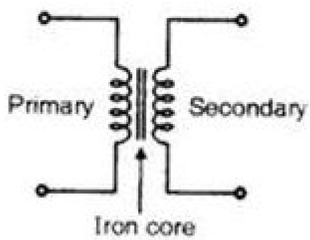
UNIT 3: TRANSFORMER

SHORT QUESTIONS AND ANSWERS

1) Define transformer.

ANS: A transformer is a static device which transfers electric energy from one circuit to another circuit without changing the frequency of the system. It works on electromagnetic induction principle.



2) Transformer rating in kVA but not in kW like other machine .Justify.

ANS: Copper loss of a transformer depends on current and iron loss on voltage. Hence total losses depends on Volt- Ampere and not on phase angle between voltage and current i.e independent of load the power factor. That is why the rating of Transformers are in kVA and not in kW.

3) Explain why transformer cannot operate on dc supply.

ANS: 1) If rated DC supply is applied to the primary winding of a transformer, the flux produced in the transformer core will not vary but remain constant in magnitude and therefore, no EMF will be induced in the primary and secondary windings.

2) If there is no self induced EMF in the primary winding ,to oppose the applied voltage and since the resistance of the primary winding is low, therefore heavy current will flow through the primary winding which may result in damage of the winding. **This is the reason why DC is never applied to the transformer.**

4) List four applications of a transformer. What are the applications of step-up & step-down transformer?

Applications of transformer

1. It can raise or lower the voltage or current in an AC circuit.
2. It can act as an impedance transferring device by increasing or decreasing the value of a capacitor, inductor or resistance in an AC circuit.
3. It can isolate two circuits electrically.
4. It can be used to prevent DC from passing from one circuit to another

Applications of Step-Up:

Step-up transformers are used in generating stations. Normally the generated voltage will be either 11kV. This voltage (11kV) is stepped up to 110kV or 220kV or 400Kv and transmitted through transmission lines (simply called as sending end voltage).

Applications of Step-Down:

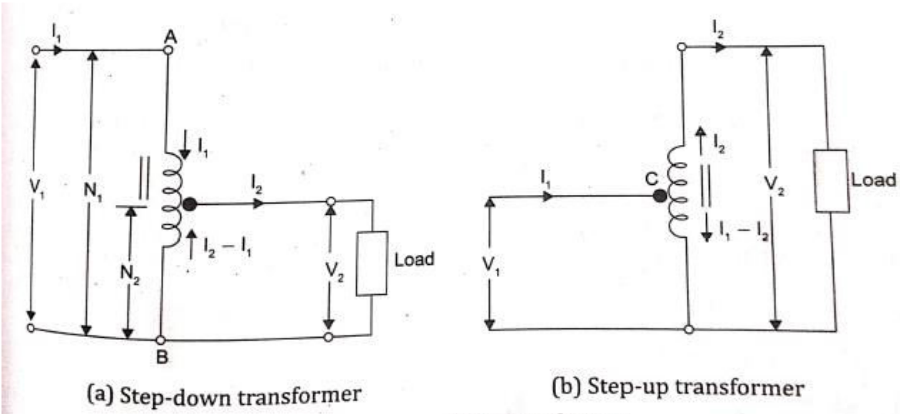
Step-down transformers are used in receiving stations. The voltage are stepped down to 11kV or 22kV are stepped down to 3phase 400V by means of a distribution transformer and made available at consumer premises. The transformers used at generating stations are called power transformers.

5) Compare Ideal transformer and practical transformer

IDEAL TRANSFORMER	PRACTICAL TRANSFORMER
An ideal transformer is one that has (i) no winding resistance (ii) no leakage flux i.e the same flux links with both the windings (iii) no iron losses(i.e eddy current and hysteresis losses) in the core.	An ideal transformer is one that has (i) iron losses, (ii) winding resistances and, (iii) magnetic leakage, giving rise to leakage reactance.

6) What is auto transformer? What are its advantages, disadvantages and applications?

ANS:
A transformer in which a part of the winding is common to both primary and secondary circuits is called an auto transformer.



Auto-transformer

Advantages:
1) It requires less conducting material (copper) than a 2 winding transformer
2) Its efficiency is higher, when compared to a 2 winding transformer as losses are less.
3) The size, cost is less compared to 2 winding transformer.
4) It has better voltage regulation than 2 winding transformer of the same rating.

Disadvantages:
1) The two windings are not electrically separate and in case of failure of insulation between the two, a severe shock may be felt on the low voltage side.

2) The use of auto transformer is more economical only when the transformation ratio is nearer to unity

Applications:

1) Generally used for starting of induction motors
2) These are used to compensate for voltage drops in transmission and distribution lines.when used for this purpose they are known as booster transformers.
3) Autotransformers are used for continuously variable supply.
4) These are used in control equipment for 1-phase and 3-phase electrical locomotives.

7) Define voltage regulation?

Voltage regulation in transformers is the difference between the no load voltage and the full load voltage. This is usually expressed in terms of percentage.

$$Voltage\ regulation\ (\%) = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2 R_2 \cos\theta_2 + I_2 X_2 \sin\theta_2}{V_2} \times 100(\%)$$

%regulation = voltage drop in transformer/ no load voltage of transformer

The voltage regulation up is expressed mathematically by

$$\%\mu = \frac{{}_0V_2 - V_2}{{}_0V_2} \times 100 = \frac{I_2\left(R_{02}\cos\theta \pm X_{02}\sin\theta\right)}{{}_0V_2} \times 100 \qquad (1.55)$$

Positive sign is for lagging power factor and negative sign is for leading power factor.

8) Derive the condition for zero regulation and maximum regulation

Condition for Zero Regulation

$$Voltage\ regulation\ (\%) = \frac{E_2 - V_2}{V_2} \times 100(\%)$$

$$= \frac{I_2 R_2 \cos\theta_2 + I_2 X_2 \sin\theta_2}{V_2} \times 100(\%)$$

For zero voltage regulation, we have

${}_0V_2 + V_2 = 0$

i.e., $I_2(R_{02}\cos\theta + X_{02}\sin\theta) = 0$

$\mathrm{Tan}\theta = -(R_{02}/X_{02})$

negative sign indicates that zero regulation occurs at the leading power factor .

Condition for Maximum Voltage Regulation

Maximum voltage regulation can be obtained for lagging power factor. For maximum voltage regulation, we have

$$\frac{d}{d\theta}\left[\frac{I_2\left(R_{02}\cos\theta+X_{02}\sin\theta\right)}{{}_0V_2}\right]=0$$

i.e., $-R_{02}\sin\theta+X_{02}\cos\theta=0$

i.e., $\tan\theta= X_{02}/ R_{02}$

This is satisfied only when the power factor of the load is lagging. The regulation is maximum when the load power factor angle is equal to the impedance angle of the transformer.

