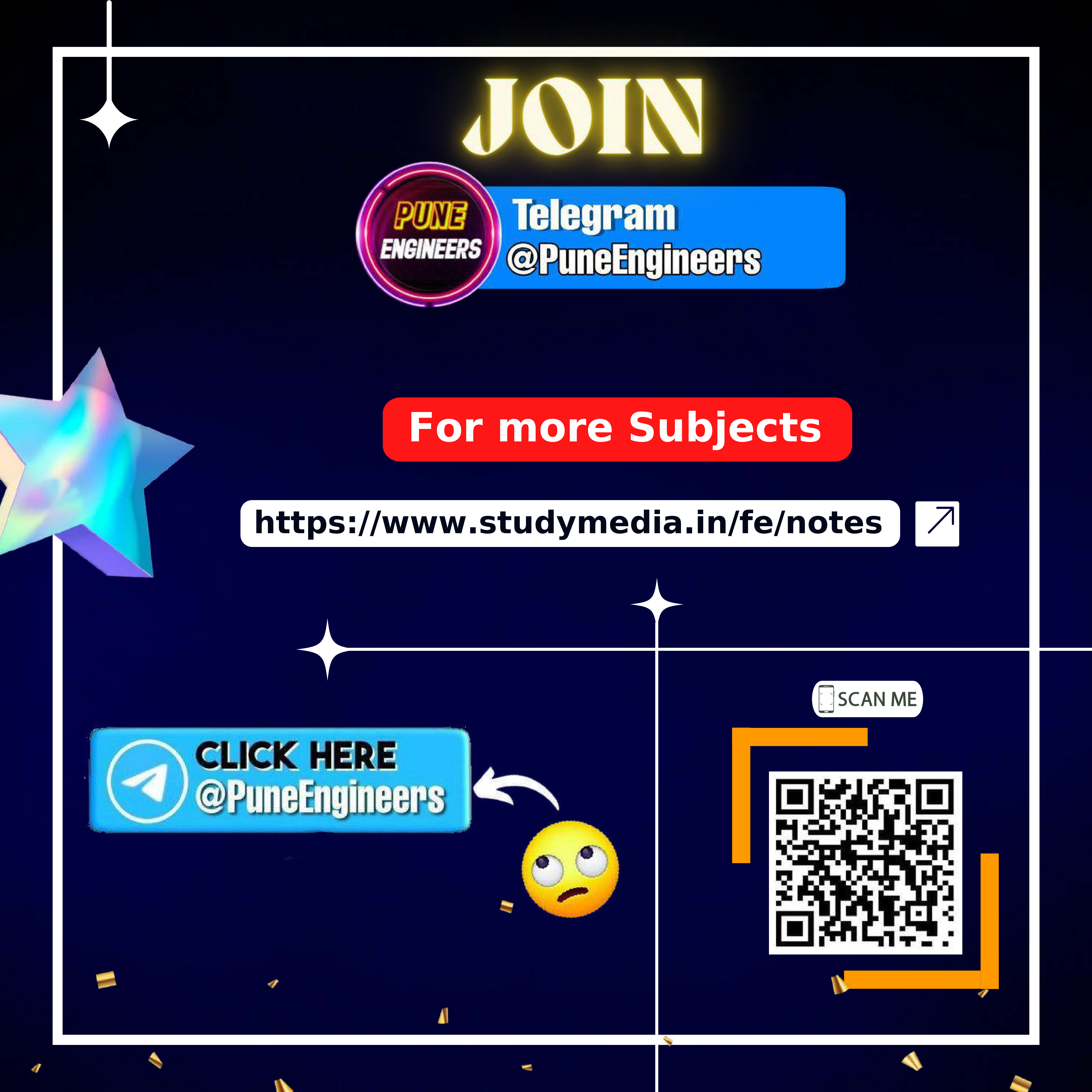
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# Single Phase Transformer

Unit IV(A)

Assistant Prof B.S Bobdey

# Introduction

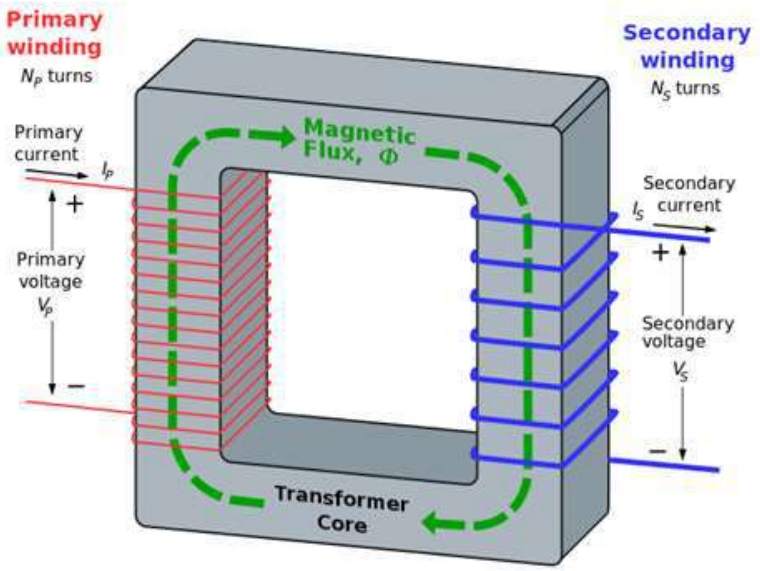
- The transformer is probably one of the most useful electrical devices ever invented.
- It can change the magnitude of alternating voltage or current from one value to another.
- Electrical energy is generated and transmitted at an extremely high voltages. The voltage is to be then reduced to a lower value for its domestic and industrial use.
- Transformers have no moving parts, rugged and durable in construction,thus requiring very little attention.
- They also have a very high efficiency as high as 99%.

In this chapter, we shall study some of the basic properties of transformers.

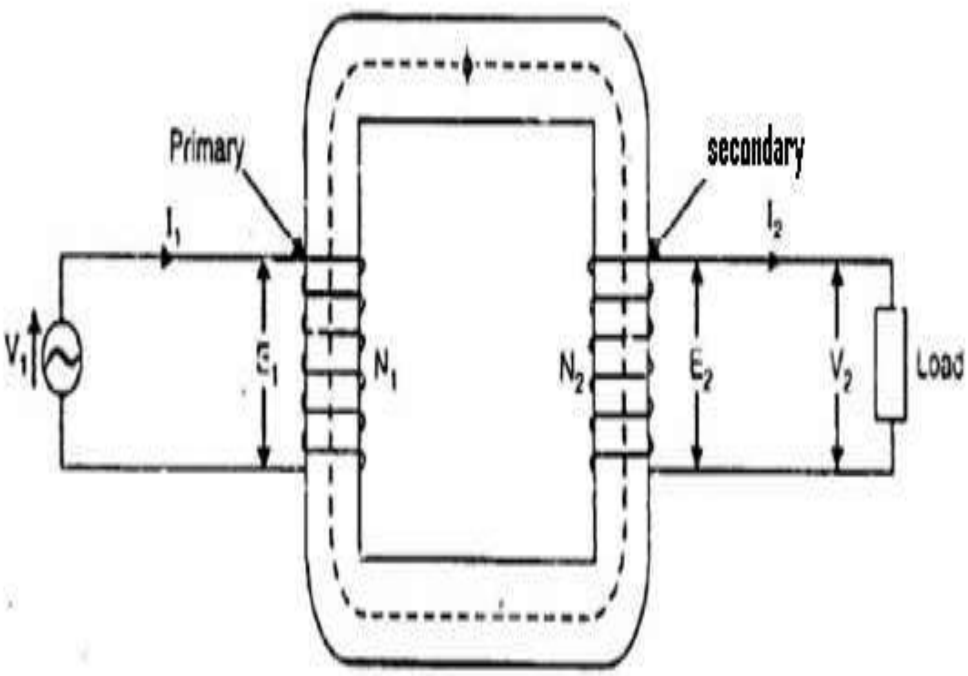
# Working Principle

Law of Electromagnetic Induction(Mutual Induction)

❖ When an alternating voltage V1 is applied to the primary, an alternating flux ϕ is set up in the core. This alternating flux links both the windings and induces e.m.f.s E1 and E2 in them according to Faraday's laws of electromagnetic induction. The e.m.f. E1 is termed as primary e.m.f. and e.m.f. E2 is termed as secondary e.m.f.



# Contd…...




(i) The transformer action is based on the laws of electromagnetic induction.

(ii) There is no electrical connection between the primary and secondary.
The a.c. power is transferred from primary to secondary through magnetic flux.

(iii) There is no change in frequency i.e., output power has the same frequency as the input power.

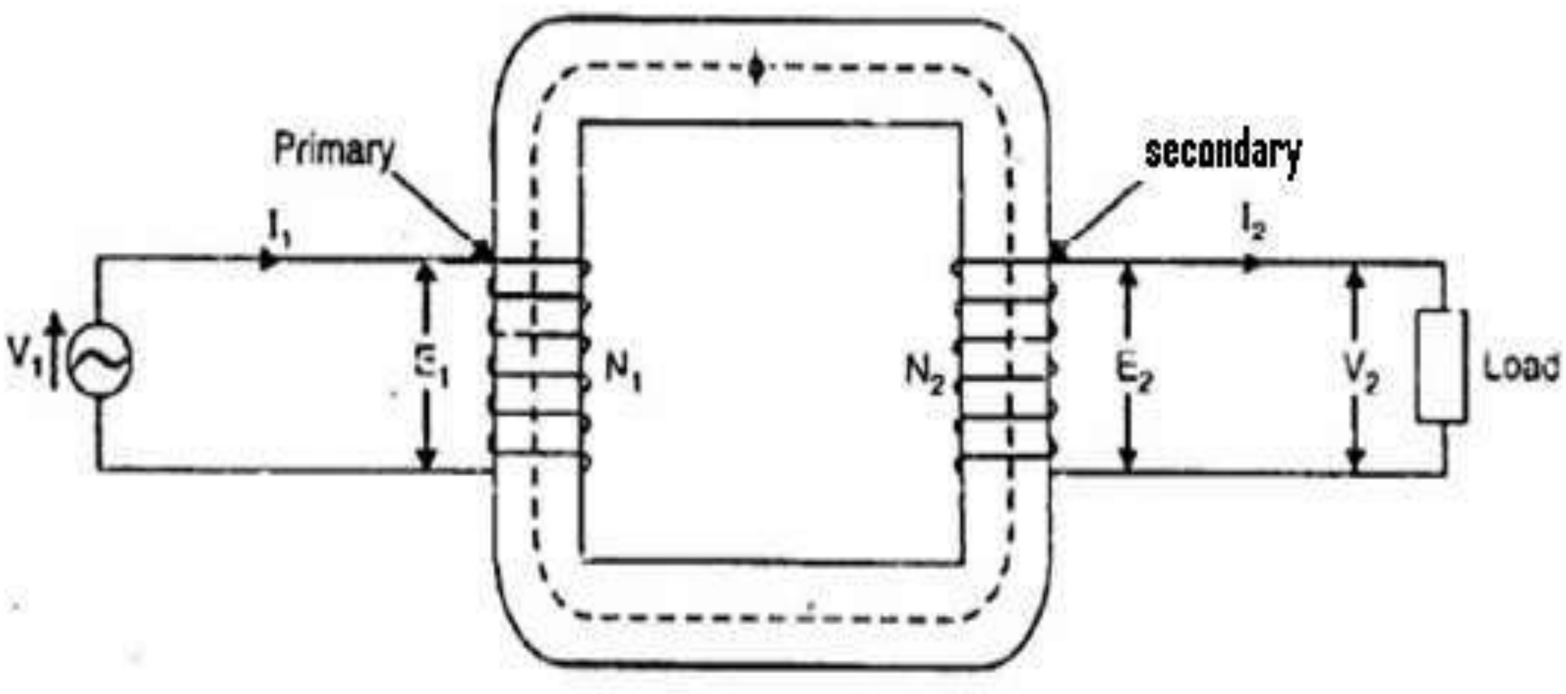
# Can the transformer operate on DC

Answer :- NO

Reasons:-

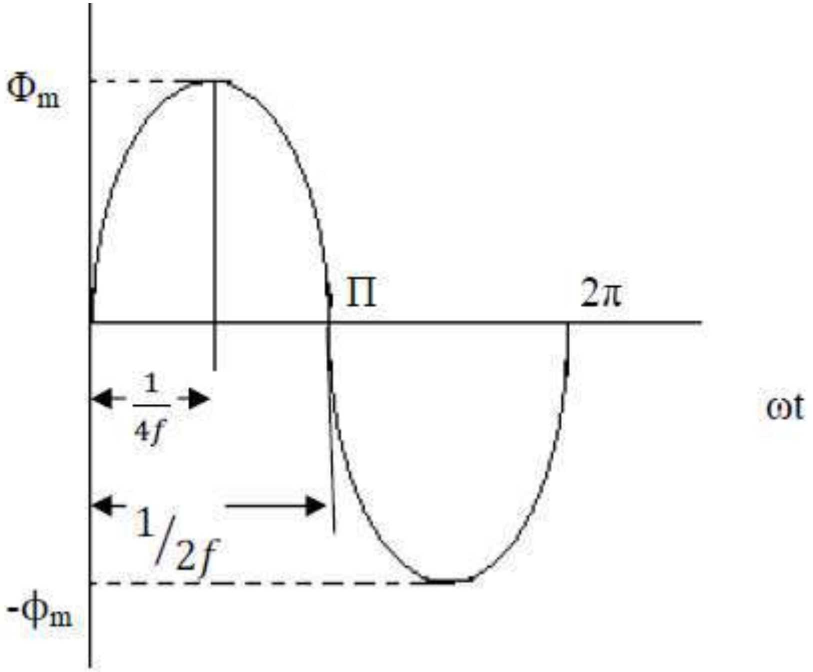
- Working Principle Electromagnetic Induction
- Alternating Flux
- Frequency in DC

# Emf Equation of Transformer



# Contd...

Consider that an alternating voltage V1 of frequency f is applied to the primary as shown in Fig.The sinusoidal flux ϕ produced by the primary can be represented as:




$\phi = \phi m \sin \omega t$

Φ - Flux

Φm - maximum value of flux

N1 - Number of primary turns

N2 - Number of secondary turns

F - Frequency of the supply voltage

E1 - R.m.s value of the primary induced e.m.f

E2 - R.m.s. value of the secondary induced e.m.f

# Contd...

From faraday's law of electromagnetic induction

Average e.m.f per turns = $\frac{d\emptyset}{dt}$

$d\phi$ = change in flux

$dt$ = time required for change in flux

The flux increases from zero value to maximum value $\phi m$ in 1/4f of the time period

That is in 1/4f seconds

The change of flux that takes place in 1/4f seconds = $\phi m-0 = \phi m$ webers

$$\frac{d\phi}{dt} = \frac{dt}{1/4f} = 4f\phi_m \; W_b/sec.$$

# Contd...

Since flux $\phi$ varies sinusoidally, the R.m.s value of the induced e.m.f is obtained by multiplying the average value with the form factor

Form factor of a sin wave= $\frac{\text{R.m.s value}}{\text{Average value}} = 1.11$

R.M.S Value of e.m.f induced in one turns= $4\phi_m f \times 1.11$ Volts.

$= 4.44\phi_m f$ Volts.

R.M.S Value of e.m.f induced in primary winding = $4.44\phi_m f\, N1$Volts.

R.M.S Value of e.m.f induced in secondary winding= $4.44\phi_m f\, N2$Volts.

# EMF Equation of Transformer

The expression of E1 and E2 are called e.m.f equation of a transformer

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

$$E_2 = 4.44\phi_m f N_2 \text{ Volts.}$$

# Voltage Ratio

Voltage transformation ratio is the ratio of e.m.f induced in the secondary winding to the secondary winding to the e.m.f induced in the primary winding.

This ratio of secondary induced e.m.f to primary induced e.m.f is known as voltage transformation ratio

1. If N2>N1 i.e. K>1 we get E2>E1 then the transformer is called step up transformer.
2. If N2<N1 i.e. K<1 we get E2<E1 then the transformer is called step down transformer.
3. If N2=N1 i.e. K=1 we get E2=E1 then the transformer is called isolation transformer or 1:1 transformer.

$$\frac{E2}{E1} = \frac{4.44\phi mf\,N2}{4.44\phi mf\,N1}$$

$$\boxed{\frac{E2}{E1} = \frac{N2}{N1} = K}$$

$$E_2 = KE_1 \qquad \text{where } K = \frac{N2}{N1}$$

# Current Ratio

Current ratio is the ratio of current flow through the primary winding (I1) to the current flowing through the secondary winding (I2)

In an ideal transformer

Apparent input power = Apparent output power.

