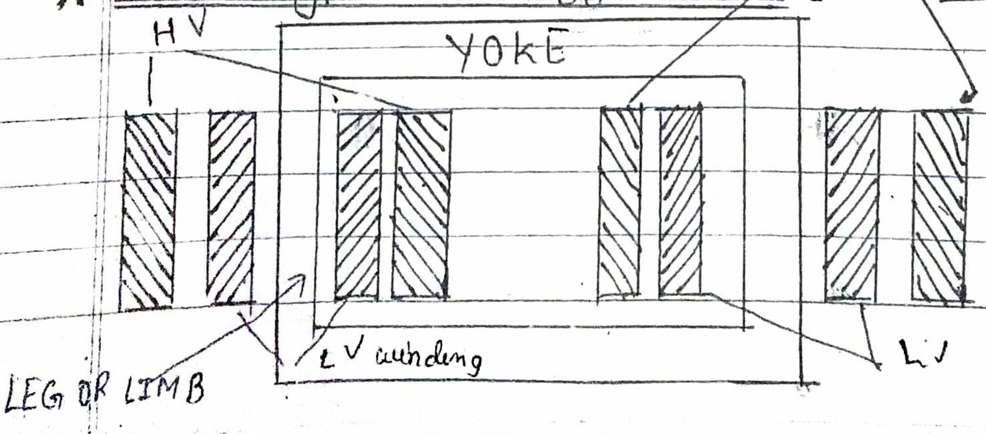

Fig : Core type transformer

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→ A core type transformer is one in which the iron or steel core is surrounded by the windings whereas a shell type transformer is one in which the windings are surrounded by the iron or steel core as shown in the figure.

The core of both types of transformer is built from steel core lamination containing ~~high~~ low percent of silicon i.e. about 3 to 4 % (CRGO) steel.
↳ cold rolled gained orie...

Note: If 40 to 50 % of silicon is added to the core brittleness in the core increases.

→ The thickness of each lamination is usually between 0.35 mm to 0.5 mm

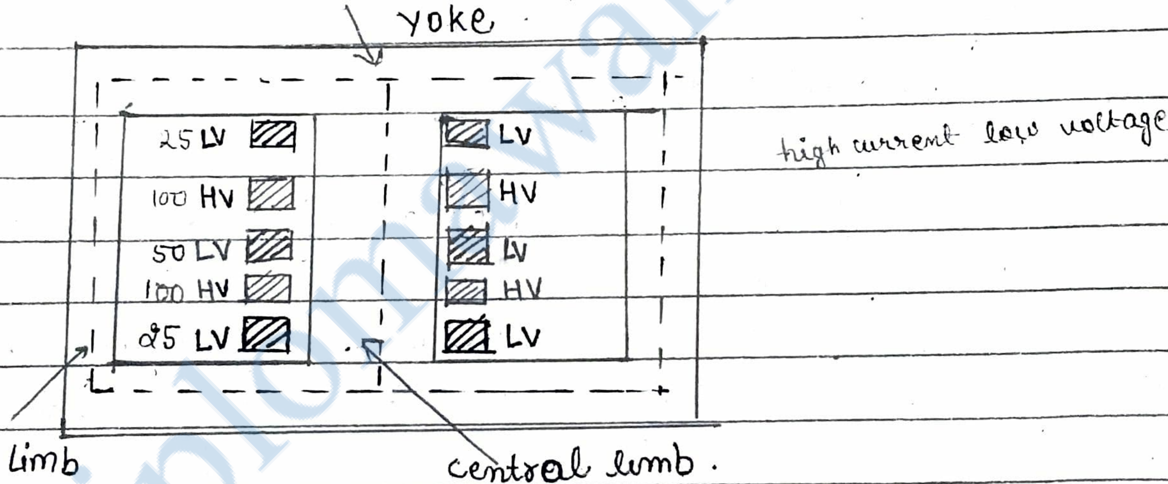
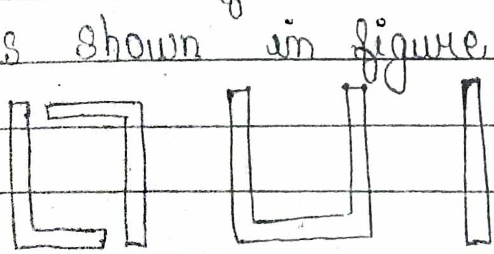
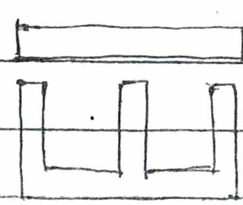


Fig: Shell-type transformer

→ Core of core type transformer may be built from L-shape, U-shape and I-shape laminatio[n]. However, the core of the shell type transfor[mer] is built from E-shape and I-shape lamination as shown in figure.



Core type transformer Core lamination



Shell type transformer core lamination

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→ To reduce the iron losses i.e eddy current and hysteresis loss in the transformer core, the core is laminated. In the laminated core layer are separated by insulating material like (a) Red oxide, (b) China clay (c) oil paper

→ All these layers are stack together. The process of bunching of all the layer is called as staggering.

Note: Due to improper staggering in transformer core the following disadvantages are present
a) Due to improper staggering air gaps are present between the layers.
It increases reluctance of the magnetic ckt.
To maintain the constant flux in the above magnetic ckt magnetising current drawn by the transformer is high.
Due to high magnetising current no load power factor of the transformer is decrease.

(Reluctance) $S = \frac{l}{A \mu_0 \mu_r}$

opposes the flux

$S_{air} > S_{material}$

$S \uparrow \quad \downarrow \phi = \frac{MMF}{S} = \frac{N I_\mu \uparrow}{S \uparrow}$

$I_\mu \uparrow \quad \cos\phi \downarrow$

No load power factor ↳ $\phi = 75$ | 0.2

$P = VI\cos\phi$

$\uparrow I = \frac{P}{V\cos\phi \downarrow}$

(b) It will produce more noise due to magnetostriction (चुम्बकीय विरूपण)

★ Magnetostriction :- Magnetostriction is a property of material that causes them to change their shape or dimensions (ferromagnetic material) during the process of magnetisation. This effect causes energy loss due to frictional heating. This effect is also responsible for low pitched humming sound that can be heared coming from transformer caused by oscillating AC current which produce a change in magnetic field.

★ Advantages Of Placing Low voltage winding nearer to the core in core type transform

1. Insulating material required b/w the core and winding is less.
2. Size is small and cost of the system is low.

Note 3. It is easy to select desirable tapping points from high voltage winding. Tapping is given where current rating is low.

★ Advantages Of Sandwich winding In shell type transformer

1. Due to above arrangement insulating material required between the core and winding at the edges is less.

2. Due to above arrangement the leakage flux will be less.

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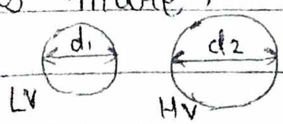
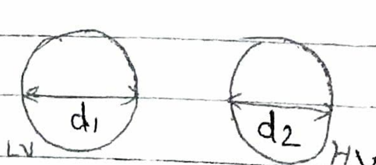
Note 3) In shell type transformer upper low voltage winding and lower low voltage winding have half the number of turn of the middle low voltage winding.

★ Comparision B/W Core and Shell Type Transformer

Core type transformer	Shell type transformer
1. Core is surrounded by the winding	1. winding is surrounded by the core.
2. For the passes of the flux only single path is present. (series magnetic circuit).	2) For the passes of the flux two path are present (parallel magnetic ckt)
3. Leakage flux is high	3) Leakage flux are less.
4. Regulation of transformer is high since leakage reactance is high $\uparrow L = \frac{N\phi}{I}\uparrow$ $\uparrow X = 2\pi f L \uparrow$ $\uparrow V.G = \frac{\uparrow IZ}{V} \times 100$	4) Regulation of transformer is less since leakage reactance is less.
5. Copper material required is more.  $d_1 < d_2$	5) Copper material required is less  $d_1 = d_2$

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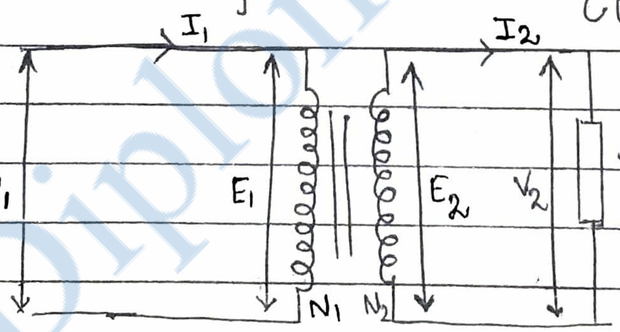
6. Less insulating material is required. (11/33 kv में 11 KV को Prefer किया जाता है।)	6. More insulating material is required. (11/33 kv में 33 kV को prefer किया जाता है)
7. It is used in low current application.	7. It is used in high current application.
8. It is used in high voltage application.	8) It is used in low voltage application
9. It is used in high power application.	9) It is used in low power application
10. Core is made up of L,U type of lamination.	10) Core is made up of E & I type of lamination.

☆ Impedance Transformation.



Since, $Z_2 = \dfrac{V_2}{I_2}$ —— (1)

We know that

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

$$V_2 = \left(\frac{N_2}{N_1}\right) V_1 = kV_1 \quad \text{—— (2)}$$

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again,

$$\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{k}$$

$$\therefore I_2 = \left(\frac{N_1}{N_2}\right) I_1 = \frac{I_1}{k} \quad \text{--- (3)}$$

Substituting the value of 'V_2' and 'I_2' from eq^n (2) and (3) in eq^n (1) we get

$$Z_2 = \frac{\left(\frac{N_2}{N_1}\right) V_1}{\left(\frac{N_1}{N_2}\right) I_1} = \frac{k V_1}{\frac{I_1}{k}}$$

$$Z_2 = \left(\frac{N_2}{N_1}\right)^2 \frac{V_1}{I_1} = k^2 \frac{V_1}{I_1}$$

$$Z_2 = \left(\frac{N_2}{N_1}\right)^2 Z_1 = k^2 Z_1$$

$$\boxed{\frac{Z_2}{Z_1} = \left(\frac{N_2}{N_1}\right)^2 = k^2}$$

Impedance is directly proportional to square of the transformation ratio.

In another word an impedance Z_2 in the secondary becomes $\frac{Z_2}{k^2}$ when transferred to primary.

Likewise as an impedance Z_1 in primary becomes $k^2 Z_1$ when transferred to the secondary.

When the secondary impedance referred to the primary side then it is denoted by Z_2' &

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its value is

i.e. $$\boxed{Z_2' = \frac{Z_2}{k^2}}, \quad Z_2' = \left(\frac{N_1}{N_2}\right)^2 \cdot Z_2$$

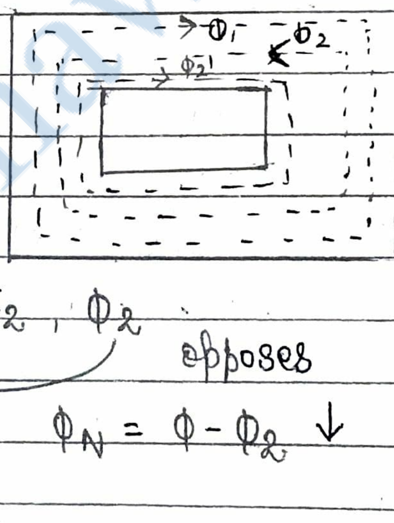
where Z_2' is called secondary impedance referred to primary side

Similarly, when the primary impedance referred to secondary side then it is denoted by Z_1' and its value is equal to $Z_1' = k^2 Z_1$

$$Z_1' = \left(\frac{N_2}{N_1}\right)^2 \cdot Z_1$$

where Z_1' is called the primary impedance referred to the secondary side.

★ Explain why is the transformer a constant flux machine.



ϕ, E_2, I_2, ϕ_2 opposes

$$\phi_N = \phi - \phi_2 \downarrow$$

ϕ_2, $\phi_N \downarrow$, $E_1 \downarrow$, I_2', ϕ_2'

$$\phi_N = \phi - \phi_2 + \phi_2'$$

$$\boxed{\phi_N = \phi}$$

Since $N_2 I_2 = N_1 I_2'$

$$\phi_2 = \phi_2'$$

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→ When some load is connected b/w the secondary terminal of the transformer, the transformer is said to be on load. Due to the load on the secondary a finite secondary current starts flowing. Depending on the type of load (resistive, inductive, capacitive) the secondary current I_2 will be in phase, lag or lead the load voltage V_2.

S.I No	TYPE OF LOAD	LOAD CURRENT
1.	Resistive (R)	I_2 is in phase with V_2
2.	(R+L) type	I_2 lags V_2
3	(R+C) type	I_2 leads V_2

→ Due to loading of the transformer the primary current increases above its no load value. The increase in primary current takes place as under —

→ When the transformer is loaded, the load current I_2 will start flowing. Due to increase in load current I_2, the secondary ampere turn (N_2I_2) will also increases. This increased secondary MMF will increase the flux ϕ_2 set up by the secondary current.

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→ This flux opposes the main flux (ϕ) set up in the core by the current flowing through the primary winding. Hence, the secondary MMF $N_2 I_2$ is called as demagnetising ampere tur

→ Due to reduction in the main flux ϕ, the indu emf in the primary winding E_1 will also reduc Hence, the difference b/w V_1 and E_1 will increase and the primary current will increase

→ The addition current drawn by the primary winding due to the loading is called as the load component (I_2'). This current I_2' is 180° out of phase with the load current I_2. The current I_2' produces its own magnetic flux ϕ_2' as shown in fig

→ ϕ_2' is in the opposite direction to that of ϕ_2.

→ Hence, its helps the main flux ϕ as ϕ and ϕ are in the same direction. Thus, the reduction in the main flux due to ϕ_2 is compensated by ϕ_2' and the core flux ϕ will almost remains constant.

→ Therefore, from no load to full load i.e. for any load the core flux will alway remains constant.

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2. Electric Circuit.

→ The electric ckt mainly consist of primary winding and secondary winding. Both winding i.e primary and secondary winding are made from low resistive conductive material such as copper or aluminium. But till now enamelled copper wires are commonly used. coat or decorated apply nail polish

→ The way of representing the two winding in core type transformer is shown in fig. is simply to discuss its working principle and doesnot show actual placing of the windings on the limbs.

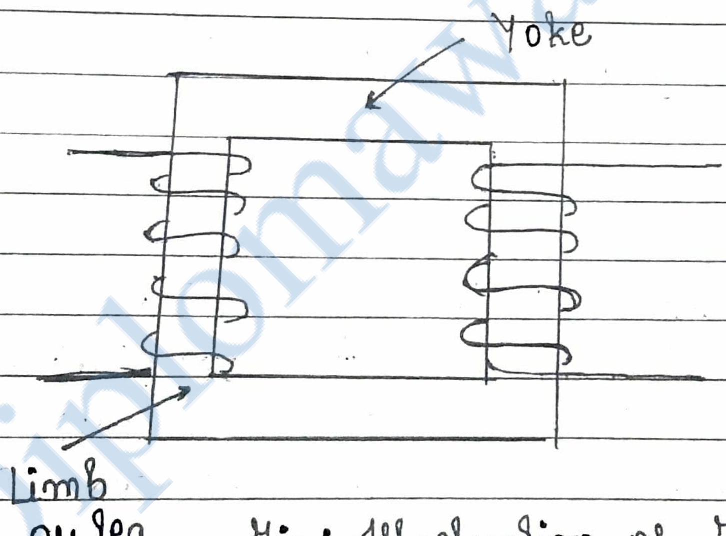
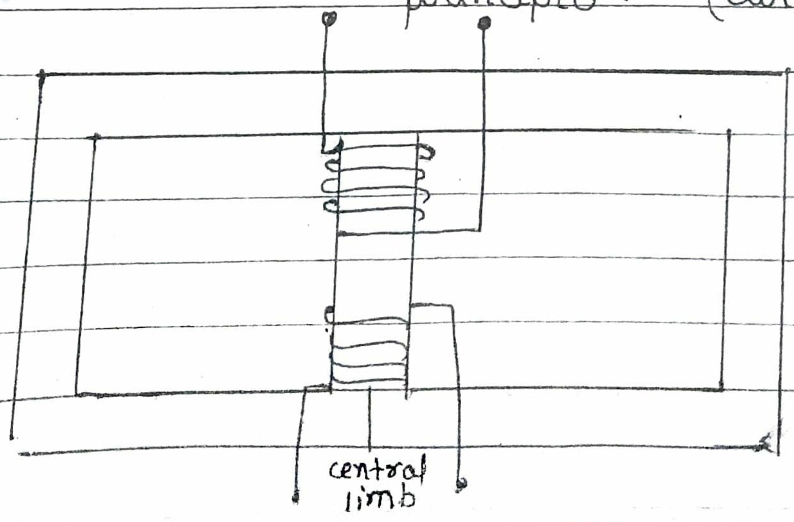


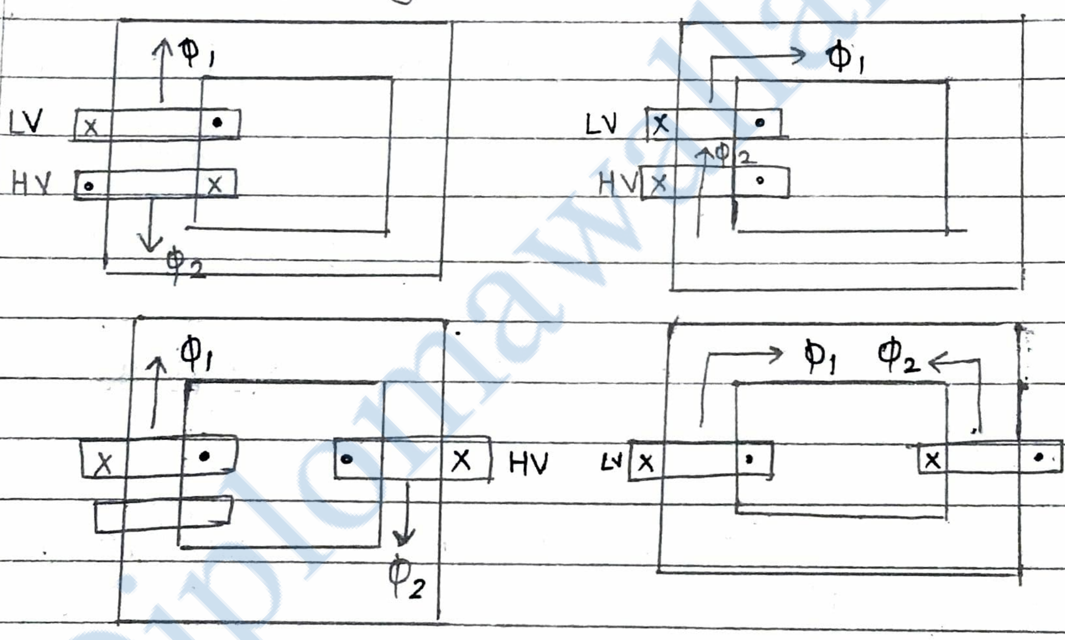
Fig: Illustration of Transformer principle. (core type)



Shell type

→ In actual construction half of each winding is placed on each limb one after another, this is to reduces the leakage flux. However in shell type transformer both winding are placed one after the other on central limb as shown in figure.

Note: In the transformer to maintain the constant flux from no load to full load, repulsive force should be present b/w high voltage and low voltage winding.



1. When low voltage winding & HV winding are arranged on the same leg or limb to obtain repulsive force current direction of high voltage & low voltage winding should be opposite in direction

→ When LV winding and HV winding are arranged on the separate leg or limb to obtained replusive forces, Current direction of LV and HV should be same direction

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without cooling ← powerrating → with cooling

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Dielectric Or Insulation.

- Like other electrical machine and equipments insulation is provided b/w various parts of transformer to prevent leakage of current and to isolate the conductor from non electrical metallic part.

- Enamelled copper wire of single or double polish is generally used for both the windings and further proper insulation is also provided between turns, layers and coils of both the windings to isolate the winding from eachother and from core.

- Insulation is provided between low and high voltage winding. The insulating material used are bakelite, paper, mica or press board.

- Oil is also used for providing better insulation and cooling of the transformer. Oils used in the transformer as an insulation are natural minerals oils, Askarels, Pyroclor. खनिज तेल which is free from FATTY acids.

Tank And Other Accessories

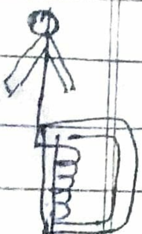
Tank: The complete assembly of the transformer i.e core and winding are placed in a suitable container called as main tank.