9) Give equivalent resistance, reactance & impedance referred to primary circuit and referred to secondary circuit.

equivalent resistance, reactance & impedance referred to primary circuit

Req = R2 +R1' = R2+ R1'/k²

Xeq = X2 +X1' = X2+ X1'/k²

Zeq = Z2 + Z1' = Z2+ Z1'/k²

equivalent resistance, reactance & impedance referred to secondary circuit

Req = R1 +R2' = R1+k² R2'

Xeq = X1 +X2' = X1+k² X2'

Zeq = Z1 +Z2' = Z1+k² Z2'

where k=N2/N1

10) What are the advantages and disadvantage of different three phase transformer connection.

ANS:

(i)Star –Star connection:

ADVANTAGES:

1) Due to star connection, phase voltage is $1/\sqrt{3}$ times of the voltage. Hence less number of turns are required.

2) There is no phase shift between the primary and secondary voltages

3) As the neutral is available ,it is suitable for 3 phase ,4 wire system.

DISADVANTAGES:

1) If the neutral is not provided, the phase voltages tend to become severely unbalanced when the load is unbalanced. Therefore star-star connection is not satisfactory for unbalanced loading in absence of neutral connection.

2)Even though the star or neutral point of primary is earthed,the third harmonic present in alternator voltage may appear on the secondary side. This causes distortion in the secondary phase voltages.

(ii)Delta –Delta connection:

ADVANTAGES:

1) This connection is satisfactory for both balanced load and unbalanced loading.

2) If a third harmonic is present ,it circulates in a closed path and therefore does not appear in the output voltage wave

3) If one transformer gets damaged or is removed from service, the remaining two can be operated in open delta or V-V connection.

DISADVANTAGES:

1) As the neutral ,it is not suitable for 3 phase 4 wire system.

2)More insulation is required due to more number of turns per phase when compared to star-star

(iii) star - Delta connection:

ADVANTAGES:

1)The primary is star connected. Hence less number of turns is required

2)The neutral ,available on the primary can be earthed to avoid distortion.

DISADVANTAGES:

1)In this connection, the secondary voltage is not in phase with primary. Hence this connection cannot be paralleled with star-star or delta –delta connected transformers.

(iv) Delta –star connection:

ADVANTAGES:

1) In the primary side due to delta connection, winding cross section is less.

2)There is no distortion due to third harmonic components.

3)In secondary side neutral is available ,due to which it can be used for 3 phase ,4 wire supply system

DISADVANTAGES:

1) In this connection, the secondary voltage is not in phase with primary. Hence this connection cannot be paralleled with star-star or delta –delta connected transformers.

LONG QUESTIONS AND ANSWERS

1) Explain the working principle of transformer

ANS:

1)A transformer is a static device which transfers electric energy from one circuit to another circuit without changing the frequency of the system. It works on electromagnetic induction principle. (According to this principle an emf is induced in a coil if it links a changing flux.)

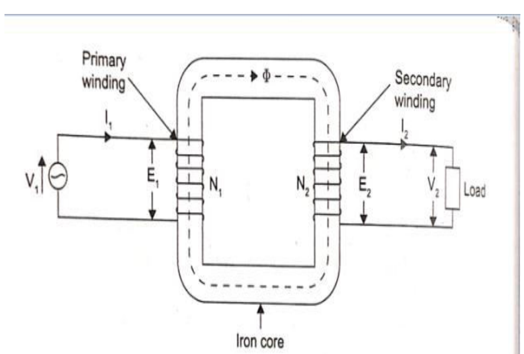
2)Consider two coils 1 and 2 wound on a simple magnetic circuit as shown. These two coils are insulated from each other and there is no electrical connection but magnetically coupled. The two coils posses high mutual inductance.

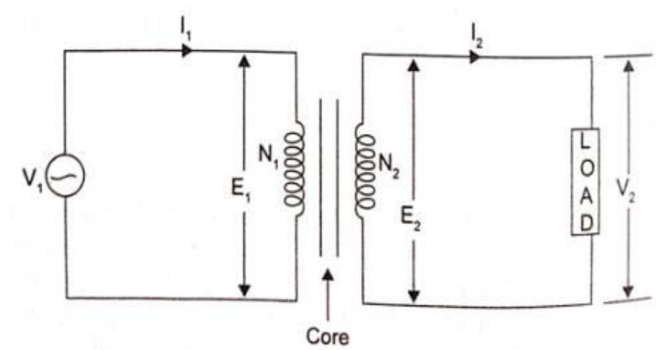
3)If one coil is connected to a source of alternating voltage ,and alternating flux is set up in the laminated core, most of which is linked with the other coil ,in which it produces mutually induced EMF according to faradays' law of electromagnetic induction(According to this principle an emf is induced in a coil if it links a changing flux.)

4)If the secondary coil circuit is closed , current flows in it and so an electrical energy transfers from the first coil to the second coil.

5)Coil 1 which receives energy from the sources of AC supply is called the primary coil or primary winding and coil2 which is connected to the load and delivers energy to the load is called secondary coil or secondary winding.

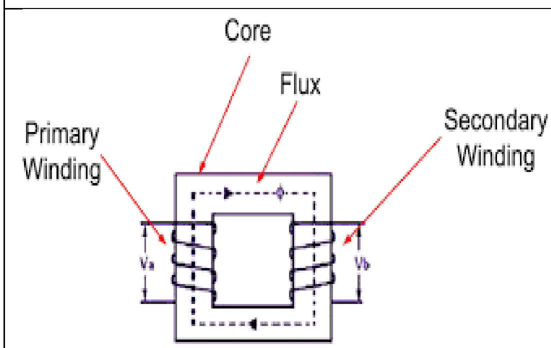
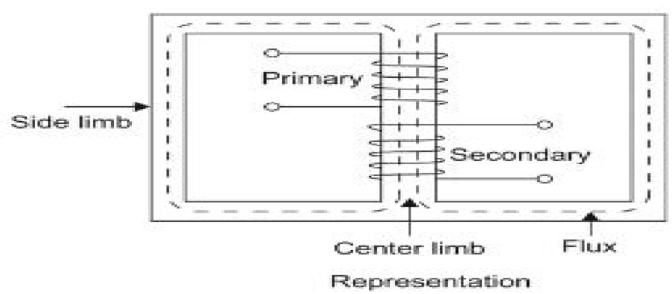
6)The two vertical lines in symbol of transformer represents magnetic core which signify the tight magnetic coupling the winding





Arrangement of Simple transformer Symbolic Representation

2) Explain differences between core type transformer and shell type transformer.

