Unit 4:
Polyphase AC Circuit and Single Phase Transformer (Q No. 3 and Q. No. 4)

Part A: Polyphase AC Circuit

1. State the advantages of three phase ac system over single phase ac system.

Ans: There are several reasons why three-phase system is superior to single-phase system.

(i) The rating of three-phase motor and three-phase transformer are about 150% greater than single-phase motor or transformer with a similar frame size.

(ii) The power delivered by a single-phase system pulsates. The power falls to zero, three times during each cycle. The power delivered by a three-phase circuit pulsates also, but it never falls to zero. So in three-phase system, power delivered to the load is same at any instant. This produces superior operating characteristics for three-phase system.

(iii) To transmit certain amount of power at a given voltage over a given distance, three-phase transmission line requires less amount of copper than single-phase line. This reduces the cost of material required, hence, becomes economical.

(iv) Power factor of three-phase motor is greater than single-phase motor for same rating.

(v) Three-phase motors are self-starting, as the magnetic field produced by three-phase supply is rotating. But the magnetic field produced by single-phase system is pulsating, so most of the single-phase motors are not self-starting.

2. Define the following terms :

(i) Symmetrical System (ii) Phase sequence (iii) balanced load

Ans: **(i) Symmetrical System:** A three-phase system is said to be symmetrical when voltages of same frequency in different phases are equal in magnitude and displaced from one another by equal phase angles.

(ii) Phase sequence: A sequence in which three voltages will achieve their positive maximum values is called phase sequence.

(iii) Balanced load: The load is said to be balanced when loads in each phase are equal in magnitude and identical in nature.

3. Derive the relation between line and phase values of currents and voltages for balanced three phase star connected (Resistive/ Inductive/ Capacitive) load.

Ans: Consider the balanced star-connected load.

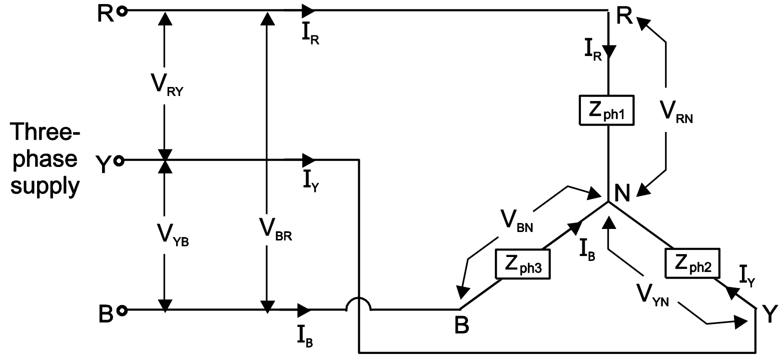


Fig. Circuit diagram

Line voltages, $V_L = V_{RY} = V_{YB} = V_{BR}$

Line currents, $I_L = I_R = I_Y = I_B$

Phase voltages, $V_{ph} = V_{RN} = V_{YN} = V_{BN}$

Phase currents, $I_{ph} = I_R = I_Y = I_B$

As path for line current, I_L and phase current, I_{ph} is same, $\boxed{I_L = I_{ph}}$

To derive relation between V_L and V_{ph}, let us consider line voltage $V_L = V_{RY}$.

$$\overline{V}_{RY} = \overline{V}_{RN} + \overline{V}_{NY}$$

as $$\overline{V}_{NY} = -\overline{V}_{YN}$$

Hence, $$\overline{V}_{RY} = \overline{V}_{RN} - \overline{V}_{YN} \dots \text{(i)}$$

Similarly, $$\overline{V}_{YB} = \overline{V}_{YN} - \overline{V}_{BN} \dots \text{(ii)}$$

$$\overline{V}_{BR} = \overline{V}_{BN} - \overline{V}_{RN} \dots \text{(iii)}$$

The phasor diagram will give relation between line voltage and phase voltage.