V1I1 = V2I2

$$\frac{I1}{I2} = \frac{V2}{V1} = \frac{N2}{N1} = \mathrm{K}$$

# KVA Rating

i) The transformer rating is specified as the products of voltage and current (VA rating).

ii) On both sides, primary and secondary VA rating remains same. This rating is generally expressed in KVA (Kilo Volts Amperes rating).

$$\frac{V1}{V2} = \frac{I2}{I1} = \text{K}$$

$$V_1 I_1 = V_2 I_2$$

$$\text{KVA Rating of a transformer} = \frac{V1I1}{1000} = \frac{V2I2}{1000} \text{ (1000 is to convert KVA to VA)}$$

# KVA Rating

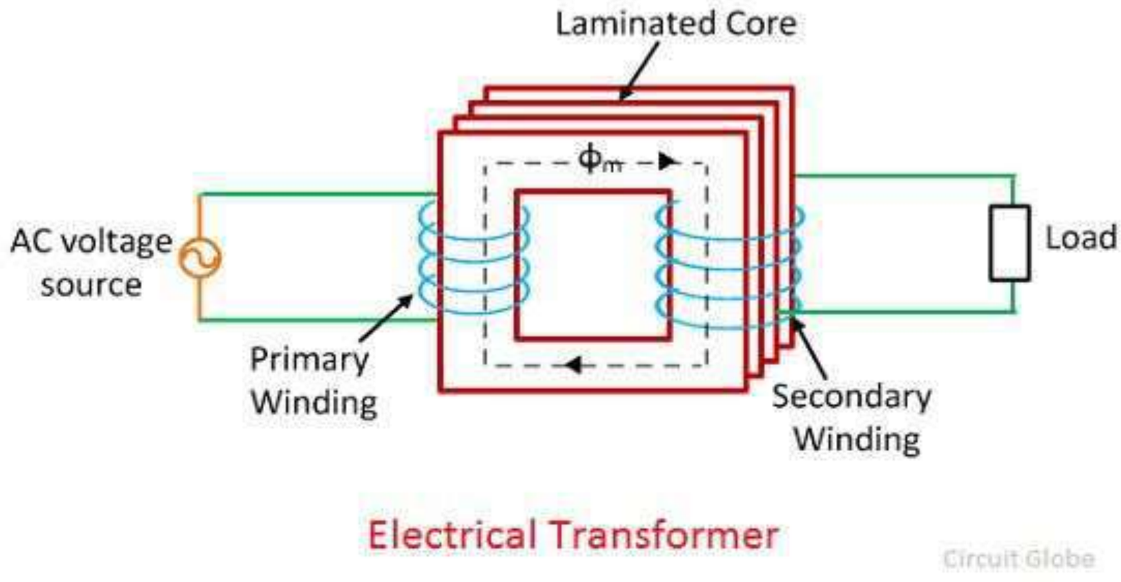
Full load current and it is safe maximum current.

V1 and V2 are the Vt of primary and secondary by using KVA rating we can calculate I1 and I2.

$$I_1 \text{ Full load current} = \frac{KVA\ Rating\ X\ 1000}{V1}$$

$$I_1 \text{ Full load current} = \frac{KVA\ Rating\ X\ 1000}{V2}$$

# Construction Of Transformer




**Other Subjects: https://www.studymedia.in/fe/notes**

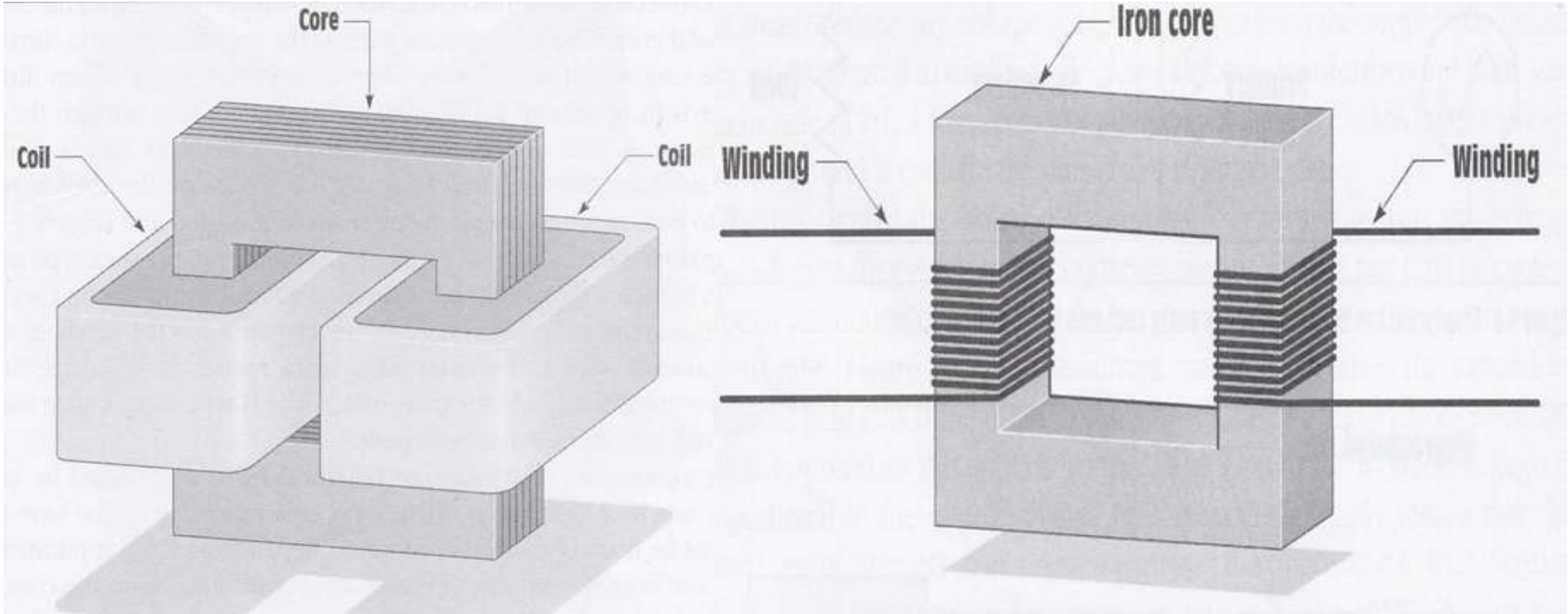
# Types of Transformer

The transformer are of different types depending on the arrangement of the core and the winding as follows.

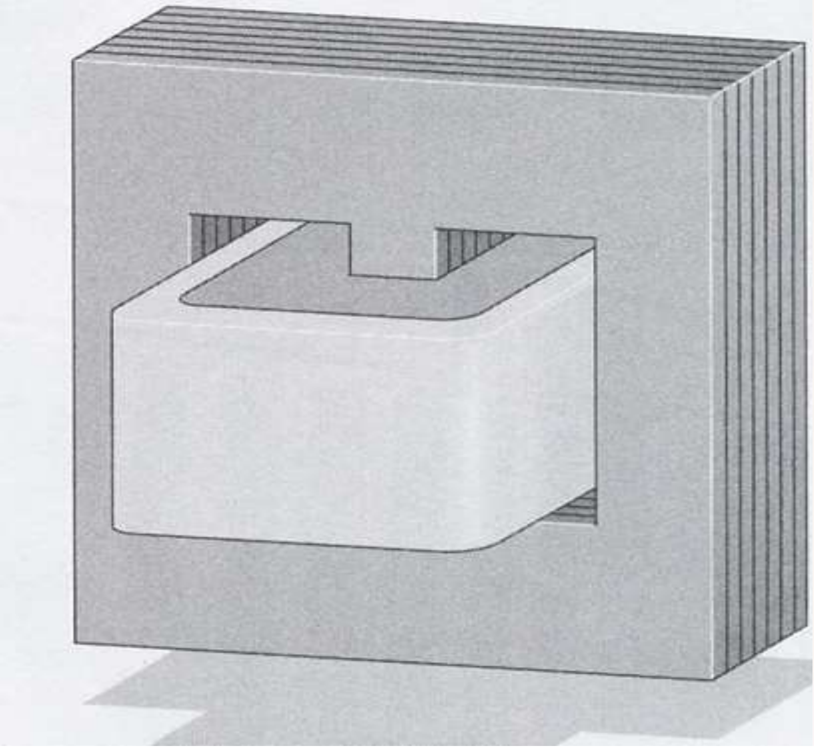
- Core Type
- Shell Type
- Berry Type

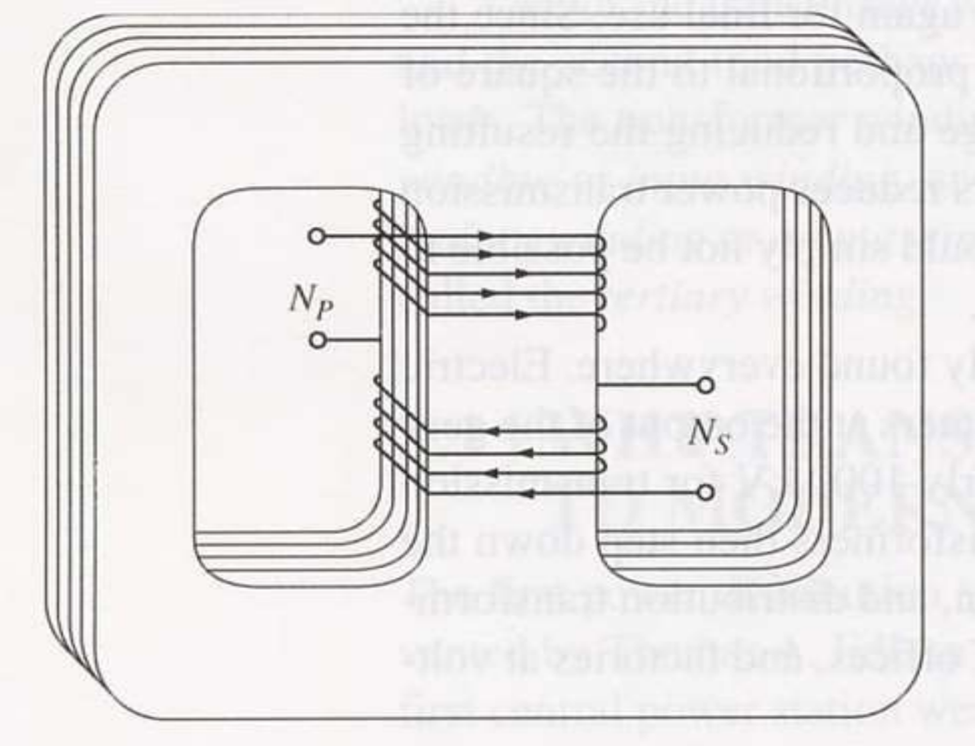
The magnetic core is a stack of thin silicon-steel laminations about 0.35 mm thick for 50 Hz transformer. In order to reduce the eddy current losses, these laminations are insulated from one another by thin layers of varnish.

# Core Type Transformer

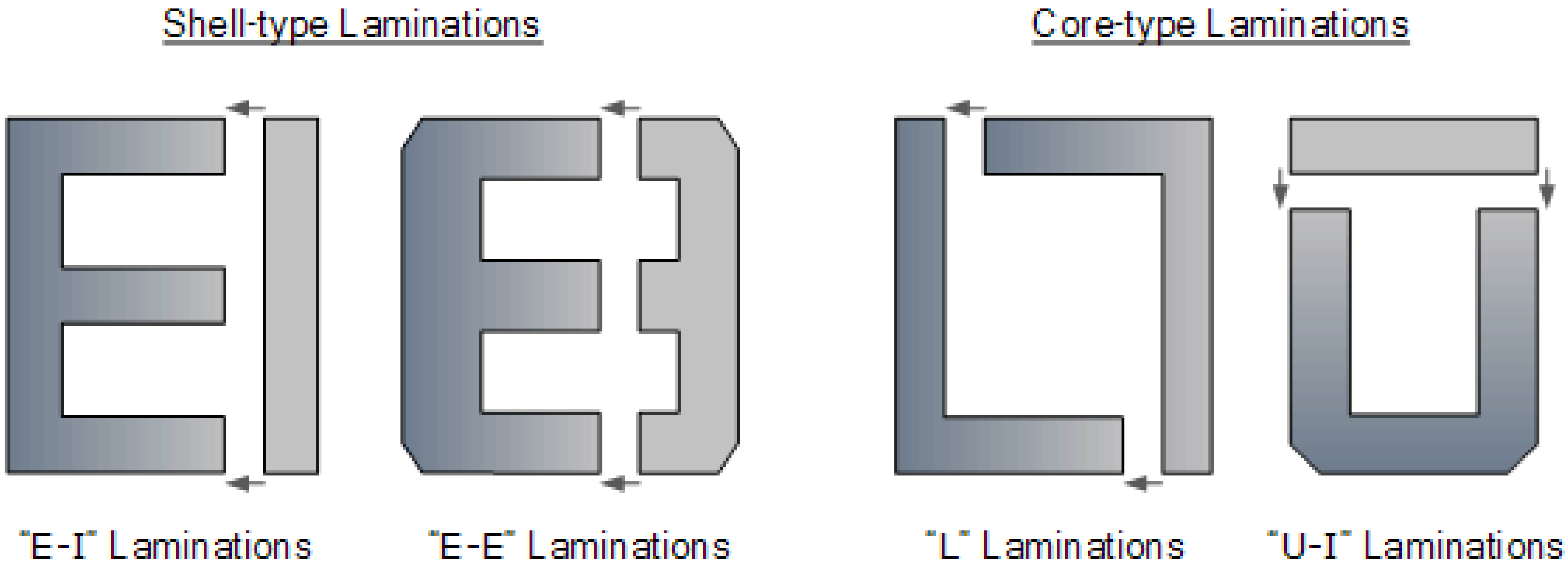


# Shell Type Transformer





# Laminations

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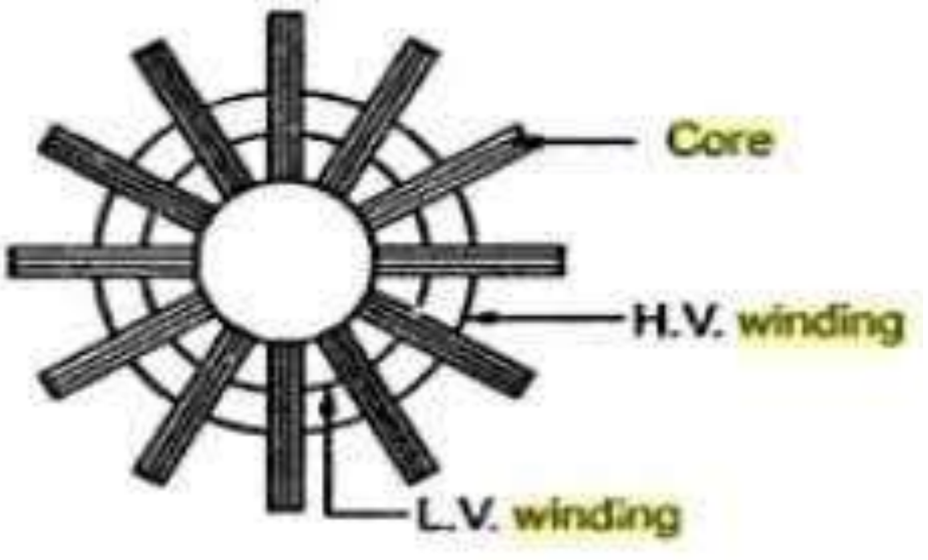
# Berry Type Transformer



# Losses in Transformer

The power losses in a transformer are of two types, namely

1. Core or Iron losses
2. Copper losses

These losses appear in the form of heat and produce
(i) an increase in Temperature and
(ii) a drop in efficiency.

# Core or Iron losses (Pi)

These consist of hysteresis and eddy current losses and occur in the transformer core due to the alternating flux. These can be determined by open-circuit test.

$$\textbf{Hysteresis loss} = k_h\, f\, B_m^{1.6} \text{ watts}$$

Kh – hysteresis constant depend on material

f - Frequency

Bm – maximum flux density

$$\textbf{Eddy current loss} = K_e\, f^2\, Bm^2 t^2 \text{ watts}$$

Ke – eddy current constant

t - Thickness of the core

Both hysteresis and eddy current losses depend upon

(i) maximum flux density Bm in the core

(ii) supply frequency f.

Since transformers are connected to constant-frequency,constant voltage supply, both f and Bm are constant. Hence, core or iron losses are practically the same at all loads.

Iron or Core losses, Pi = Hysteresis loss + Eddy current loss = Constant losses(Pi)
The hysteresis loss can be minimized by using steel of high silicon content
Whereas eddy current loss can be reduced by using core of thin laminations.

## Copper losses (Pcu)

These losses occur in both the primary and secondary windings due to their ohmic resistance. These can be determined by short-circuit test. The copper loss depends on the magnitude of the current flowing through the windings.

$$\text{Total copper loss} = I_1^2R_1 + I_2^2R_2 = I_1^2(R_1 + R_2') = I_2^2(R_2 + R_1')$$

$$\text{Total loss} = \text{iron loss} + \text{copper loss} = Pi + Pcu$$

# Why Transformer Rating in kVA

An important factor in the design and operation of electrical machines is the relation between the life of the insulation and operating temperature of the machine.
Therefore,
Temperature rise resulting from the losses is a determining factor in the rating of a machine.

We know that copper loss in a transformer depends on current and iron loss depends on voltage.
Therefore, the total loss in a transformer depends on the volt-ampere product only and not on the phase angle between voltage and current i.e., it is independent of load power factor. For this reason, the rating of a transformer is in kVA and not kW.

# EQUIVALENT RESISTANCE

1) It would now be shown that the resistances of the two windings can be transferred to any one of the two winding.

2) The advantage of concentrating both the resistances in one winding is that it makes calculations very simple and easy because one has then to work in one winding only.