Core type transformer	**Shell type transformer**
1) It has a single magnetic circuit.	1) It has a double magnetic circuit,
2) The winding surround the core.	2) The core surrounds the winding.
3)The core is rectangular, having two limbs.Winding are wound on the two limbs The two vertical portions are called limbs ,each carry one half of the primary and one half of the secondary windings.	3) The core has three limbs ,Both the windings are wound on the center limbs. shell type transformers are preferred for high voltage applications.
4) Core is made up of silicon steel laminations to reduce eddy current loss The core is usually rectangular or square type .	4) Core is also made up of silicon steel laminations to reduce eddy current loss
5) As the windings are uniformly distributed over the two limbs the natural cooling is more effective.	5) As the core surrounds by the windings,the natural cooling does not exist
6) The coils can be easily removed by removing the lamination of the top yoke for maintenance.	6) For removing any winding for maintenance large numbers of laminations are required to be removed.
	 Shell type transformer

3) Explain ideal transformer. Derive an expression for EMF induced in a transformer

ANS: **Ideal transformer**

An ideal transformer is one that has

(i) no winding resistance

(ii) no leakage flux i.e the same flux links with both the windings

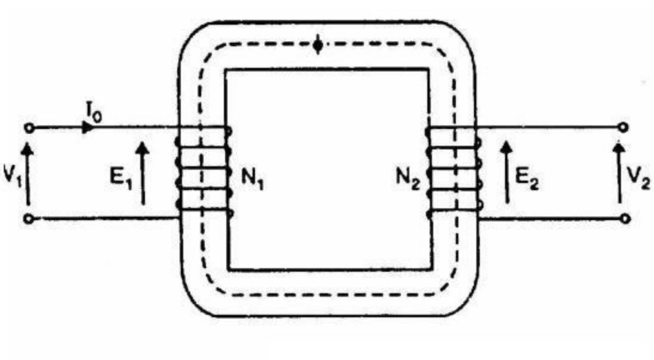
(iii) no iron losses (i.e eddy current and hysteresis losses) in the core.

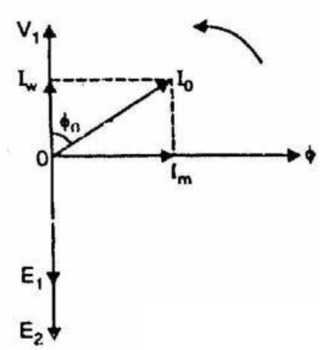
1)Consider an **ideal transformer on no load** i.e., the secondary is open-circuited as shown in the figure. Under such conditions, the primary is simply a coil of pure inductance.
2)When an alternating voltage V_1 is applied to the primary, it draws a small magnetizing current Im which lags behind the applied voltage by 90°. This alternating current Im produces an alternating flux ϕ in primary which is in phase with it.

3)The alternating flux ϕ links both the windings and induces e.m.f. E_1 in the primary and e.m.f. E_2 in the secondary. The primary e.m.f. E_1 is, at every instant, equal to and in opposition to V_1 (Lenz's law)(induced emf opposes the cause producing it which is supply voltage v1). Both e.m.f.s E_1, and E_2 lag behind flux ϕ by 90°. However, their magnitudes depend upon the number of primary and secondary turns.

4)The phasor diagram of an ideal transformer on no load is also shown above. Since flux ϕ is common to both the windings, it has been taken as the reference phasor.

5)The primary e.m.f. E_1 and secondary e.m.f. E_2 lag behind the flux ϕ by 90°. E_1 and E_2 are in phase. But E_1 is equal to V_1 and 180° out of phase with it.





EXPRESSION FOR EMF INDUCED IN A TRANSFORMER

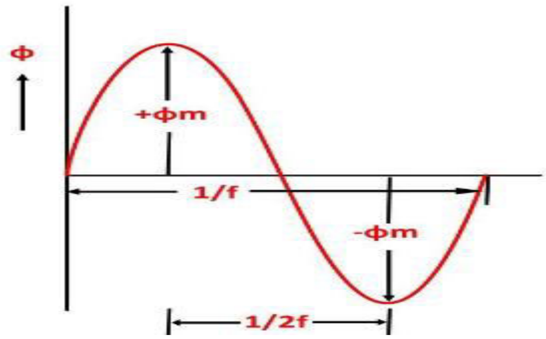
When a sinusoidal voltage is applied to the primary winding of a transformer, alternating flux ϕ_m sets up in the iron core of the transformer. This sinusoidal flux links with both primary and secondary winding. The function of flux is a sine function.

The rate of change of flux with respect to time is derived mathematically.

The derivation of the **EMF Equation** of the transformer is shown below. Let

- ϕ_m be the maximum value of flux in Weber
- f be the supply frequency in Hz
- N_1 is the number of turns in the primary winding
- N_2 is the number of turns in the secondary winding
- Φ is the flux per turn in Weber

  As shown in the above figure that the flux changes from + ϕ_m to – ϕ_m in half a cycle of 1/2f seconds.



By Faraday's Law

Let E_1 be the emf induced in the primary winding

$$E_1 = -\frac{d\psi}{dt} \ldots\ldots\ldots (1)$$

Where $\Psi = N_1\phi$

$$\text{Therefore, } E_1 = -N_1 \frac{d\varphi}{dt} \ldots\ldots\ldots(2)$$

Since ϕ is due to AC supply $\phi = \phi_m \text{Sinwt}$

$$E_1 = -N_1 \frac{d}{dt} (\varphi_m \text{ Sinwt})$$

$$E_1 = -N_1 w\varphi_m \text{ Coswt}$$

$$E_1 = N_1 w\varphi_m \text{ Sin}(wt - \pi/2) \ldots\ldots\ldots (3)$$

So the induced emf lags flux by 90 degrees.

Maximum valve of emf

$$E_1 max = N_1 w\varphi_m \ldots\ldots\ldots (4)$$

But $w = 2\pi f$

$$E_1 max = 2\pi f N_1 \varphi_m \ldots\ldots\ldots (5)$$

Root mean square RMS value is

$$E_1 = \frac{E_{1max}}{\sqrt{2}} \ldots\ldots\ldots (6)$$

Putting the value of E_1max in equation (6) we get

$$E_1 = \sqrt{2}\pi f N_1 \varphi_m \text{ ....(7)}$$

Putting the value of $\pi = 3.14$ in the equation (7) we will get the value of E_1 as

$$E_1 = 4.44 f N_1 \varphi_m \dots\dots\dots (8)$$

Similarly

$$E_2 = \sqrt{2}\pi f N_2 \varphi_m$$

Or

$$E_2 = 4.44 f N_2 \varphi_m \dots\dots\dots (9)$$

4) Explain practical transformer .Draw and explain phasor diagram of practical transformer under no load.

ANS:

A) Practical Transformer

A practical transformer differs from the ideal transformer in many respects. The practical transformer has,

1. iron losses,
2. winding resistances and,
3. Magnetic leakage, giving rise to leakage reactance.

1. Iron Losses

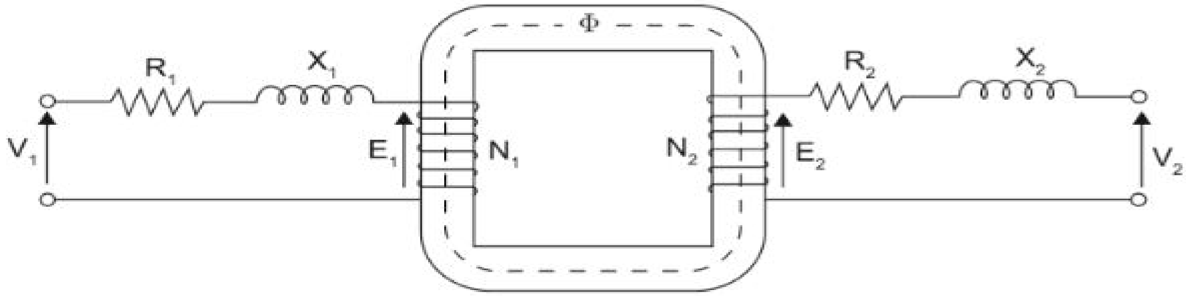
i) Since the iron core is subjected to alternating flux, there occurs eddy current and hysteresis loss in it. These two losses together are known as iron losses or core losses.
ii) The iron losses depend upon the supply frequency, the maximum flux density in the core, volume of the core, etc.
iii) It may be noted that the magnitude of iron losses is quite small in a practical transformer.