This tank contains transformer oil. The oil provide cooling as well as insulation. The tank acts as a protecting cover to the entire assembly of the transformer.

2. **Buchholz's relay** :- This is a gas operated protective relay. It gives alarm to indicate the shortage of oil or the presence of gas in case of overloading or minor fault, and to take out the transformer with the help of ckt breaker out of the circuit in case of severe (major or) fault.

3. **Terminal Bushings** :- Each single phase transform has two terminals on each side for making connections. The terminal bushing may be either of porcelain, oil field or condenser type. (Ceramic type)

Porcelain



4. **Conservator Tank** :- This tank is provided in many transformer with main tank in order to slow down the detarioation (reduce) of the oil and to keep the main tank full of oil.

5. **Temperature Guage** :- This is provided for the measurement of temperature of the hot transformer oil and hottest spot.

6. **Oil Gauge** :- This is provided to indicate oil level inside the tank.

7. **Breather** :- It is attached to conservator tank

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and contains silica gel which prevents the moist air from entering into the tank during contraction of oil.
When transformer is working oil is hot and there is expansion and when cooled it contract. In first situation gas passes to atmosphere through it, and in the second case there is inhaling of the air that is why it is called breather.

Cooling Tube :- To obtained the effective cooling apart from using various other methods of cooling, the transformer tank surface area is increased by tubes known as cooling tubes.

→ Cooling surface area of the transformer can also be increased by using radiator.
Radiator : Radiators are heat exchangers used to transfer thermal energy from one medium to another for the purpose of cooling and heating.

→ **Relays :-** Relay is a device which senses the faulty part of the power system and sends a tripping sig to a ckt breaker

→ **Circuit breaker →** It is a device which isolate the faulty part of the power system after receiving the trip command from the relay.

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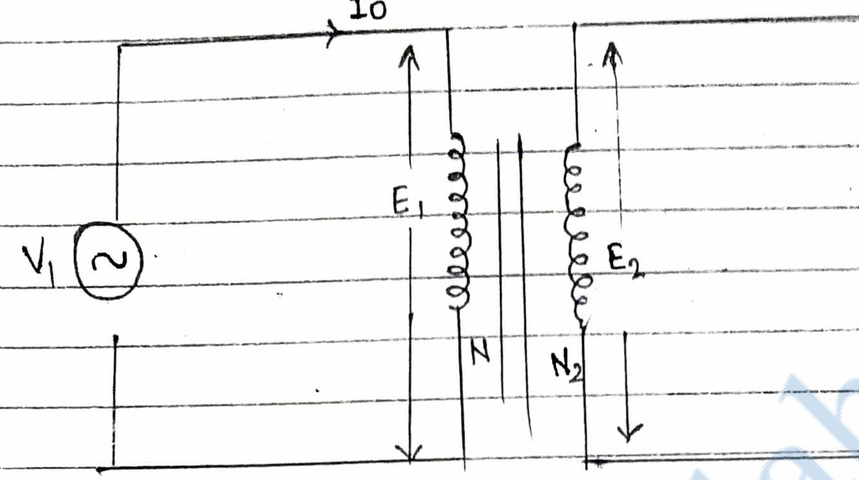
Practical Transformer

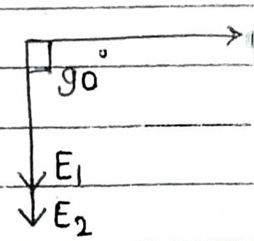
(No load phasor diagram)



When sinusoidal voltage is applied to the primary of the transformer, similar nature of flux will be set up in the core of the transformer.

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

then, $E = E_m \sin(\omega t - \pi/2)$



Hence, from above equation expression of the induced emf we conclude that induced voltage is lagging the flux by 90°. If E_1 & E_2 are the primary and secondary induced emf respectively then the phasor diagram of the flux and the induced emf is shown in figure.

Since, $V_1 = -E_1$ where 'V_1' is the applied voltage to the primary and since transformer is connected to supplied but nothing is connected on secondary side i.e. the transformer is at Noload. Under such situation transformer draws a small amount of current 'I_0' (about 3 to 5% of full load current) which will be lagging the voltage

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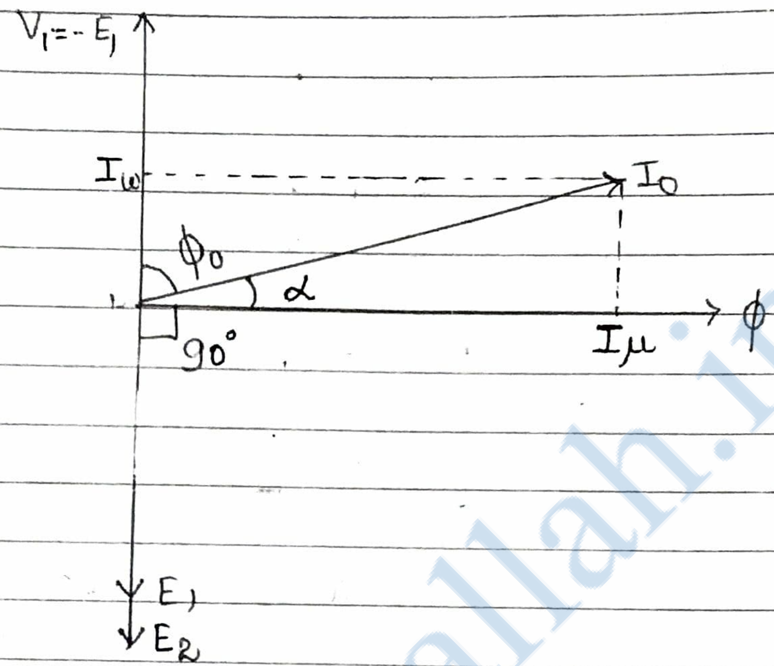
V_1 by a large angle ϕ_0 as transformer itself is highly inductive.



where α = hysteresis angle

I_0 = No load component of current or exciting current

I_μ = magnetising current or watt less component of current.

I_w = working current or active current or wattfull component of current.

ϕ_0 = No load power factor angle.

Note :→ 1. I_μ = 2 to 3 times of I_w

2. $\cos\phi_0 = 0.2$ (lagging)

$\phi_0 = 75°$

3. I_μ = 4 to 6 % of full load current.

4. I_w = 1 to 2 % of full load current.

5. I_0 = 3 to 5 % of full load current.

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Again, $I_\mu = I_0 \sin\phi_0$

$I_w = I_0 \cos\phi_0$

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

$$\phi_0 = \tan^{-1}\left(\frac{I_\mu}{I_w}\right)$$

→ The no load current I_0 can be resolved into two components. One in phase of flux and another in phase of applied voltage. The component of the no load current in phase of the flux is denoted by I_μ and is equal to $I_\mu = I_0 \sin\phi_0$.

→ This current is known as magnetising current i.e a current which sets up a flux in the core.

→ The component of the no load current in the phase with the applied voltage is known as working current and it is denoted by Iw and is equal to $I_w = I_0 \cos\phi_0$

1 No-load primary current I_0

(I_μ) Magnetizing component

This component magnetizes the core i.e produce flux

(I_w) Working componen

This component supply the total losses at no-load.

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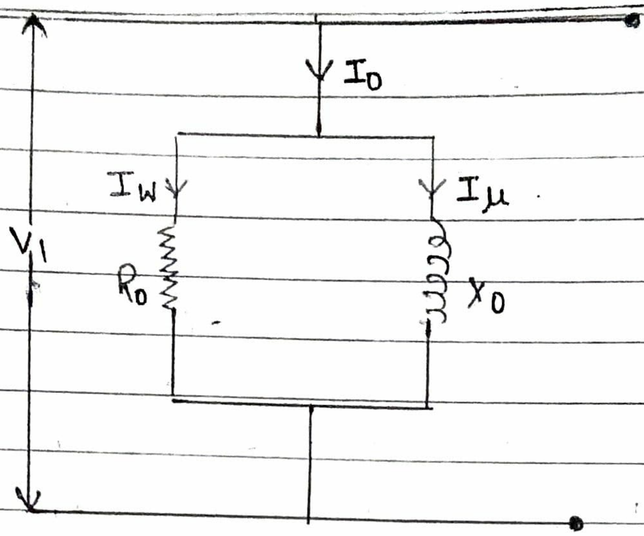
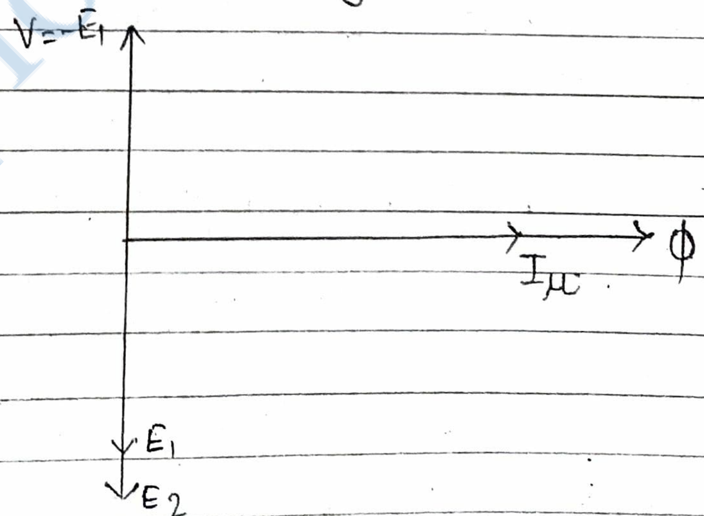


Fig: Equivalent ckt under No-load condition.

Note:- In the transformer the no load power factor is less since magnetizing current is greater than working component of the current.

Ideal Transformer

No load phasor diagram



Equivalent Circuit of the transformer

Step : 1

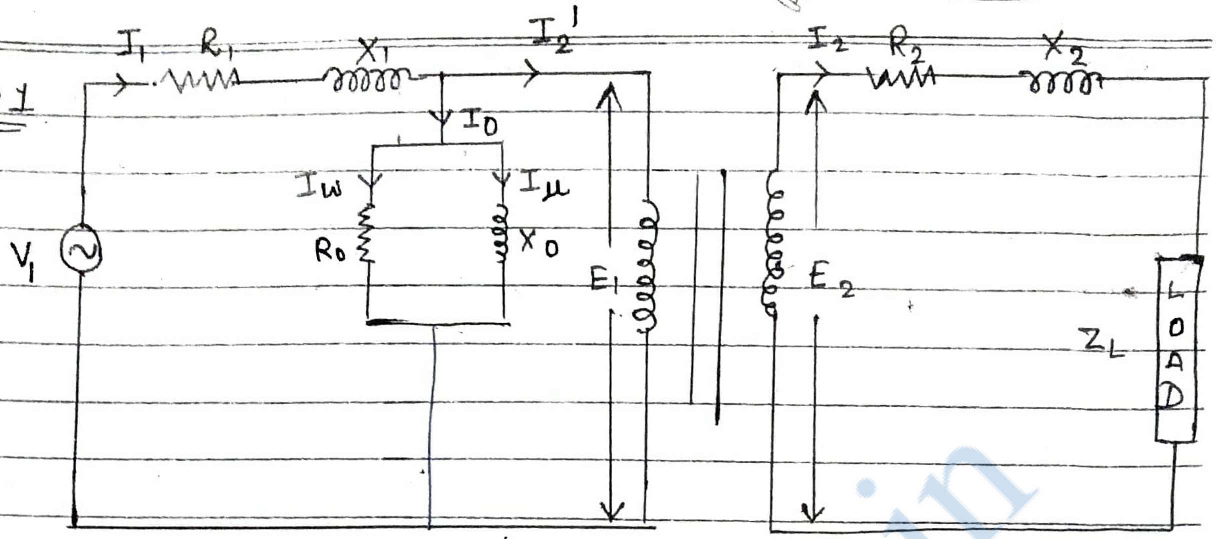
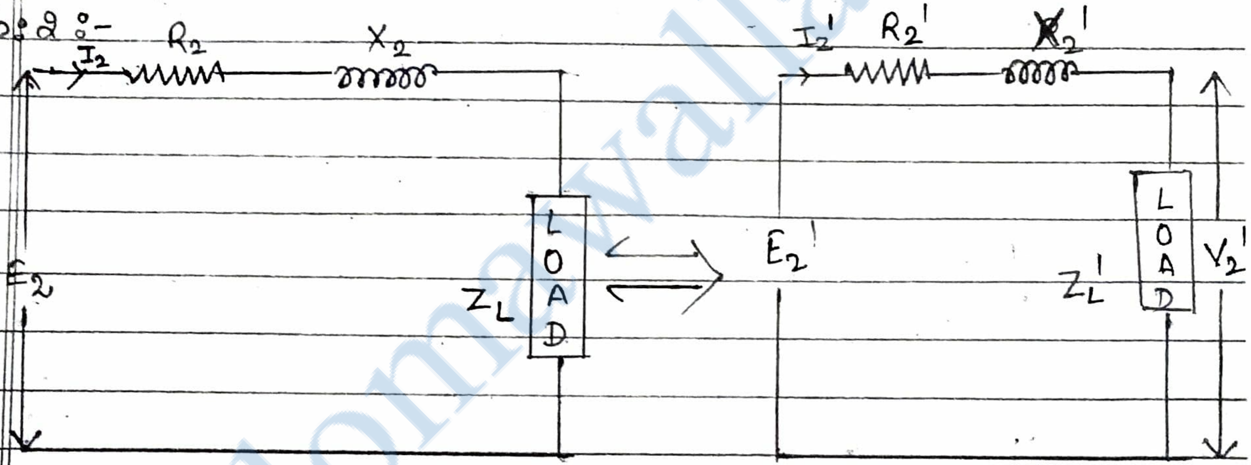


Fig : Exact Equivalent circuit of the transformer

Step 2 :-



Where $E_2' = \frac{E_2}{K} = E_2\left(\frac{N_1}{N_2}\right)$

$I_2' = KI_2 = \left(\frac{N_2}{N_1}\right) I_2$

$R_2' = \frac{R_2}{K^2} = \left(\frac{N_1}{N_2}\right)^2 \cdot R_2$

$X_2' = \frac{X_2}{K^2} = \left(\frac{N_1}{N_2}\right)^2 \cdot X_2$

$Z_L' = \frac{Z_L}{K^2} = \left(\frac{N_1}{N_2}\right)^2 \cdot Z_L$

$V_2' = \frac{V_2}{K} = \left(\frac{N_1}{N_2}\right) V_2$

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Step 3:

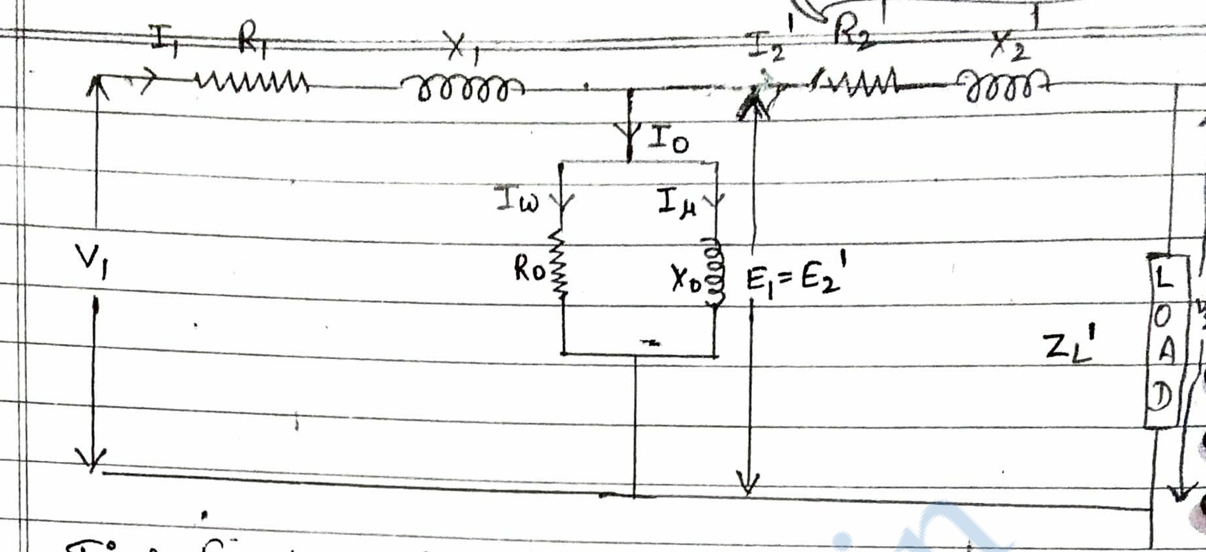

Fig : Exact equivalent ckt of the transformer referred to primary side.

Step 4:

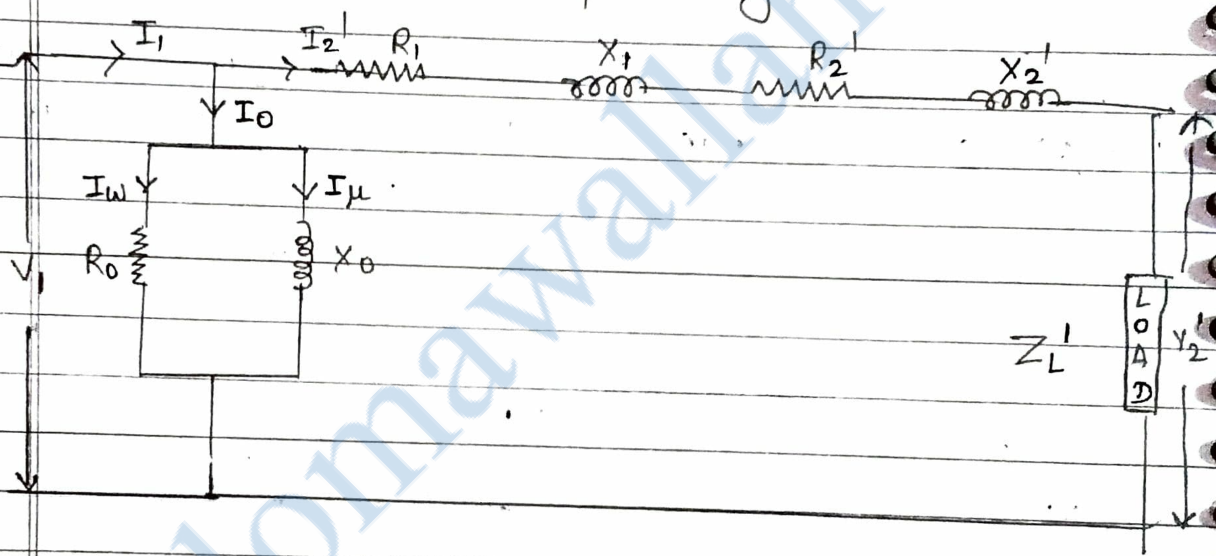

Fig :- Approximately equivalent ckt of the transformer referred to primary side.

Step 5:

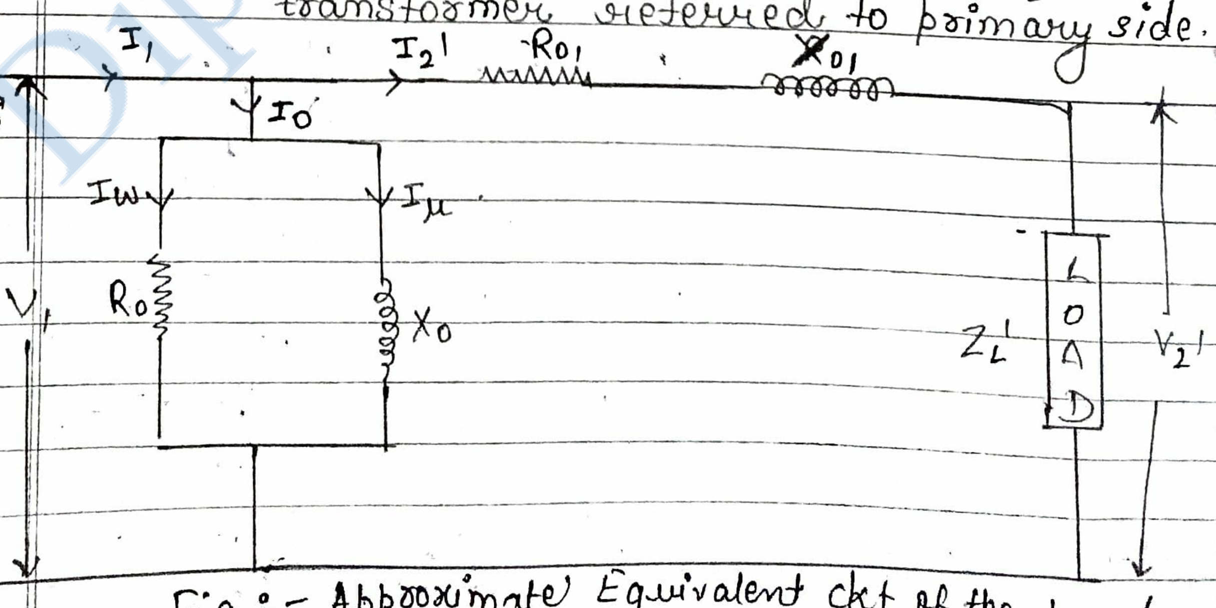

Fig :- Approximate Equivalent ckt of the transformer referred to primary side.