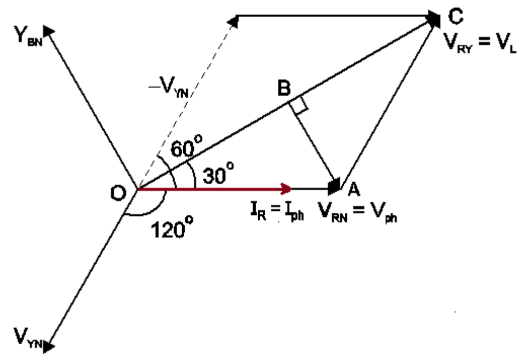


Fig. Phasor diagram for resistive load

As shown in Fig. take phase voltage V_{RN} as reference. The three-phase voltages are displaced by 120° from each other.

The phasor V_{RY} line voltage is addition of $\overline{V}_{RN}$ and $-\overline{V}_{YN}$, to get $-\overline{V}_{YN}$, $\overline{V}_{YN}$ is reversed.

The perpendicular is drawn from point A on phasor OC representing V_L. OB = BC = $\frac{V_L}{2}$

Angle between V_{RN} and – V_{YN} is 60^o.

So $\angle$ AOB = 30^o (OC bisects $V_{RN} \wedge -V_{YN}$)

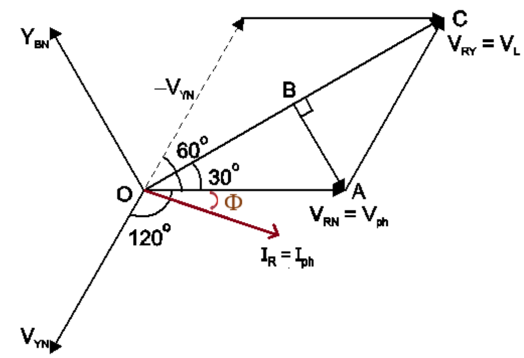
From Δ AOB, $$\cos 30 = \frac{OB}{OA} = \frac{\frac{V_{RY}}{2}}{V_{RN}}$$

$$\frac{\sqrt{3}}{2} = \frac{\frac{V_L}{2}}{V_{ph}}$$

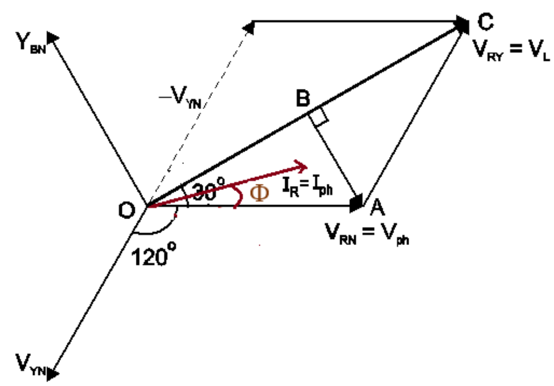
$$\boxed{V_L = \sqrt{3}\, V_{ph}}$$

Thus, line voltage is $\sqrt{3}$ times the phase voltage and line current and phase currents are same.

Phasor diagram for Inductive load



Phasor diagram for Capacitive load



4. Derive the relation between line and phase values of currents and voltages for balanced three phase Delta connected (Resistive/ Inductive/ Capacitive) load.

Consider the balanced delta-connected load.