2. Winding resistances

i) Since the windings consist of copper conductors, it immediately follows that both primary and secondary will have winding resistance.
ii) The primary resistance R_1 and secondary resistance R_2 act in series with the respective windings as shown in the figure.
iii) When current flows through the windings, there will be power loss as well as a loss in voltage due to IR drop. This will affect the power factor and E_1 will be less than V_1 while V_2 will be less than E_2.

3. Leakage reactances

i) Both primary and secondary currents produce flux. The flux ϕ which links both the windings is the useful flux and is called mutual flux.
ii) However, the primary current would produce some flux which would not link the secondary winding. Similarly, the secondary current would produce some flux that would not link the primary winding.
iii) The flux which links only one winding is called leakage flux. The leakage flux paths are mainly through the air. The effect of these leakage fluxes would be the same as though inductive reactance were connected in series with each winding of the transformer that had no leakage flux as shown in the figure.
iv) In other words, the effect of primary leakage flux ϕ_1 is to introduce an inductive reactance X_1 in series with the primary winding as shown. Similarly, the secondary leakage flux ϕ_2 introduces an inductive reactance X_2 in series with the secondary winding.There will be no power loss due to leakage reactance. However, the presence of leakage reactance in the windings changes the power factor as well as there is voltage loss due to IX drop.



Practical transformer

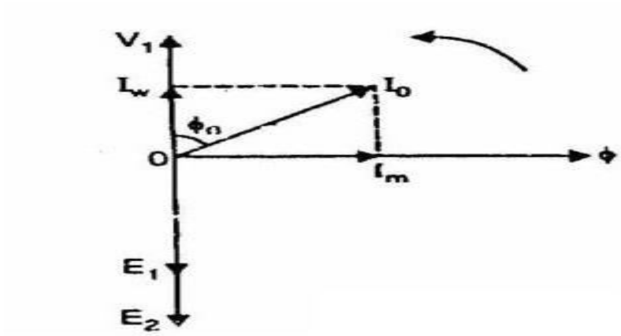
B)Practical Transformer on No Load

1)The primary will draw a small current I_0 to supply
(i) the iron losses and
(ii) a very small amount of copper loss in the primary.

2)Hence the primary no load current I_0 is not 90° behind the applied voltage V_1 but lags it by an angle $\Phi_0 < 90°$ as shown in the phasor diagram.

No load input power, $W_0 = V_1 I_0 \cos\Phi_0$

3)As seen from the phasor diagram, the no-load primary current I_0 can be resolved into two rectangular components viz.



1. I_w
2. I_m

(i) The component I_w in phase with the applied voltage $V_{1.}$ This is known as active or working or iron loss component and supplies the iron loss and a very small primary copper loss.
$I_w = I_0 \cos\Phi_0$
(ii) The component I_m lagging behind V_1 by 90° and is known as magnetizing component. It is this component which produces the mutual flux Φ in the core.
$I_m = I_0 \sin\Phi_0$

Clearly, I_0 is phasor sum of I_m and I_w.

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

No load power factor, $\cos\Phi_0 = I_w/I_0$

5) Explain practical transformer on load. Draw phasor diagram of practical transformer under load.

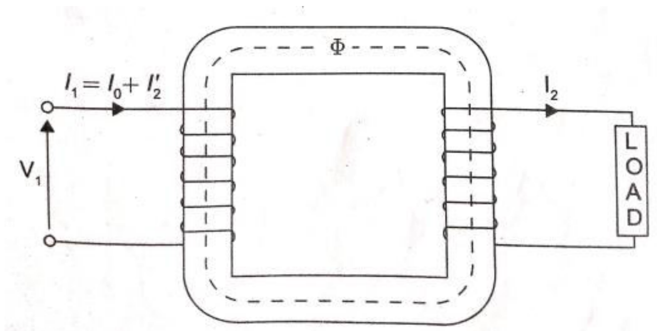


Figure (5.11): *Transformer on load*

1) When the transformer is loaded the secondary current i_2 is set up ,i_2 will be in phase with v_2 if the load is resistive,it lags v_2 if the load is inductive it leads v_2 if the load is capactive.

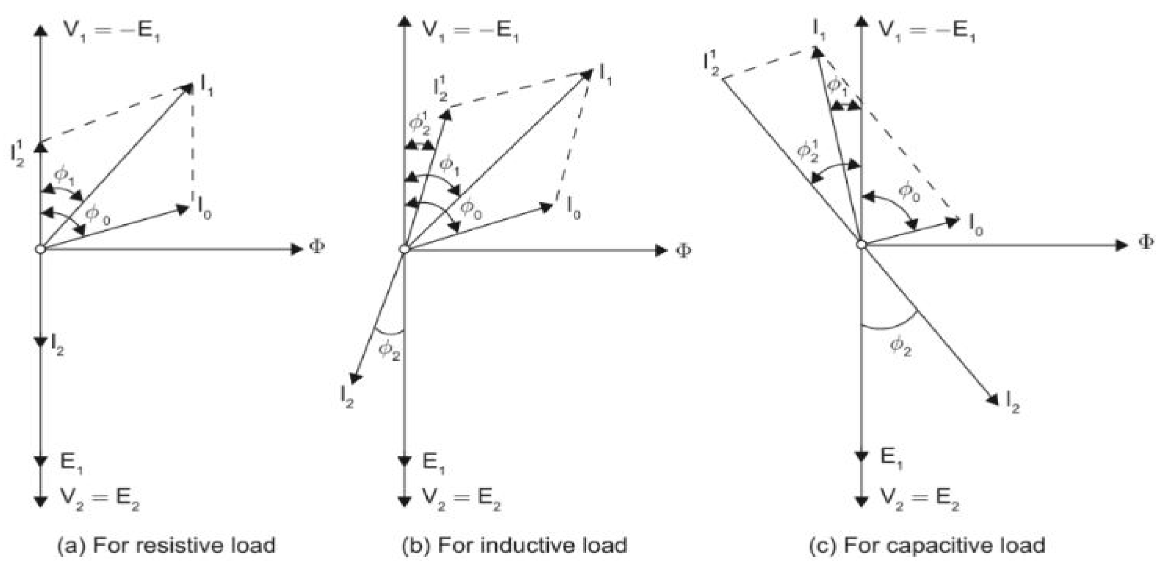
2)The secondary current I_2 sets up its own MMF($=N_2I_2$) and hence it produces flux ϕ_2 which is in opposition to the main primary flux ϕ_1 which is due to I_o.