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Where $R_{01} = R_1 + R_2'$ = Equivalent resistance of the transformer referred to primary side

$X_{01} = X_1 + X_2'$ = Equivalent reactance of the transformer referred to primary side.

Step 6 :-

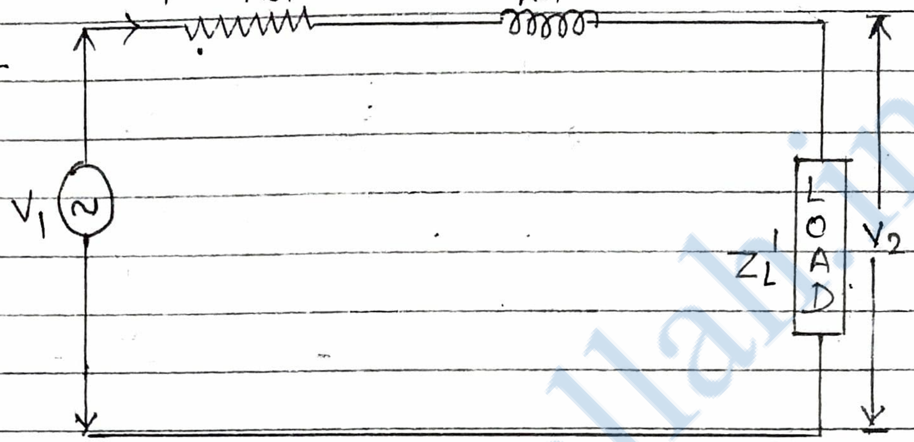

Fig: Approximate Equivalent ckt.

★ By shifting shunt branch parameter towards source side the following variation are present

→ The drop in the primary resistor and reactor is reduced (drop due to no load current in the primary resistor and reactor are negli

→ Copper losses in the primary circuit are reduced (no load current power losses are not considered.

→ Magnetizing current and working component current are increases since source voltage is greater than E_2 voltage.

→ Eddy current losses are increased :

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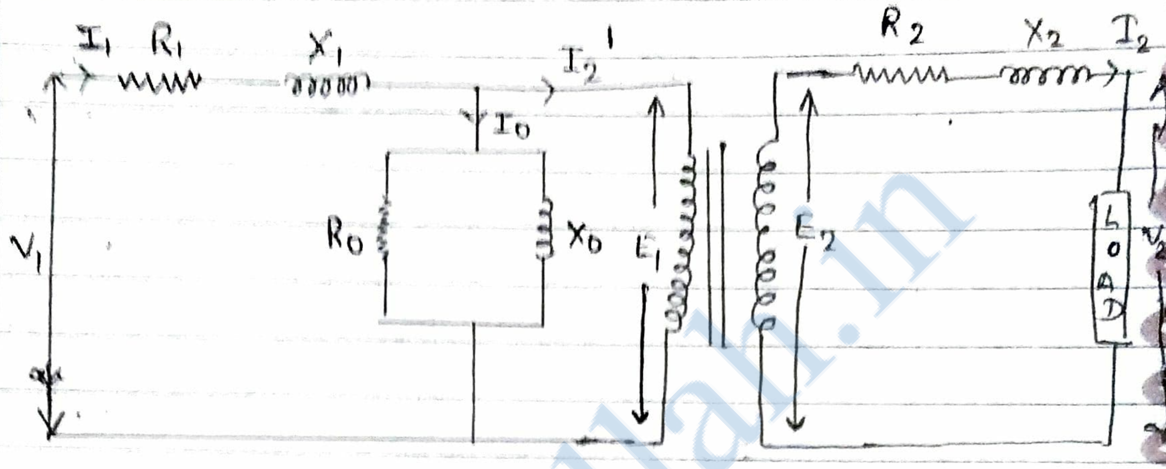
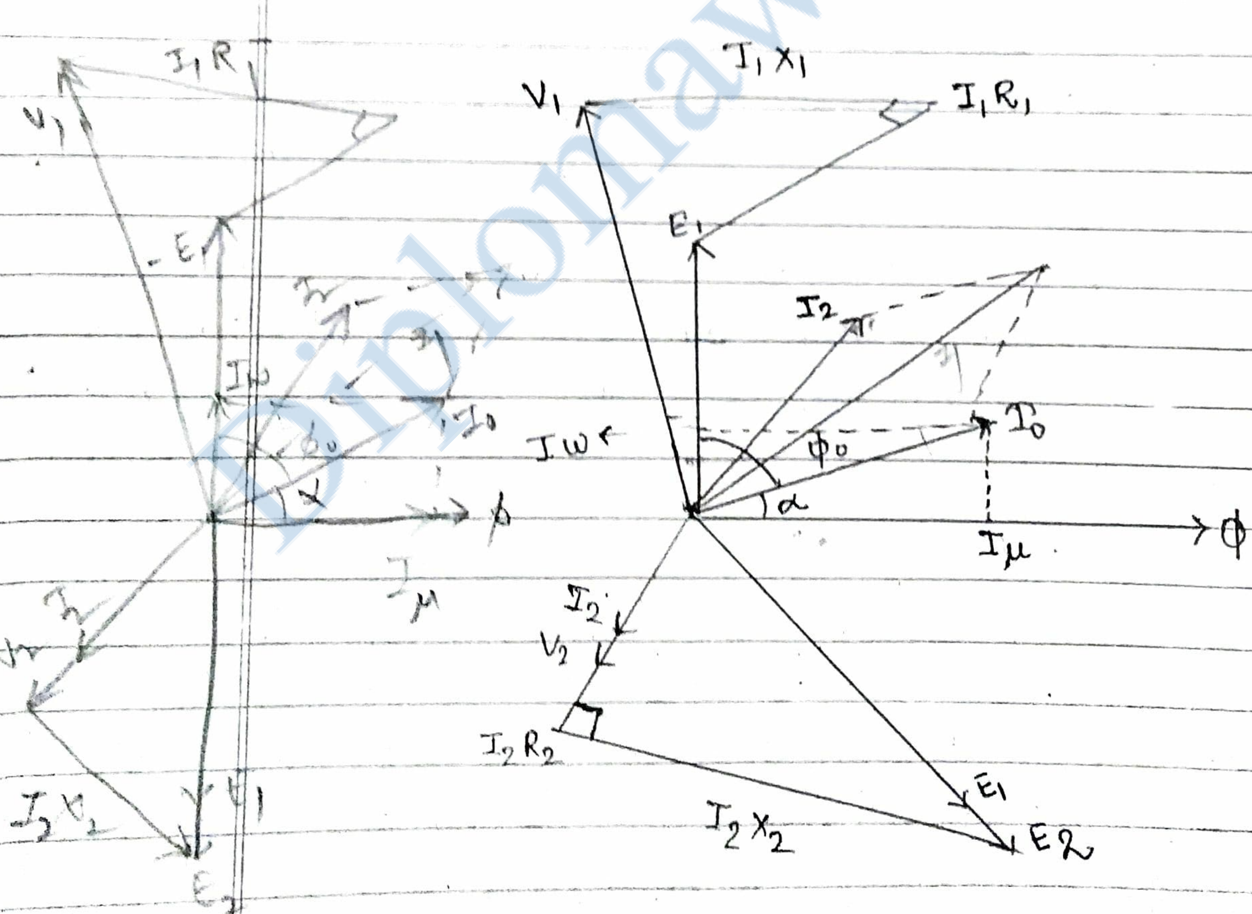
Practical Transformer (ON LOAD CONDITION)

Case I: Phasor diagram when the load is resistive in nature.





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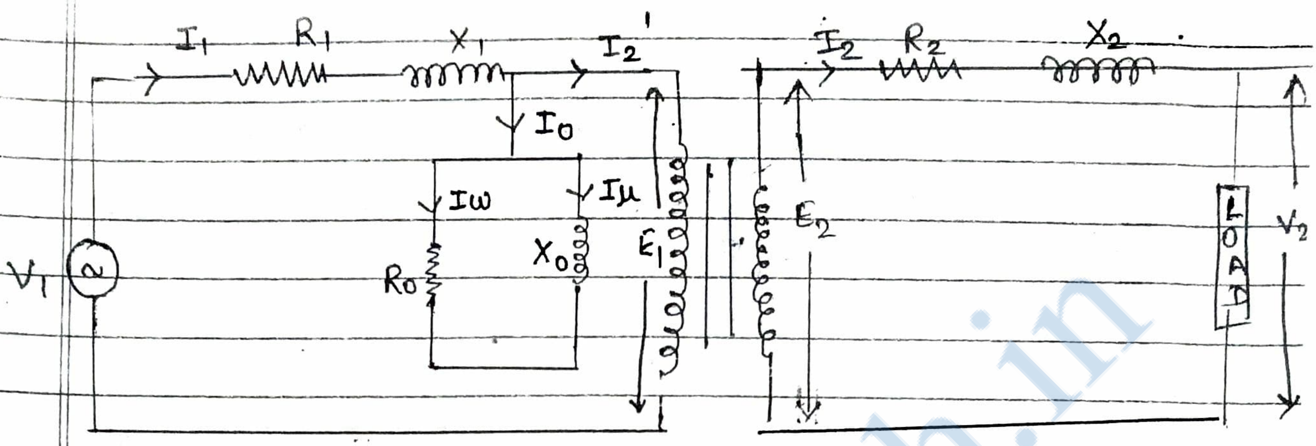
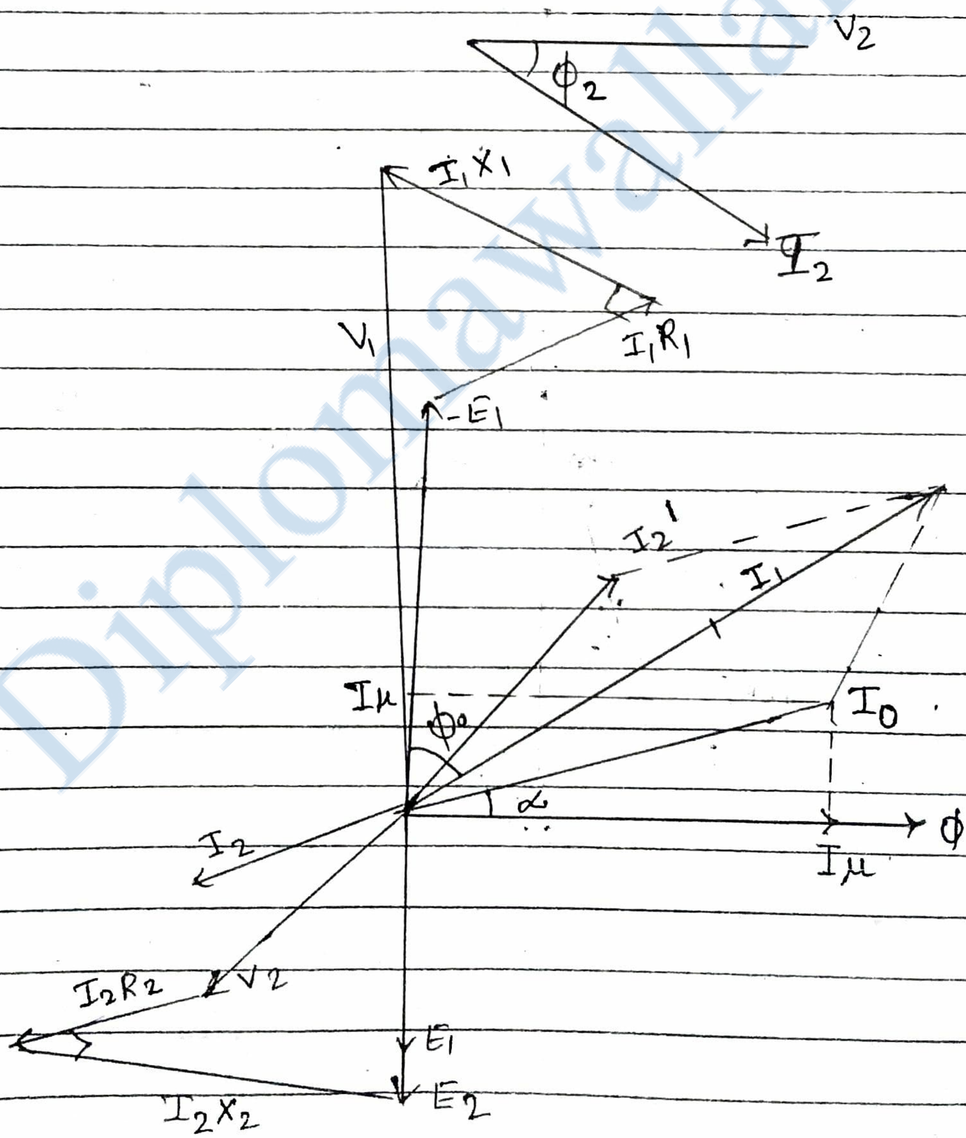
Case II : Phasor diagram when the load is inductiv in nature.





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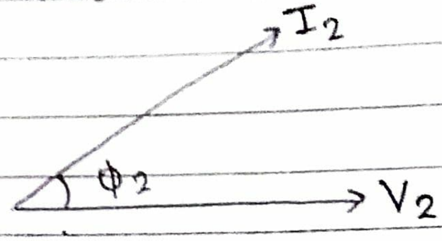
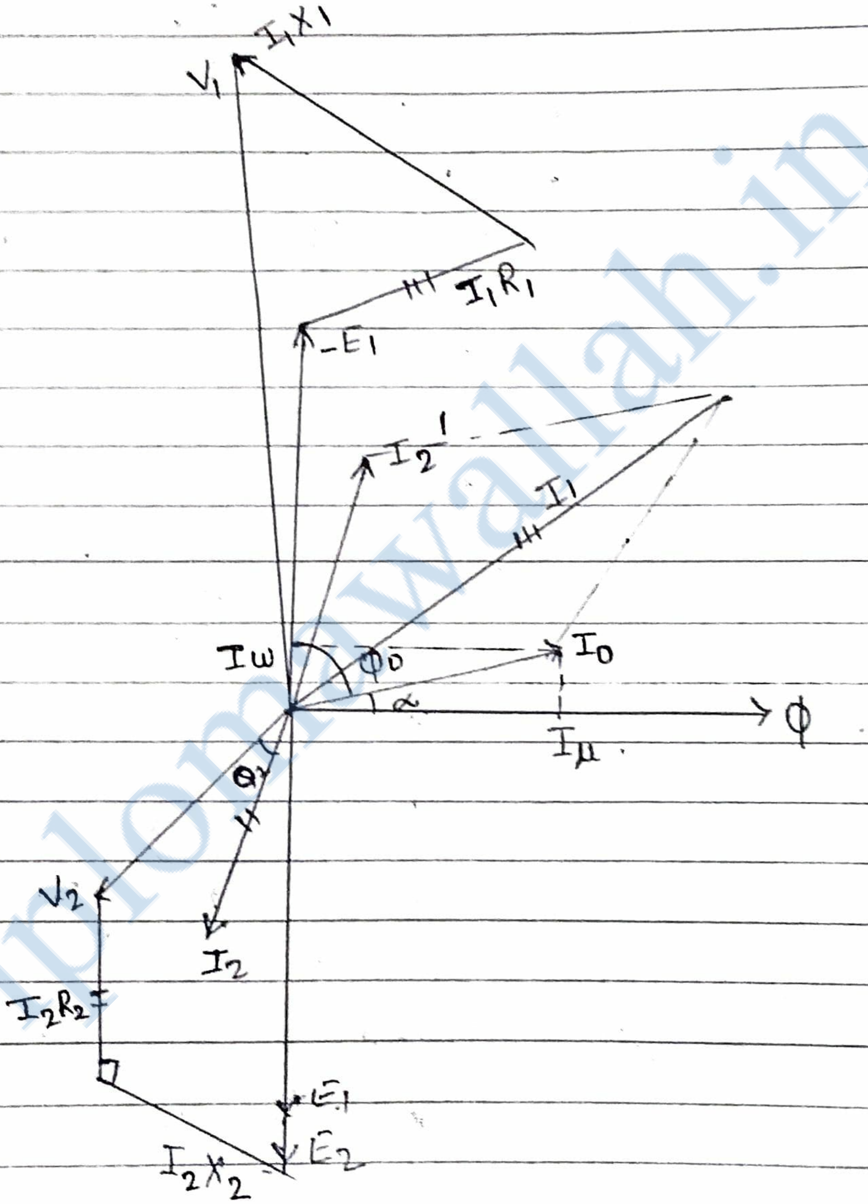
Case III: Phasor diagram when the load is capacitive in nature





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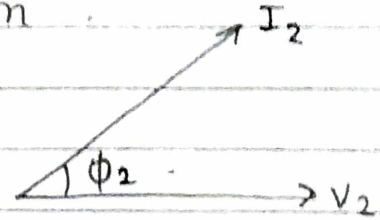
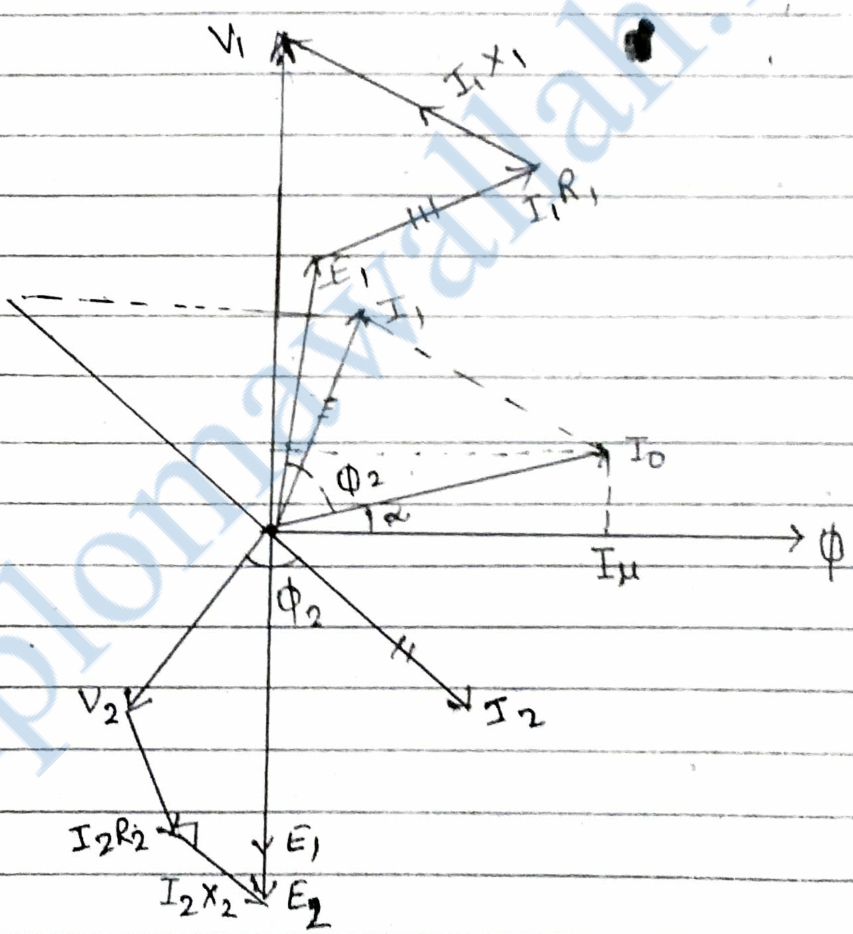
Case IV : Phasor diagram when the load is highly capacitive in medium





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★ Voltage Regulation Of a Transformer

1. Inherent regulation or voltage drop $(E_2 - V_2)$
2. Step-up regulation $\left(\frac{E_2 - V_2}{V_2} \times 100\right)$ Alternator use
3. Step-down regulation $\left(\frac{E_2 - V_2}{E_2} \times 100\right)$ Transformer use

Voltage Regulation

→ The term voltage regulation is used to identify the characteristics of the voltage change in a transformer with loading.