3) Transfer to any one side either primary or secondary without affecting the performance of the transformer

# Contd…..

The total copper loss due to both the resistances.

$$\text{Total copper loss} = I_1^2 R_1 + I_2^2 R_2$$
$$= I_1^2 [R_1 + \frac{I2^2}{I1^2}]$$
$$= I_1^2 [R_1 + \frac{1}{K} R_2]$$

$\frac{R2}{K^2}$ is the resistance value of $R_2$ shifted to primary side and denoted as $R_2$

$R_2$' is the equivalent resistance of secondary referred to primary

$$\boxed{R_2' = \frac{R2}{K^2}}$$

# Equivalent Resistance

Therefore Equivalent resistance of transformer referred to primary

$$R_{1e} = R_1 + R_2' = R_1 + \frac{R2}{K^2}$$

# Equivalent Resistance

Similary

Total copper loss $= I_1^2R_1 + I_2^2R_2 = I_2^2\,[\frac{I1^2}{I2^2}R_1 + R_2]$

$= I_2^2[K^2R_1 + R_2]$

$K^2R1$ is primary resistance referred to secondary denoted as R1'.

$$R_1' = K^2R_1$$

Equivalent resistance of transformer referred to secondary, denoted as R2e

$$\boxed{R_{2e} = R_2 + R_1' = R_2 + K^2R_1}$$

# Equivalent Resistance

Thus

While calculating Copper loss  Equivalent resistance referred to secondary is taken

$$R_{2e} = R_2 + R_1' = R_2 + K^2 R_1$$

$$\text{Total copper loss} = I_2^2 \, R_{2e}$$

# Efficiency of a Transformer

Like any other electrical machine, the efficiency of a transformer is defined as the ratio of output power (in watts or kW) to input power (watts or kW) i.e.,

Power output = power input – Total losses

Power input = power output + Total losses = power output + Pi + Pcu

Power output = $V_2 I_2 \cos\phi$,

Cos $\phi$ = load power factor

Transformer supplies full load of current $I_2$ and with terminal voltage $V_2$

Pcu = copper losses on full load = $I_2^2 R_{2e}$

# Contd...

$$\text{Efficiency} = \frac{V2I2\ \cos\phi}{V2I2\ \cos\phi + Pi + I2^2 R2e}$$

$$\boxed{\%\ \text{Efficiency} = \frac{(\text{VA rating})\text{X}\ \cos\phi}{(\text{VA rating})\text{X}\ \cos\phi + Pi + I2^2 R2e}\ \text{X}\ 100}$$

This is full load efficiency and I2 = full load current

We can now find the full-load efficiency of the transformer at any p.f. without actually loading the transformer.

# Contd...

Also for any load equal to n x full-load

Corresponding total losses = Pi + $n^2P_{Cu}$

n = fractional by which load is less than full load= $\frac{actual\ load}{full\ load}$

$$n = \frac{half\ load}{fullload} = \frac{(\frac{1}{2})}{1} = 0.5$$

$$\text{Corresponding (n) \% Efficiency} = \frac{n(\text{VA rating})\text{X} \cos\phi}{n(\text{VA rating})\text{X} \cos\phi + Pi + n^2Pcu} \text{X } 100$$

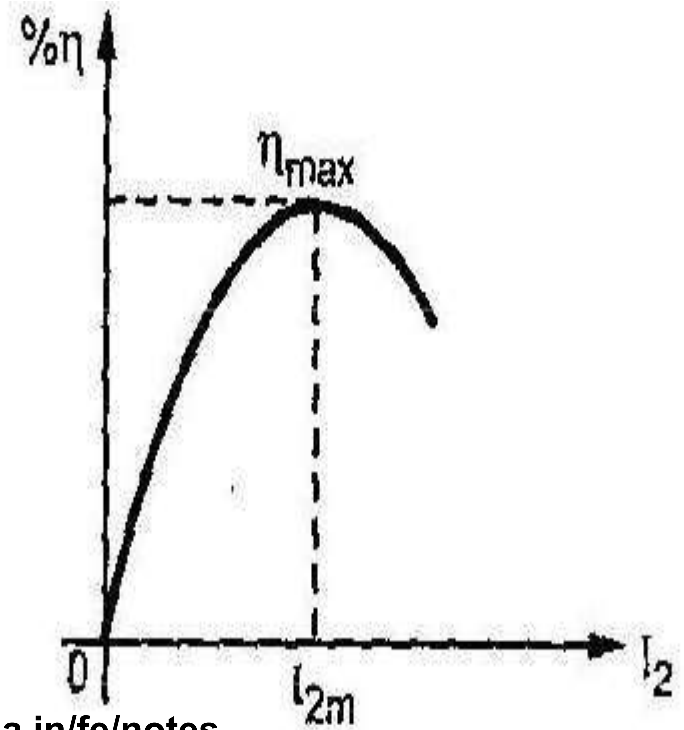
# Condition for Maximum Efficiency

Voltage and frequency supply to the transformer is constant the efficiency varies with the load.

As load increases, the efficiency increases. At a certain load current, it loaded further the efficiency start decreases as shown in fig.

Pcu loss = Pi iron loss

The output current which will make Pcu loss equal to the iron loss. By proper design, it is possible to make the maximum efficiency occur at any desired load.



# Load current $I_{2m}$ at maximum efficiency

$$I_{2m} = (I_2)\,F.L.\ \sqrt{\frac{Pi}{[Pcu]F.L}}$$

This is the load current at $n_{max}$ in terms of full load current

# KVA SUPPLIED AT MAXIMUM EFFICIENCY

$$\boxed{\text{KVA at } \eta_{max} = (\text{KVA rating}) \text{ X} \sqrt{\frac{Pi}{[Pcu]\text{F.L}}}}$$

Substituting condition for $n_{max}$ in the expression of efficiency, we can write expression for $n_{max}$ as

$$\% \, \eta_{max} = \frac{KVA \, for \, \eta \max \cos\varphi}{KVA \, for \, \eta \max \cos\varphi + 2Pi}$$

as Pcu = Pi

# Testing of Transformer

The testing of transformer means to determine efficiency and regulation of a transformer at any load and at any power factor condition.

There are two methods

i) Direct loading test

ii) Indirect loading test

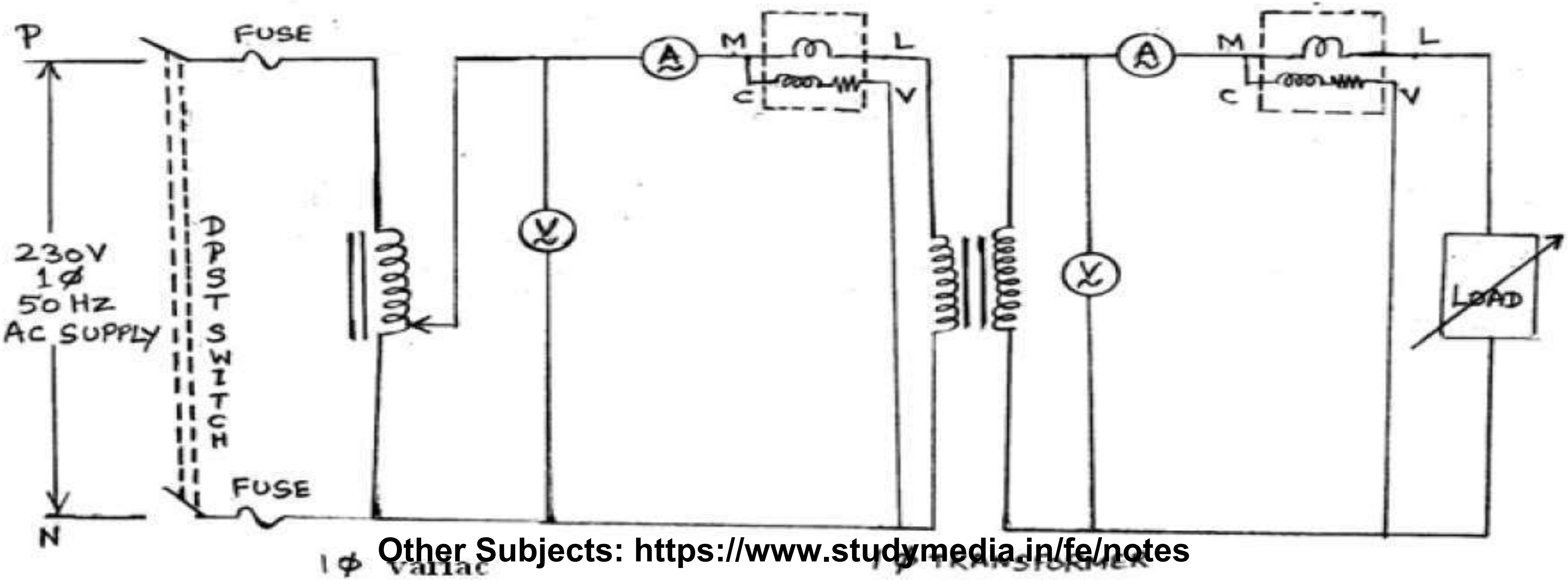
a. Open circuit test

b. Short circuit test

We will study Direct loading test

# Load test on transformer

This method is also called as direct loading test on transformer because the load is directly connected to the transformer.



# Observation Table

| S.No. | Primary side | | | Secondary side | | |
|---|---|---|---|---|---|---|
| | $V_1$ (v) | $I_1$ (A) | $W_1$ (W) | $V_2$ (V) | $I_2$ (A) | $W_1$ (W) |
| 1 | Rated | | | $E_2$ | 0 | 0 |
| 2 .. | | | | | | |

The load is varied from no load to full load in desired steps. All the time, keep primary voltage V1 constant at its rated value with help of variac and tabulated the reading.

The first reading is to be noted on no load for which I2 = 0 A and W2 = 0W

# Calculation

From the observed reading

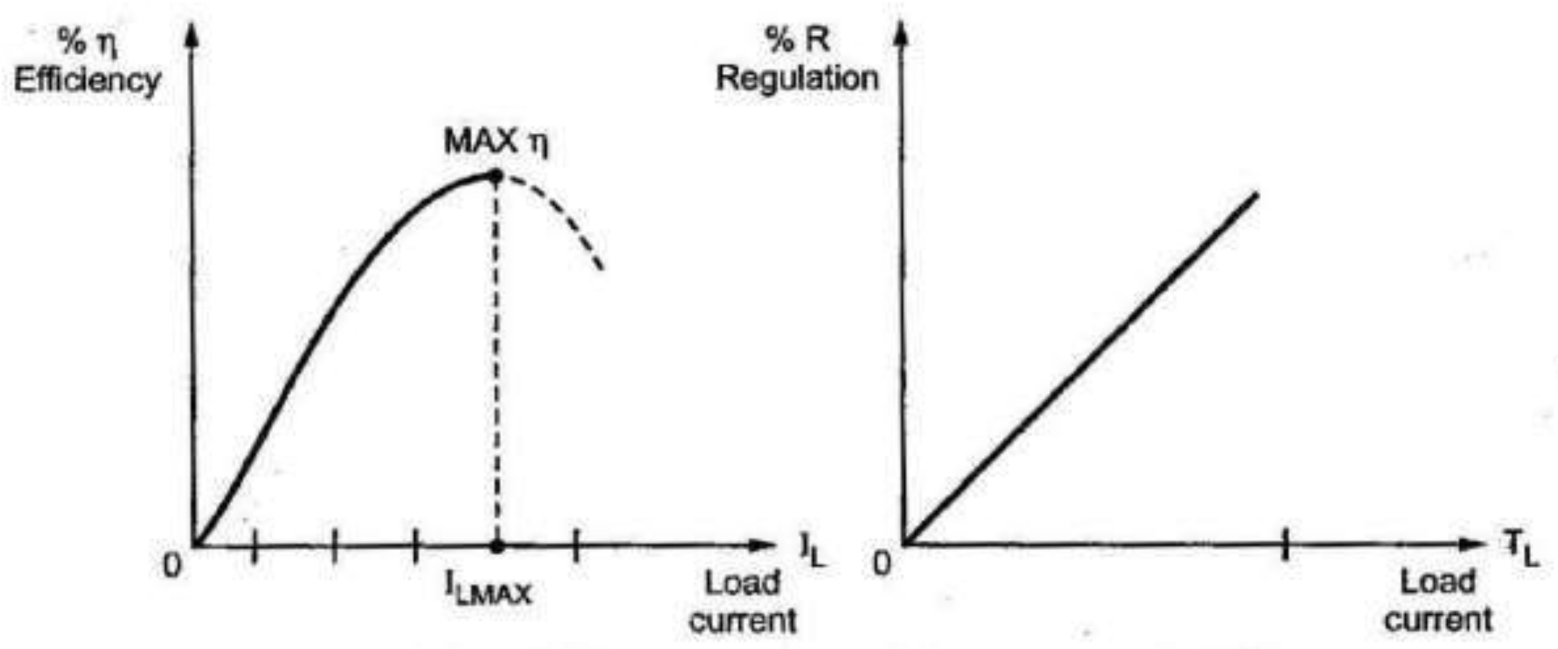
W1 = input power to the transformer

W2 = output power delivered to the load

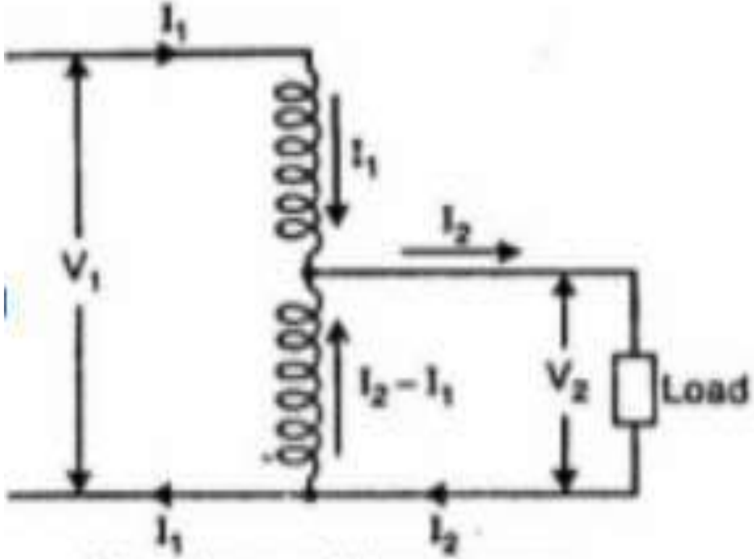
$$\% \eta = \frac{W2}{W1} X\ 100$$

$$\% R = \frac{E2 - V2}{V2} X\ 100$$

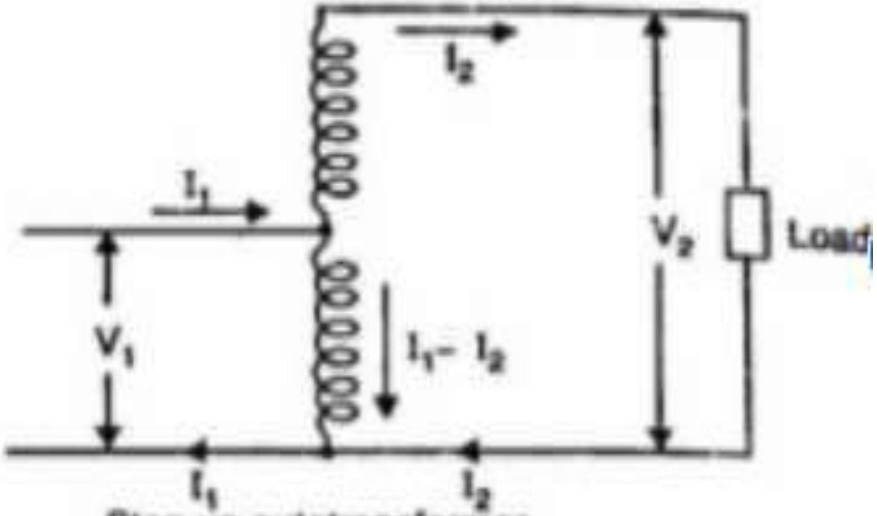
# Efficiency and regulation characteristics



# Autotransformer



Step-down autotransformer



Step-up autotransformer

# Advantage And Disadvantage of Autotransformer

Advantages

- The size of the **auto transformer**
- The saving in cost of the material
- An auto transformer has higher efficiency
- Auto transformer has better voltage regulation

Disadvantages

- The leakage flux between the primary and secondary windings is small  hence the impedance is low.
- it is not possible to earth neutral of one side only
- It is more difficult to maintain the electromagnetic balance of the winding when voltage adjustment tappings are provided

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# PolyPhase System

## BEE Unit – IV (B)

Asst Prof B S Bobdey

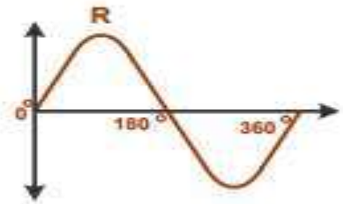
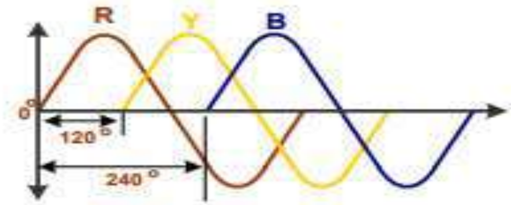
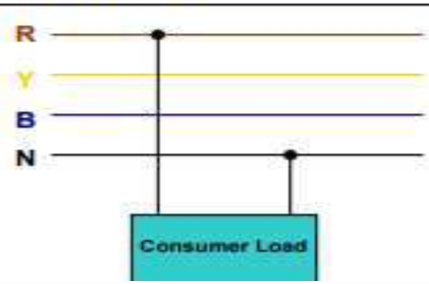
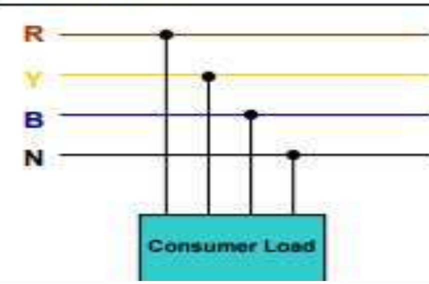
# Introduction

- The system which has three phases, i.e., the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system.

