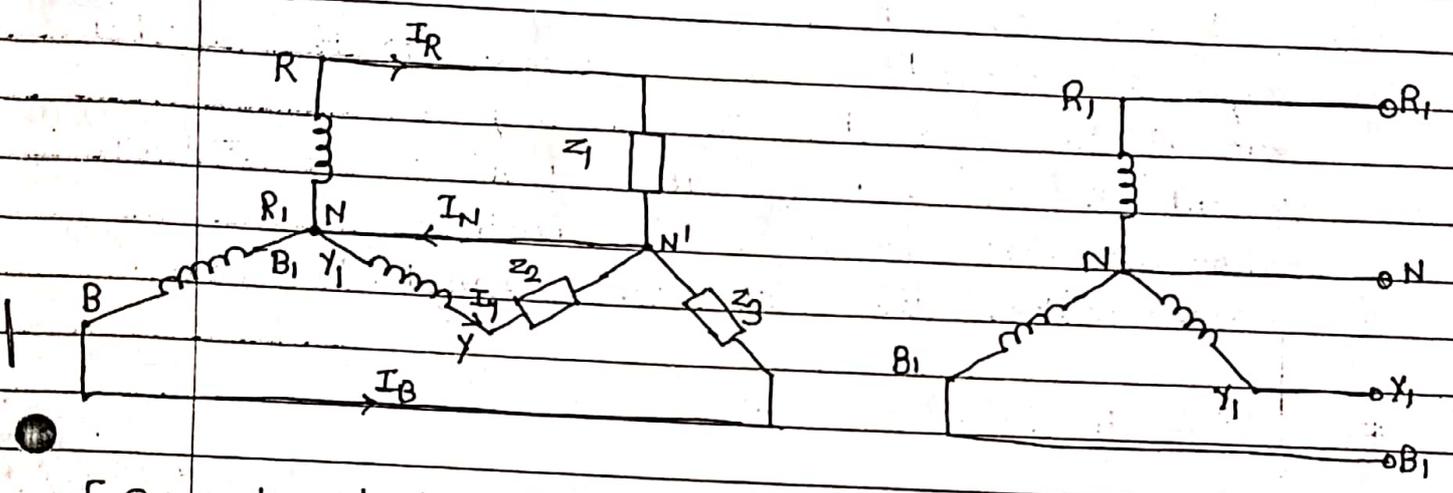


In 3 ϕ , power never falls to zero, less conductor, greater o/p, less space, η is high, 11 operation possible, economical

Three phase circuits
Interconnection of three phases :-

X. Star Connection:



[Conventional Fig:]

[3- ϕ 4-wire system]

- In star connection ends R_1, Y_1, B_1 of the three coils are joined together while the remaining three ends R, Y and B form three output terminals.
- The conventional representation of star connection is shown in fig.
- The common point N at which the ends of the three coils are joined together is known as neutral point or a star point.
- The three conductors meeting at the neutral point N are replaced by a single conductor known as neutral conductor.
- Such a system is known as 3- ϕ 4-wire system.
- The current in the neutral conductor is given by according to KCL

$$\bar{I}_N = \bar{I}_R + \bar{I}_Y + \bar{I}_B$$

- When the three phase emfs are applied across a balanced symmetrical load, the current in the neutral conductor will be equal to the algebraic sum of the currents I_R , I_Y and I_B .

- But I_R , I_Y and I_B are equal in magnitude and displaced by 120° from one another. This makes the vector sum equal to zero.

* Definitions:

① Phase voltage: It is the voltage between any one and the neutral of the supply system. It is also defined as the voltage in each winding of the alternator. It is denoted by E_{ph} or V_{ph} .

② Line voltage: It is the voltage between any two lines of the supply system. It is represented by V_L .

③ Phase Current: The current flowing in each phase winding is called phase current. It is represented by I_{ph} .