→ The regulation of transformer generally expressed as % regulation may be defined as.

$$\left(\frac{\text{Secondary no load voltage} - \text{Secondary full load voltage}}{\text{Secondary no load voltage}}\right) \times 100$$

If E_2 = Secondary no load voltage and
V_2 = the terminal voltage at secondary or secondary full load voltage.

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

Therefore % regulation of a transformer is defined as "the percentage decrease in the terminal voltage of the transformer from no load to full load condition at a constant applied voltage".

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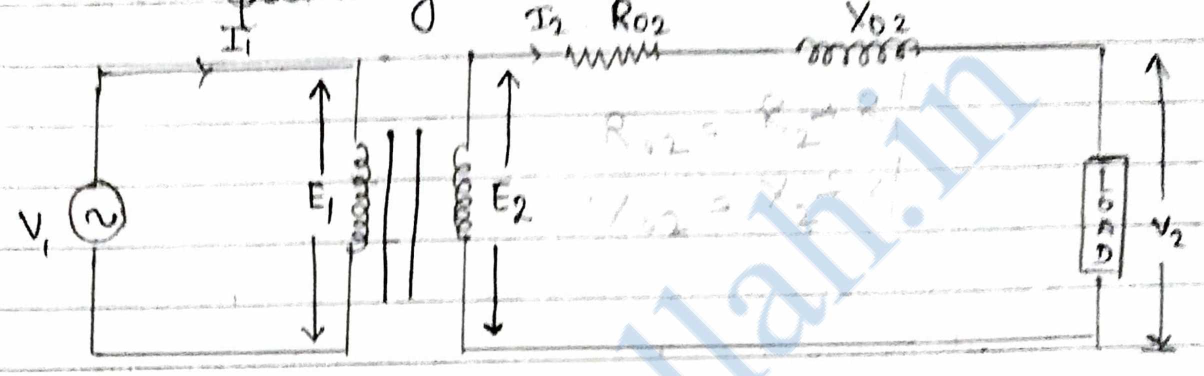
Expression for percentage Regulation

Let us considered the equivalent circuit of a transformer referred to the secondary side as shown in figure.

Fig: Approximate equivalent circuit referred to secondary side.



$R_{02} = R_2 + R_1'$ = Equivalent resistance referred to secondary.

$X_{02} = X_2 + X_1'$ = Equivalent reactance referred to secondary

★ When the load is connected to the secondary s... current I_2 will start flowing.
Depending upon the nature of load, current I_2 may be lagging the voltage V_2 for inducti... load, in phase of the voltage V_2 for resistive load and leading the voltage V_2 for capacitive load

★ Hence, on the basics of the above current voltage phasor relation, the load has a lagging power factor, a unity power factor and a leading power factor respectively

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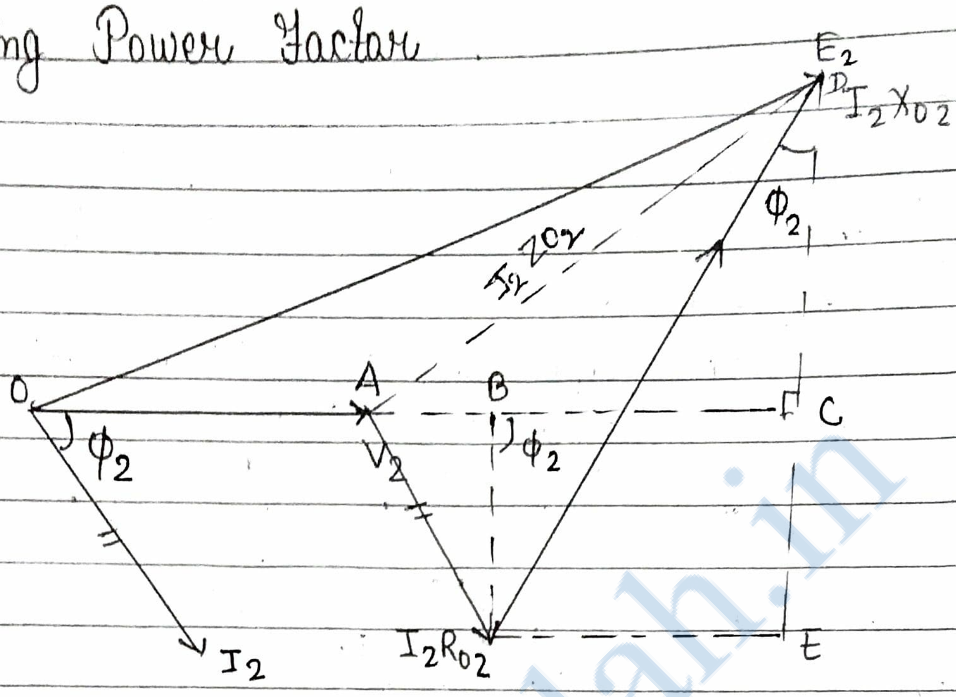
Lagging Power Factor



The phasor diagram of the transformer referred to as the secondary when suppling a load of lagging power factor load has been shown in figure where

E_2 = The no load voltage

V_2 = The load voltage

I_2R_{02} = The resistive drop referred to secondary

I_2X_{02} = the reactive drop referred to secondary

ϕ_2 = the angle between V_2 and I_2 i.e $\cos\phi_2$ is power factor of the load.

From Phasor Diagram

$$(OD)^2 = (OC)^2 + (CD)^2$$

$$(OD)^2 = (OA + AB + BC)^2 + (DE - CE)^2$$

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$$E_2^2 = (V_2 + I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2)^2 + (I_2 X_{02} \cos\theta_2 - I_2 R_{02} \sin\theta_2)^2$$

Since,
$(I_2 X_{02} \cos\phi_2 - I_2 R_{02} \sin\phi_2)$ is very small being the difference of two quatities so it can be easily neglected.

$$E_2^2 = (V_2 + I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2)^2$$

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

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

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

$$\% \text{ reg} = \frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2}{E_2} \times 100$$

$$\% \text{ Reg} = \left(\frac{I_2 R_{02} \cos\phi_2}{E_2} + \frac{I_2 X_{02} \sin\phi_2}{E_2} \right) \times 100$$

$$\% \text{ Reg} = (R_{pu} \cos\phi_2 + X_{pu} \sin\phi_2) \times 100.$$

$R_{pu} = \frac{I_2 R_{02}}{E_2}$ = per unit resistance

$X_{pu} = \frac{I_2 X_{02}}{E_2}$ = per unit reactive.

P.U × 100 = Percentage.

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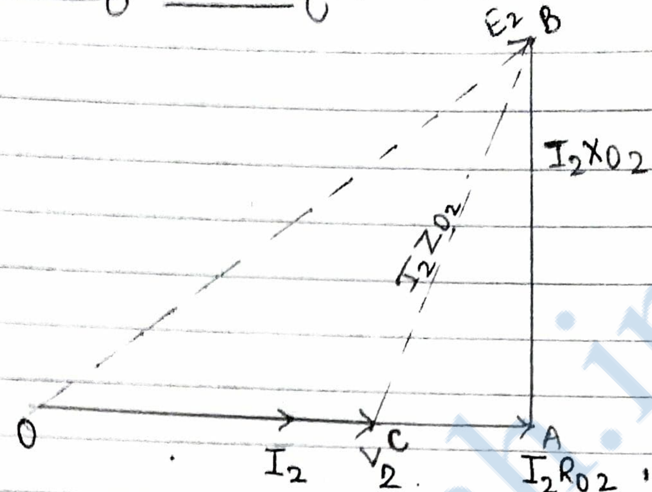
★ Unity Power Factor



Phasor diagram at unity power factor referred to secondary.

From the phasor diagram

$$(OB)^2 = (OA)^2 + (AB)^2$$

$$(OB)^2 = (OC + CA)^2 + (AB)^2$$

$$\boxed{E_2^2 = (V_2 + I_2R_{02})^2 + (I_2X_{02})^2}$$

★ The second term I_2X_{02} is neglected as it doesn't contribute much in the change in the magnitude of V_2. On the other hand it is responsible for phase shift between E_2 & V_2. Hence we can neglected I_2X_{02}.

$$E_2^2 = (V_2 + I_2R_{02})^2$$

$$E_2 = V_2 + I_2R_{02}$$

$$\boxed{E_2 - V_2 = I_2R_{02}}$$

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

$$\boxed{\% \text{ Reg.} = \frac{I_2R_{02}}{E_2} \times 100}$$

$$\boxed{\% \text{ regulation} = R_{pu} \times 100}$$

$\because R_{pu} = \frac{I_2R_{02}}{E_2}$ = PU resistance.

★ Since, the term I_2X_{02} is very small as compare to the term $(V_2 + I_2R_{02})$, therefore the term I_2X_{02} is neglected.

★ Leading Power Factor

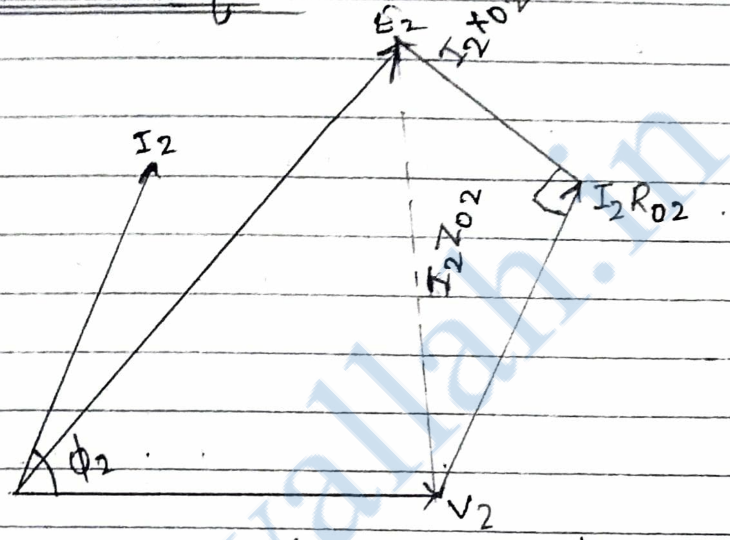


Fig: Phasor diagram of leading Power fact

From phasor diagram

Taking V_2 as reference

$$V_2 = V_2(1 + j0)$$

$$I_2 = I_2(\cos\phi_2 + j\sin\phi_2)$$

Also,

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

Again

$$E_2 = V_2 + I_2Z_{02}$$

$$E_2 = (V_2 + j0) + I_2(\cos\phi_2 + j\sin\phi_2)(R_{02} + j$$

$$E_2 = V_2 + I_2R_{02}\cos\phi_2 + jI_2X_{02}\cos\phi_2 + jI_2R_{02}\sin($$
$$- I_2X_{02}\sin\phi_2$$

$$E_2 = (V_2 + I_2R_{02}\cos\phi_2 - I_2X_{02}\sin\phi_2) + j(I_2X_{02}\cos\phi_2 + I_2R_{02}s$$

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$$E_2^2 = (V_2 + I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2)^2 + (I_2 X_{02} \cos\phi_2 + I_2 R_{02} \sin\phi_2)^2$$

Since, $(I_2 X_{02} \cos\phi_2 + I_2 R_{02} \sin\phi_2)$ is very small as compare to $(V_2 + I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2)$, so it is neglected.

~~% regulation = $I_2 R_{02} \cos\phi$~~

$$E_2^2 = (V_2 + I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2)^2$$

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

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

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

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

$$\% \text{ reg} = \left(\frac{I_2 R_{02}}{E_2} \cos\phi_2 - \frac{I_2 X_{02}}{E_2} \times \sin\phi_2\right) \times 100$$

$$\% \text{ Reg} = (R_{pu} \cos\phi_2 - X_{pu} \sin\phi_2) \times 100$$

Condition for Maximum Regulation.

We can drive the condition for the maximum regulation using the expression for regulation. The regulation will be maximum if the

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differentiation of regulation with respect to pha angle ϕ_2 is equal to zero.

i.e $\% Reg = \frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2}{E_2} \times$

For maximum regulation

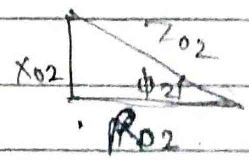
$$\frac{d}{d\phi_2}(\% Reg) = 0$$

$$\frac{d}{d\phi_2}\left[\frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2}{E_2}\right] \times 100 = 0$$

$$-I_2 R_{02} \sin\phi_2 + I_2 X_{02} \cos\phi_2 = 0$$

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

$$\frac{\sin\phi_2}{\cos\phi_2} = \frac{X_{02}}{R_{02}}$$



$$\boxed{\tan\phi_2 = \frac{X_{02}}{R_{02}}}$$

$$\boxed{\phi_2 = \tan^{-1}\left(\frac{X_{02}}{R_{02}}\right)}$$

ϕ_2 = Load power factor angle

Load Power factor

$$\boxed{\cos\phi_2 = \frac{R_{02}}{Z_{02}}}$$

Note: Maximum regulation only at lagging power facto and when $\phi_2 = \tan^{-1}\left(\frac{X_{02}}{R_{02}}\right)$

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Condition For Minimum (Zero) Regulation

We can use the expression to find the condition for which the regulation of the transformer is zero or minimum.

For minimum regulation

$$\% \, Reg = 0$$

$$\frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2}{E_2} \times 100 = 0$$

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

$$\frac{\sin\phi_2}{\cos\phi_2} = -\left(\frac{R_{02}}{X_{02}}\right)$$

$$\boxed{\tan\phi_2 = -\left(\frac{R_{02}}{X_{02}}\right)}$$

- ★ The -ve sign in the above condition indicate that zero regulation is possible at leading power factor
- ★ Also if the transformer is not loaded than $E_2 = V_2$ and this also give zero regulation.
- ★ Thus, the regulation is zero (minimum) if the transformer is open ckted or operated at a leading power factor.

i.e $\boxed{\tan\phi_2 = \frac{R_{02}}{X_{02}}} \Rightarrow \boxed{\phi_2 = \tan^{-1}\left(\frac{R_{02}}{X_{02}}\right)}$

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Power factor

$$\cos\phi_2 = \frac{X_{02}}{Z_{02}}$$

Note :-

- When the regulation of the transformer is max^m $\left(\frac{X}{R}\right)$ ratio of the transformer & $\left(\frac{X}{R}\right)$ ratio of the load are equal

$$\left(\frac{X}{R}\right)_{load} = \left(\frac{X}{R}\right)_{Transformer}$$

- When the regulation is minimum $\left(\frac{X}{R}\right)$ ratio of the load is equal to reciprocal of $\left(\frac{X}{R}\right)$ ratio of transformer.

i.e $$\left(\frac{X}{R}\right)_{load} = \frac{1}{(X/R)_{transformer}}$$

Q: Prove that $\boxed{\%\,Reg = \%\,Z}$

Sol^n

$$\%\,Reg = \frac{I_2R_{02}\cos\phi_2 + I_2X_{02}\sin\phi_2}{E_2} \times 100$$

$$\%\,Reg = \left(\frac{I_2R_{02}}{E_2}\cos\phi_2 + \frac{I_2X_{02}}{E_2}\sin\phi_2\right) \times 100$$

$$\%\,Reg = \left(R_{pu}\cos\phi_2 + X_{pu}\sin\phi_2\right) \times 100$$

$$= \left(R_{pu}\times 100\cos\phi_2 + X_{pu}\times 100\sin\phi_2\right)$$

$$\%\,Reg = \left(\%\,R\cos\phi_2 + \%\,X\sin\phi_2\right)$$

$$\cos\phi_2 = \frac{R}{Z} = \frac{R_{p.u}}{Z_{p.u}} = \frac{\%\,R}{\%\,Z}$$

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$$\sin\phi_2 = \frac{X}{Z} = \frac{X_{pu}}{Z_{pu}} = \frac{\%X}{\%Z}$$

$$\% Reg = \left(\%R \times \frac{\%R}{\%Z} + \%X \times \frac{\%X}{\%Z} \right)$$

$$= \frac{(\%R)^2}{\%Z} + \frac{(\%X)^2}{\%Z}$$

$$= \frac{(\%R)^2 + (\%X)^2}{(\%Z)}$$

$$= \frac{(\%Z)^{\not 2}}{\not{\%Z}}$$

$$\boxed{\% Reg = \%Z}$$

Numerical

Q:- Find the primary number of turn of a 440/220 V, 50 Hz single phase transformer, if the maximum value of flux at no load is 1 mwb

Solⁿ Given, $E_1 = V_1 = 440$ $\quad f = 50\,Hz$

$E_2 = V_2 = 220$ $\quad \phi_m = 1 \times 10^{-3}\,wb$

$N_1 = ?$

From the emf eqⁿ of transformer

$$E_1 = 4.44 f N_1 \phi_m$$

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

$$= \frac{440}{4.44 \times 50 \times 1 \times 10^{-3}} = 1981.98$$

$\simeq$ 1982 turns

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Q. A single phase transformer has 200 primary & 800 secondary turn. The net cross sectional area of the core is 100 cm^2. If the primary winding be connected to a 50 Hz supply of 250 V, Calculate i) the peak value of flux density in the core. ii) the voltage induced in the secondary winding iii) what is the value of transformation ratio

Soln Given, $N_1 = 200$ $f = 50\ Hz$
$N_2 = 800$ $V_1 = 250$
$A = 100\ cm^2$
$= 100 \times 10^{-4}\ m^2$

From the emf eqn

1. Peak value :→ $E = 4.44 f N \phi_m$

$E = 4.44 f N_1 B_m A$

$B_m = \dfrac{E_1}{4.44 f N_1 A}$

$= \dfrac{250 \times 10^4}{4.44 \times 50 \times 200 \times 100}$

$0.563\ wb/m^2$

2. $\dfrac{N_1}{N_2} = \dfrac{V_1}{V_2}$

$\dfrac{200}{800} = \dfrac{250}{x}$

$x = \dfrac{250 \times 800}{200} = 1000\ V.$

3. Transformatio Ratio $(k) = \dfrac{N_2}{N_1} = \dfrac{800}{200} = 4.$

Q:→ A 20 kVA, single phase transformer has 300 turn on the primary and 15 turns on the secondary. The primary is connected to a 1000 V, 50 Hz

supply. Calculate i) the secondary voltage on open ckt. ii) the max^m value of the flux
iii) The value of the current in both the winding at full load.

Q:→ A single phase transformer has 450 primary and 1800 secondary turn. The net cross sectional area of the core is 40 cm². If the primary is connected to a 415 V, 50 Hz single phase supply. Determine.
i) the voltage induced in the secondary.
ii) the max^m value of flux density in the core in Tesla.

Q) The primary winding of a single phase transformer is connected to a 3000 V, 50 Hz supply. The secondary winding has 2000 turn. If the max^m value of flux in the core is 2 mwb then, calculate
i) The number of turns on primary winding.
ii) The secondary induce emf.
iii) The max^m flux density in the core if the net cross sectional area is 80 cm².

Sol^m $V_1 = 3000V$ $f = 50H$ $N_2 = 2000$ $\phi_m = 2\times10^{-3}wb$.

$E_1 = 4.41 f N_1 \phi_m$

$3000 = 4.41\times50\times N_1\times2\times10^{-3}$

(1) $N_1 = \dfrac{3000}{4.41\times50\times2\times10^{-3}} = 6802.72 \rightarrow 6803$ turns.