3) Secondary flux ϕ_2 weakens the main flux phi momentarily and hence primary back emf E1 tends to be reduced.

4)For a moment V1 gains the upper hand over E1 and hence causes additional current I_2^{I} to flow in primary and hence flux ϕ_2 (due to MMF N_1I_2') which counter balances the secondary flux ϕ_2.

5) Here I_2' is known as load component of primary current.This current is in anti-phase with I_2

The phasor digram of a transformer under load conditions can be drawn



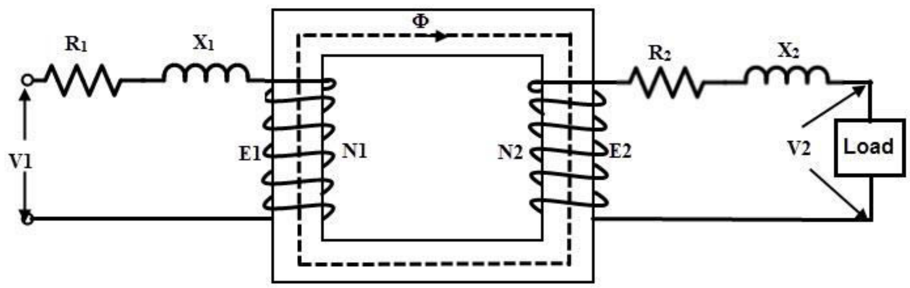
Phasor diagram of transformer on load

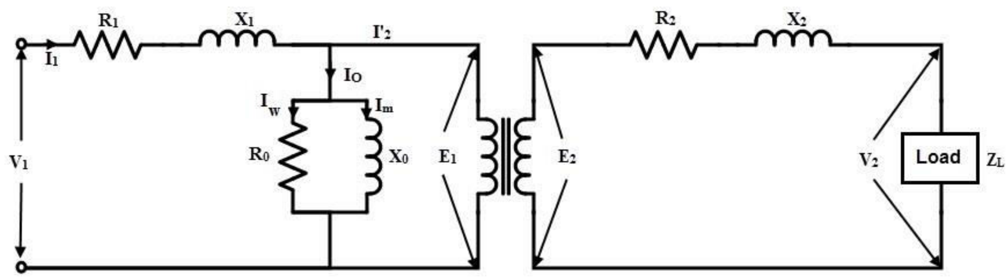
6) Draw and derive the equivalent circuit parameters of a single phase transformer.

ANS:

Equivalent circuit diagram of a transformer is basically a diagram which can be resolved into an equivalent circuit in which the resistance and leakage reactance of the transformer are imagined to be external to the winding.

The equivalent circuit diagram of transformer is given below:-





Where,

R_1 = Primary Winding Resistance.

R_2= Secondary winding Resistance.

I_0= No-load current.

I_M = Magnetizing Component,

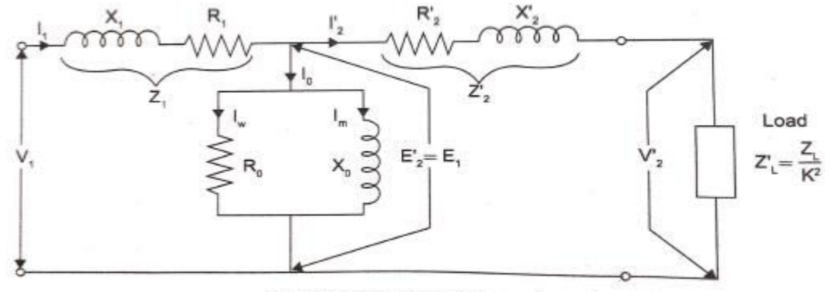
I_w = Working Component,

This I_m & I_w are connected in parallel across the primary circuit. The value of E_1 (Primary e.m.f) is obtained by subtracting vectorially $I_1 Z_1$ from V_1 . The value of $X_0 = E_1 / I_0$ and $R_0 = E_1 / I_w$. We know that the relation of E_1 and E_2 is $E_2 / E_1 = N_2 / N_1 = K$, (transformation Ratio)

From the equivalent circuit , we can easily calculate the total impedance of to transfer voltage, current, and impedance either to the primary or the secondary.

i) Equivalent circuit when referred to primary

If all the secondary quantities are transferred to primary,we get the equivalent circuit of transformer referred to primary.



Equivalent circuit when referred to primary

E'_2=primary equivalent of secondary emf=E2/K=E1

V'_2=primary equivalent of secondary terminal voltage=$V_2/K=E_1$
$I_1V_2'=I_2V_2 \Rightarrow V_2'=(I_2/I_1)V2= V_2/K$

I_2'=primary equivalent of secondary current=KI_2

Secondary resistance referred to the primary side is given as:

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

Secondary reactance referred to the primary side is given as:

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

ii) Equivalent circuit when referred to secondary

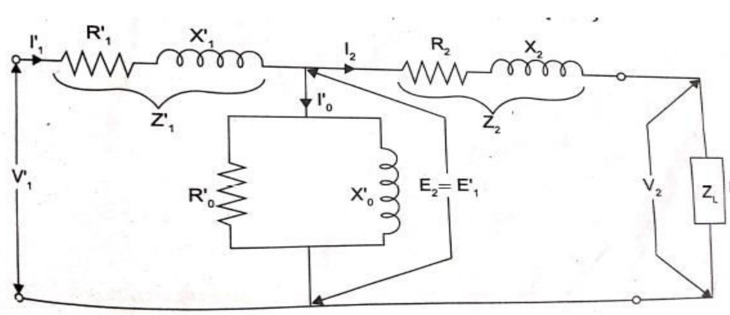
If all the primary quantities are transferred to secondary,we get the equivalent circuit of transformer referred to secondary.

$$R_1' = K^2R_1, \qquad X_1' = K^2X_1, \qquad Z_1' = K^2Z_1$$

$$E_1' = KE_1, \qquad I_1' = \frac{I_1}{K}, \qquad I_0' = \frac{I_0}{K}$$

$$R_{02} = R_2 + K^2R_1, \quad X_{02} = X_2 + K^2X_1, \quad Z_{02} = R_{02} + j\,X_{02}$$

Similarly, the exciting circuit parameters also get transferred to secondary as R_o' and X_o'. The equivalent circuit referred to secondary is shown below



Equivalent circuit when referred to secondary

7) Explain different types of losses in a transformer.