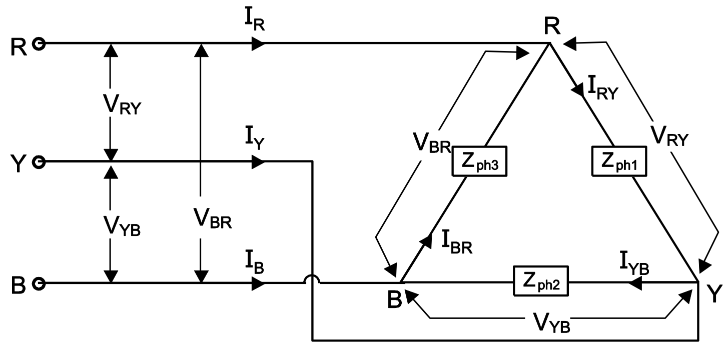


Fig. Circuit diagram

Line voltages, $V_L = V_{RY} = V_{YB} = V_{BR}$

Line currents, $I_L = I_R = I_Y = I_B$

Phase voltages, $V_{ph} = V_{RY} = V_{YN} = V_{BR}$

Phase currents, $I_{ph} = I_{RY} = I_{YB} = I_{BR}$

As seen earlier, $V_L = V_{ph}$ for delta-connected load. To derive relation between I_L and I_{ph}, apply KCL at the node R of the load as shown in Fig.

$$\Sigma \text{current entering} = \Sigma \text{ current leaving the node R}$$

$$\overline{I_R} + \overline{I_{BR}} = \overline{I_{RY}}$$

$$\overline{I_R} = \overline{I_{RY}} - \overline{I_{BR}} \qquad \text{... (i)}$$

Similarly, at node Y and node B, we get

$$\overline{I_Y} = -\overline{I_{RY}} \qquad \text{... (ii)}$$

$$\overline{I_B} + \overline{I_{BR}} = -\overline{I_{YB}} \qquad \text{... (iii)}$$

The phasor diagram will give relation between line current and phase current.

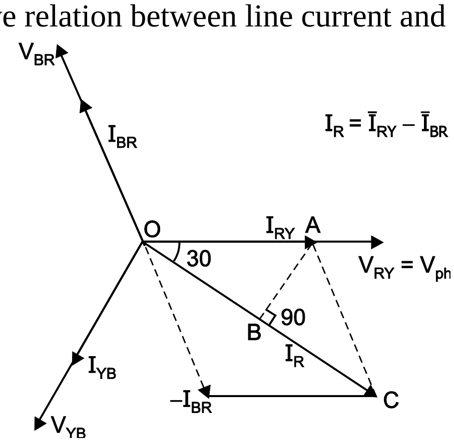


Fig. Phase diagram for resistive load

As shown in Fig., take phase voltage V_{RY} as reference. Three-phase voltages are displaced by 120^o from each other.

Consider resistive load. Draw I_{ph} in phase with V_{ph}. Angle between I_{RY} and $-I_{BR}$ is 60°. OC will bisect $I_{RY}\wedge -I_{BR}$. $\angle AOB = 30°$. Draw perpendicular on OC representing I_L.

$$OB = OC = \frac{I_R}{2} = \frac{I_L}{2}$$

$$\cos 30° = \frac{OB}{OA} = \frac{\frac{I_R}{2}}{I_{RY}} = \frac{\frac{I_L}{2}}{I_{ph}}$$

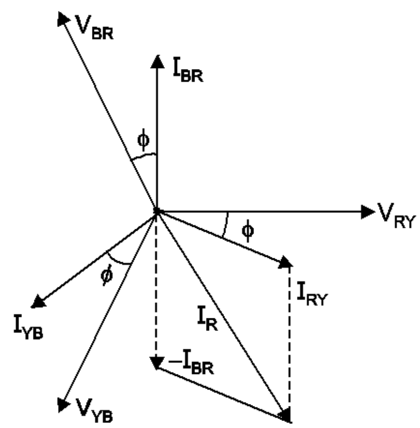
$$\frac{\sqrt{3}}{2} = \frac{\frac{I_L}{2}}{I_{ph}}$$