(2) $\dfrac{V_1}{V_2} = \dfrac{N_1}{N_2} = \dfrac{3000}{V_2} = \dfrac{6803}{2000} \Rightarrow V_2 = \dfrac{3000\times2000}{6803} = 882$

(3) $E_1 = 4.44 f N_1 \cdot B \cdot A$

$B = \dfrac{3000}{4.44\times50\times6803\times80\times10^{-4}} = 0.24\ wb/m^2$

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Sol^n $N_1 = 300$ $N_2 = 15$

$V_1 = 1000V$ $F = 50Hz$

i) We know that

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

$$\frac{300}{15} = \frac{1000}{V_2}$$

$$V_2 = \frac{1000 \times 15}{300}$$

$$V_2 = 50\ V$$

ii) We know from emf eq^n of transformer

$$E_1 = 4.41 f N_1 \phi_m$$

$$1000 = 4.41 \times 50 \times 300 \cdot \phi_m$$

$$\phi_m = \frac{1000}{4.44 \times 50 \times 300}$$

$$= 0.015\ wb.$$

iii) Output VA $= V_2 I_2$

$$20 \times 10^3 = 50 I_2$$

$$I_2 = \frac{20 \times 10^3}{50} = 400$$

$$I_1 = \frac{P}{V_1} = \frac{20000}{1000}$$

$$= 20\ Amp$$

(2.) $N_1 = 450$ $A = 40cm^2 = 40 \times 10^{-4} m^2$

$N_2 = 1800$

$V_1 = 415$ $f = 50 Hz$

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{415}{V_2} = \frac{450}{1800}$$

$$\Rightarrow V_2 = \frac{1800 \times 415}{450}$$

$$V_2 = 1660\ V$$

and $E_1 = 4.44 f N_1 B_m$

$$\frac{415 = 4.44 \times 50 \times B_m}{40 \times 10^{-4}}$$

$$B_m = \frac{415}{45 \times 4.44 \times 50 \times 4 \times 10^{-4}}$$

$B_m = 1.038$ wb/m

Losses In Transformer.

There are mainly two losses occurs in a transformer, which are following—

1. Core losses or Iron losses or Constant losses
2. Copper losses, or ohmic losses, or variable losses or I^2R losses
3. Stray load losses.
4. Dielectric losses.

1. Core losses, Iron losses or Constant losses. (P_C or P_I)

Core losses or iron losses are occurs in the magnetic core of the transformer due to the alternating flux. This losses is the sum of the hysterisis losses (P_h) and eddy current losses (P_e). Therefore Total core losses occurs in the transformer is given by

$$P_C \text{ or } P_I = P_h + P_e$$

Hysteresis losses (P_h):- The alternating flux gets set up in the core of the transformer and it undergoes a cycle of magnetisation and demagnetisation. When the core of the transformer is subjected to magnetic reversal some energy is loss or wastage. This loss is called hyteresis losses and is given by

$$P_h = k_h B_{max}^{x} f v$$

where, k_h = hyteresis constant depending upon the material

B_{max} = max^{m} flux density in the magnetic material

f = frequency of the magnetic reversal

v = volume of magnetic material

The exponent 'x' is called "Steinmetz constant" whose value varies from 1.5 to 2.5. Generally the value of Steinmetz constant is taken as 1.6 for silicon steel

i.e. $$P_h = k_h B_{max}^{1.6} f V$$

→ The hyteresis loss can be minimised by using good quality magnetic material for the core.

Case I: $\frac{V}{f}$ = constant, B_{max} = constant

$E = 4.44 f \phi_m N$

$= 4.44 f N B_m A$

$B_m = \frac{E}{4.44 f N A}$

$B_m \propto \frac{E}{f} \propto \frac{V}{f}$

$B_m \propto \frac{V}{f}$

$P_h = k_h \left(\frac{V}{f}\right)^{1.6} f V$

$$P_h \propto f$$

★★ $$P_h = A f$$

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Case II : $\frac{V}{f}$ variable

$$P_h = k_h \left(\frac{V}{f}\right)^{1.6} f\, v$$

$$P_h = k_h V^{1.6} f^{-0.6} v$$

** $P_h \propto V^{1.6}$

** $P_h \propto f^{-0.6}$

V.V.I → From no load to full load hyteresis losses are constant. Since, in the mathematical representation of hystersis loss, load component of current is not present.

→ The power taken by the transformer for continuous reversal of dipole direction is called as hyteresis loss.

→ Lohys → means low hyteresis material are preferred for the construction of core.

Eddy Current Losses. (P_e)

When a magnetic core carries a time varying flux, voltage are induce in all possible path enclosing the flux. The result is the production of circulating current in the core of the transformer. This current are known as

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eddy current. Eddy current produces heat which is undesirable for the operation of the transformer. This loss of energy is called eddy current loss and is given by

$$P_e = k_e B_{max}^2 f^2 t^2 v$$

where, k_e → eddy current constant whose value depends on the nature of the material.

B_{max} → max^m flux density in the magnetic material.

f → frequency of magnetic revers

t → thickness of lamination

v → volume of the magnetic mater

★ The eddy current loss can be minimize by using the laminated core.

Case I : $\frac{V}{f}$ = constant

$$P_e = k_e \left(\frac{V}{f}\right)^2 f^2 t^2 v$$

$$P_e \propto f^2$$

★★ $$P_e = B f^2$$

Case II : $\frac{V}{f}$ = variable

$$P_e = k_e \left(\frac{V}{f}\right)^2 f^2 t^2 v$$

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$$P_e = K_e \frac{V^2}{f^2} \times f^2 t^2 v$$

★★ $P_e \propto V^2$

Note :→ The eddy current losses are the constant from no load to full load, since no load component of current is not present in the mathematical expression.

V.V.I → When $\frac{V}{f}$ ratio is variable eddy current losses are independent of frequency.

★ The losses in the iron core due to the conductivity of the core are called as the eddy current losses.

$$P_e \propto I_I^2 R_I$$

$I_I \propto \sigma$ (conductivity)

$R_I \propto \frac{1}{\sigma}$

$$P_e \propto \sigma^2 \times \frac{1}{\sigma}$$

★★ $P_e \propto \sigma$

Note : $K_e = \frac{\pi}{6} \times \sigma$

$$P_e = K_e B_m^2 f^2 t^2 v$$

$2f \uparrow \quad t/2 \downarrow$

50 Hz − 0.5 mm

60 Hz = 0.35 mm

$f \propto \frac{1}{t}$

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Copper Losses / Ohmic / Variable losses (P_{cu})

Copper losses is the I^2R losses which take place in the primary and secondary windi[ng] because of the winding resistance. Hence the total copper losses in the transforme[r] are equal to the primary winding copper loss + secondary winding copper loss.

∴ Total copper losses = Primary winding copp[er] loss + secondary winding copper l[oss]

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

Total copper losses in terms of equivalent primary winding resistance

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

$$= I_1^2 (R_1 + R_2')$$

$$= I_1^2 R_{01}$$

Total copper losses in term of equivalent secondary winding resistance

$$= I_2^2 (R_2 + R_1')$$

$$= I_2^2 R_{02}$$

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To reduce power loss in the winding

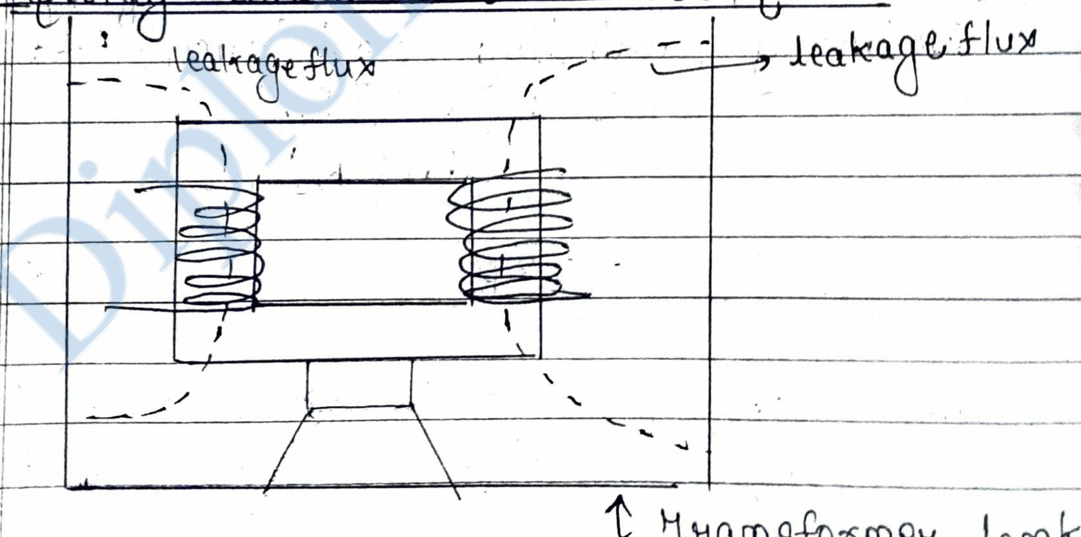
1. Winding should made up of good conductive material (copper).
2. Winding should made up of multistrained wire.
3. Copper losses are depends on load magnitude. Hence this losses are also called as variable losses.

Stray Load Losses.

Stray load losses are of two types.

i) Stray load iron losses.
ii) Stray load copper losses

Stray load iron losses.



The losses which are produced in the auxiliary parts of the transformer (transformer tank, conservator, input & output leads (terminal), bolts, etc.) are

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called as stray load iron losses.

→ To reduce stray load iron losses, half of the H.V winding is accomodated on first leg half of the H.V winding is accomodated on second leg and LV winding also distribute equally on two legs, thereby coefficient of coupling between the coil is increased.

Stray Load Copper Losses

localized current
↓
Stray load 'cu'-losses.

→ The power loss is due to localized current in the winding is called as stray load copper loss.

→ To reduce the above losses multistrained wires are used.

Note:→ The stray load losses are approximately 0.5 % of the full load losses so it is neglected.

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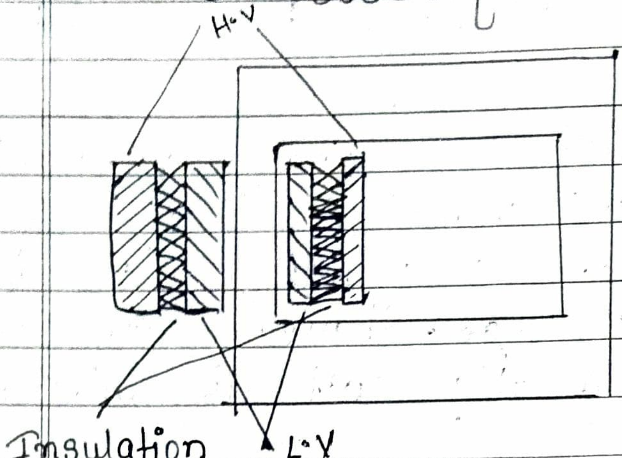
Dielectric Losses.



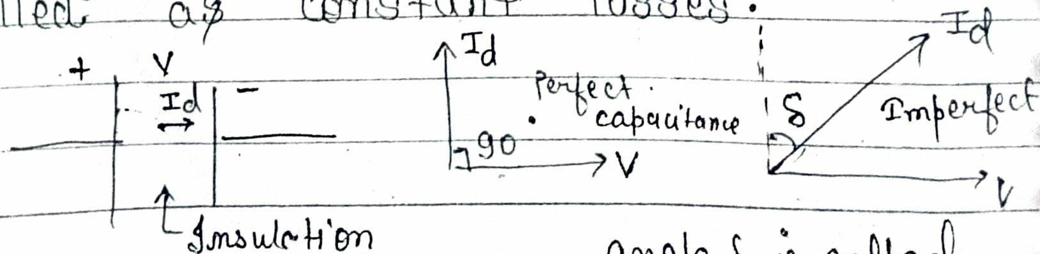
Insulation
↳ a) Solid
b) Liquid (Transformer oil)

→ Dielectric losses occurs in insulating material i.e in the transformer oil (liquid insulation) and the solid insulation of high voltage transformer.

→ The dielectric losses are approximately 0.25 % of the full load losses, so it can be neglected.

→ When tanδ (index of insulation) is high material is having poor insulating property.

→ Dielectric loss depends upon induced voltage. Hence, this losses are also called as constant losses.



angle δ is called loss angle.

δ = loss angle

Power loss = $VI\cos\phi$

$\therefore \quad P_d = VI_d \cos(90-\delta)$

$$P_d = VI_d \sin\delta$$

Efficiency Of The Transformer.

- The efficiency of the transformer is defined as the ratio of output power to input pow. It is denoted by η

i.e Efficiency $\eta = \dfrac{\text{output power}}{\text{input power}}$

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

$$= \frac{\text{Input power - losses}}{\text{Input power}}$$

- Since, the output power is always less than the input power. Due to losses in the transformer efficiency of the practical transformer are usually very high (95 to 99 %). The efficiency of the ideal transformer will be equal to (1 or 100 %) because the losses in ideal transformer will be zero.

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Again,

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

$$\frac{1}{\eta} = \frac{\text{output power + losses}}{\text{output power}}$$

$$\frac{1}{\eta} = 1 + \frac{\text{losses}}{\text{output power}}$$

$$\boxed{\text{losses} = \left(\frac{1}{\eta} - 1\right) \times \text{output power}}$$

Also,

$$\eta = \frac{\text{Input power - losses}}{\text{Input power}}$$

$$\eta = 1 - \frac{\text{losses}}{\text{Input power}}$$

$$\boxed{\text{Losses} = (1-\eta) \times \text{Input power}}$$

Again, The output power at full load

$$= V_2 I_2 \cos\phi_2 \text{ Watt}.$$

This can be expressed in terms of kVA rating as :-

$$\text{output power at full load} = \frac{V_2 I_2 \times 1000 \cos\phi_2}{1000}$$

$$= (\text{kVA}) \cos\phi_2 \times 1000 \text{ watt}$$

$$\boxed{\text{output power at full load} = \text{kVA} \cos\phi_2 \text{ kW}}$$

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If the copper loss is denoted by Pcu and Iron loss by P_I then the efficiency is given by

$$\text{Efficiency}, \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_{cu} + P_I}$$

$$\text{Efficiency at full load } \eta_{FL} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_{cu} + P_I}$$

$$= \frac{kVA \cos\phi_2 \times 1000}{kVA \cos\phi_2 \times 1000 + P_{cu} + P_I}$$

	Current	Copper loss	Iron loss
Full load	I	I^2R	P_I
½ - load	$I/2$	$\frac{I^2R}{4}$	P_I
x - load	xI	$(xI)^2 \cdot R$ x^2I^2R	P_I

General Expression for Efficiency.

$$\text{Efficiency } \eta_{x\,load} = \frac{x V_2 I_2 \cos\phi_2}{x V_2 I_2 \cos\phi_2 + x^2 P_{cu} + P_I}$$

Note:-

- When the load is decrease then the current changes and voltage remains constant.

Condition for Maximum Efficiency.

To determine the condition of maximum efficiency, let u

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assume that the power factor remain constant and secondary terminal voltage is constant. Therefore efficiency becomes only a function of load current.

Since, we know that the efficiency of a transformer is given by.

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_{cu} + P_I}$$

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

$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \left(I_2 R_{02} + \frac{P_I}{I_2}\right)}$$

The transformer being operated at constant terminal voltage and constant power factor. Obviously the efficiency will be maximum when $\left(I_2 R_{02} + \frac{P_I}{I_2}\right)$ is minimum.

i.e. $\frac{d\eta}{dI_2} = 0$.

$$\Rightarrow \frac{d}{dI_2}\left(I_2 R_{02} + \frac{P_I}{I_2}\right) = 0$$

$$\Rightarrow R_{02} - \frac{P_I}{I_2^2} = 0$$

$$\Rightarrow \boxed{R_{02} I_2^2 = P_I}$$

$P_I \neq P_{cu}$ (not accurate)

$\boxed{P_{cu} = P_I}$ $\Rightarrow$ Variable losses = constant losses.

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→ Hence, the efficiency of the transformer is max^{m} when the variable loss is equal to constant lo

Note: $P_I = I_2^2 R_{02}$, we cannot write like this because constant losses is not equal to variable losses.

Load Current At Max^{m} Efficiency

Since, we know that the efficiency of the transformer is max^{m} when the variable losses is equal to constant losses

$$P_{cu} = P_I$$

$$I_2^2 R_{02} = P_I$$

$$I_2^2 = \frac{P_I}{R_{02}}$$

$$\boxed{I_2 = \sqrt{\frac{P_I}{R_{02}}}}$$ ← current corresponding to max^{m} efficiency w.r.t secondary.

Similary

$$\boxed{I_1 = \sqrt{\frac{P_I}{R_{01}}}}$$ ← current corresponding t max^{m} efficiency w.r.t primary.

$$I_2 = \sqrt{\frac{P_I}{R_{02}}}$$

$$I_2 = I_{FL}\sqrt{\frac{P_I}{I_{FL}^2 R_{02}}}$$

$$\boxed{I_2 = I_{FL}\sqrt{\frac{P_I}{P_{cuFL}}}}$$

I_2 = load current at max^{m} η

I_{FL} = full load current

$$I_{FL} = \frac{\text{Rated KVA} \times 1000}{\text{secondary terminal voltage}}$$

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★ KVA At Max^m Efficiency :

Since, we know that,

$$I_2 = I_{FL}\sqrt{\frac{P_I}{P_{cuFL}}}$$

$$V_2 I_2 = V_2 I_{FL}\sqrt{\frac{P_I}{P_{cuFL}}}$$

$$\boxed{(kVA)_{(max^m)} = (kVA)_{FL\,(rated)}\sqrt{\frac{P_I}{P_{cuFL}}}}$$

★ Power Factor Vs Efficiency.

To determine the condition of Power factor at which efficiency is max^m. Let us assume that the secondary terminal voltage V_2 and load current I_2 is constant. Therefore, efficiency depends only on a function of ϕ_2.

Since, we know that the efficiency of transformer is

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_{cu} + P_I}$$

At max^m efficiency

$$P_{cu} = P_I$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + 2P_I} \quad \text{—— (1)}$$

Differentiating eq^n i) w.r.t ϕ_2 and equate it to 0 we get

$$\frac{d\eta}{d\phi_2} = 0$$

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$$\frac{d}{d\phi_2}\left(\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + 2P_I}\right) = 0$$

$$\Rightarrow \left(V_2 I_2 \cos\phi_2 + 2P_I\right)\cdot\left(-V_2 I_2 \sin\phi_2\right) - \left(V_2 I_2 \cos\phi_2\right)\left(-V_2 I_2 \sin\phi_2\right)$$

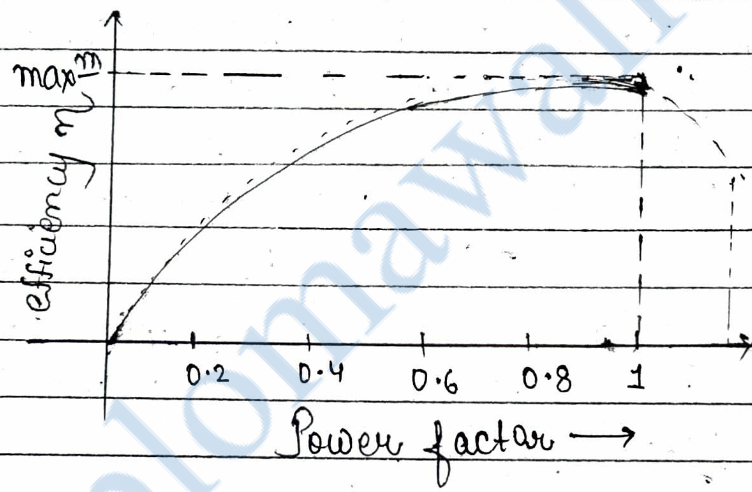
$$\Rightarrow -V_2^2 I_2^2 \cos\phi_2 \sin\phi_2 - 2P_I V_2 I_2 \sin\phi_2 + V_2^2 I_2^2 \cos\phi_2 \sin\phi_2 = 0$$

$$= -2P_I V_2 I_2 \sin\phi_2 = 0$$

$$\sin\phi_2 = 0$$

$$\phi_2 = \sin^{-1}(0) = 0$$

$$\therefore \boxed{p.f = \cos\phi_2 = \cos 0 = 1}$$



Note :

- From the above graph it is concluded that the efficiency of the transformer is max^m at unity power factor.

Efficiency Vs Load Curve

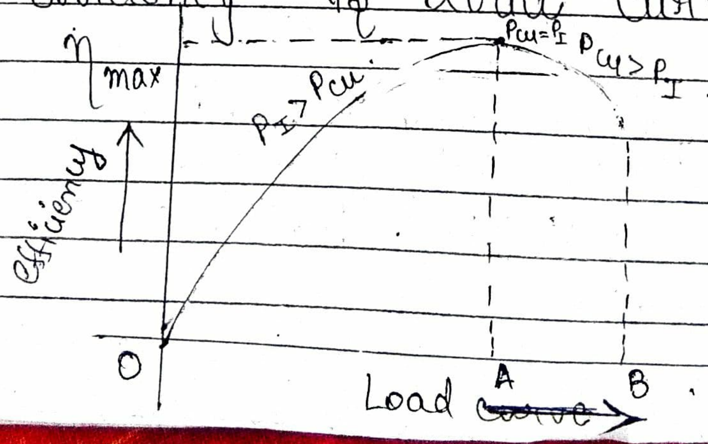


Fig: Efficiency of load curve

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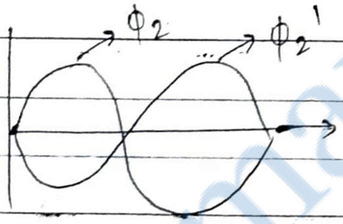
Note :→

- When iron losses are greater than copper losses if the load on the transformer is increase, Efficiency of the transformer increases

- When copper losses are greater than iron losses, if the load of the transformer is increased, then efficiency of transformer is decrease.