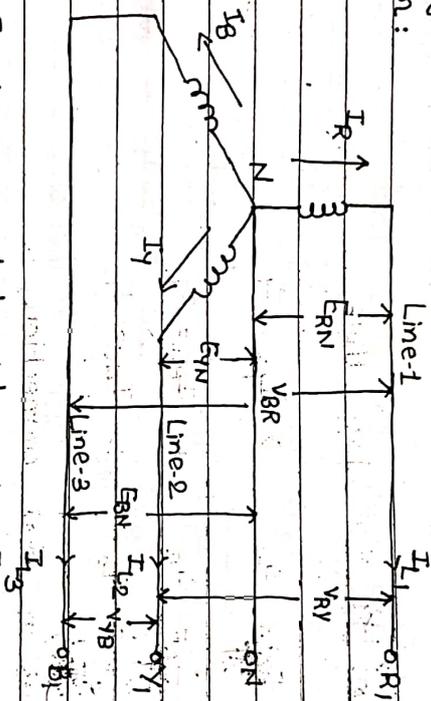
④ Line Current: The current flowing in each line is known as line current. It is represented by I_L .

⑤ Balanced System: It is one in which voltages in all phases are equal in magnitude and are displaced by 120° from one another.

also the currents in these phases are equal in magnitude and are displaced from one another by equal angles.

{ Balanced load: If it is one in which the loads in all the phases are equal in magnitude & phase.

* Voltage and Current relations in Star Connected System:



[3- ϕ , 4-wire balanced system] Fig: A

Fig. shows 3-phase 4-wire system.

The end across each winding is called phase voltage.

They are denoted by E_{RN} , E_{YN} and E_{BN} and voltage betwⁿ any two lines is called line voltage.

They are represented by V_{RY} , V_{YB} and V_{BR} respectively. Similarly current flowing in each winding is known as phase current and current flowing in each line is called line current.

→ Since the system is balanced

$$I_R = I_Y = I_B = I_{ph}$$

$$I_{L1} = I_{L2} = I_{L3} = I_L$$

$$E_{RN} = E_{YN} = E_{BN} = E_{ph}$$

$$V_{RY} = V_{YB} = V_{BR} = V_L$$

⇒ Relation betⁿ line current and phase current

→ From fig, it is clear that

$$I_R = I_{L1} \rightarrow I_{ph} = I_L$$

$$I_Y = I_{L2} \rightarrow I_{ph} = I_L$$

$$I_B = I_{L3} \rightarrow I_{ph} = I_L$$

Thus in star connection,

$$\boxed{\text{Line Current } I_L = \text{Phase Current } I_{ph}}$$

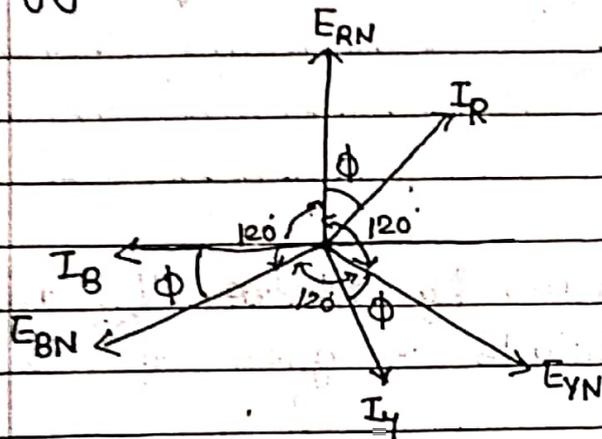
⇒ Relation betⁿ line voltage and phase voltage

From fig, it is seen that in star connection, there are two phase windings betⁿ each pair of terminals.

→ Since similar ends of these two windings connected together, the emfs across them each other and their instantaneous values have opposite polarities.

→ Therefore the rms value of line voltage between any two lines will be obtained by the vector difference of the two phase voltages.

→ The phasor diagram of the phase emfs and currents in a star connected system is shown in fig. below.



→ From fig. A, the line voltages can be obtained from the phase voltages as shown below.

→ Line voltage between terminals R and Y

Fig: B

∵ $E_{RN} \nmid E_{YN}$ have opposite polarities, we can say that

$$V_{RY} = E_{RN} + E_{NY}$$

$$= E_{RN} + (-E_{YN})$$

$$= E_{RN} - E_{YN}$$

= phase difference

Similarly

$$E_{YB} = E_{YN} - E_{BN}$$

$$E_{BR} = E_{BN} - E_{RN} = E_{BN} + E_{RN}$$

→ Hence it is clear that in a star connected system, the line voltage is obtained as the vector difference of the two corresponding phase voltages.