The Losses occurring in transformer are

(i)Core or iron losses

(ii)copper losses

(i)Core or iron losses

A) This is the power lloss that occurs in the iron part .This loss is due to the alternating flux in the core

Iron losses are further classified into two types

1)Hysteresis loss 2)Eddy current loss

Hysteresis loss	**Eddy current loss**
1)Due to alternating flux setup in the magnetic core of the transformer,it undergoes a cycle of magnetization and demagnetization result in loss of energy which is called as Hysteresis loss.	1)This power loss is due to alternating flux linking the core ,which will induce an emf in the core called eddy emf,due to which a current called the eddy current is being circulated in the core.As there is some resistance in the cire with this eddy current circulation ,converts into heat called the eddy current power loss.
2) Hysteresis loss is given by =Hysteresis constant ,depends on material BmaxMaximum flux density f=frequency V=volume of the core.	2) Eddy current is given by Ke =eddy current constant T=thickness of the core
3)Hysteresis loss can be minimized by using steel of high silicon content	3)eddy current loss can be reduced by using core of thin laminations

Both hysteresis and eddy current losses depends upon (i)maximum flux density B_m in the core (ii)supply frequency f.Since transformers are connected to constant frequency, constant voltage supply, both f and B_m are constant. Hence core or iron losses are practically same at all loads

Iron or core losses =hysteresis loss+eddy current loss= constant losses

(ii) Copper losses:

1)Copper loss is the power wasted in the form of heat due to resistance of the primary and secondary windings.

Total losses= $(I_1)^2R_1+(I_2)^2 R_2$

2)This loss is proportional to the square of the load hence it is called the variable loss where iron loss is called the constant loss as the supply voltage and frequency are constant

8) Define efficiency. Derive the condition for maximum efficiency in a single phase transformer. How to calculate efficiency at desired load.

Let us consider primary side

Primary input $= V_1 I_1 \cos\phi_1$

Iron losses , $W_i = W_h + W_e$

Copper losses, $W_{cu} = I_1^2 R_{01}$ (or) $I_2^2 R_{02}$

$$\text{Efficiency} = \frac{input - losses}{input}$$

$$\Rightarrow \eta = \frac{V_1 I_1 \cos\phi_1 - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi_1} = 1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}$$

For 'η' to be maximum. $\frac{d}{d I_1}(\eta) = 0$

$$\Rightarrow \frac{d}{d I_1}\left(1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}\right) = 0$$

$$\Rightarrow \frac{-R_{01}}{V_1 \cos\phi_1} + \frac{W_i}{V_1 I_1^2 \cos\phi_1} = 0$$

$$\Rightarrow \frac{R_{01}}{V_1 \cos\phi_1} = \frac{W_i}{V_1 I_1^2 \cos\phi_1}$$

$$\Rightarrow I_1^2 R_{01} = W_i$$

$\Rightarrow$ copper losses = iron losses

Hence the transformer efficiency will be maximum when copper losses are equal to iron losses.

$$\therefore\ I_1^2 R_{01} \text{ (or) } I_2^2 R_{02} = W_i$$

Current corresponding to maximum efficiency is $I_1 = \sqrt{\frac{W_i}{R_{01}}}$ (or) $I_2 = \sqrt{\frac{W_i}{R_{02}}}$

In general, the efficiency at any desired load can be calculated as follows:

Let S = Full load kVA of the transformer

W_{cu} = Full load copper loss

$\cos\phi$ = p.f of the load

x = ratio of actual load to full load

For example, at ½ F.L, $x = 1/2$ & at ¼ F.L, $x = 1/4$

$\therefore$ output of the transformer $= xS\cos\phi$

Iron loss $= W_i$

Copper loss $= x^2 W_{cu}$

Therefore, the efficiency at any load is given by

$$\eta = \frac{Output\ power}{Input\ power} = \frac{Output\ power}{Output\ power + Losses}$$

$$\eta_{at\ any\ load} = \frac{xS\cos\phi}{xS\cos\phi + W_i + x^2W_{cu}}$$

Where x = Fraction of F.L. at which the transformer is working

For maximum efficiency

copper losses = iron losses

$$x^2W_{cu} = W_i$$

$$\Rightarrow x = \sqrt{\frac{W_i}{W_{cu}}} = \sqrt{\frac{Iron\ loss}{F.L.\ copper\ loss}}$$

KVAmax/Full load kVA= $\sqrt{\frac{\text{iron loss}}{\text{F.L.copper loss}}}$

Load kVA max=full load kVA $\sqrt{\frac{\text{iron loss}}{\text{F.L.copper loss}}}$

9. Describe the principle of operation of auto transformer, what is the saving of copper in this transformer when compared with two winding transformer.

The length of copper required in a winding is proportional to the number of turns and the area of cross-section of the winding wire is proportional to the current rating. Therefore, the volume and hence weight of copper required in a winding is proportional to current × turns i.e.,

Weight of Cu required in a winding $\propto$ current × turns

2-winding transformer:

$$\text{Weight of Cu required in a winding} \propto (I_1N_1 + I_2N_2) \qquad (5.31)$$

Auto- transformer:

Weight of Cu required in section A-C $\propto I_1 (N_1 - N_2)$

Weight of Cu required in section C-B $\propto (I_2 - I_1)N_2$

$$\therefore \text{Total weight of Cu required} \propto I_1 (N_1 - N_2) + (I_2 - I_1)N_2 \qquad (5.32)$$

$$\frac{\text{Weight of Cu in } auto-transformer}{\text{Weight of Cu in } 2-winding\ transformer} = \frac{I_1\ (N_1 - N_2) + (I_2 - I_1)N_2}{(I_1N_1 + I_2N_2)}$$

$$= \frac{I_1N_1 - I_1N_2 + I_2N_2 - I_1N_2}{(I_1N_1 + I_2N_2)} = \frac{I_1N_1 + I_2N_2 - 2I_1N_2}{(I_1N_1 + I_2N_2)}$$

$$= 1 - \frac{2I_1N_2}{(I_1N_1 + I_2N_2)} = 1 - \frac{2I_1N_2}{2I_1N_1} \quad (\because I_1N_1 = I_2N_2)$$

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

$\therefore$ Weight of Cu in auto-transformer = (1 − K) × Weight of Cu in 2-winding transformer

$$\text{or} \quad W_{auto} = (1-K)W_{2-wdg} \qquad (5.33)$$

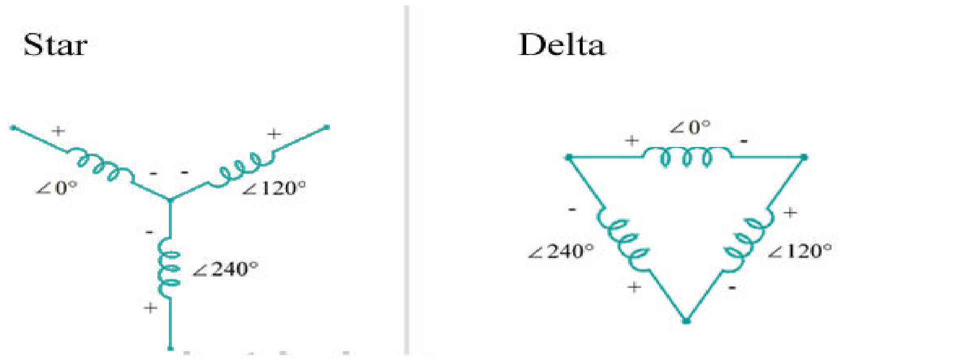
$$\therefore Saving\ \ in\ Cu = W_{2-wdg} - W_{auto} = W_{2-wdg} - (1-K)W_{2-wdg} = K \times W_{2-wdg}$$

$$\text{or} \quad \text{Saving in Cu} = K \times \text{Weight of Cu in 2-winding transformer} \qquad (5.34)$$

Thus if K = 0.1, the saving of Cu is only 10% but if K = 0.9, saving of Cu is 90%. Therefore, the nearer the value of K of auto-transformer is to 1, the grater is the saving of Cu.