GATE :→ A transformer is operating at full load 0.8 p.f lagging. The efficiency of transformer is 90%. When transformer is operating at full load, 0.8 pf leading, find the efficiency of the transformer. (a) 90% , b) 92% , c) 88% ✓ d) 60%)

Solⁿ

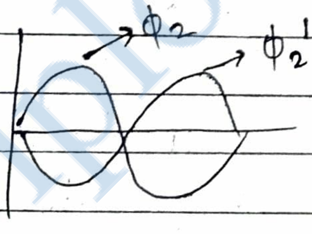


Here $\phi_2 > \phi_2'$

$\phi_N = \phi - \phi_2 + \phi_2'$

$\phi_N \downarrow$ (Demagnetizating)

$P_h \downarrow \; P_e \downarrow \quad \eta = 90\%$



Here $\phi_2' > \phi_2$

$\phi_N = \phi - \phi_2 + \phi_2'$

$\phi_N \uparrow$ (magnetization)

$P_h \uparrow P_e \uparrow \; \eta \downarrow$

Testing Of Transformer

The efficiency and regulation of a transformer are calculated by two type of test.

i) Direct test (Direct loading test)

ii) Indirect test

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a) Open ckt test (O.C test)

b) Short ckt test (S.C test)

(c) Back to back te (Sumpner's te

iii) Polarity test.

Note :- The direct loading test is used to find the effici and regulation of the transformer.

- (O.C and S.C test) are carried out to obtained the equivalent ckt component and losses.

Identical transformer.

- Sumpner's test is used to find total powe losses at full load without actually loadin the transformer.
- Polarity test is useful to understand the phase relation between primary and secondary winding.

Direct test (Direct loading test)

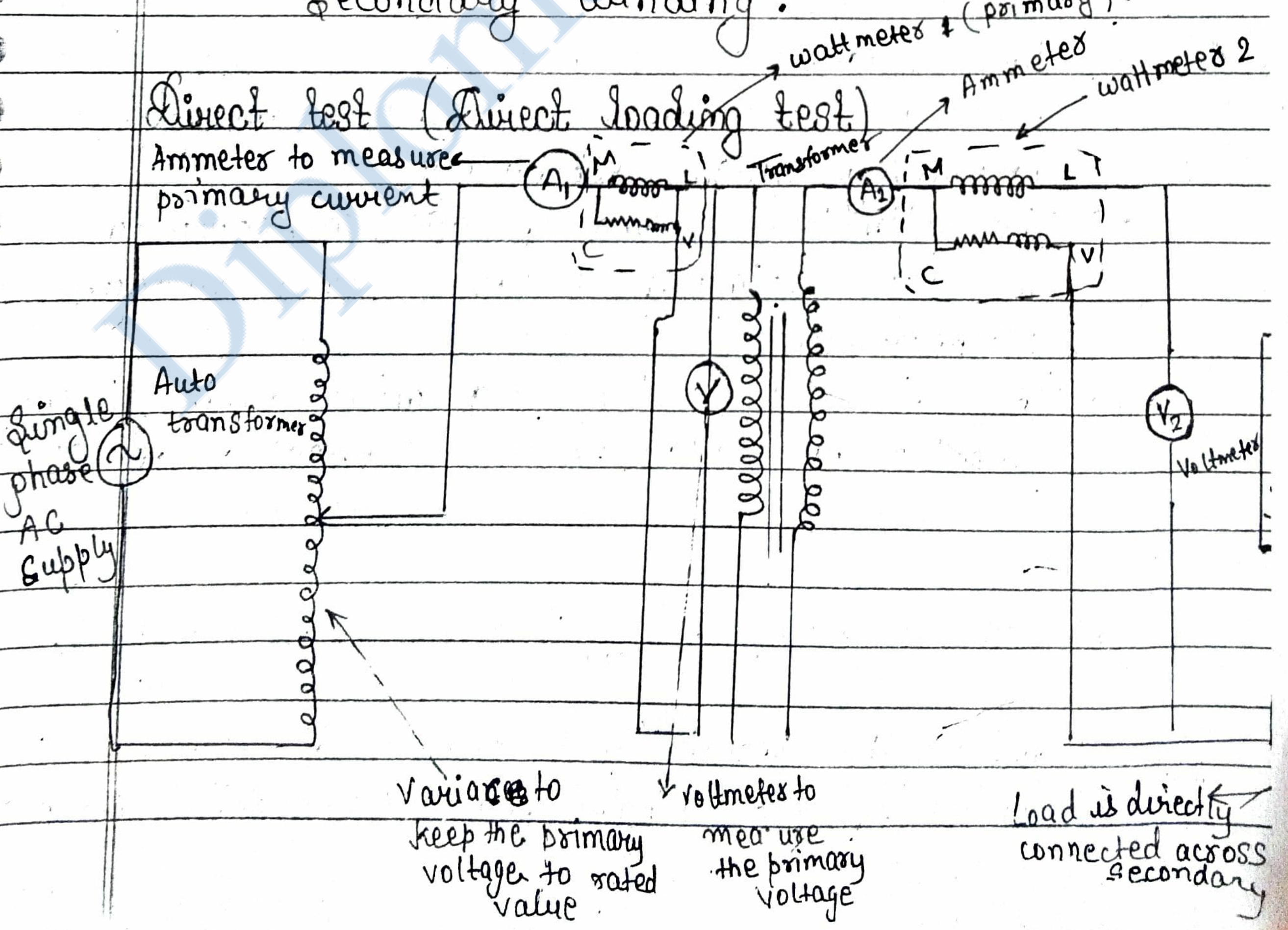

Fig: Experimental set-up to determine regulation and efficiency.

We can obtain the values of effeciency and regulation by using the direct loading method. In this method, the secondary winding is directly connected across the load for which regulation and efficiency are to be obtained. The experimental setup for this is shown in figure.

Description of the step up.

→ A variac is connected across the single phase AC supply in order to keep the primary voltage constant to its rated value.

→ Ammeters A_1 and A_2 are used to measure the primary and secondary currents respectively.

→ Two wattmeters W_1 and W_2 are used to measure the power on the primary and secondary sides respectively.

→ The voltmeter V_1 and V_2 are connected to measure primary voltage & load voltage respectively.

→ The load for which regulation and efficiency are to be obtained is connected across the secondary as shown in figure.

- Procedure for efficiency measurement.

→ Connect the desire load across the secondary.

→ Switch on the single phase AC supply connected

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across variac and adjust to get the rated primary voltage (measure by voltmeter V_1)

→ Measure the primary and load power by means of W_1 and W_2 respectively and calculate the % efficiency as follows.

$$\% \eta = \frac{\text{output power delivered to the load}}{\text{Input power}} \times 100$$

$$\boxed{\% \eta = \frac{W_2}{W_1} \times 100}$$

Note: $W_1 = V_1 I_1 \cos\phi_1$
$W_2 = V_2 I_2 \cos\phi_2$.

Procedure Of the regulation measurement.

→ Donot connect the load. This is the no load condition ($I_2 = 0$, $E_2 = V_2$)

→ Switch on the AC power supply and adjust the variac to obtain the rated primary voltage V_1. Measure the voltage V_2, this voltage is called as the no load voltage.

Therefore, $E_2 = V_2$ (under No-load condition)

→ Switch off the AC supply and connect the desired load.

→ Turn ON the power supply again and measure V_2. This voltage is the full load secondary voltage. Calculate the regulation as.

$$\% \text{ regulation} = \frac{V_{2NL} - V_{2FL}}{V_{2NL}} \times 100$$

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

Note :-

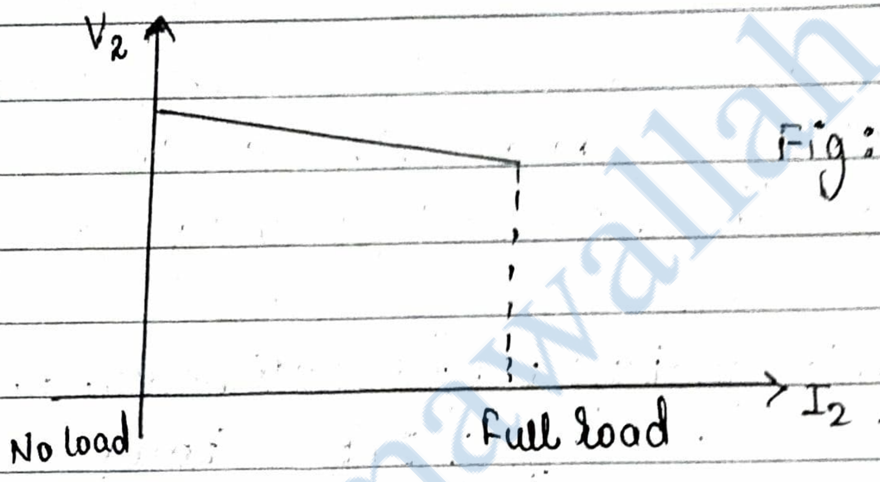

Fig : graph b/w V_2 & I_2

Load ↑ I ↑ I_{XL} ↑
V_{reg} ↓

ii) Direct test is economical only for low rating machine.

iii) The direct load method cannot be used for finding the equivalent ckt parameters (I_0, I_w, I_μ) of transformer.

iv) To overcome the above difficulty for higher rating of the transformer to predetermine regulation and efficiency at different load condition, indirect test are used.

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Indirect Test

1. Open circuit test (O.C test) (Iron loss finding)

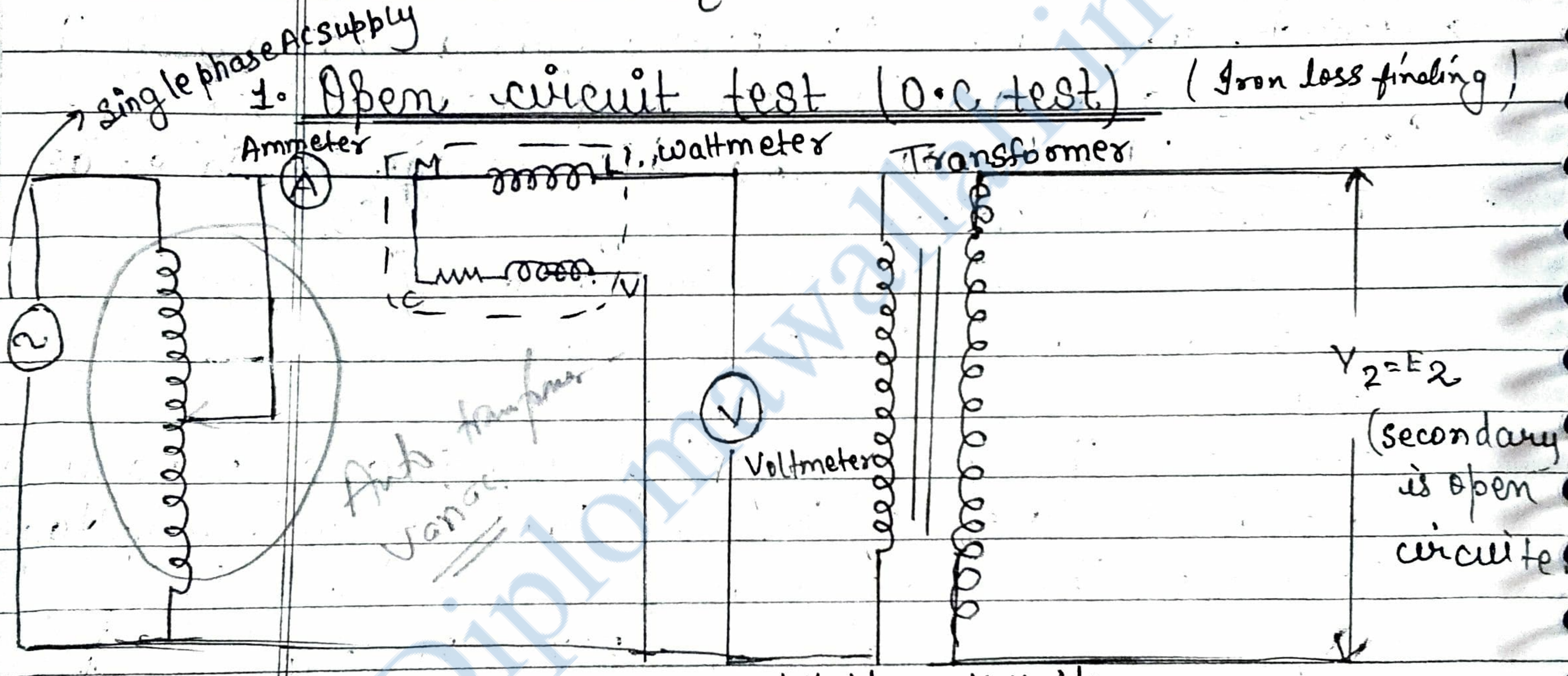

Fig: Experimental set-up for O.C test

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→ Experimental setup for OC test of transformer is shown in fig. The primary winding of the transformer is connected to rated AC volt by means of using a variac.

→ A voltmeter is connected across the primary winding to measure the primary voltage.

→ An ammeter is used for measuring the primary current and the wattmeter is connec to measure the input power.

→ The secondary is open ckted because it is an OC test. Sometime a voltmeter is connected acro the secondary to measure $V_2 = E_2$

→ Note that the AC supply voltage is generally applied to the low voltage side and H.V sid is used as secondary which is open circuited.

→ Procedure.

→ Connect the circuit as shown in the fig.

→ Keep the variac at its minimum voltage position.

→ Switch on the AC supply and adjust the variac to get the rated primary voltage as measured by voltmeter V across the primar

→ Now, measure the primary current and powe using the ammeter A and wattmeter W respectively.

→ The two component of no load current I_0 are $I_\mu = I_0 \sin\phi_0$, $I_w = I_0 \cos\phi_0$.

→ The no load power factor is given by $\cos\phi_0$ and the input power at no load is given by

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

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3(c)

→ The no load current I_0 is very small as compared to full load current.

→ The no load current I_0 is about 3 to 5% of the full load current.

→ As I_2 is zero, the secondary copper loss is zero. The primary copper loss will be negligible because I_0 is very small.

→ Therefore total copper loss is very small. and can be assumed to be equal to '0'. Hence, the wattmeter reading W_0 represents the iron loss.

$$\boxed{W_0 = P_I = \text{Iron losses}}$$

Calculations Of Parameters.

Ammeter = I_0
Voltmeter = V_1
Wattmeter = W_0.

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

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

$$\therefore I_w = I_0 \cos\phi_0$$
$$I_\mu = I_0 \sin\phi_0$$

and $R_0 = \dfrac{V_1}{I_w}$ $\quad X_0 = \dfrac{V_1}{I_\mu}$.

Note: Generally in open circuit test in the LV winding meters are connected and HV winding is open circuited. Due to following advantages.

1. At low rated voltage itself desired iron losses are obtained.

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used in S.C
Series
brand
param

2. It is possible to measure accurately no load current of L.V winding.

→ To conduct OC test. The following meters are us
a) Wattmeter - LPF (Low power factor)
b) Voltmeter - Rated voltage of LV
c) Ammeter - low rating.

→ The value of cos ϕ_0 is very small therefore it is necessary to use Low power factor type wattmet to avoid any possibility of error in measuremen

Short Circuit Test.

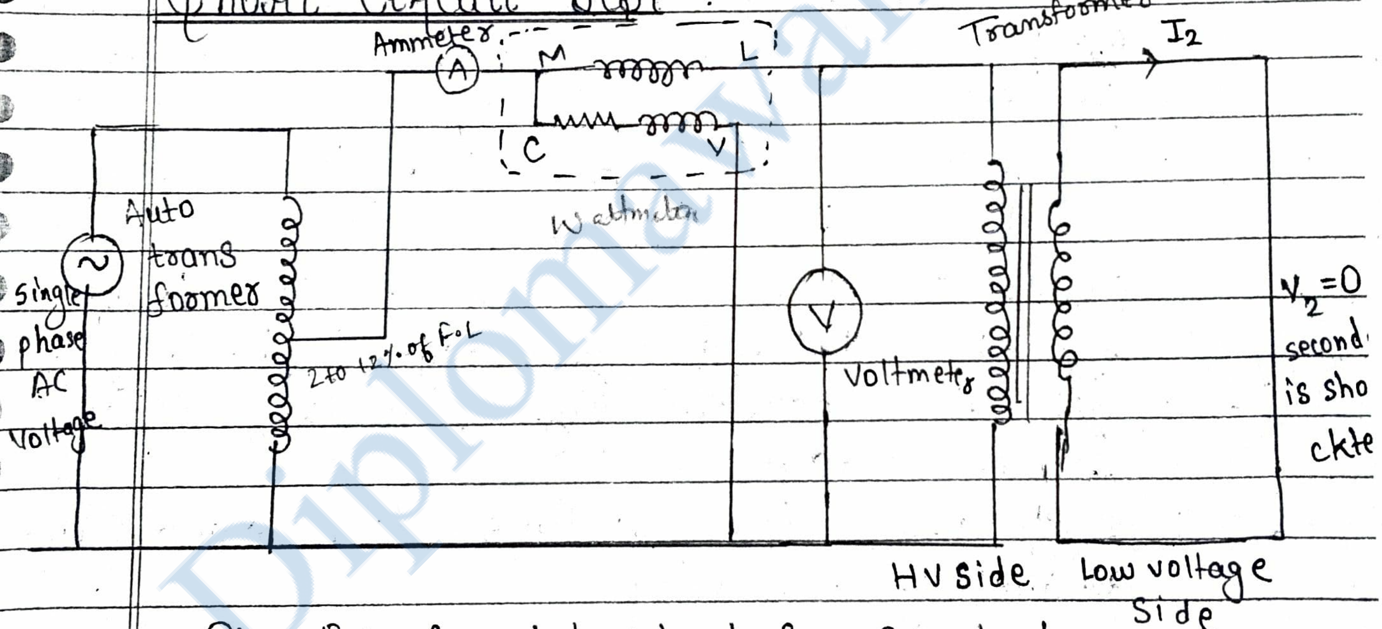

Fig: Experimental set up for SC test.

→ The experimental set up for carrying out the S.C te on a transformer is shown in fig

→ Variac is used to adjust the input voltage to the rated voltage if required.

→ The voltmeter is connected to measure the primar voltage (V_{SC}

→ The ammeter measure the S.C rated primary current (ISC) and the wattmeter measure the S.C input power (Wsc).
→ Secondary is short ckt with the help of thick copper wire.
→ Generally, the high voltage side is connected to the A.C supply and low voltage high current side is shorted.

Procedure :

→ Connect the ckt as shown in figure.
→ Short ckt the secondary which is a low voltage high current, low resistance winding
→ Keep the variac at its minimum voltage position and switch on the AC supply voltage.
→ Increase the primary voltage gradually and adjust it to get the primary current equal to the rated value Isc. Donot increase the primary voltage further.
→ Vsc is approximately 2 to 12 % of full load voltage.
→ Note down the wattmeter, voltmeter and ammeter reading.

Parameter's Calculation

→ The primary and secondary current are the rated current, therefore, the total copper loss is the full load copper loss
→ Iron losses are a function of applied voltage. As the applied voltage in S.C test is small

The iron losses will be negligibilly small.

Ammeter = I_{sc}
Voltmeter = V_{sc}
Wattmeter = W_{sc}

Since,

$$W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}$$

$$\cos\phi_{sc} = \frac{W_{sc}}{V_{sc} I_{sc}} \simeq 0.6$$

Note: Power factor of the transformer during S.C test is 0.6 lagging.

$$W_{sc} = I_{sc}^2 R_{sc}$$

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2}$$

and,

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

also,

$$Z_{sc}^2 = R_{sc}^2 + X_{sc}^2$$

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

Note: While conducting S.C test generally meters are connect in the H.V side, since at low rated current itself copper losses are obtained.