$$\boxed{I_L = \sqrt{3}\, I_{ph}}$$

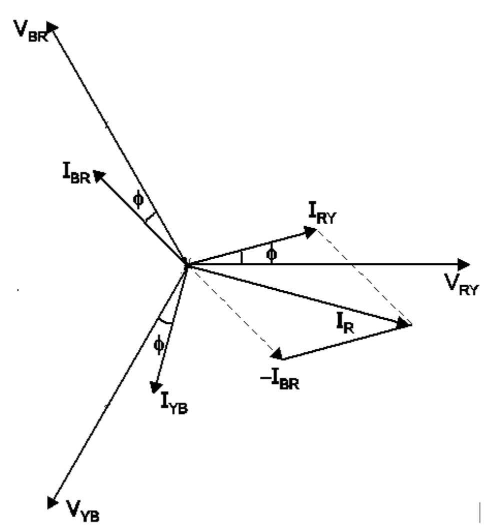
Line voltage V_L appears across load. Hence the voltage across load, V_{ph} is same as V_L.

$$\boxed{V_L = V_{ph}}$$

Phasor diagram for Inductive load



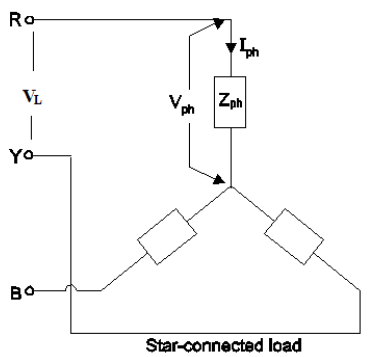
Phasor diagram for Capacitive load

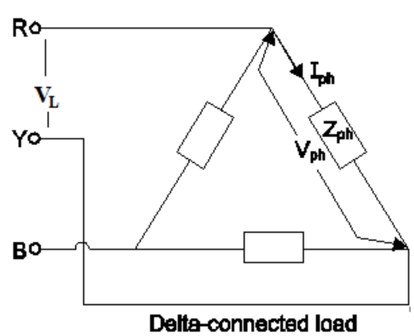


5. State the relations between line and phase values of voltages and currents in case of star and delta connected three phase system.

	Voltage Relation V_L(Line Voltage) & V_{ph}(Phase voltage)	**Current Relation** I_L(Line Current) & I_{ph}=(Phase Current)
Star Connection	$V_L = \sqrt{3} V_{ph}$	$I_L = I_{ph}$
Delta Connection	$V_L = V_{ph}$	$I_L = \sqrt{3} I_{ph}$

6. Prove that power taken by three phase delta connected balanced load is always three times to power taken by three phase star connected balanced load.





For Star $V_L = \sqrt{3} V_{ph}$, $I_L = I_{ph}$	For Delta $V_L = V_{ph}$, $I_L = \sqrt{3} I_{ph}$
$P_{(star)} = 3\, V_{ph}\, I_{ph} \cos\phi$	$P_{(Delta)} = 3\, V_{ph}\, I_{ph} \cos\phi$
$= 3 \times \frac{V_L}{\sqrt{3}} \times \frac{V_{ph}}{Z_{ph}} \times \cos\phi$	$= 3 \times V_L \times \frac{V_{ph}}{Z_{ph}} \times \cos\phi$
$= 3 \times \frac{V_L}{\sqrt{3}} \times \frac{V_L}{\sqrt{3}\, Z_{ph}} \times \cos\phi$	$= 3 \times V_L \times \frac{V_L}{Z_{ph}} \times \cos\phi$
$= \frac{V_L^2}{Z_{ph}} \times \cos\phi$	$= 3 \frac{V_L^2}{Z_{ph}} \times \cos\phi$

Single Phase Transformer

7. Define transformer and explain its working principle

Transformer can be defined as the static device which transfers electrical energy from one alternating current circuit to another circuit with desired change in voltage or current without change in frequency.