10. Explain the various three transformer phase connections.

Three phase transformer connections In three phase system, the three phases can be connected in either star or delta configuration.



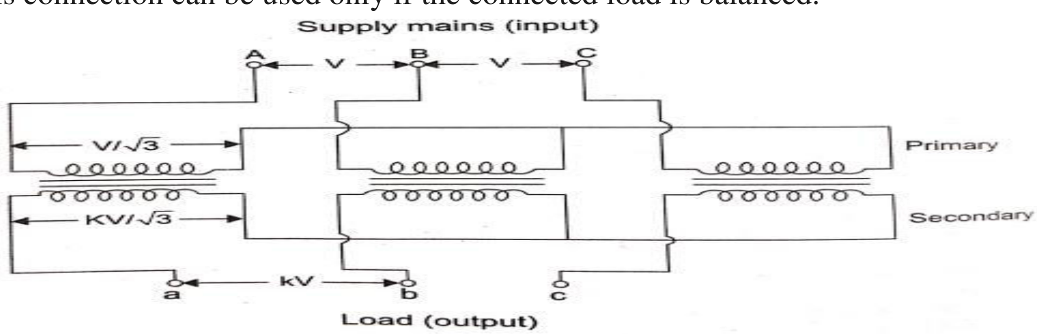
Center point must tie either all '-' or all '+' ends together.

The winding polarities must stack together in a complemetary manner (+ to -)

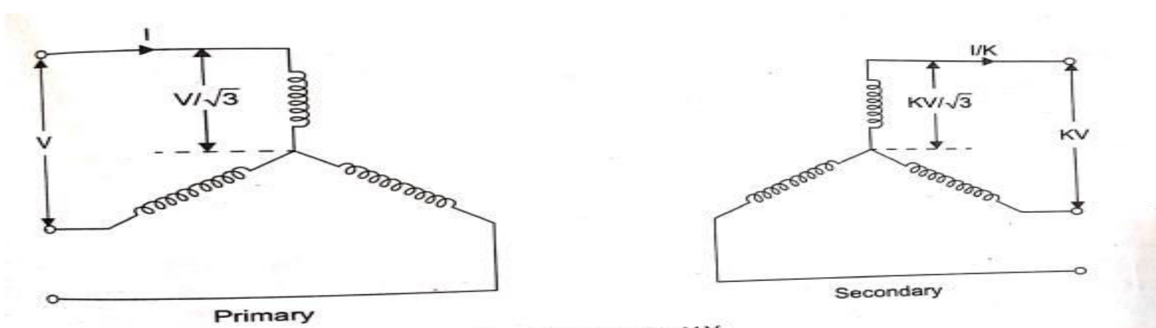
Windings of a three phase transformer can be connected in various configurations as (i) star-star, (ii) delta-delta, (iii) star-delta, (iv) delta-star. These configurations are explained below.

Star-Star (Y-Y)

- Star-star connection is generally used for small, high-voltage transformers. Because of star connection, number of required turns/phase is reduced (as phase voltage in star connection is $1/\sqrt{3}$ times of line voltage only). Thus, the amount of insulation required is also reduced.
- The ratio of line voltages on the primary side and the secondary side is equal to the transformation ratio of the transformers.
- Line voltages on both sides are in phase with each other.
- This connection can be used only if the connected load is balanced.



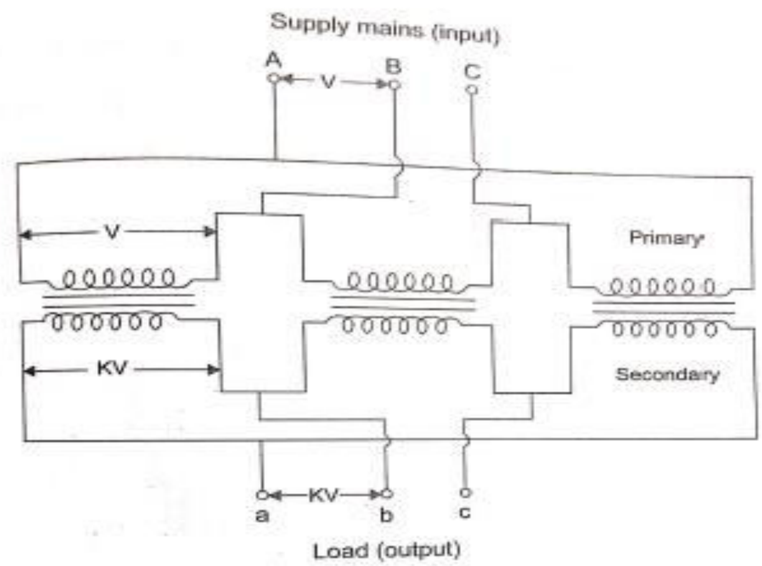
- (a) Schematic diagram



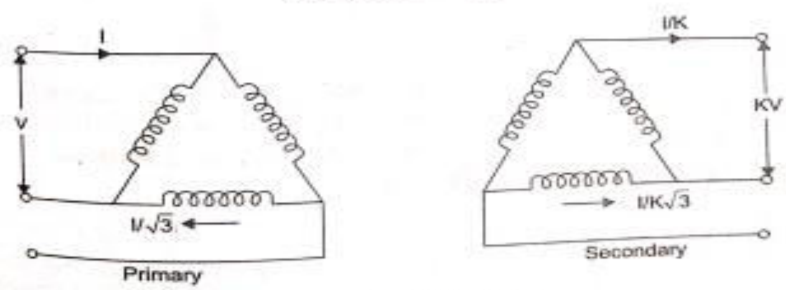
(b) Windings in Y-Y

Delta-Delta (Δ-Δ)

- This connection is generally used for large, low-voltage transformers. Number of required phase/turns is relatively greater than that for star-star connection.
- The ratio of line voltages on the primary and the secondary side is equal to the transformation ratio of the transformers.
- This connection can be used even for unbalanced loading.
- Another advantage of this type of connection is that even if one transformer is disabled, system can continue to operate in open delta connection but with reduced available capacity.