- In other words, the system which uses three wires for generation, transmission and distribution is known as the three phase system.

- The three phase system is also used as a single phase system if one of their phase and the neutral wire is taken out from it. The sum of the line currents in the 3-phase system is equal to zero, and their phases are differentiated at an angle of $120^o$

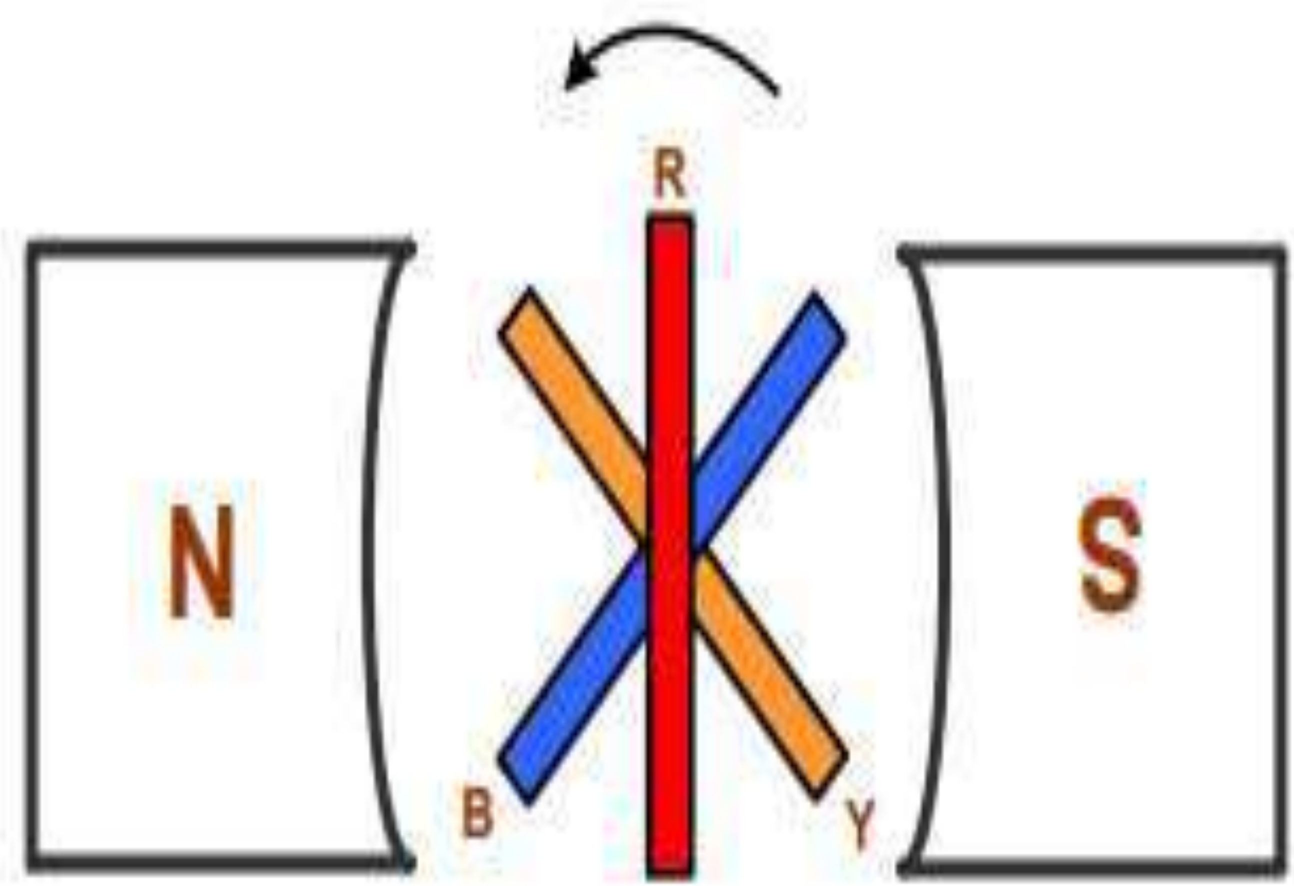
# Comparision 1phase and 3Phase

| Basis for Comparison | Single Phase | Three Phase |
|---|---|---|
| Definition | The power supply through one conductor. | The power supply through three conductors. |
| Wave Shape |  |  |
| Number of wire | Require two wires for completing the circuit | Requires four wires for completing the circuit |
| Voltage | Carry 230V | Carry 415V |
| Phase Name | Split phase | No other name |
| Network | Simple | Complicated |
| Loss | Maximum | Minimum |
| Power Supply Connection |  |  |
| Efficiency | Less | High |
| Economical | Less | More |
| Uses | For home appliances. | In large industries and for running heavy loads. |

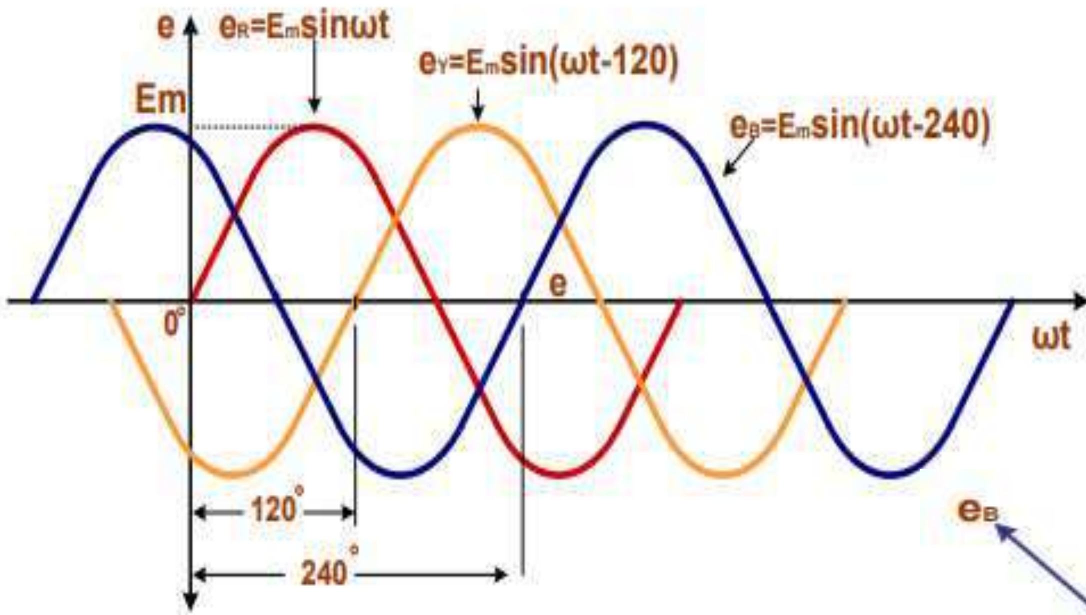
# Generation of three phase EMF

- According to Faraday's law of electromagnetic induction, we know that whenever a coil is rotated in a magnetic field, there is a sinusoidal emf induced in that coil.
- Now, we consider 3 coil C1(R-phase), C2(Y-phase) and C3(B-phase), which are displaced 1200 from each other on the same axis. This is shown in fig.
- The coils are rotating in a uniform magnetic field produced by the N and S poll in the counter clockwise direction with constant angular velocity.
- According to Faraday's law, emf induced in three coils. The emf induced in these three coils will have phase difference of $120^0$. i.e. if the induced emf of the coil C1 has phase of $0^0$, then induced emf in the coil C2 lags that of C1 by $120^0$ and C3 lags that of C2 $120^0$.

# Generation of Three Phase



# Three Phase Waveform



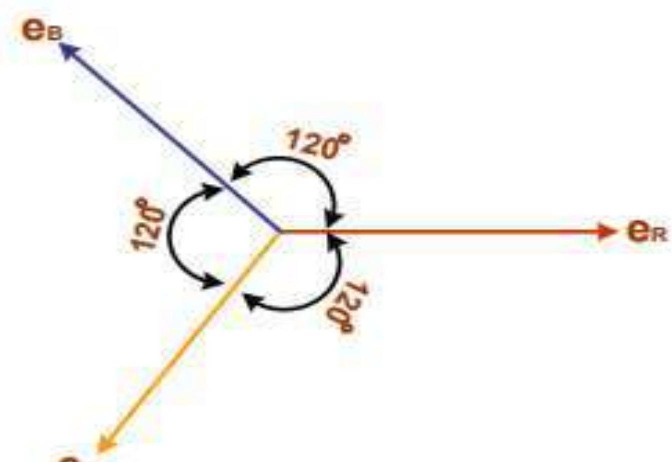

Thus, we can write,

$$e_R = E_m \sin \omega t$$

$$e_Y = E_m \sin\left(\omega t - 120^0\right)$$

$$e_B = E_m \sin\left(\omega t - 240^0\right)$$

The above equation can be represented by their phasor diagram as in the Fig.



# Important Definition

- **Phase sequence :**The order in which three coil emf or currents attain their peak values is called the phase sequence. It is customary to denoted the 3 phases by the three colours. i.e. red (R), yellow (Y), blue (B).

- **Balance System:** A system is said to be balance if the voltages and currents in all phase are equal in magnitude and displaced from each other by equal angles.

- **Unbalance System:** A system is said to be unbalanced if the voltages and currents in all phase are unequal in magnitude and displaced from each other by unequal angles.

- **Balance load:** In this type the load in all phase are equal in magnitude. It means that the load will have the same power factor equal currents in them.

- **Unbalance load:** In this type the load in all phase have unequal power factor and currents.

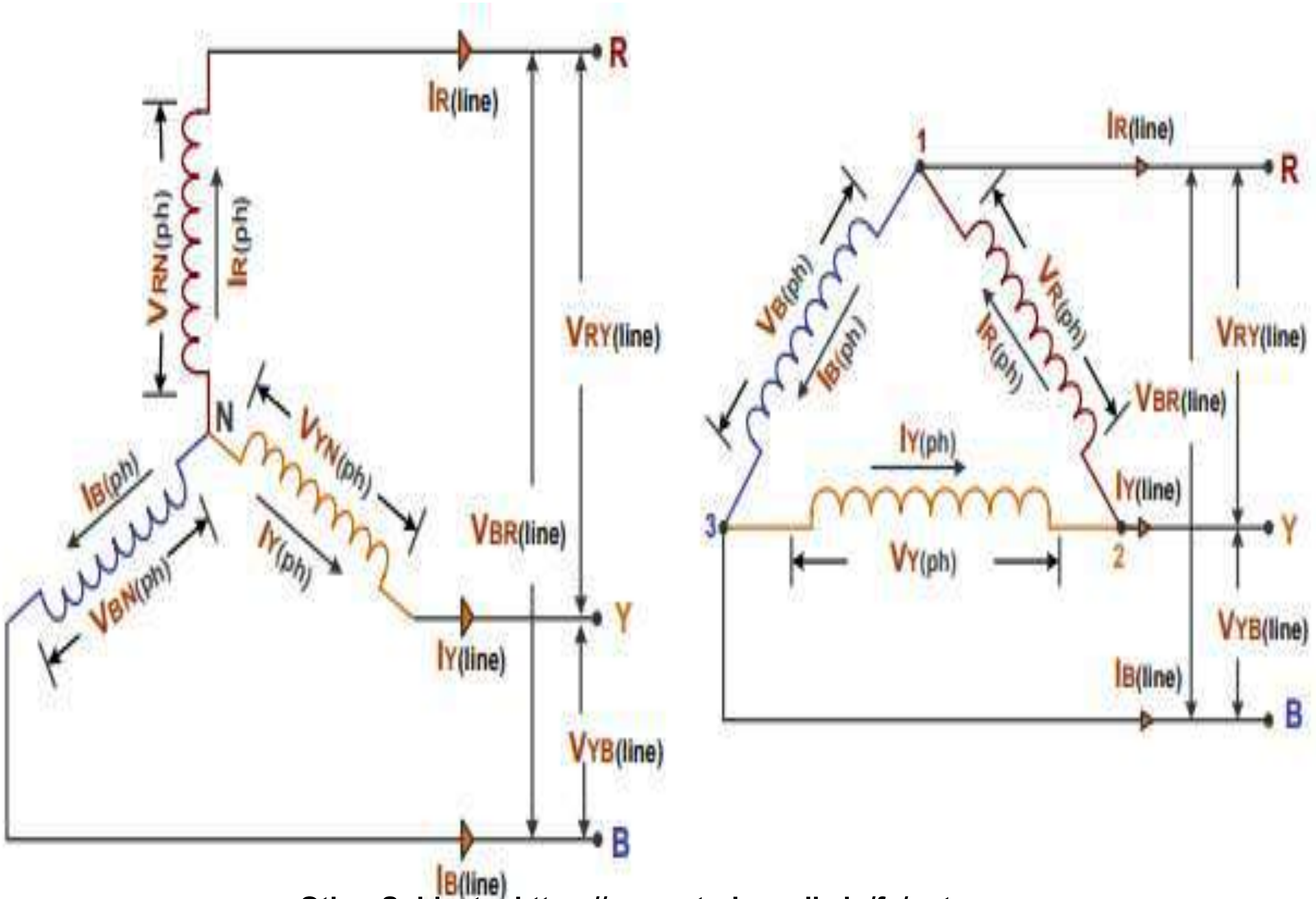
# Important Definition

➢**Phase Voltage** : It is defined as the voltage across either phase winding or load terminal. It is denoted by Vph. Phase voltage VRN, VYN and VBN are measured between R-N, Y-N, B-N for star connection and between R-Y, Y-B, B-R in delta connection.

➢ **Line voltage:** It is defined as the voltage across any two-line terminal. It is denoted by VL. Line voltage VRY, VYB, VBR measure between R-Y, Y-B, B-R terminal for star and delta connection both.

➢ **Phase current :** It is defined as the current flowing through each phase winding or load. It is denoted by Iph. Phase current IR(ph), IY(ph) and IB(Ph) measured in each phase of star and delta connection. respectively.

➢ **Line current :** It is defined as the current flowing through each line conductor. It denoted by IL. Line current IR(line), IY(line), and IB((line) are measured in each line of star and delta connection



R
IR(line)
VRN(ph)
IR(ph)
VRY(line)
N
VYN(ph)
IB(ph)
IY(ph)
VBN(ph)
VBR(line)
Y
IY(line)
VYB(line)
B
IB(line)
1
IR(line)
R
VB(ph)
IB(ph)
VR(ph)
IR(ph)
VRY(line)
VBR(line)
IY(ph)
IY(line)
3
Y
2
VY(ph)
VYB(line)
IB(line)
B

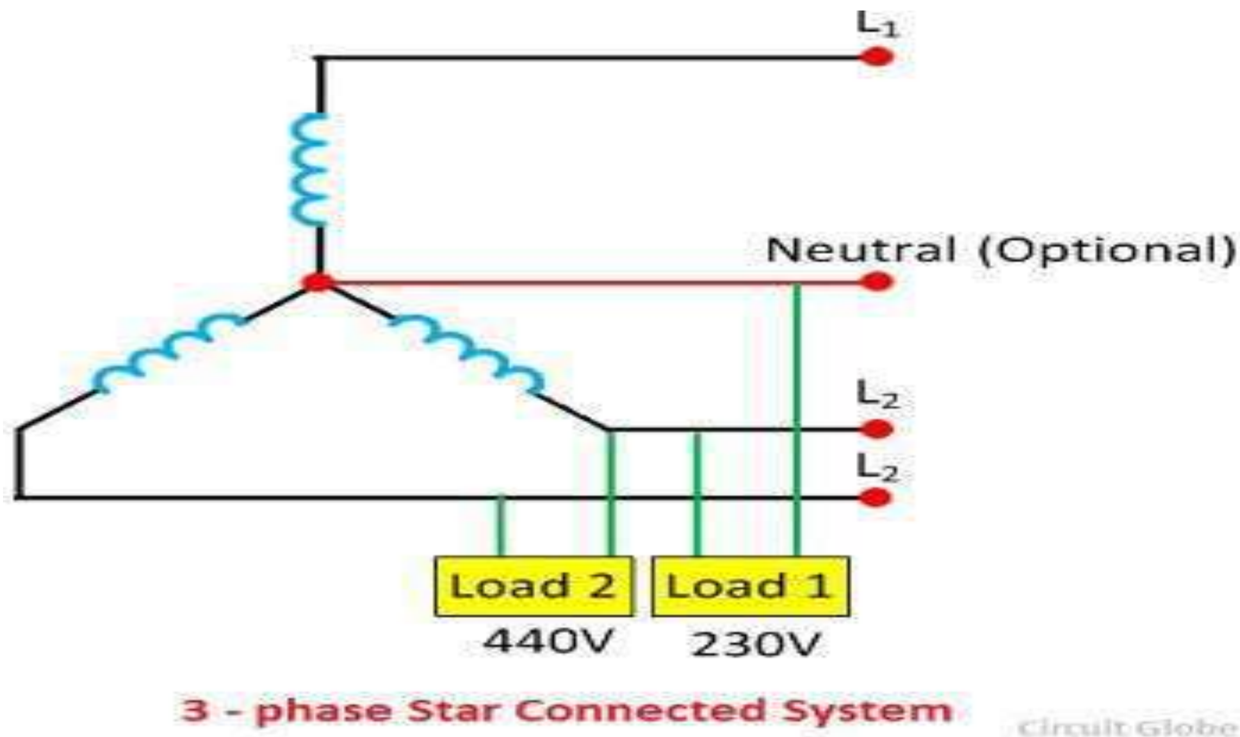
# Types of Connections in Three-Phase System

The three-phase systems are connected in two ways, i.e.,

- the star connection and
- the delta connection.