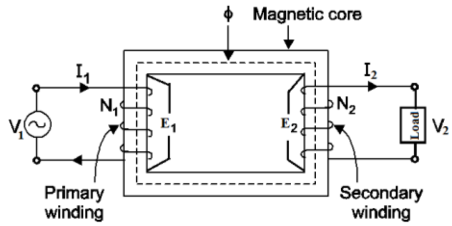
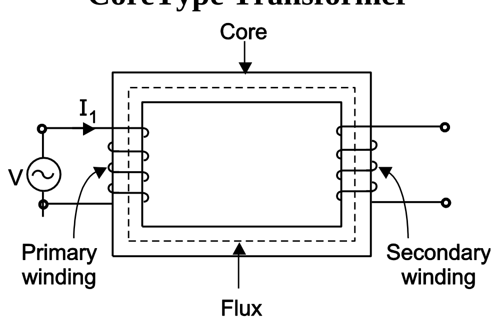
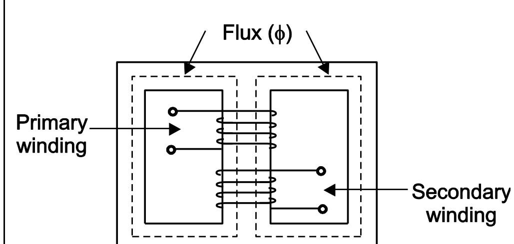


Figure: Basic Transformer

Consider the two coils with N_1 and N_2 be the number of turns say 1 and 2 wound on simple magnetic circuit. These coils are isolated from each other, and there is no electrical connection between them. The coil which is connected across the supply voltage is called as primary winding and the coil which delivers energy to the load is called as secondary winding. When the supply voltage (V_1) is applied across the coil 1, the current (I_1) starts flowing through it. This alternating current produces an alternating flux (Φ) in the magnetic core, which links the N_1 turns of coil 1 and induces anemf(E_1) in it, by self-induction. Assuming it is an ideal transformer, all the flux produced by coil 1 links the turns of coil 2. Thus, induces an emf(E_2) in coil 2 due to principle of mutual induction. As the coil 2 is connected to load, the alternating current (I_2) starts flowing through it. Thus the energy will be delivered to the load.

8. Compare core type and shell type transformer

<table>
<tr><th>Sr. No.</th><th>CoreType Transformer</th><th>ShellType Transformer</th></tr>
<tr><td>1.</td><td>

It has single magnetic circuit.</td><td>

It has double magnetic circuit.</td></tr>
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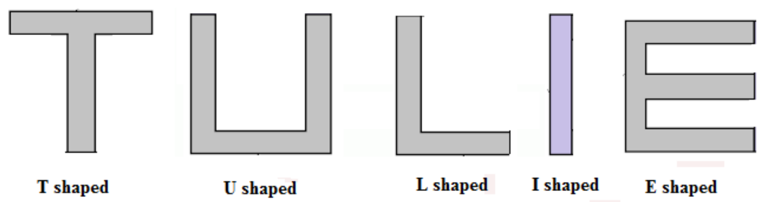
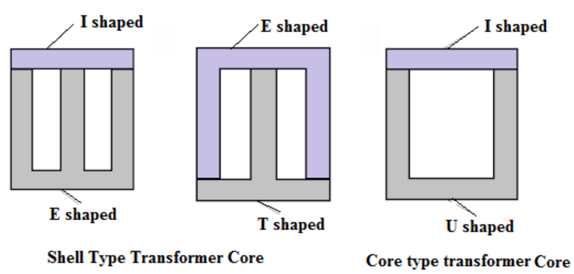
2.	Windings used in core type transformer are cylindrical in form.	Sandwich type windings are used.
3.	Core is surrounded by the winding.	The windings are surrounded by the core.
4.	It is easy for repair and maintenance.	It is difficult for repair and maintenance.
5.	Natural cooling is good.	Natural cooling is poor.

9. Explain different types of laminations used in transformer.

The magnetic core of the transformer is made up of laminations with a thickness of 0.35mm to 0.5 mm to form the frame required for Core type as well as shell type transformer. Laminated magnetic core is used to reduce eddy current losses. The laminations are cut in the form of a strip of T's, U's, L's, I's, E's and I's as shown in the figure.