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By connecting O·C or S·C test either in L·V side or in H·V side reading of the wattmeter is same

→ To conduct the S·C test the following meters are required i) Ammeter (low rated current)
ii) Voltmeter (low rating)
iii) Wattmeter UPF (unity power factor)

→ By conducting S·C test copper losses and series parameter of transformer are obtained.

→ To find the efficiency of the transformer both O·S and S·C test are conducted.

Polarity test.

Polarity of transformer

1. The transformer works on the principle of mutual induction.

→ The direction of winding decide the polarity of the mutually induce emf, but practically it is not always possible to draw the coil as per their winding directions.

→ Hence, to indicate the winding direction easily dot convenction are used.

→ If two coils are mutually coupled then the terminal bearing the dots will be having in phase induced voltages, such dots are marked on winding of the transformer as shown in fig.

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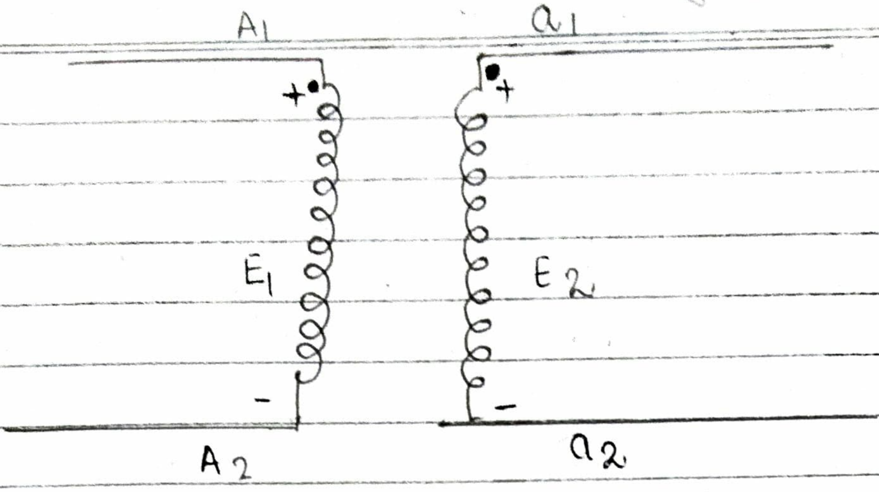


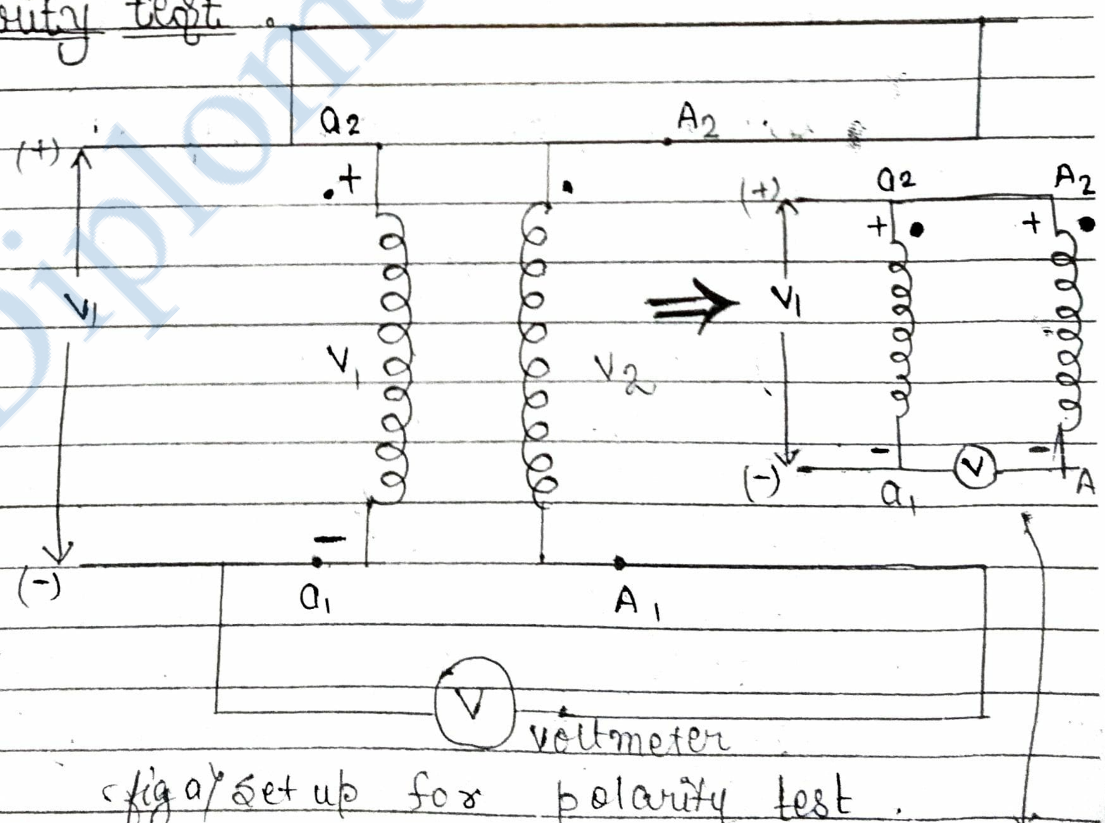
Fig polarity marking

→ The dots are marked on the primary and secondary winding so as to indicate the similo polarity ends of the two windings.

→ The similar polarity ends of the two winding are those ends which becomes simultaneous +ve & -ve when the emf is induced in them

→ For example points A_1 and a_1 are simultaneous +ve

Polarity test.



(fig a) Set up for polarity test.

fig b) Equivalent ckt arrangement

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→ The polarity test is carried out in order to determine the relative polarity of the two windings of a transformers.

→ The set up for the polarity test is shown in fig. It shows that the ~~two winding are con~~ voltmeter is connected in series across the two winding. The equivalent ckt of this connection is shown in figure.

→ If the polarities of the winding voltages are as shown in figure B, then the voltmeter reading is

$$V = V_1 - V_2$$

B'

$$V = V_2 - V_1$$

→ And if the voltmeter reads $V = V_1 + V_2$ Then the polarity marking on one of the winding should be interchanged.

→ In this way the polarity of two windings of the transformer are identical.

All day Efficiency Of The transformer

We have already defined the power effeciency of a transformer

$$\text{i.e } \eta = \frac{\text{output power}}{\text{Input power}}$$

But for the distribution transformer the power efficiency doesn't give the ~~true~~ idea about the transformer performance. Hence, especially type of effeciency called as All day efficiency or energy efficiency is specially defined as follows

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i.e. % All day η = $\frac{\text{output energy in kwh perday}}{\text{input energy kwh perday}}$

η_{Allday} = $\frac{\text{output energy in kwh perday}}{(\text{output energy in kwh per day}) + (\text{Energy spen perday (for to loss}}$

Note :- All day efficiency is calculated only for distribution transformer.

→ $\eta_{commercial} > \eta_{all\ day}$

Auto Transformer

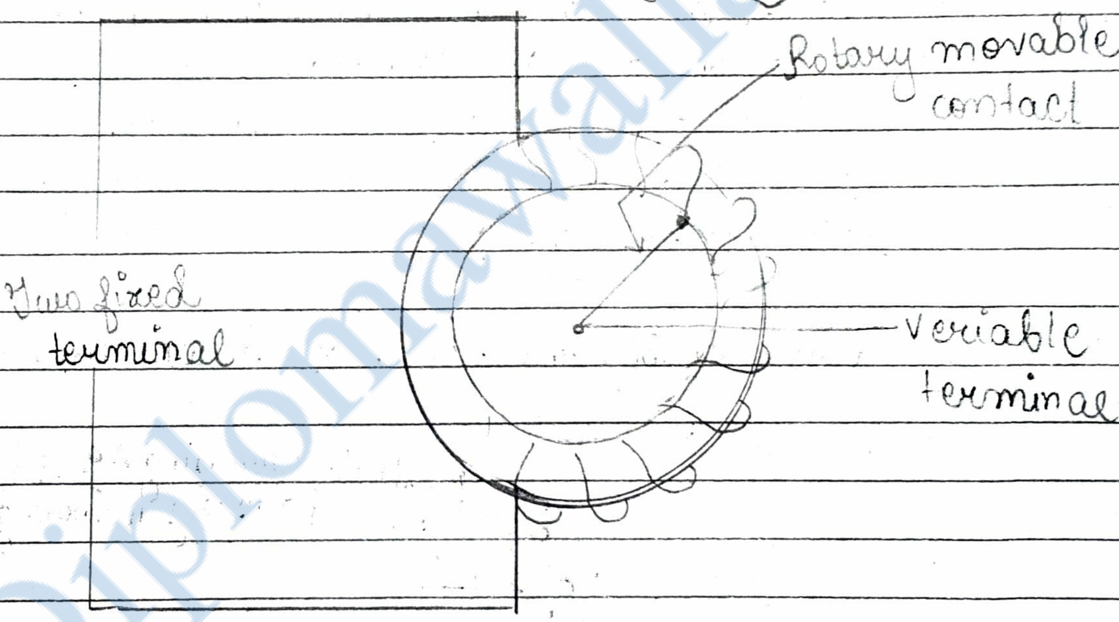

Fig : construction of an auto transformer

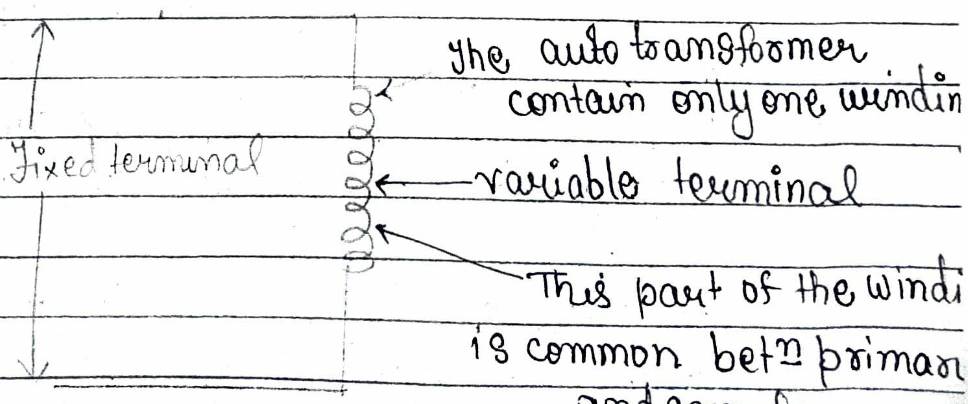

Fig : Symbol of an auto transformer.

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→ The normal transformer has seperate primary and secondary winding but the auto transformer is a special transformer in which a part of the winding is common for the primary and secondary winding.

→ The construction of an auto transformer is shown in fig. It consist of only one winding wound on a laminated magnetic core with a rotary movable contact.

→ Thus, from the auto transformer three terminals are brough out for connection.

→ The autotransformer can operate as a step down or a step up transformer.

→ The symbol of an auto transfo

⇒ Auto-transformer a step-down transformer

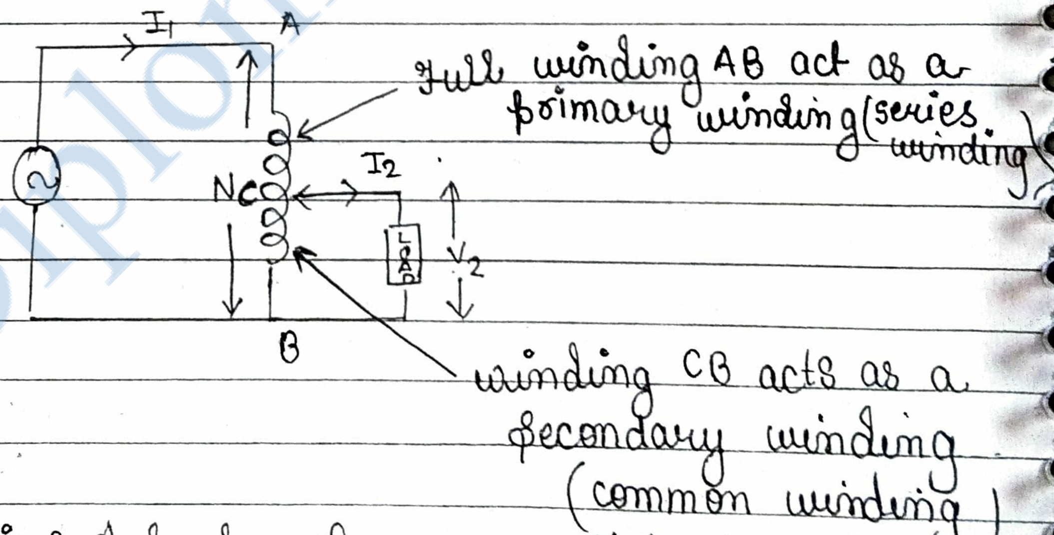

Fig: Auto-transformer as step-down transformer

The connection of auto-transformer as a step down transformer is shown in fig. It

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shows that the two fixed terminal A and B are connected to singal phase AC supply 'V_1'. Thus, winding AB acts as a primary winding (Series windings). A part of the complete winding act as a secondary winding (common winding) across which the load is connected.

The operating principle of an auto transformer is same as that of the normal transformer. Therefore, the load voltage for this configuration is given by, V_2

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

where, N_2 = Number of turn corresponding to secondary i.e CB

N_1 = Number of turns corresponding to primary i.e AB.

As the number of turns corresponding to winding CB i.e N_2 is less than that of winding AB that is N_1. So this configuration operates as step-down transformer.

→ If we neglect the losses, the magnetising current and leakage reactances then the transformation ratio

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

where,

I_1 = primary current

I_2 = secondary current

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⇒ Auto-transformer as step-up transformer.

Figure shows the connection of an auto transformer for operating as step-up transformer

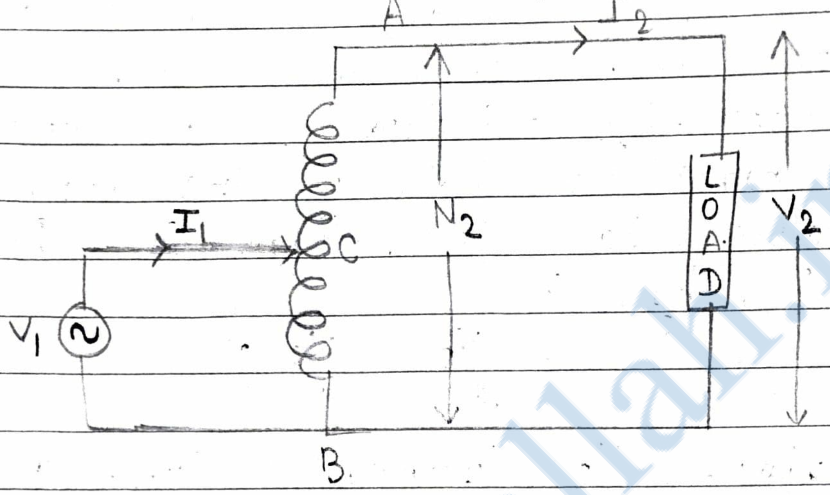

Fig: Auto-transformer as step-up transformer

→ The part CB of the complete winding acts as the primary winding. The AC voltage V_1 is applied between terminal C and B.

→ The full winding AB acts as the secondary winding and the load is connected between these terminal.

→ As the number of turns of winding AB that is N_2 is higher than the number of turns of winding CB that is N_1. Thus, the autotransformer now acts as a step-up transformer.

→ Neglecting the loss magnetising current and the leakage reactances the load voltage is given by

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

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Advantages of an auto transformer.

→ As only one winding is used the copper mater required for the transformer is very less.

→ The size and hence the cost is reduced as compare to the conventional transformer.

→ The losses taking place in the winding are reduc hence the efficiency is higher than the convent ional transformer.

→ Due to reduced resistance the voltage regulation is better than conventional transformer.

Disadvantages of an auto transformer.

→ If the common point of the winding breaks (open circuited) then the transformer action is loss and the full primary voltage appears across the secondary

→ It posses a low impedance hence, if the secondary circuit is short circuited then a large current will flow on the secondary side

→ There is no electrical isolation between the prima and secondary winding this can prove dangerous for high voltage application.

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Application Of An Auto-transformer.

* It can be used as a variac that is variable AC supply to vary the AC voltage applied to the load smothly.

* In order to start the AC machine such as induction motors or syndronus motors.

* In the distribution system to compensate the voltage drop, auto transformer is used as a boostor.

* To vary the supply voltage as per requirements of a furmance.

* As a dimmerstate :- when the variac is used to control the intensity of lamps in the cinema halls or on the stage of play etc, it is called as a dimmerstat.

Comparision Of Two Winding And Auto-transformer.

S. No	Parameter	Two winding transformer	Auto transformer
1.	Winding	primary & secondary winding are separated.	a part of winding is common betn primary and secondary

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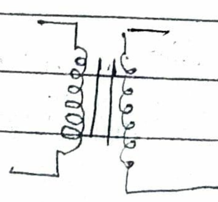
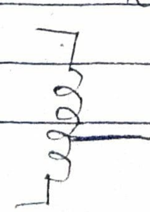
2.	Movable contacts	No movable contact	there is a movable conto
3.	Copper saving	Nun	Copper savir takes place
4.	Possibility of getting a variable secondary voltage	No	Yes
5.	Electrical isolation	Yes	No
6.	Size	Large	small
7.	Cost	high	low
8.	Loss in the winding	high	low
9.	Efficiency	low	high
10.	Regulation	poor	better
11.	Application	Main transformer, isolation transformer, power supply, welding	variac star of AC mot atlmme st
12.	Type	It can operate as step-up or step-down	It can wo as stepu or step do
13.	Symbol		

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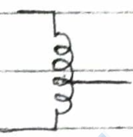
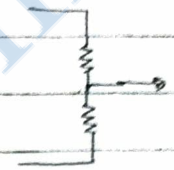
Comparision between Power transformer and distribution transformer.

S.No.	Power transformer	Distribution transformer
1.	voltage level is greater than 33kV	voltage level is less than 33kV
2.	voltage fluctuation is very less since this transformer is located in substation and main station.	More voltage fluctuation are present since, transformer is nearer to the consumer
3.	It is operated at full load condition.	load on the transformer depends on load cycle
4.	Core is made up of CRGO material.	Core is made up of silicon steel.
5.	Max^{m} flux density of the core is 1.6 to 2wb/m^2	Max^{m} flux density of core is 1 to 1.2 wb/m^2
6.	Specific weight is less	Specific weight is light
7.	Operation is depends on only on power.	Operation is depends on power & time
8	Iron losses are more.	Iron losses are less
9.	It is connected in a system based on load demand	It is connected in a system irrespectively of the load demand it is connected for full day

10.	Winding is designed are such that copper losses are less.	Copper loss are more

Comparision between auto-transformer and potential divider.

S.No	Parameter	Auto-transformer	Potential divider
1.	Symbol		
2.	Winding	One	None.
3.	Movable contact	Yes	No
4.	Type	Step up or step down	only step down
5.	Copper saving	Yes	No.
6.	Electrical isolation	No	No
7.	Power loss	Low	high
8.	Efficiency	high	Low
9.	Application	variac, starting of AC motor etc.	voltage reduction
10.	Cost	high	low.

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	Size	large	large.
11.	Transfer of power	due to induction and conduction	due to conduction
12.	Magnitude of O/P voltage	higher or lower or equal to the I/P voltage	always less than or at the most equal to I/P voltage

Q: A single phase transformer has 200 and 100 turn respectively in its secondary & primary winding. The resistance of primary winding is 0.05 Ω and that of secondary is 0.3 Ω. Find the resistance of i) primary winding referred to secondary. ii) secondary winding referred to primary, also find the equivalent resistance of transformer referred to the primary.

Solⁿ Given $n_2 = 200$

$n_1 = 100$

$R_1 = 0.05$

$R_2 = 0.3\ \Omega$

1. Resistance of primary winding referred to secondary

$$R_1' = \left(\frac{N_2}{N_1}\right)^2 \cdot R_1$$

$$= \left(\frac{200}{100}\right)^2 \times 0.05 = 0.2\ \Omega$$

2. Resistance of secondary winding referred to primary

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$$R_2' = \left(\frac{N_1}{N_2}\right)^2 \cdot R_2$$

$$= \left(\frac{100}{200}\right)^2 \cdot 0.3 = 0.075\ \Omega$$

(3.) Equivalent resistance referred to primary is

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

$$R_{01} = 0.05 + 0.075 = 0.125\ \Omega.$$

Also,

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

$$= 0.3 + 0.2 = 0.5\ \Omega.$$

Q:→ A transformer has 4% resistance and 6% reactance drop. Find the voltage regulation at full load

i) 0.8 power factor lagging

ii) 0.8 power factor leading

iii) Unity power factor

Solⁿ Given $\%R = 4$ → $R_{pu} = 0.04$

$\%X = 6$, $X_{pu} = 0.06$.