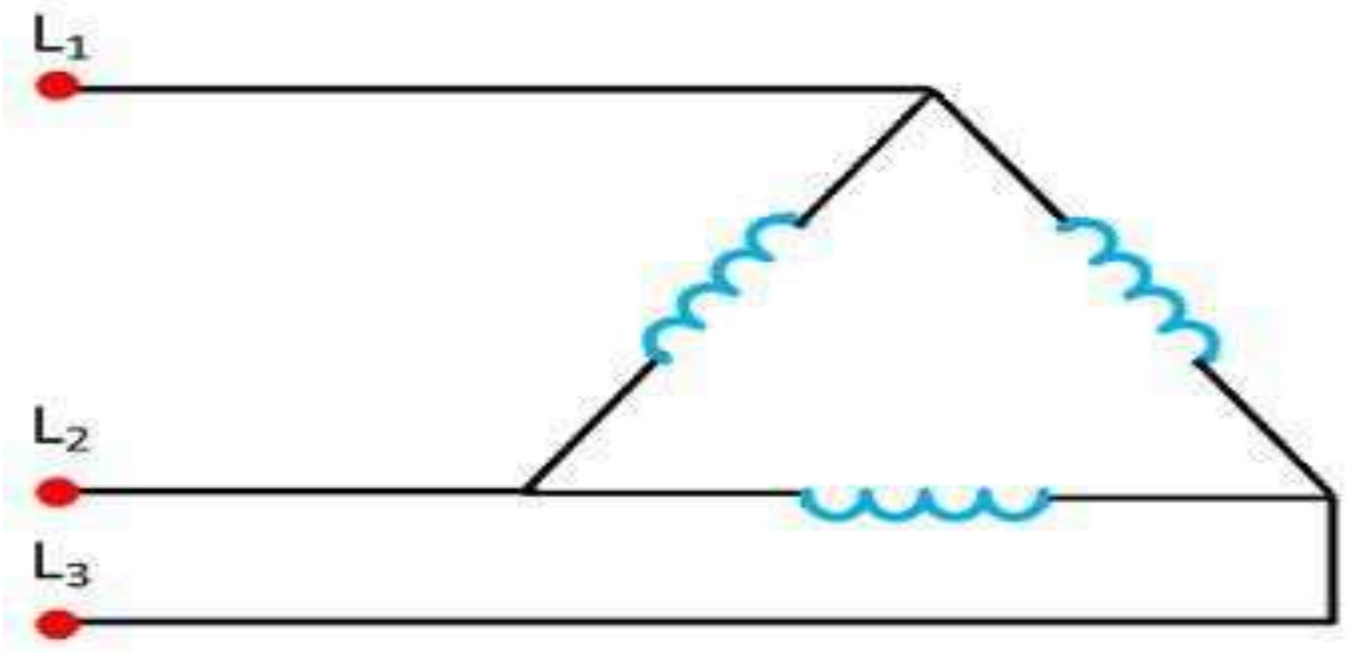
# Star Connection

- The star connection requires four wires in which there are three phase conductors and one neutral conductor



# Delta Connection

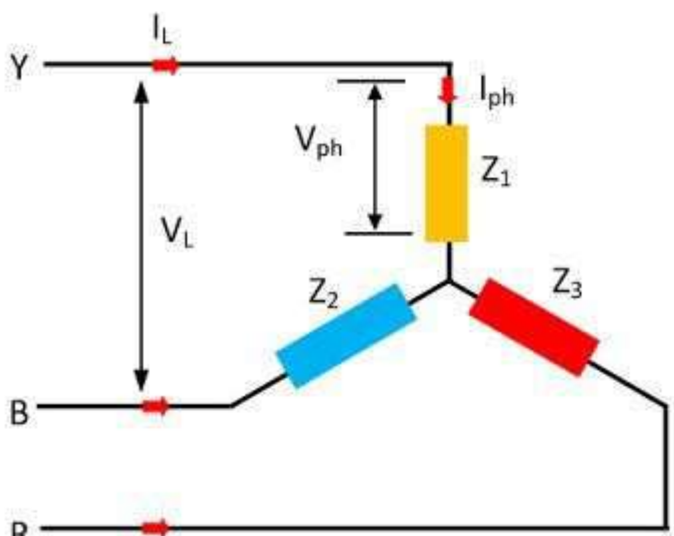
The delta connection has three wires, and there is a no neutral point. The delta connection is shown in the figure below

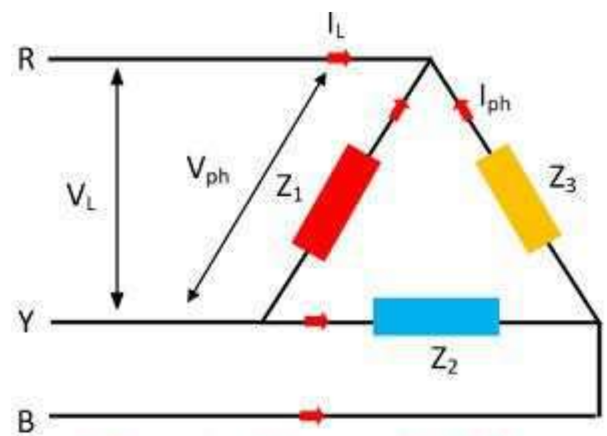



3 - Phase Delta Connection

# Connection of Loads in Three Phase System

- The loads in the three-phase system may also connect in the star or delta. The three phase loads connected in the delta and star is shown in the figure below.
- The three phase load may be balanced or unbalanced. If the three loads (impedances) $Z_1$, $Z_2$ and $Z_3$ has the same magnitude and phase angle then the three phase load is said to be a balanced load.
- Under balance condition, all the phases voltages are equal and the line voltages are equal in magnitude.

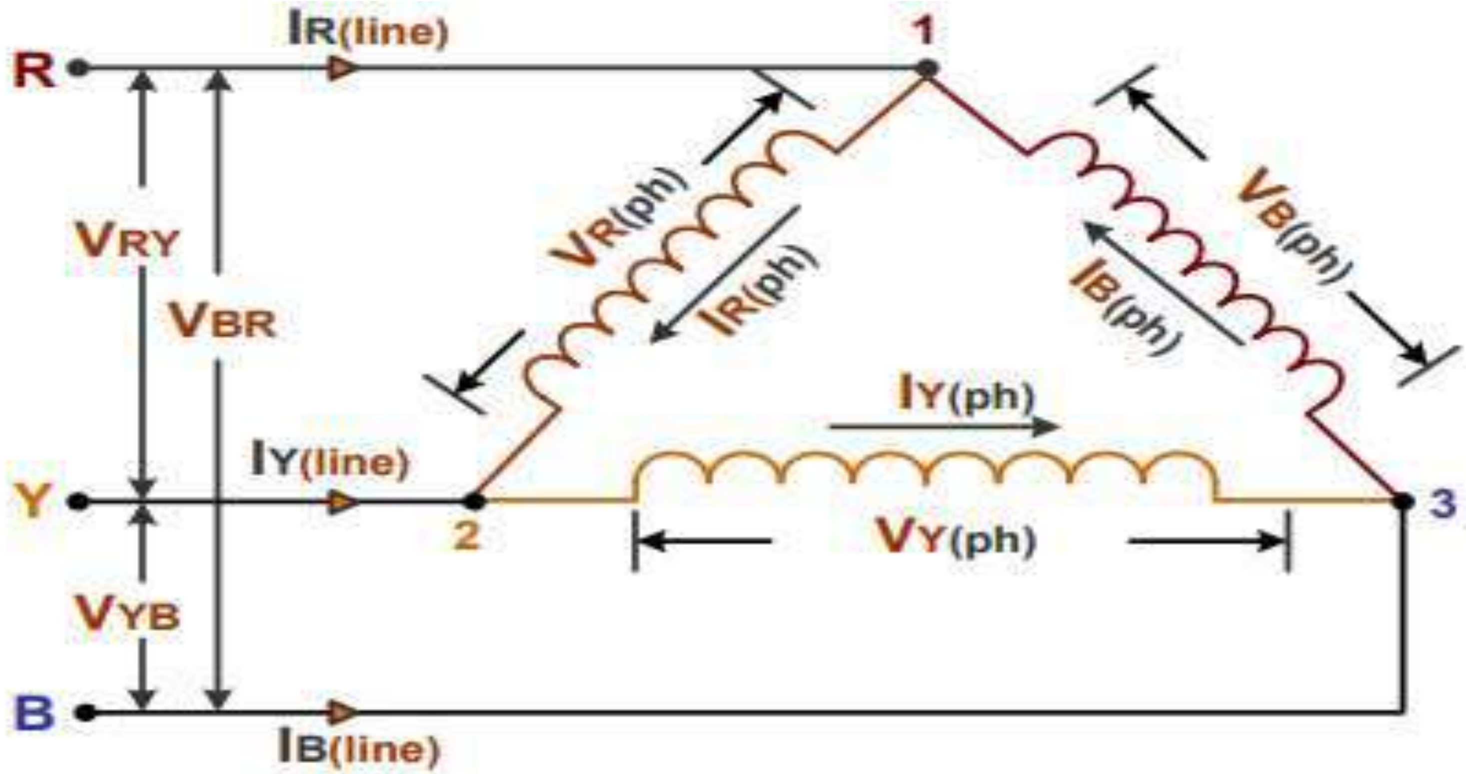



3 - Phase Load Connected in Delta

# Relation between line and phase values for voltage and current in case of balanced delta connection

➢ Delta (Δ) or Mesh connection, starting end of one coil is connected to the finishing end of other phase coil and so on which giving a closed circuit.



# Contd....

- Let,

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

  Phase voltage, $V_{R(ph)} = V_{Y(ph)} = V_{B(ph)} = V_{ph}$

  Line current, $I_{R(line)} = I_{Y(line)} = I_{B(line)} = I_{line}$

  Phase current, $I_{R(ph)} = I_{Y(ph)} = I_{B(ph)} = I_{ph}$

**Relation between line and phase voltage**

- For delta connection line voltage $V_L$ and phase voltage $V_{ph}$ both are same.

$$V_{RY} = V_{R(ph)}$$

$$V_{YB} = V_{Y(ph)}$$

$$V_{BR} = V_{B(ph)}$$

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

Line voltage = Phase Voltage

# Contd...

- For delta connection,

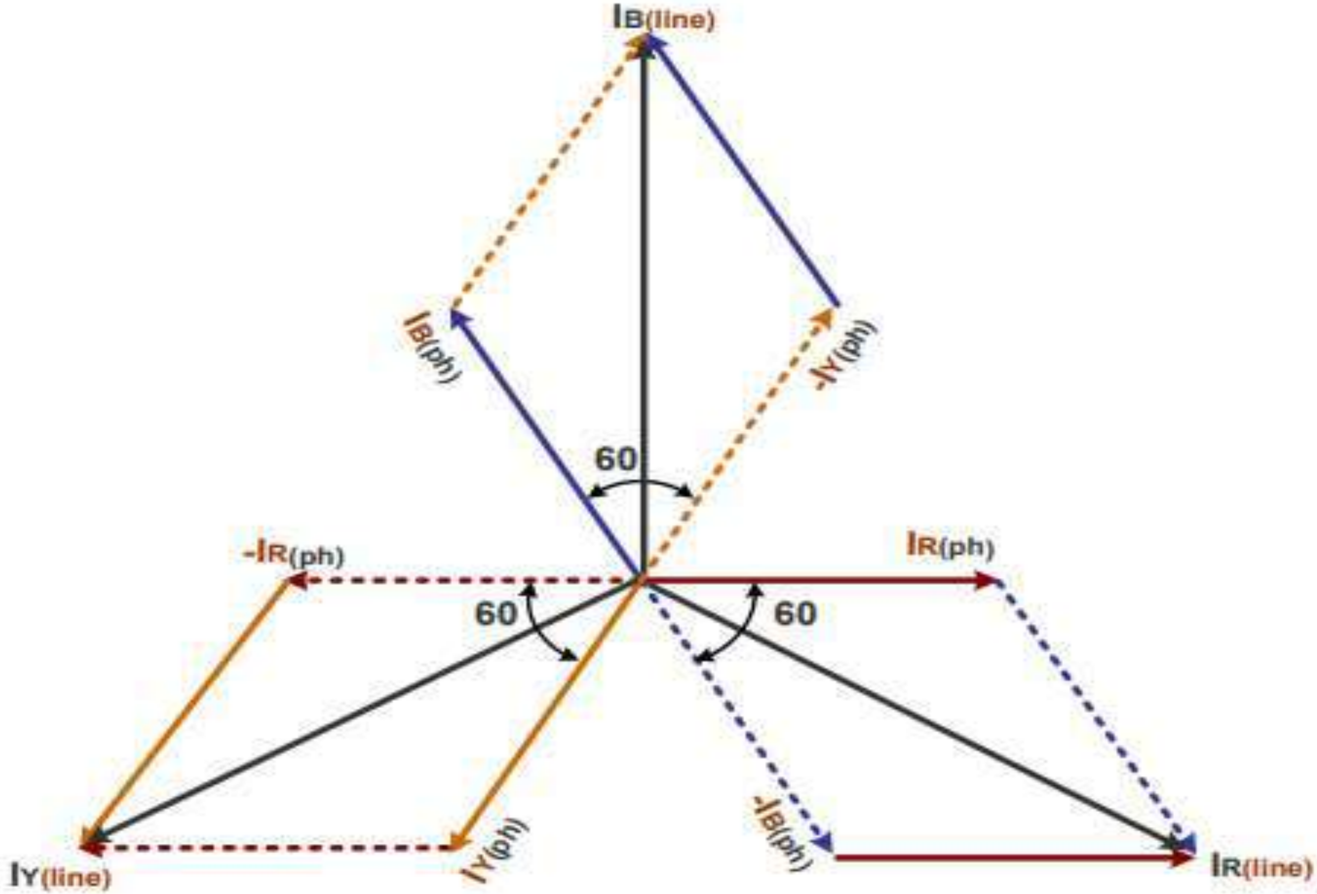
$$I_{R(line)} = I_{R(ph)} - I_{B(ph)}$$

$$I_{Y(line)} = I_{Y(ph)} - I_{R(ph)}$$

$$I_{B(line)} = I_{B(ph)} - I_{Y(ph)}$$

# Contd...

- i.e. current in each line is vector difference of two of the phase currents.



# Contd….

- So, considering the parallelogram formed by $I_R$ and $I_B$.

$$I_{R(line)} = \sqrt{I_{R(ph)}^2 + I_{B(ph)}^2 + 2I_{R(ph)}I_{B(ph)}\cos\theta}$$

$$\therefore I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}I_{ph}\cos 60^\circ}$$

$$\therefore I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}^2 \times \left(\frac{1}{2}\right)}$$

$$\therefore I_L = \sqrt{3I_{ph}^2}$$

$$\therefore I_L = \sqrt{3}I_{ph}$$

- Similarly, $I_{Y(line)} = I_{B(line)} = \sqrt{3}\ I_{ph}$
- Thus, in delta connection Line current = $\sqrt{3}$ Phase current

# Condt...

**Power**

$$P = V_{ph}I_{ph}\cos\phi + V_{ph}I_{ph}\cos\phi + V_{ph}I_{ph}\cos\phi$$

$$P = 3V_{ph}I_{ph}\cos\phi$$

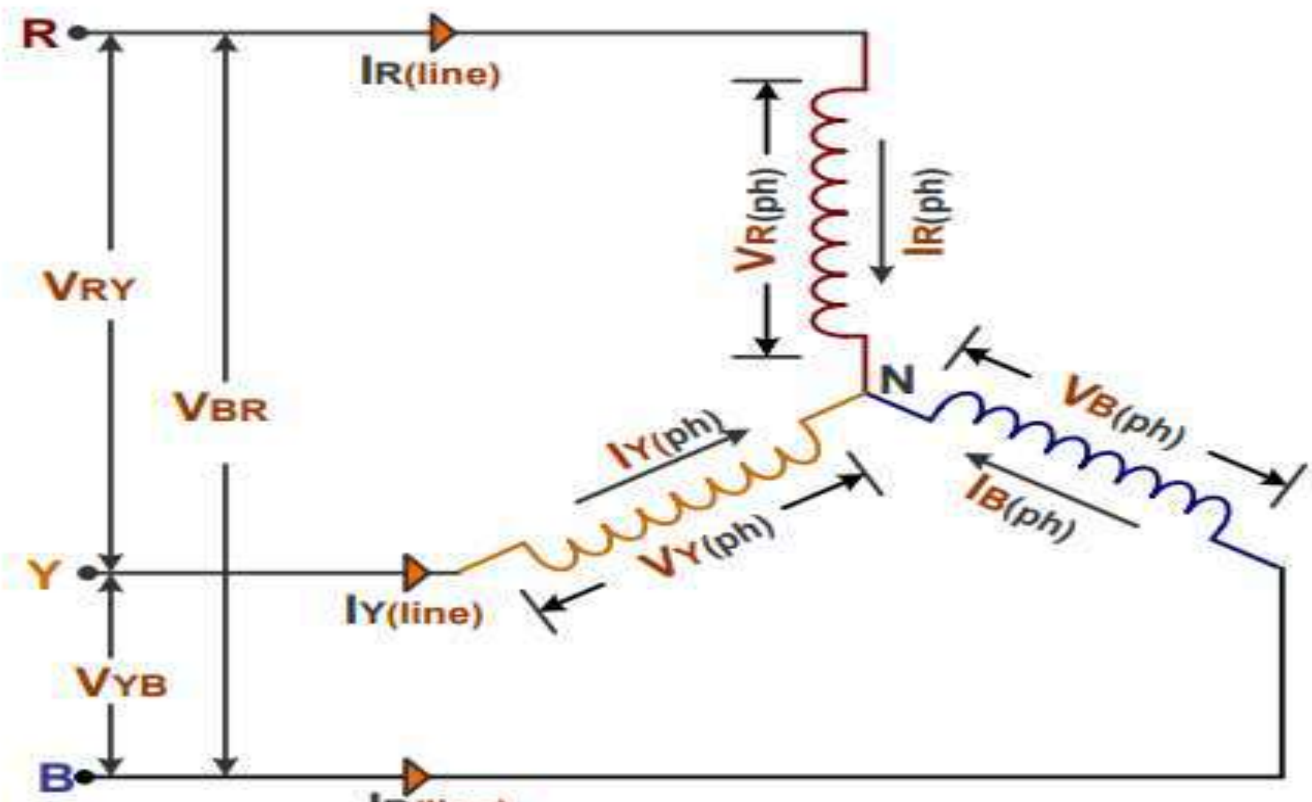
$$P = 3V_L\left(\frac{I_L}{\sqrt{3}}\right)\cos\phi$$

$$\therefore P = \sqrt{3}V_L I_L\cos\phi$$

# Relation between line and phase values for voltage and current in case of balanced star connection.

➢ In the Star Connection, the similar ends (either start or finish) of the three windings are connected to a common point called star or neutral point.