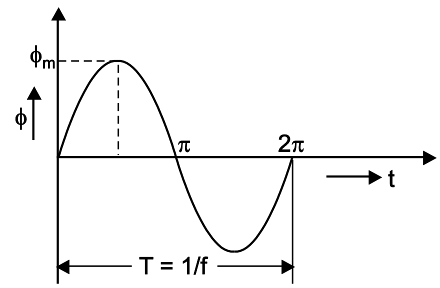
Typical combination of laminations used to form a magnetic core of core type and shell type transformer is shown below.



10. Derive the EMF equation of single phase transformer

When transformer primary winding is connected across the alternating current supply, the current starts flowing through it. This alternating current produces alternating flux which links with primary and secondary winding and induces an emf of E_1 and E_2 in it respectively. Magnitude of E_1 and E_2 can be derived using following method

Let us consider the flux waveform, as shown below



According to the Faraday's law of electromagnetic induction the average emfget induced in each turn.

Average emf induced in each turn = $\dfrac{d\phi}{dt}$

where, $d\phi$: be the change in flux and dt : be the time required for change in flux

Now, considering quarter cycle of the flux waveform.

$$d\phi : \phi_m - 0 \quad \text{and} \quad dt : T/4$$

$\therefore$ Substituting this in above equation, average emf induced in each turn,

$$\frac{d\phi}{dt} = \frac{\phi_m - 0}{T/4} = \frac{4\,\phi_m}{T}$$

But,Time period, $T = \dfrac{1}{f}$

$$\therefore \quad \frac{d\phi}{dt} = \frac{4\,\phi_m}{1/f} = 4\,\phi_m f$$

But the flux considered very sinusoidally with time, the emf induced is also sinusoidal in nature.

For pure sine wave:Hence, Form Factor= $\dfrac{\text{RMS value}}{\text{Average value}} = 1.11$

$\therefore$ RMS value of emf induced in each turn,

$$= \text{Average value} \times 1.11$$

$$= 4\,\phi_m f \times 1.11 = 4.44\,\phi_m f \text{ volt}$$

Total emf induced in primary winding with N_1 number of turns

$$E_1 = 4.44\,\phi_m f N_1 \text{ volt.}$$

Similarly, emf in induced in the secondary winding with N_2turns due to mutual induction.

$$E_2 = 4.44\,\phi_m f N_2 \text{ volt}$$

11. What is KVA rating of transformer? Explain, why rating of transformer is expressed in KVA.

KVA rating: It is the output given by transformer at rated voltage and rated frequency under usual service conditions without exceeding the standard limits of temperature rise.

If I_1 and I_2 be the rated full load current and V_1, V_2 be the rated primary and secondary voltages.

Then kVA rating of transformer,

$$\text{kVA rating} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

The transformer rating is always expressed in kVA because:

The transformer is designed for a particular value of operating voltage and current for each of the winding not for particular value of output power. The load connected across the secondary side of the transformer may be lagging, leading or unity. Thus, for the same operating voltage and current the out power can be different at different loading conditions. Hence, only the operating voltage and current are specified for transformer. This operating voltage and current are called as rated voltage and rated current of particular winding. Hence, product of rated voltage and rated current is called as 'Volt-Ampere' rating of transformer. In large transformer it is expressed in kVA i.e. Volt-Ampere divided by 1000.

12. What are the different types of losses taking place in the transformer? How these losses are minimized. State the parts in which it takes place.

Since, the transformer is a static device and not a rotating machine, therefore friction and windage losses are not present. The losses which takes place in a transformer are of two types (i) Iron losses or core losses (constant losses), [takes place in transformer magnetic core]

(ii) Copper losses (variable losses). [Takes place in transformer copper windings]

(i) Iron Losses

These losses occurs due to the alternating flux in the **transformer core.** These losses consist of: (a) Hysteresis loss, (b) Eddy current loss.

These losses **remains constant** at any load condition.