(a) At 0.8 p.f lagging

$$\cos\phi_2 = 0.8$$

$$\sin\phi_2 = 0.6$$

$$\%\ \text{regulation} = R_{pu}\cos\phi_2 + X_{pu}\sin\phi_2$$

$$= 0.04 \times 0.8 + 0.06 \times 0.6$$

$$= 0.068 \text{ or } 6.8\%$$

b) At 0.8 P.f leading

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

$$\%\ \text{regulator} = R_{pu}\cos\phi_2 - X_{pu}\sin\phi_2$$

$$= 0.04 \times 0.8 - 0.06 \times 0.6$$

$$= -0.004 \text{ or } -0.4\%.$$

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(c) At unity P.f

% reg = R_{pu}

= 0.04 or 4 %

Q:→ A 220/1100 V single phase transformer has a resistance of 0.6 Ω and leakage reactance is 1.5 Ω both referred to high voltage side. Find the P.f at which regulation is 0. The full load Primary current is 30 A.

Soln $\frac{V_1}{V_2} = \frac{220}{1100}$, $R_2 = 0.6$, $X_2 = 1.5\ \Omega$, $I_1 = 30A$.

% reg = 0 p.f = ?

We know that

$$\%\ regulation = R_{pu}\cos\phi_2 + X_{pu}\sin\phi_2$$

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

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

$$= \frac{220}{1100} \times 30 = 6A.$$

$$\Rightarrow 0 = \frac{6\times 0.6}{1100}\cos\phi_2 + \frac{6\times 1.5 \times \sin\phi_2}{1100}$$

$$\Rightarrow \frac{-6\times 0.6}{1100}\cos\phi_2 = \frac{6\times 1.5}{1100}\sin\phi_2$$

$$\tan\phi_2 = -0.4$$

$$\phi_2 = -\tan^{-1}(0.4)$$

$$= -21.92\ \text{(leading)}$$

the -ve sign indicates leading P.f.

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and power factor,

$$\cos\phi_2 = \cos(-21.92)$$
$$= 0.92 \text{ (leading)}$$

Q:→ A 5 kVA, 440/220 V single phase transformer ha a primary and secondary winding resistanc of 2 Ω and 0.8 Ω respectively. The primary an secondary reactances are 10 Ω and 1.5 Ω respectiv Find the secondary terminal voltage at full load at 0.8 p.f lagging.

Soln Given, output kVA = 5, $R_1 = 2\Omega$ $R_2 = 0.8$

$\frac{E_1}{E_2} = \frac{440}{220}$ $X_1 = 10\Omega$ $X_2 = 1.5$

$\cos\phi_2 = 0.8$ (lagging)

$\sin\phi_2 = 0.6$

Let E_2 be the terminal voltage at no load and V_2 be the terminal voltage at full lo

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

Equivalent resistance referred to secondary

$$R_{02} = R_2 + R_1'$$
$$= R_2 + \left(\frac{N_2}{N_1}\right)^2 \cdot R_1$$
$$= 0.8 + \left(\frac{220}{440}\right)^2 \times 2 = 1.3\Omega$$

Equivalent reactance referred to secondary

$$X_{02} = X_2 + X_1'$$
$$= 4\Omega$$

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Again $I_2 = \frac{O/P}{E_2} = \frac{5\times10^3}{220} = 22.73\ A$

$\therefore V_2 = 220 - (22.73\times1.3\times0.8) - (22.73\times4\times0.6)$

$V_2 = 141.80$ Volt.

Q:→ A 500 kVA, single phase transformer 2000/200 V, 50 Hz transformer has high voltage resistance 0.2 Ω and a leakage reactance of 0.4 Ω. The low voltage winding resistance is 0.002 Ω and leakage reactance of 0.008 Ω, Find →

i) The equivalent winding resistance and reactance referred to high voltage side and ii) low voltage side

iii) The equivalent resistances and reactance drops in volts and in % of the rated winding voltages expresses in terms of high voltage quantities.

Soln Output kVA = 500 kVA = 500×10^3

$\frac{V_1}{V_2} = \frac{2000}{200}$ $R_1 = 0.2$ $R_2 = 0.002$

$X_1 = 0.4$ $X_2 = 0.008$

i) Equivalent resistance referred to primary side (HVS)

$R_{01} = R_1 + R_2'$

$= R_1 + \left(\frac{N_1}{N_2}\right)^2 \cdot R_2$

$= 0.2 + \left(\frac{2000}{200}\right)^2 \cdot 0.002$

$= 0.2 + 100\times0.002 = 0.4\ \Omega$

Equivalent reactance referred to primary side

$X_{01} = X_1 + X_2'$

$= 0.4 + \left(\frac{N_1}{N_2}\right)^2 \cdot X_2$

$= 0.4 + 100\times0.008 = 1.2\ \Omega$

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Equivalent resistance referred to secondary side

$$R_{02} = R_2 + R_1' \Rightarrow R_2 + \left(\frac{N_2}{N_1}\right)^2 \cdot R_1$$

$$\Rightarrow 0.002 + \left(\frac{200}{2000}\right)^2 \times 0.2 = 0.004$$

Equivalent reactance referred to secondary side

$$X_{02} = X_2 + X_1' = X_2 + \left(\frac{N_2}{N_1}\right)^2 \cdot X_1$$

$$= 0.008 + \left(\frac{200}{2000}\right)^2 \times 0.4 = 0.012$$

Equivalent resistance drop referred to high voltage s

$$\Rightarrow I_1 R_{01} = 250 \times 0.4 = 100\ V$$

Equivalent reactance drop referred to high voltage

$$= I_1 X_{01} = 250 \times 1.2 = 300\ V$$

% equivalent resistance drop referred to h.v sid

$$= \frac{I_1 R_{01}}{V_1} \times 100 = \frac{100 \times 100}{200} = 5\%.$$

% Equivalent reactance drop referred to H.V sid

$$\frac{I_1 X_{01}}{V_1} = \frac{300}{2000} \times 100 = 15\%.$$

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Q. At 400 V and 50 Hz, the total core loss of a transformer was found to be 2400 watt. When the transformer is supplied at 200 V and 25 Hz. The core loss is 800 W. Calculate the hystresis & eddy current loss at 400 V and 50 Hz.

Solⁿ Given,

Case I. $\frac{V_1}{f_1} = \frac{400}{50} = 8$.

$P_{I_1} = 2400$ W.

Case II $\frac{V_2}{f_2} = \frac{200}{25} = 8$.

$P_{I_2} = 800$ W

Since we know that when V/f = constant.

$P_I = P_h + P_e$

$P_I = af + bf^2$.

$2400 = a \times 50 + b(50)^2$.

$2400 = 50a + 2500b$ —— (1)

$P_I = P_h + P_e$.

$= af + bf^2$.

$800 = a \times 25 + 625b$.

$25a + 625b = 800$ —— (2)

Solving (1) & (2)

$a = 16$ $b = 0.64$

$P_h = af = 16 \times 50 = 800$ watt.

$P_e = bf^2 = 0.64 \times 625 = 1600$ watt

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Q:→ In a transformer, the core loss is 100 watt at 40 Hz, and 72 W at 30 Hz Find the hystresis and eddy current losses at 50 Hz.

Sol^n $P_I = af + bf^2$

Case I : $100 = 40a + 1600b$ —— ①

Case II : $72 = 30a + 900b$ —— ②

Solving ① & ②.

$a = 2.1$ $b = 0.01$

$\therefore$ $P_h = af = 2.1 \times 50 = 105$ watt

$P_e = bf^2 = 0.01 \times (50)^2 = 25$ watt.

Q:→ A 2300/230 V, 500 kVA, 50 Hz distribution transformer has core loss of 1600 watt at rated voltage and copper loss 7.5 kW at full load. During the day it is load as follows :-

% load	0%	20%	50%	80%	100%	125%
P.f	~~0.7 lag~~	0.7 lag	0.8 lag	0.9 lag	1	0.85 la
hours	2	4	4	5	7	2

Determine the all day efficiency of the transformer

Sol^n η_{allday} ? Given, $\frac{V_1}{V_2} = \frac{2300}{230}$ output kVA = 500

$f = 50$ Hz $P_I = 1600$ watt

$P_{cu} = 7.5$ kW.

Total energy output over 24 hours period is given into

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% Load (x)	P.f	KVA cos φ x	kW	hr	output Energy kWh
20%	0.7	500×0.7×0.2	70	4	280
50%	0.8	500×0.8×0.5	200	4	800
80%	0.9	500×0.9×0.8	360	5	1800
100	1	500×1×1	500	7	3500
125	0.85	500×0.85×1.25	531.25	2	1062.5
					7442.5 kWh

Therefore total energy output over 24 hours period excluding 2 hours at no load

$W_o = 7442.5$ kWh.

The various energy losses in the winding of the transformer can be calculated as given in the following table.

% rated load	x	Cu loss $x^2 P_u$	hrs	Energy loss in the winding ($x^2 P_{cu} \cdot hrs$) kWh
20%	0.2	$(0.2)^2 \times 7.5$	4	1.2
50%	0.5	$(0.5)^2 \times 7.5$	4	7.5
80%	0.8	$(0.8)^2 \times 7.5$	5	24
100%	1	$(1)^2 \times 7.5$	7	52.5
125%	1.25	$(1.25)^2 \times 7.5$	2	23.44
			Total =	108.64 kWh

Total copper loss in the transformer winding for 24 hours excluding 2 hours at no load.

$W_{cu} = 108.64$ kWh.

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Total iron loss or core loss for 24 hours including 2 hours at no load.

$$W_I = 1600 \times 24$$
$$= 38.4 \text{ kWh}$$

Total energy loss in 24 hours

$$= W_{cu} + W_I$$
$$= 108.64 + 38.4$$
$$= 147.04 \text{ kWh}$$

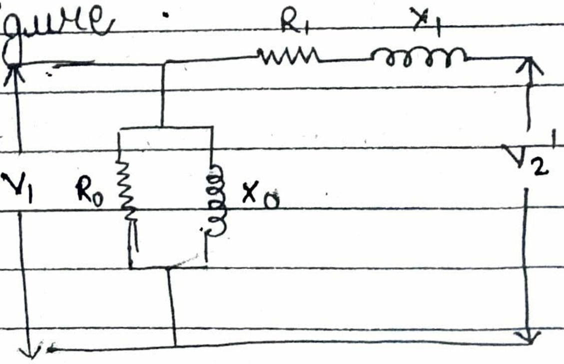
Therefore

All day efficiency $\eta = \dfrac{W_{out}}{W_{out} + W_{cu} + W_I}$

$$= \frac{7442.5}{7442.5 + 147.04}$$

$$\boxed{\eta = 98.06\,\%}$$

Q. Calculate the values of R_0, X_0, R_1 and X_1 in the diagram show in figure of a single phase 8 kVA, 220/440 V, 50 Hz transformer of which the following are the test results.



open ckt test :-

220 V, 0.9 A, 90 W on the low voltage side.

Short ckt test

20 V, 15 A, 100 W on the high voltage side.

Given, output kVA = 8 kVA

$\frac{V_1}{V_2} = \frac{220}{440}$ V

$f = 50$ Hz

Open ckt test

$V_1 = 220$V

$I_0 = 0.9$

$P_0 = 90$W

Short ckt test

$V_{SC} = 20$V

$I_{SC} = 15$A

$P_{SC} = 100$ W

From open ckt test

$P_0 = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \frac{P_0}{V_1 I_0} = \frac{90}{220 \times 0.9} = 0.4545$

$\sin\phi_0 = 0.89$.

$I_\mu = I_0 \sin\phi_0 = 0.9 \times 0.89 = 0.80$

$I_w = I_0 \cos\phi_0 = 0.9 \times 0.4545 = 0.40$

$\therefore R_0 = \frac{V_1}{I_w}$ $X_0 = \frac{V_1}{I_\mu}$

$= \frac{220}{0.409} = 537.83\Omega$, $= \frac{220}{0.801} = 274.65\Omega$

From, Short Circuit test

$R_{02} = \frac{P_{SC}}{I_{SC}^2} = \frac{100}{(15)^2} = 0.44\Omega$

$Z_{02} = \frac{V_{SC}}{I_{SC}} = \frac{20}{15} = 1.33\Omega$.

$X_{02} = \sqrt{Z_{02}^2 - R_{02}^2}$

$= \sqrt{(1.33)^2 - (0.44)^2}$

$= 1.253\Omega$.

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Figure shows the equivalent resistance & reactance referred to the low voltage side or primary si

$$R_1 = R_{02}' = R_{02}\left(\frac{N_1}{N_2}\right)^2$$

$$= 0.44\left(\frac{220}{440}\right)^2 = 0.111\,\Omega$$

$$X_1 = X_{02}' = X_{02}\left(\frac{N_1}{N_2}\right)^2$$

$$= 1.253 \times \left(\frac{220}{440}\right)^2$$

$$= 0.313\,\Omega$$

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Q Short ckt test performmed on the H.V side of a 100KVA, 6600/440 V, single phase transformer yield the following results.

100 V, 6 A, 200 W ← Sc test. If the low voltage side i delivering full load current at 0.85 powerfacto lagging and at 440 V, find the voltage applied to the H.V side.

Solⁿ Given,

output KVA = 100 $\quad \frac{V_1}{V_2} = \frac{6600}{440}$ volt

$V_{sc} = 100\,V \quad I_{sc} = 6A \quad P_{sc} = 200\,W \quad P.f_{L.V} = 0.8$ (la

$V_{LV} = 440$

$$R_{01} = \frac{P_{sc}}{I_{sc}^2} = \frac{200}{(6)^2} = 5.55\,\Omega$$

$$Z_{01} = \frac{V_{sc}}{I_{sc}} = \frac{100}{6} = 16.67$$

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2} = \sqrt{16.67^2 - 5.55^2} = 15.71\,\Omega$$

Secondary rated current $= \frac{100 \times 10^3}{440} = 227.27$

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If E_2 and V_2 be the secondary terminal voltage under no load or full load condition then

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

And,

$$R_{02} = R_{01} \times \left(\frac{N_2}{N_1}\right)^2$$

$$= 5.55 \times \left(\frac{440}{6600}\right)^2$$

$$= 0.02467\ \Omega$$

$$X_{02} = X_{01} \times \left(\frac{N_2}{N_1}\right)^2$$

$$= 15.7 \times \left(\frac{440}{6600}\right)^2$$

$$= 0.0698\ \Omega$$

$$E_2 - 440 = 227.27 \times 0.02467 \times 0.8 + 227.27 \times 0.0698 \times 0.6$$

$$E_2 = 454.003 \text{ volt}$$

Hence, the voltage applied to H.V side

$$E_1 = \left(\frac{N_1}{N_2}\right) E_2$$

$$= \frac{6600}{440} \times 454.003$$

$$= 6810 \text{ volt}$$

Q. A single phase 50 kVA, 2400/120 V, 50 Hz transformer gave following test results

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OC test (instrument on L.V side) ~~Secondary~~ primary. Iron

O.C 120 V, 9.85 A, 396 W

S.C test (instrument on H.V side) Primary. coppe

92 V, 20.8 A, 810 W

Calculate — i) The equivalent ckt constant,

ii) Efficiency at rated VA and P.f 0.8

iii) Voltage regulation.

Sol^n Given

$$kVA\ output = 50\ kVA$$

$$\frac{V_1}{V_2} = \frac{2400}{120}\ V$$

$$f = 50\ Hz$$

OC Test (L.V side)

$$\cos\phi_0 = \frac{P_0}{V_1 I_0} = \frac{396}{120 \times 9.85} = 0.335$$

$$\phi_0 = 70.42^\circ$$

$$\sin\phi_0 = 0.94$$

$$I_w = I_0 \cos\phi_0$$

$$= 9.85 \times 0.335 = 3.299\ Amp$$

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

$$= 9.85 \times 0.94 = 9.259\ Amp$$

$$R_0 = \frac{V_1}{I_w} = \frac{120}{3.299} = 36.37\ \Omega$$

$$X_0 = \frac{V_1}{I_\mu} = \frac{120}{9.259} = 12.96\ \Omega$$

from $R_{01} = \frac{P_{sc}}{I_{sc}^2} = \frac{810}{(20.8)^2} = 1.872\ \Omega$

$$Z_{01} = \frac{V_{sc}}{I_{sc}} = 4.423\ \Omega$$

$$X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2} = 4\ \Omega$$

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ii) Efficiency at rated VA is

$$\eta = \frac{50\times10^3\times0.8}{50\times10^3\times0.8+396+810}$$

$= 0.9707$

$= 97.07\%$

iii) Voltage regulation.

$$\%\ Reg = \frac{I_1R_{01}\cos\phi + I_1X_{01}\sin\phi}{V_1}\times100$$

$$I_1 = \frac{50\times10^3}{2400} = 20.83$$

$$= \frac{20.83\times1.872\times0.8+20.83\times4\times0.6}{2400}\times100$$

$= 3.38\%$

The maximum efficiency of a 500 kVA, 3300/500, 50 Hz single phase transformer is 0.97 pu and occurs at 75% full load and unity Power factor. if the leakage impedance is 10%, calculate the voltage regulation at full load p.f 0.8 lag.

Sol^m Output kVA = 500 kVA. $\frac{V_1}{V_2} = \frac{3300}{500}$ $f = 50\ Hz$

$\eta_{max} = 0.97\ pu$. $x = 75\%$ $\cos\phi_0 = 1$

$Z_{pu} = 10\% \Rightarrow 0.01\ pu$, V. Regulation = ? P.f = 0.8

Also. max^m Efficiency

$P_{cu} = P_I$

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$$\eta_{max} = \frac{x \, VA \cos\phi_0}{x \, VA \cos\phi + 2P_I}$$

$$0.97 = \frac{0.75 \times 500 \times 10^3 \times 1}{0.75 \times 500 \times 10^3 \times 1 + 2P_I}$$

$$P_I = 5799 \text{ watt}$$

At max^m efficiency $P_I = x^2 P_{cu}$

$$x = \sqrt{\frac{P_I}{P_{cu}}}$$

$$0.75^2 = \frac{5799}{P_{cu}}$$

$$P_{cu} = \frac{5799}{(0.75)^2}$$

$$= 10309 \text{ watt}$$

$$\% \, V.R. = (R_{pu} \cos\phi_2 + X_{pu} \sin\phi_2) \times 100$$

$$R_{pu} = \frac{I_2 R_{02}}{V_2}$$

$$= \frac{I_2^2 R_{02}}{V_2 I_2}$$

$$R_{pu} = \frac{P_{cufl}}{V_2 I_2}$$

$$= \frac{10309}{500 \times 100} = 0.02061 \text{ pu}$$

$$X_{pu} = \sqrt{Z_{pu}^2 - R_{pu}^2} = \sqrt{(0.1)^2 - (0.02061)^2}$$

$$= 0.9785 \text{ pu}$$

$$V.R. = 7.52\% \text{ or } 0.0752$$

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Parallel Operation Of Transformer

* Advantages of parallel operation of transformer

a(b)
1. Based on required future demand it is possible to increasing rating of the system.

2. Reliability of the system is high (if any one of the transformer is subjected to fault other transformer will maintain continuity of the supply).

3. Based on the load demand only number of transformer are connected in parallel (under light load condition few transformer are disconnected from the system thereby efficiency of the system increases and cost of the system decreases).

4. Maintanence is easy.

* Necessary Condition for the parallel operation of the transformer.

1. Terminal voltages of all the transformer should be equal.
2. Polarity of the transformer should be identical.
3. $\left(\frac{X}{R}\right)$ ratio of the transformer should be equal.
4. KVA rating of the transformer should be equal.

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kVA rating of the transformer is inversly proportional to impedance of the transformer

** i.e $kVA \propto \frac{1}{Z}$

5 Turns ratio of the transformer should be equal

Effect

Note: In the above condition if first two condition are not satisfied then it is not possible to operate transformer in parallel.

ii) If the third condition is not satisfied operating power factor of 1'st transformer is different from operating power factor of 2nd transformer.

iii) If the fourth condition is not satisfied, load distribution between the transformer is not equal.

iv) If the fifth condition is not satisisfied, induced voltage of the transformer are unequal, it leads to produced circulating current between the transformer.

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