**Circuit Diagram**



# Contd...

- Let,

  line voltage, $V_{RY} = V_{BY} = V_{BR} = V_L$

  phase voltage, $V_{R(ph)} = V_{Y(ph)} = V_{B(ph)} = V_{ph}$

  line current, $I_{R(line)} = I_{Y(line)} = I_{B(line)} = I_{line}$

  phase current, $I_{R(ph)} = I_{Y(ph)} = I_{B(ph)} = I_{ph}$

**Relation between line and phase voltage**

- For star connection, line current $I_L$ and phase current $I_{ph}$ both are same.

$$I_{R(line)} = I_{R(ph)}$$

$$I_{Y(line)} = I_{Y(ph)}$$

$$I_{B(line)} = I_{B(ph)}$$

$$\therefore \quad I_L = I_{ph}$$

Line Current = Phase Current

# Contd…

Relation between line and phase voltage

- For delta connection

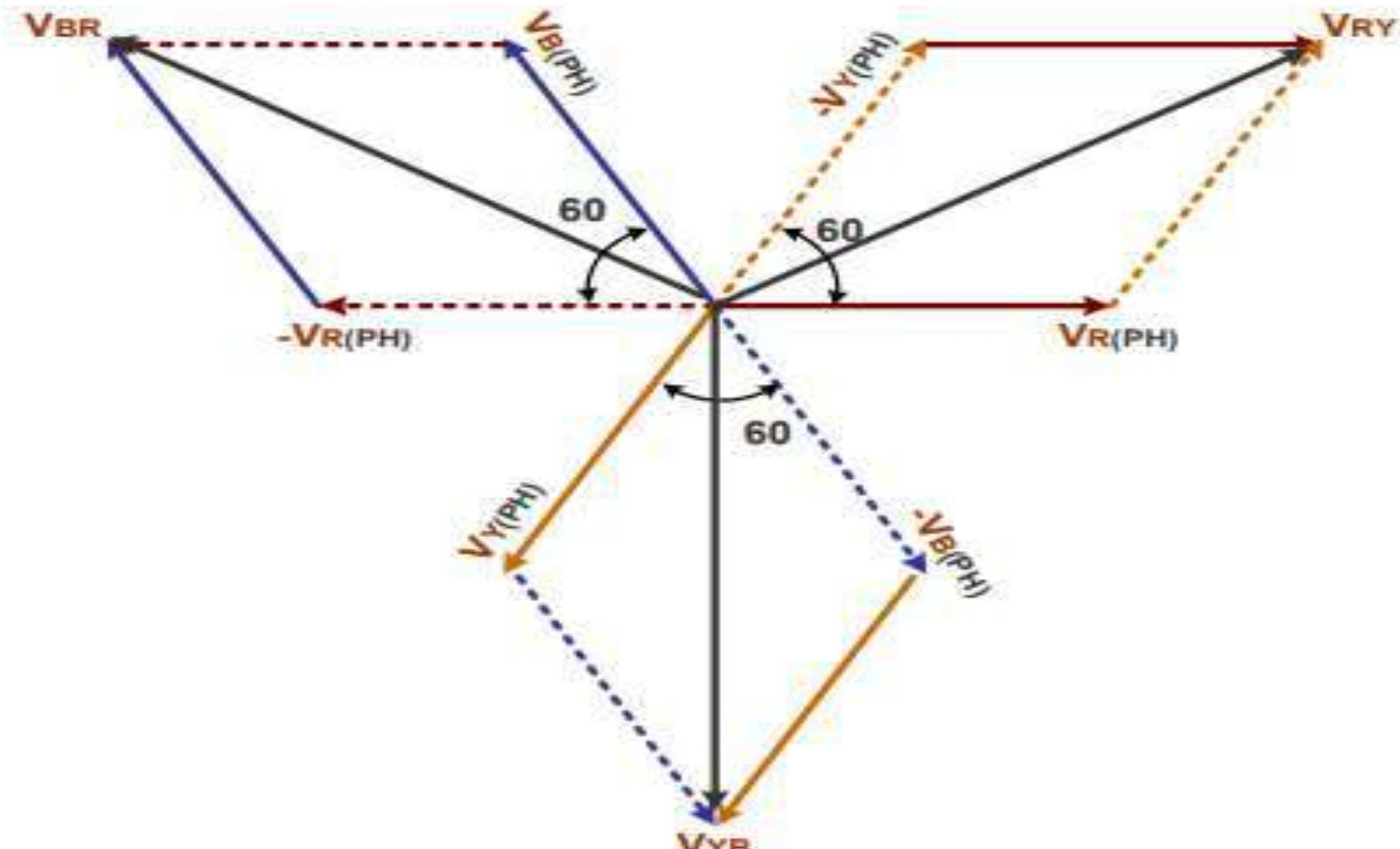
$$V_{RY} = V_{R(ph)} - V_{Y(ph)}$$

$$V_{YB} = V_{Y(ph)} - V_{B(ph)}$$

$$V_{BR} = V_{B(ph)} - V_{R(ph)}$$

- i.e. line voltage is vector difference of two of the phase voltages.

# Contd...



# Contd...

From parallelogram,

$$V_{RY} = \sqrt{V_{R(ph)}^{2} + V_{Y(ph)}^{2} + 2V_{R(ph)}V_{Y(ph)}\cos\theta}$$

$$\therefore V_L = \sqrt{V_{ph}^{2} + V_{ph}^{2} + 2V_{ph}V_{ph}\cos 60^\circ}$$

$$\therefore V_L = \sqrt{V_{ph}^{2} + V_{ph}^{2} + 2V_{ph}^{2} \times \left(\tfrac{1}{2}\right)}$$

$$\therefore V_L = \sqrt{3V_{ph}^{2}}$$

$$\therefore V_L = \sqrt{3}V_{ph}$$

- Similarly, $V_{YB} = V_{BR} = \sqrt{3}\, V_{ph}$
- Thus, in star connection Line voltage = $\sqrt{3}$ Phase voltage

# Contd...

**Power**

$$P = V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi$$

$$P = 3 V_{ph} I_{ph} \cos\phi$$

$$P = 3\left(\frac{V_L}{\sqrt{3}}\right) I_L \cos\phi$$

$$\therefore P = \sqrt{3} V_L I_L \cos\phi$$

# AISSMS

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# PolyPhase System

BEE Unit – IV (B)

Asst Prof B S Bobdey

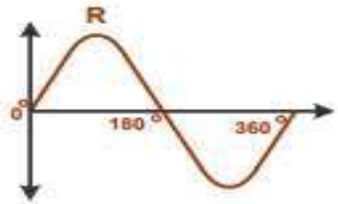
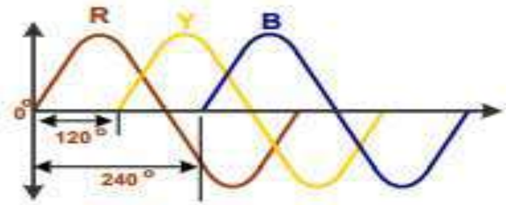
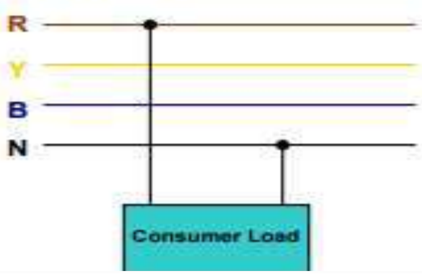
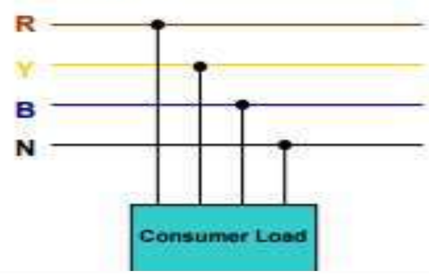
# Introduction

- The system which has three phases, i.e., the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system.

- In other words, the system which uses three wires for generation, transmission and distribution is known as the three phase system.

- The three phase system is also used as a single phase system if one of their phase and the neutral wire is taken out from it. The sum of the line currents in the 3-phase system is equal to zero, and their phases are differentiated at an angle of $120^{\circ}$

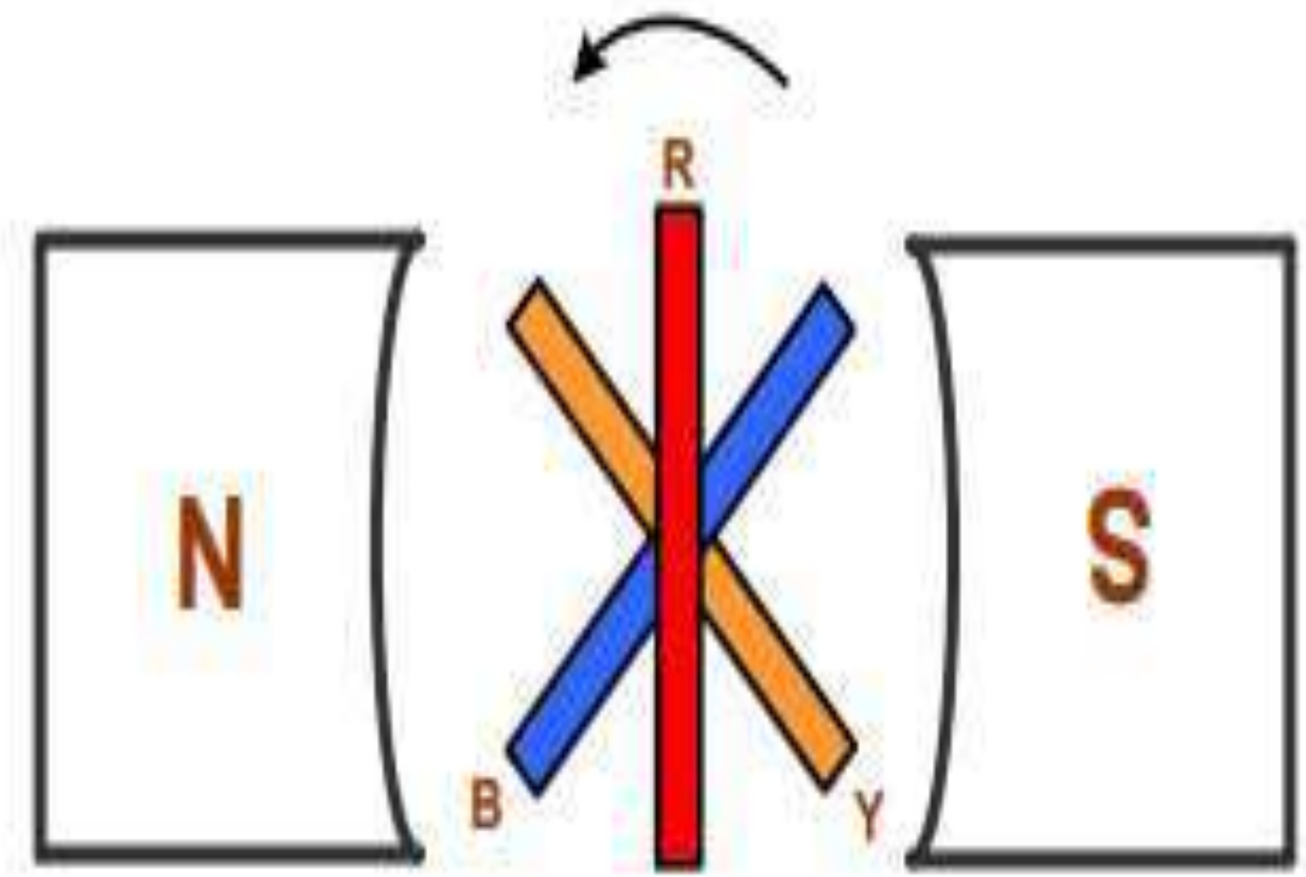
# Comparision 1phase and 3Phase

| Basis for Comparison | Single Phase | Three Phase |
|---|---|---|
| Definition | The power supply through one conductor. | The power supply through three conductors. |
| Wave Shape |   |   |
| Number of wire | Require two wires for completing the circuit | Requires four wires for completing the circuit |
| Voltage | Carry 230V | Carry 415V |
| Phase Name | Split phase | No other name |
| Network | Simple | Complicated |
| Loss | Maximum | Minimum |
| Power Supply Connection |   |   |
| Efficiency | Less | High |
| Economical | Less | More |
| Uses | For home appliances. | In large industries and for running heavy loads. |

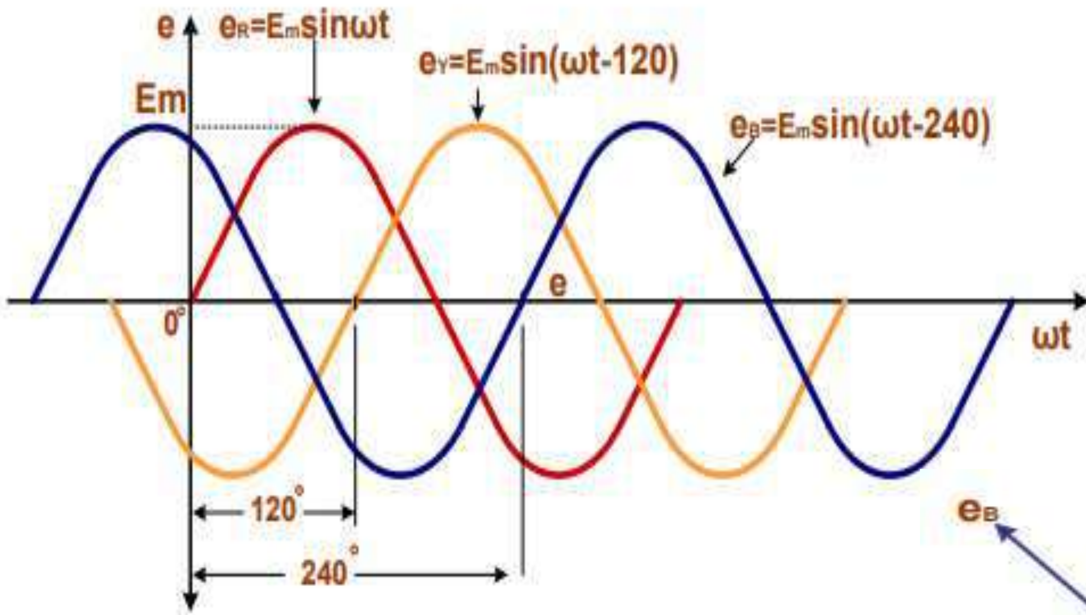
# Generation of three phase EMF

- According to Faraday's law of electromagnetic induction, we know that whenever a coil is rotated in a magnetic field, there is a sinusoidal emf induced in that coil.
- Now, we consider 3 coil C1(R-phase), C2(Y-phase) and C3(B-phase), which are displaced 1200 from each other on the same axis. This is shown in fig.
- The coils are rotating in a uniform magnetic field produced by the N and S poll in the counter clockwise direction with constant angular velocity.
- According to Faraday's law, emf induced in three coils. The emf induced in these three coils will have phase difference of $120^0$. i.e. if the induced emf of the coil C1 has phase of $0^0$, then induced emf in the coil C2 lags that of C1 by $120^0$ and C3 lags that of C2 $120^0$.