(a) Hysteresis Loss: When transformer core is subjected to a magnetic field, the molecules in the material are forced to get aligned in the direction of applied magnetic field. If the applied magnetic field is alternating in nature then, the molecules are forced to change the directions with the same frequency of applied magnetic field. But the molecules are very much reluctant to change their direction.

Hence, some energy is required in order to change their direction as per the applied alternating magnetic field. This loss of energy is called as hysteresis loss. It is dissipated in the form of heat.

It is given by empirical formula as,

$$\textbf{Hysteresis loss, } P_h = \eta B_{max}^{1.6} f v \text{ watt}$$

where, η : stenmitz constant, B_{max}: maximum flux density in the core.

f :frequency of alternating flux, v :be the volume of core material.

(b) Eddy Current Losses: Due to the linking of alternating flux to transformer core, emf get induced in the transformer core. It gives rise to circulating, current in the core. These circulating currents are called as eddy currents. Now the every path of circulating current in the core has some resistance which causes the loss of energy. The total loss of energy due to the total eddy current is called as eddy current loss. It is also dissipated in the from of heat. It is also given by an empirical formula.

$$\textbf{Eddy current loss } Pe = K_e B_{max}^2 f^2 t^2 v \text{ watt}$$

Where, K_e : constant depends on the resistivity of core material

B_{max}: maximum flux density, f : frequency of alternating flux

t :thickness of the lamination of the core, v : volume of core material

The flux density in the core remains practically constant from no load to full load as well as supply frequency also remains constant therefore iron losses are also called as constant losses.

(i) Copper Losses

These losses occurs in the primary and secondary windings due to resistance of primary and secondary winding.

Let I_1 and I_2 : the primary and secondary current.

R_1 and R_2 : the primary and secondary winding resistance.

Hence, Total copper loss $= I_1^2 R1 + I_2^2 R2$

13. With neat circuit diagram explain the direct loading test on single phase transformer for finding the voltage regulation and efficiency.

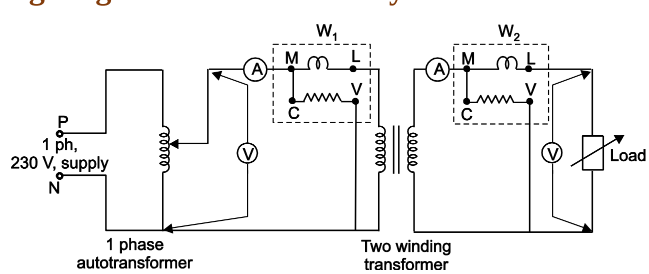


Fig. Direct Loading Arrangement on Single Phase Transformer

Theory: The efficiency and regulation of transformer can be found by direct loading method. The circuit diagram for direct loading method is as shown in Fig.

For finding the efficiency and regulation of transformer, the primary winding terminals are connected across supply and a variable load is connected directly across secondary terminals as shown above. The wattmeters i.e. W_1 and W_2 are inserted in the circuit diagram in order to measure the power input and power output of the transformer. Ammeters and voltmeters are used for measurement of current and voltage in the circuit. The load on transformer is varied step by step and the readings are noted down.

This test is useful only for small transformer and not for large ratings transformer, because of the non-availability of the load. The results obtained by this test are very accurate as the transformer is directly loaded for a particular load.

Procedure:

(1) Make the connections as per the circuit diagram.

(2) At start switch off the load.

(3) Switch on the supply and slowly increase the voltage with the help of auto transformer.

(4) Adjust the rated voltage of transformer.

(5) Now slowly increase the load on secondary and note down the readings of ammeter, voltmeter and wattmeter.

(6) Load the transformer up to the rated capacity of transformer or 25% more than the rated capacity.

Observation Table :

Sr.No.	I_1	V_1	W_1	I_2	V_2	W_2
1. 2.						