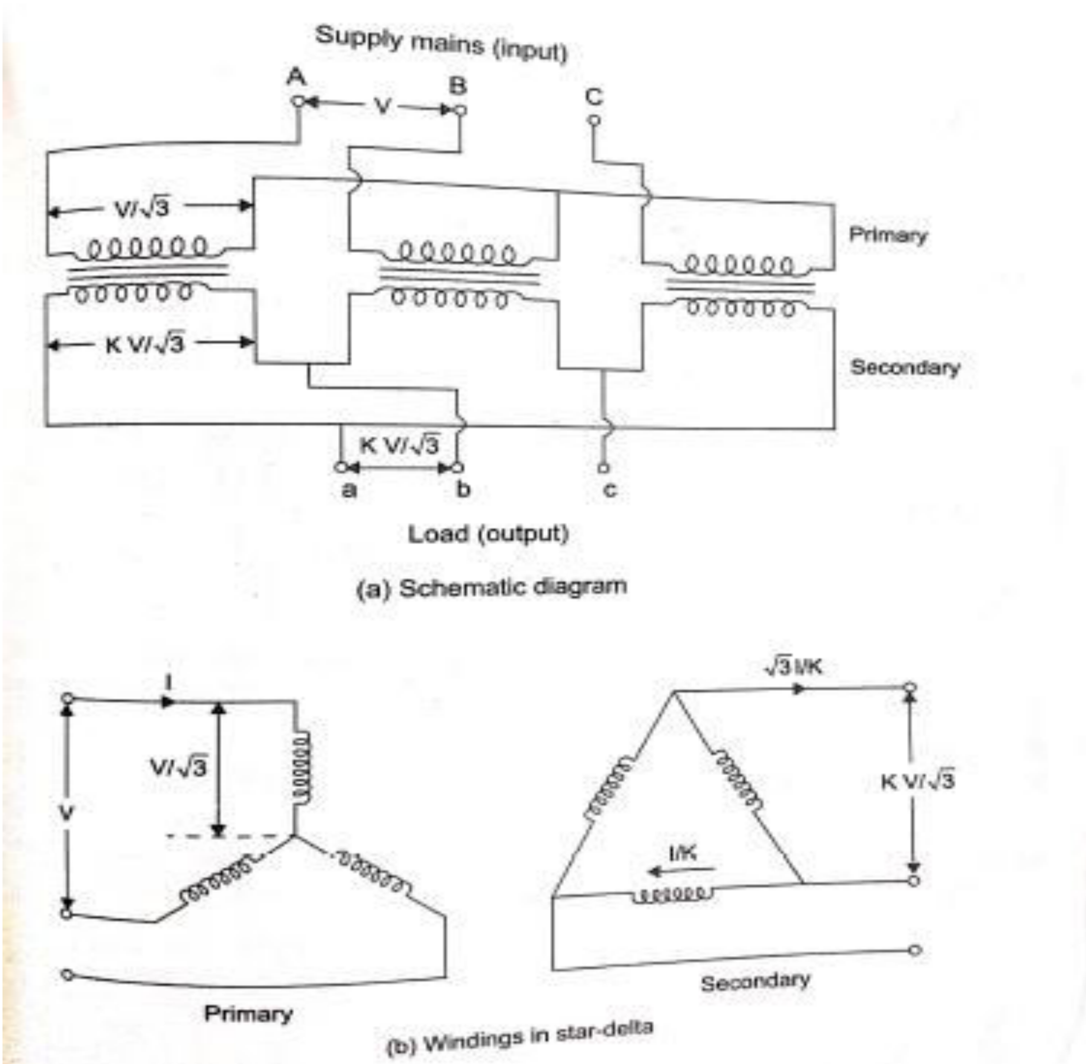
(a) Schematic diagram



(b) Windings in delta-delta

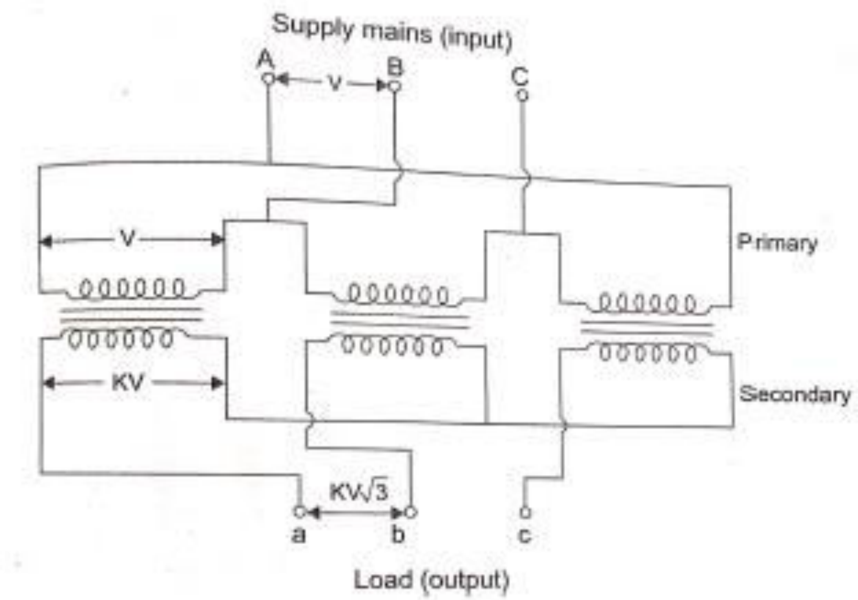
-

Star-Delta OR Wye-Delta (Y-Δ)

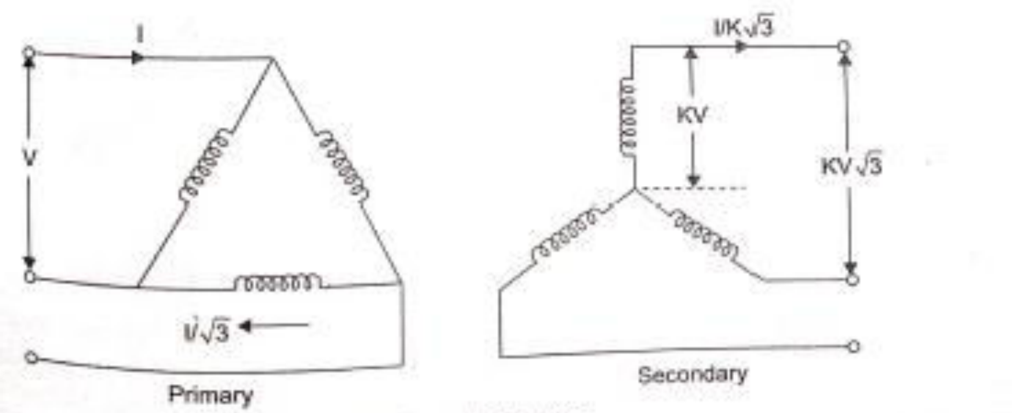
- The primary winding is star star (Y) connected with grounded neutral and the secondary winding is delta connected.
- This connection is mainly used in step down transformer at the substation end of the transmission line.
- The ratio of secondary to primary line voltage is 1/√3 times the transformation ratio.
- There is 30° shift between the primary and secondary line voltages.
- 

Delta-Star OR Delta-Wye (Δ-Y)

- The primary winding is connected in delta and the secondary winding is connected in star with neutral grounded. Thus it can be used to provide 3-phase 4-wire service.
- This type of connection is mainly used in step-up transformer at the beginning of transmission line.
- The ratio of secondary to primary line voltage is √3 times the transformation ratio.
- There is 30° shift between the primary and secondary line voltages. Above transformer connection configurations are shown in the following figure.



(a) Schematic diagram



(b) Windings in delta-star