# Generation of Three Phase



# Three Phase Waveform



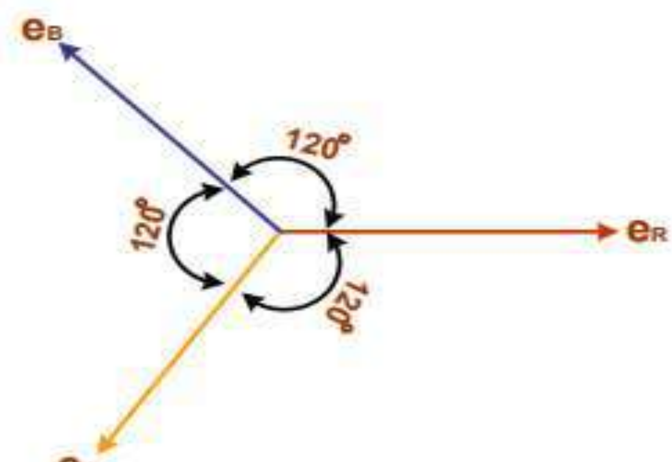

Thus, we can write,

$$e_R = E_m \sin\omega t$$

$$e_Y = E_m \sin\left(\omega t - 120^0\right)$$

$$e_B = E_m \sin\left(\omega t - 240^0\right)$$

The above equation can be represented by their phasor diagram as in the Fig.



# Important Definition

- **Phase sequence :**The order in which three coil emf or currents attain their peak values is called the phase sequence. It is customary to denoted the 3 phases by the three colours. i.e. red (R), yellow (Y), blue (B).

- **Balance System:** A system is said to be balance if the voltages and currents in all phase are equal in magnitude and displaced from each other by equal angles.

- **Unbalance System:** A system is said to be unbalanced if the voltages and currents in all phase are unequal in magnitude and displaced from each other by unequal angles.

- **Balance load:** In this type the load in all phase are equal in magnitude. It means that the load will have the same power factor equal currents in them.

- **Unbalance load:** In this type the load in all phase have unequal power factor and currents.

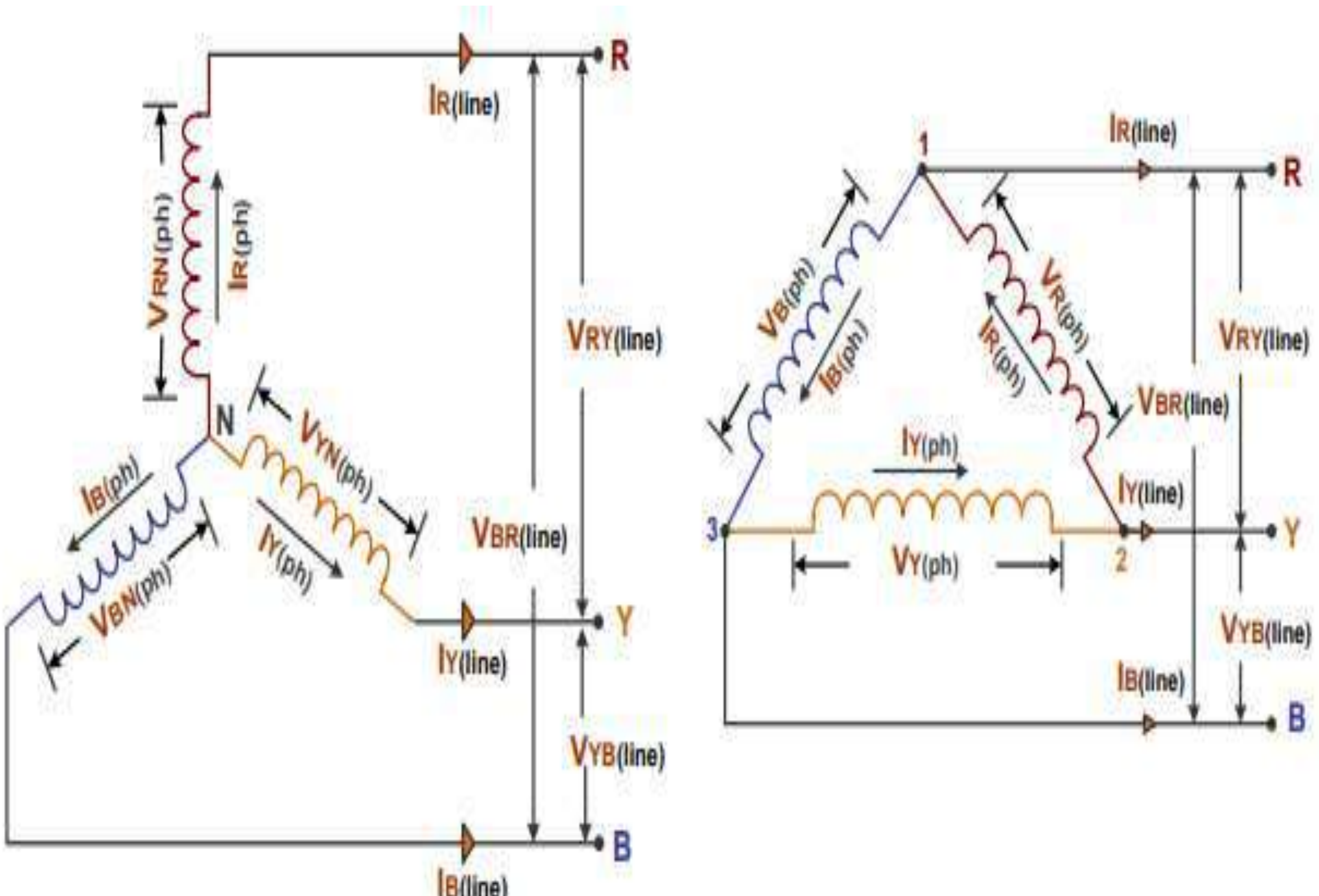
# Important Definition

➢**Phase Voltage** : It is defined as the voltage across either phase winding or load terminal. It is denoted by Vph. Phase voltage VRN, VYN and VBN are measured between R-N, Y-N, B-N for star connection and between R-Y, Y-B, B-R in delta connection.

➢ **Line voltage:** It is defined as the voltage across any two-line terminal. It is denoted by VL. Line voltage VRY, VYB, VBR measure between R-Y, Y-B, B-R terminal for star and delta connection both.

➢ **Phase current :** It is defined as the current flowing through each phase winding or load. It is denoted by Iph. Phase current IR(ph), IY(ph) and IB(Ph) measured in each phase of star and delta connection. respectively.

➢ **Line current :** It is defined as the current flowing through each line conductor. It denoted by IL. Line current IR(line), IY(line), and IB((line) are measured in each line of star and delta connection


R
IR(line)
VRN(ph)
IR(ph)
VRY(line)
N
VYN(ph)
IB(ph)
VBR(line)
IY(ph)
VBN(ph)
Y
IY(line)
VYB(line)
B
IB(line)
1
IR(line)
R
VB(ph)
VR(ph)
IB(ph)
IR(ph)
VRY(line)
VBR(line)
IY(ph)
IY(line)
3
Y
2
VY(ph)
VYB(line)
IB(line)
B

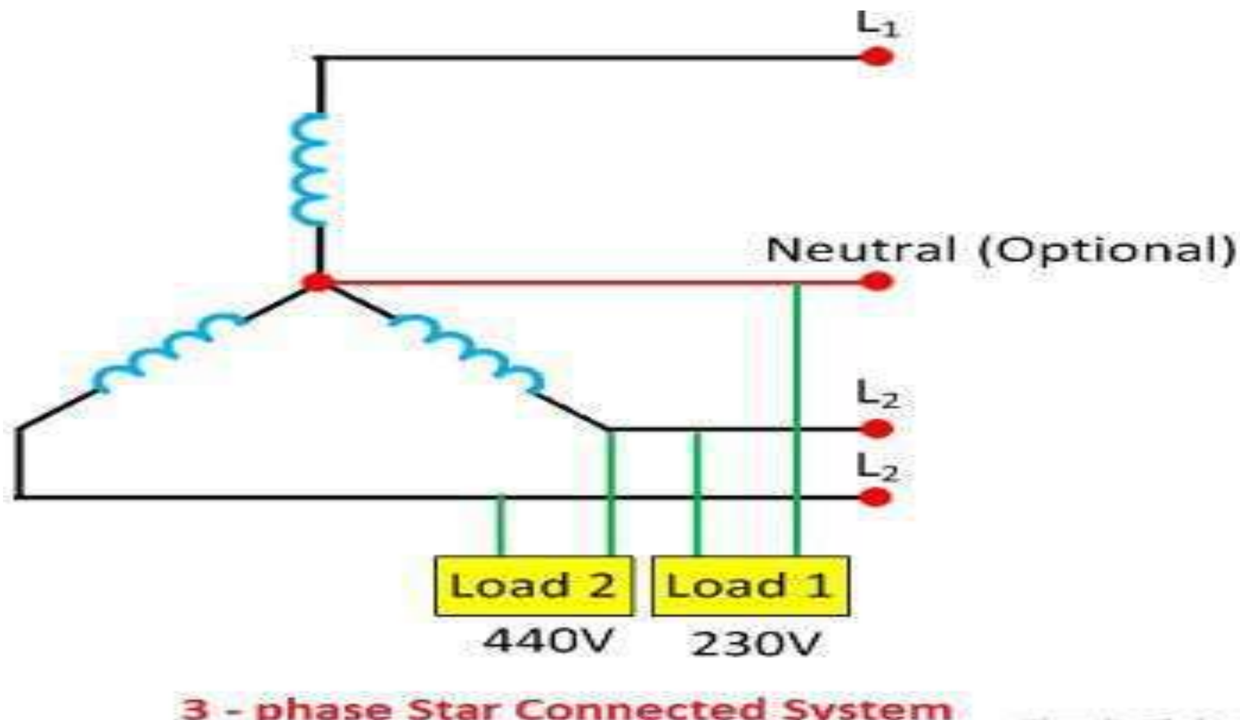
# Types of Connections in Three-Phase System

The three-phase systems are connected in two ways, i.e.,

- the star connection and
- the delta connection.

# Star Connection

- The star connection requires four wires in which there are three phase conductors and one neutral conductor



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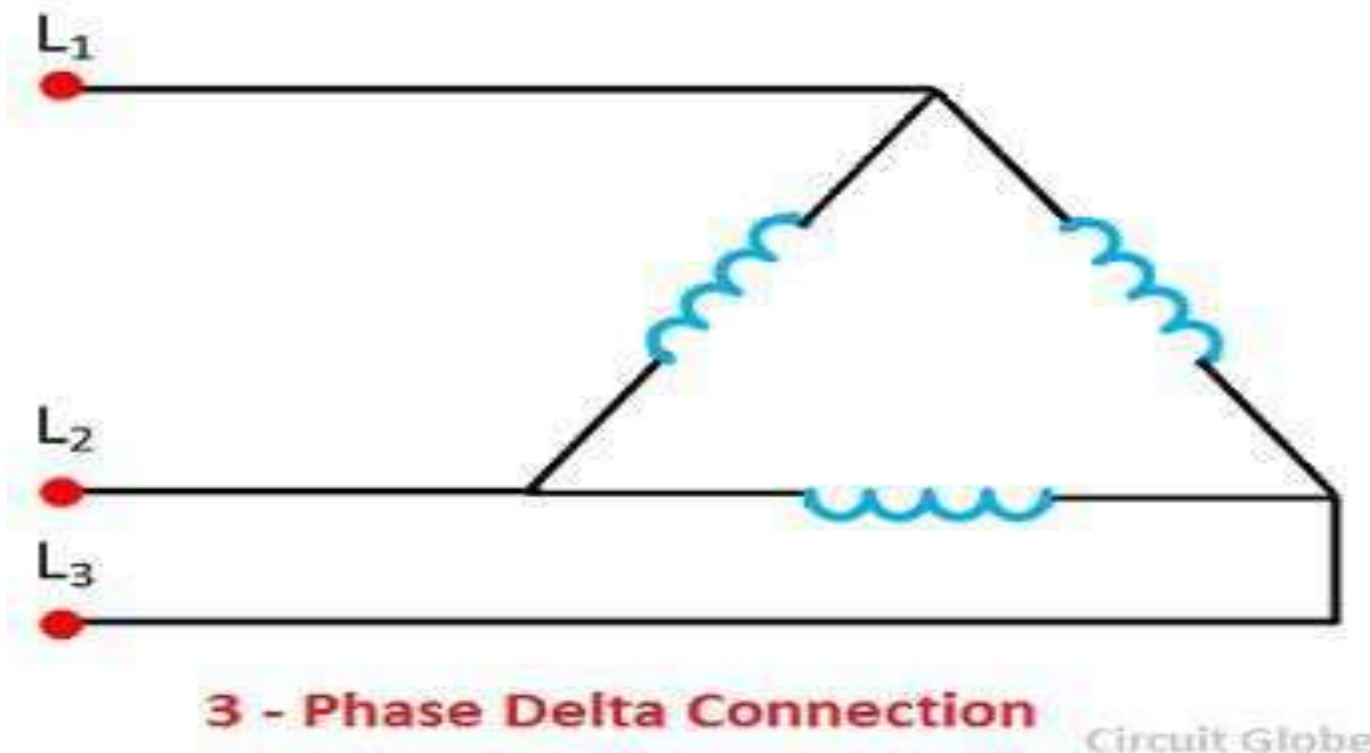

# Connection of Loads in Three Phase System

- The loads in the three-phase system may also connect in the star or delta. The three phase loads connected in the delta and star is shown in the figure below.
- The three phase load may be balanced or unbalanced. If the three loads (impedances) $Z_1$, $Z_2$ and $Z_3$ has the same magnitude and phase angle then the three phase load is said to be a balanced load.
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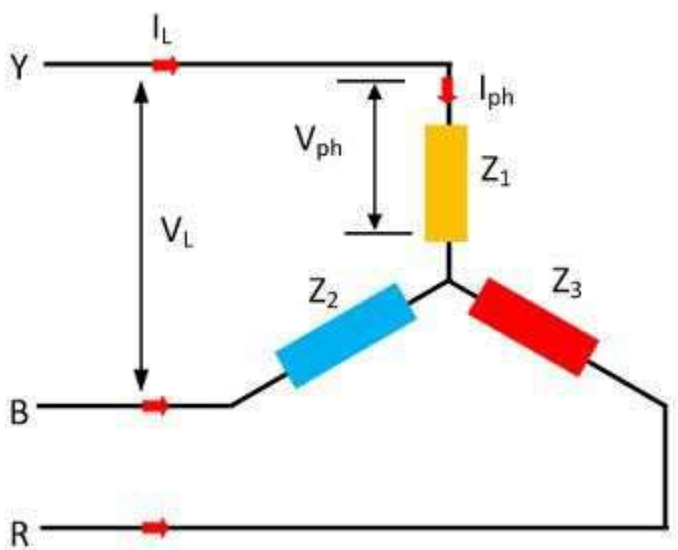


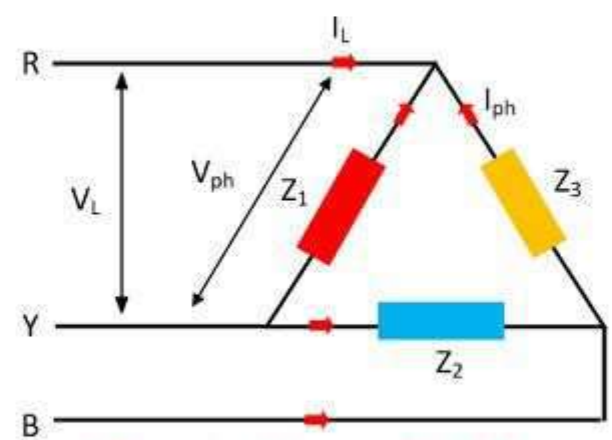


3 - Phase Load Connected in Delta

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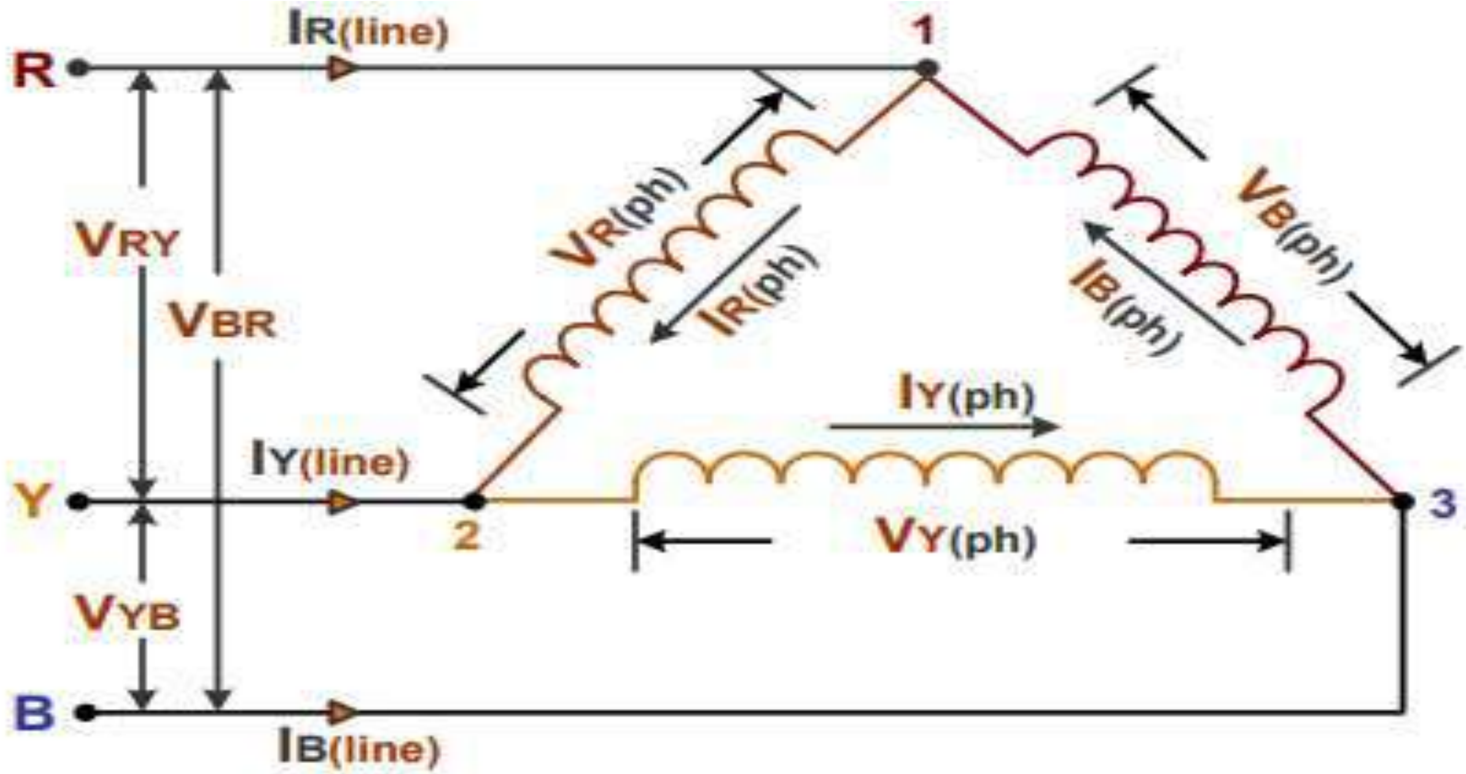