Formulae:

Efficiency: Efficiency of the transformer can be calculated as, $\therefore \% \ \eta = \dfrac{W_2}{W_1} \times 100$

Voltage Regulation :

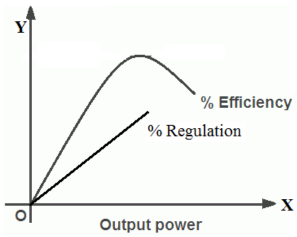
Voltage regulation of a transformer can be calculated as,

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

When the secondary is open the secondary voltage $V_2 = E_2$.

Hence, at start when the load is switched off regulation of transformer is zero. The subsequent regulations are calculated by using the above formulae.

Graphs:

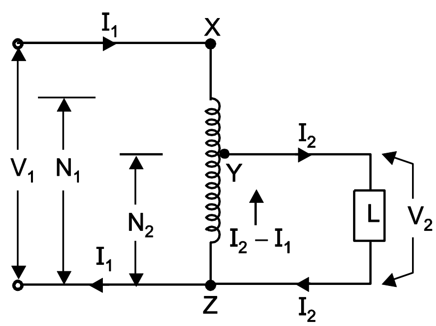


From the results obtained, curves are plotted for efficiency and regulation against load current or output power as shown in fig.

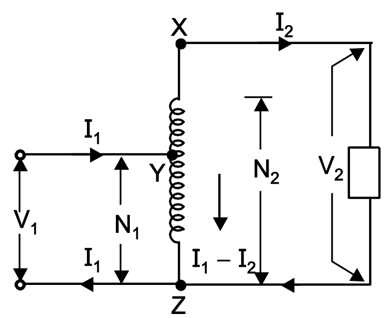
The efficiency and regulation at any desired load can be found from these curves.

14. Write a short note on Autotransformer.

An auto transformer is one in which single winding is used as primary and secondary winding. It can be used as step up or step down transformer. The step down and step up transformers are as shown in Fig. (a) and (b).



(a) Step Down transformer



(b) Step up transformer

As shown in Fig. (a), the winding XZ forms the primary winding of the transformer having N_1 number of turns. The winding YZ forms the secondary winding having N_2 number of turns. Similarly, in Fig. (b) the portion XZ forms the secondary and YZ forms the primary winding. If the transformer losses are neglected, then the same relationship holds good as in two winding transformer.

$$\text{i.e. } K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

Advantages:

(1) Copper required in case of auto transformer is always less than the two winding transformer, it is always cheaper.

(2) For same rating, weight of auto transformer is less than two winding transformer.

(3) The copper losses taking place in a transformer are less.

(4) Due to less copper loss, efficiency of the transformer is higher than that of two winding transformer.

(5) Auto transformer has better voltage regulation than that of two winding transformer.

Disadvantages:

(1) There is always risk of electric shock, as the primary and secondary are not electrically separated.

(2) In case of step down auto transformer, if the common part gets opened due to any fault, the high voltage on primary side will damage the measuring instrument (typically voltmeter) connected on secondary side.

Applications:

(1) It can be used as starter for squirrel cage induction motor.

(2) It can be used as booster to raise the voltage in A.C. feeders.

(3) It can be used in industry as furnace transformers for getting required voltage.

(4) It can be used as dimmer for dimming the light.

Questions asked in End-Sem Dec 2019 Examination

Q. Define (i) phase sequence (ii) balanced and unbalanced load. [3M] (Refer Q. No. 2)

Q. Derive the emf equation of 1-phase transformer. [6M] (Refer Q. No. 10)

Q. Why are steel laminations used for construction of transformer core? Sketch different types of laminations used for core. [3M] (Refer Q. No. 09)

Q. What are losses taking place in the transformer? State the parts in which they takes place. How to minimize these losses? [6M] (Refer Q. No. 12)

Q. Obtain the relation between phase values and line values of voltage and current in case of balanced star connected 3-ph inductive load. Assume phase sequence RYB. Draw the necessary phasor diagram. [8M] (Refer Q. No. 03)