# Contd....

- Let,

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

  Phase voltage, $V_{R(ph)} = V_{Y(ph)} = V_{B(ph)} = V_{ph}$

  Line current, $I_{R(line)} = I_{Y(line)} = I_{B(line)} = I_{line}$

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**Relation between line and phase voltage**

- For delta connection line voltage $V_L$ and phase voltage $V_{ph}$ both are same.

$$V_{RY} = V_{R(ph)}$$

$$V_{YB} = V_{Y(ph)}$$

$$V_{BR} = V_{B(ph)}$$

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

Line voltage = Phase Voltage

# Contd...

- For delta connection,

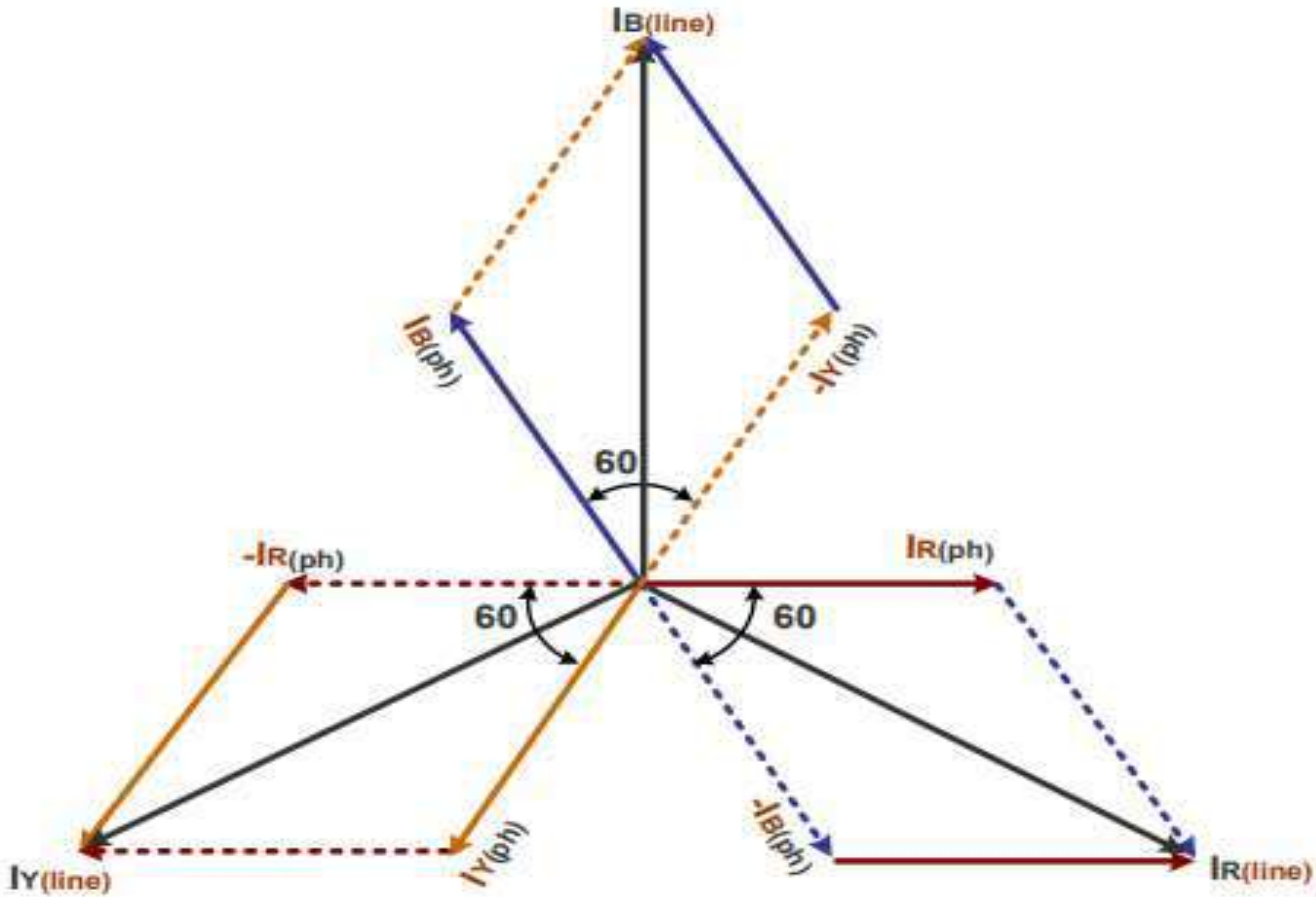
$$I_{R(line)} = I_{R(ph)} - I_{B(ph)}$$

$$I_{Y(line)} = I_{Y(ph)} - I_{R(ph)}$$

$$I_{B(line)} = I_{B(ph)} - I_{Y(ph)}$$

# Contd...

- i.e. current in each line is vector difference of two of the phase currents.



# Contd….

- So, considering the parallelogram formed by $I_R$ and $I_B$.

$$I_{R(line)} = \sqrt{I_{R(ph)}^2 + I_{B(ph)}^2 + 2I_{R(ph)}I_{B(ph)}\cos\theta}$$

$$\therefore I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}I_{ph}\cos 60^\circ}$$

$$\therefore I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}^2 \times \left(\frac{1}{2}\right)}$$

$$\therefore I_L = \sqrt{3I_{ph}^2}$$

$$\therefore I_L = \sqrt{3}I_{ph}$$

- Similarly, $I_{Y(line)} = I_{B(line)} = \sqrt{3}\, I_{ph}$
- Thus, in delta connection Line current = $\sqrt{3}$ Phase current

# Condt...

**Power**

$$P = V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi$$

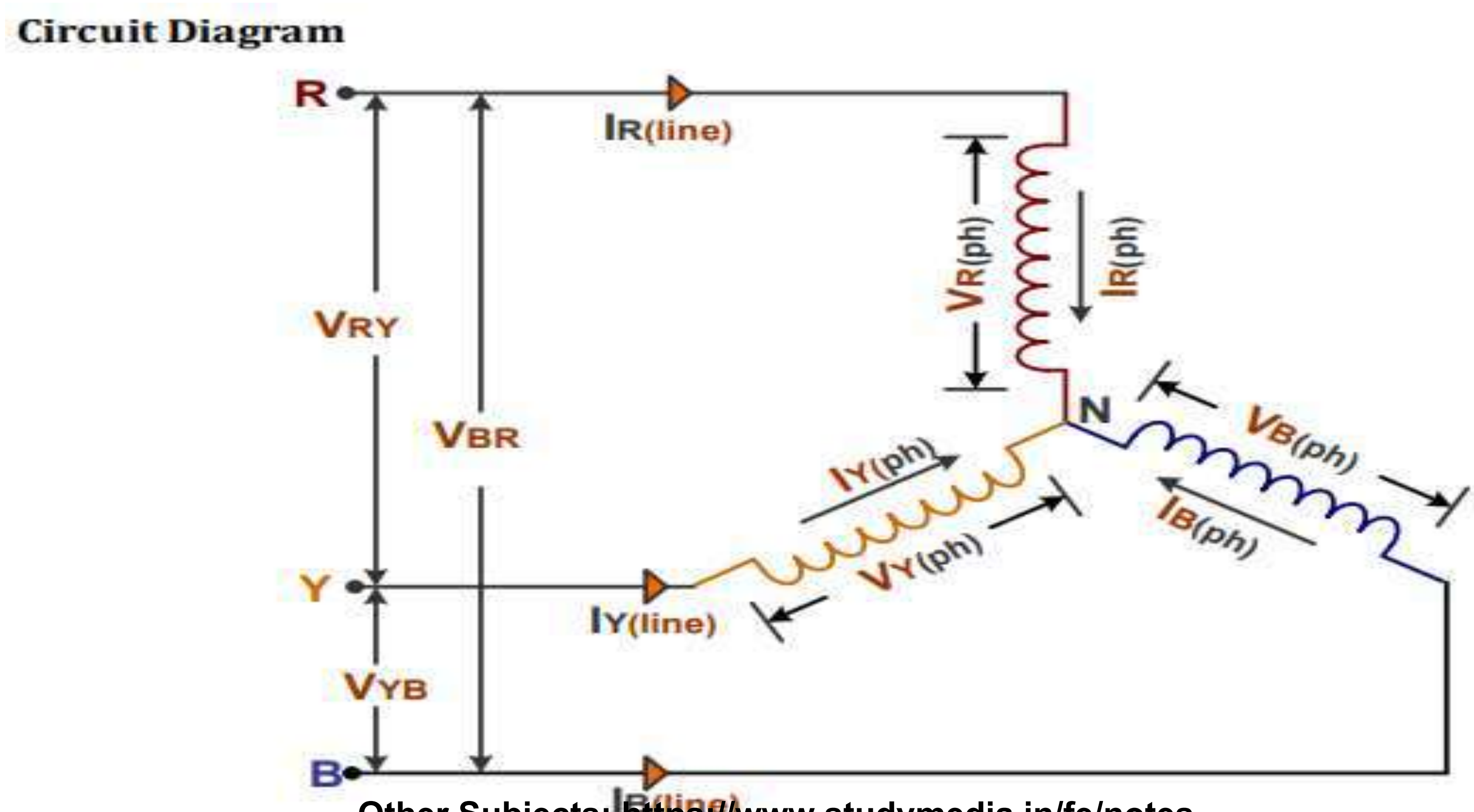
$$P = 3 V_{ph} I_{ph} \cos\phi$$

$$P = 3 V_L \left( \frac{I_L}{\sqrt{3}} \right) \cos\phi$$

$$\therefore P = \sqrt{3} V_L I_L \cos\phi$$

# Relation between line and phase values for voltage and current in case of balanced star connection.

➢ In the Star Connection, the similar ends (either start or finish) of the three windings are connected to a common point called star or neutral point.



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  phase voltage, $V_{R(ph)} = V_{Y(ph)} = V_{B(ph)} = V_{ph}$

  line current, $I_{R(line)} = I_{Y(line)} = I_{B(line)} = I_{line}$

  phase current, $I_{R(ph)} = I_{Y(ph)} = I_{B(ph)} = I_{ph}$

**Relation between line and phase voltage**

- For star connection, line current $I_L$ and phase current $I_{ph}$ both are same.

$$I_{R(line)} = I_{R(ph)}$$

$$I_{Y(line)} = I_{Y(ph)}$$

$$I_{B(line)} = I_{B(ph)}$$

$$\therefore \quad I_L = I_{ph}$$

Line Current = Phase Current

# Contd...

Relation between line and phase voltage

- For delta connection

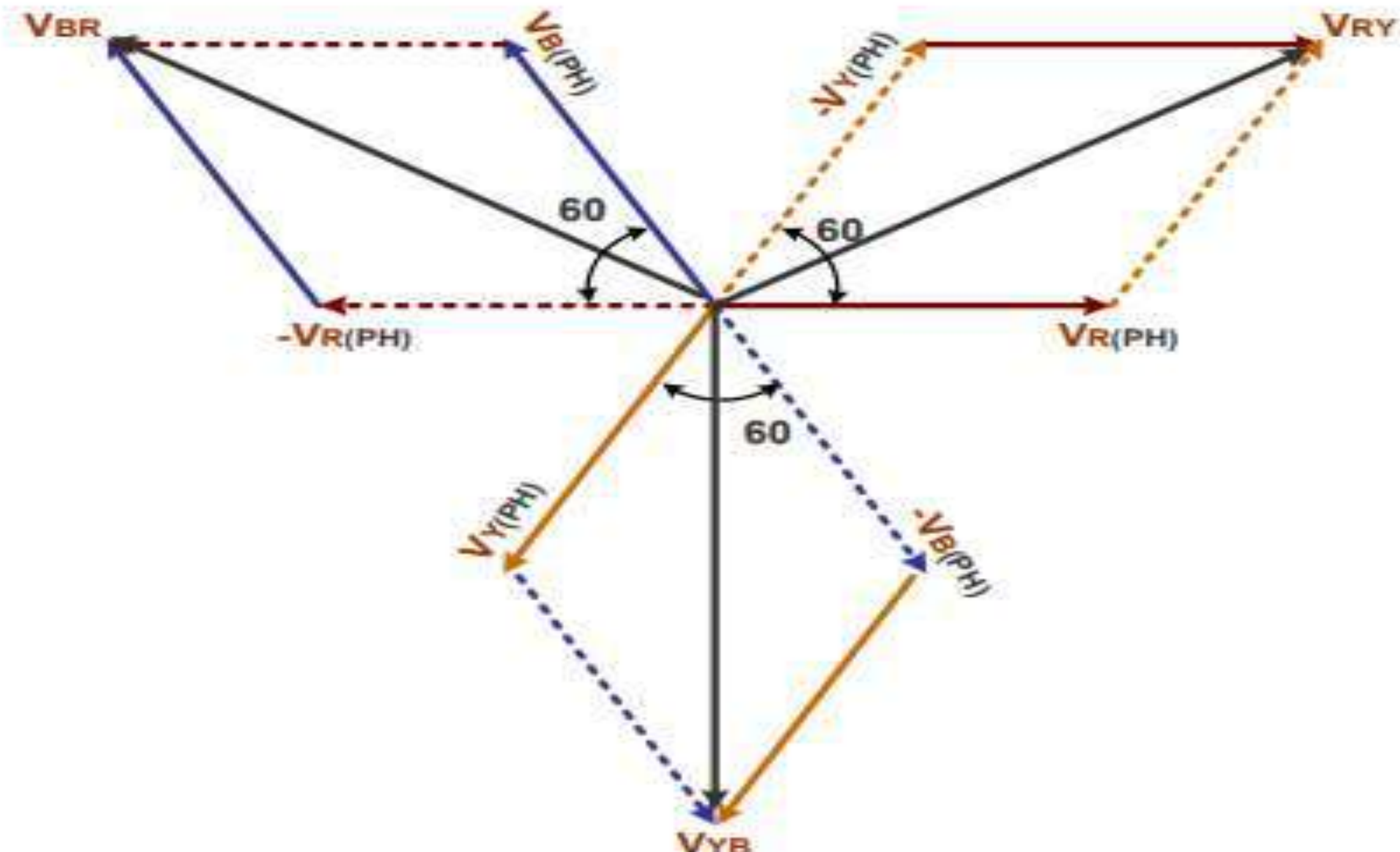
$$V_{RY} = V_{R(ph)} - V_{Y(ph)}$$

$$V_{YB} = V_{Y(ph)} - V_{B(ph)}$$

$$V_{BR} = V_{B(ph)} - V_{R(ph)}$$

- i.e. line voltage is vector difference of two of the phase voltages.

# Contd...



# Contd...

From parallelogram,

$$V_{RY} = \sqrt{V_{R(ph)}^2 + V_{Y(ph)}^2 + 2V_{R(ph)}V_{Y(ph)}\cos\theta}$$

$$\therefore V_L = \sqrt{V_{ph}^2 + V_{ph}^2 + 2V_{ph}V_{ph}\cos 60^\circ}$$

$$\therefore V_L = \sqrt{V_{ph}^2 + V_{ph}^2 + 2V_{ph}^2 \times \left(\tfrac{1}{2}\right)}$$

$$\therefore V_L = \sqrt{3V_{ph}^2}$$

$$\therefore V_L = \sqrt{3}V_{ph}$$

- Similarly, $V_{YB} = V_{BR} = \sqrt{3}\ V_{ph}$
- Thus, in star connection Line voltage = $\sqrt{3}$ Phase voltage

# Contd...

**Power**

$$P = V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi + V_{ph} I_{ph} \cos\phi$$

$$P = 3V_{ph} I_{ph} \cos\phi$$

$$P = 3\left(\frac{V_L}{\sqrt{3}}\right) I_L \cos\phi$$

$$\therefore P = \sqrt{3} V_L I_L \cos\phi$$