→ It is shown in fig. C below.

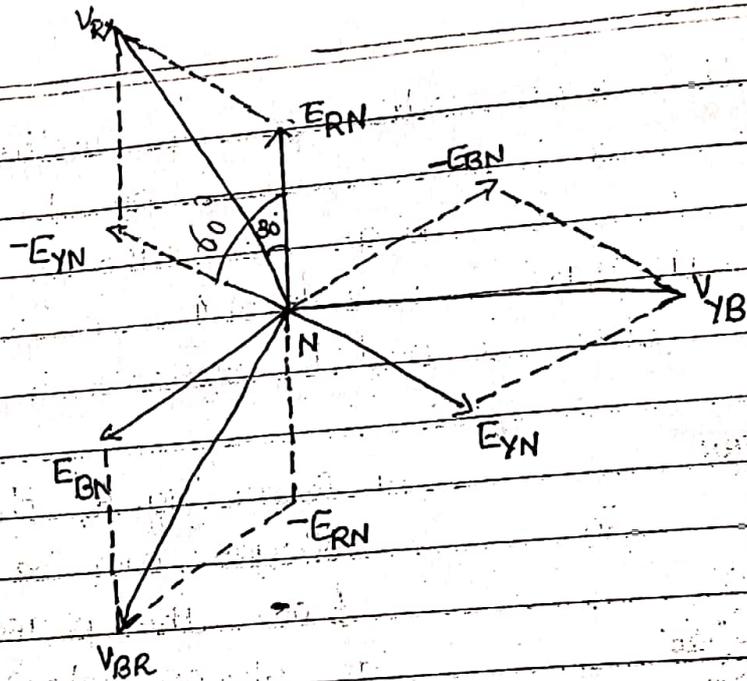


Fig. C

- For example, V_{RY} is found by adding V_{RN} and V_{YN} reversed and its magnitude is given by the diagonal of the parallelogram.

- Since sides of the parallelogram are of equal length and angle betⁿ two phase voltages is 60° , the line or line voltage is given by

If we consider parallelogram formed by V_{RN} & V_{YN} , then

sides are equal to $E_{RN} = E_{YN} = E_{ph}$

$$V_{RY} = V_{RN} - V_{YN}$$

$$= 2 V_{ph} \cos \frac{60^\circ}{2}$$

$$R = V_{pq} = \sqrt{p^2 + q^2 + 2pq \cos \theta}$$

and angle b/w E_{RN} & E_{YN} reversed is 60°

$$= 2 V_{ph} \cos 30^\circ$$

$$= 2 E_{ph} \frac{\sqrt{3}}{2}$$

If $p = q$

$$= \sqrt{p^2 + p^2 + 2p^2 \cos \theta}$$

$$= \sqrt{2p^2 + 2p^2 \cos \theta}$$

$$V_{RY} = \sqrt{3} E_{ph}$$

$$= \sqrt{2p^2 (1 + \cos \theta)}$$

Similarly $V_{YB} = V_{YN} - V_{BN}$

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

$$R = 2p \cos \frac{\theta}{2}$$

Thus in balanced star connected system,

$$V_L = \sqrt{3} E_{ph}$$

i.e Line voltage = $\sqrt{3}$ x phase voltage

POWER:

The total power dissipated in the 3-phase star connected system is the arithmetic sum of the powers dissipated in the three phases.

\therefore Total power = 3 x power per phase

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

$$= 3 \times \frac{V_L}{\sqrt{3}} \times I_L \cos \phi \quad (\text{for } \gamma)$$

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

Note: ϕ is the angle betⁿ phase voltage and phase current and not between the line voltage and line current.

* Delta connection: (Δ) Mesh Connection :-

→ In delta connection, the three coil windings are connected together such that the finishing end of one coil is connected to the starting end of the other coil and so on as shown below.

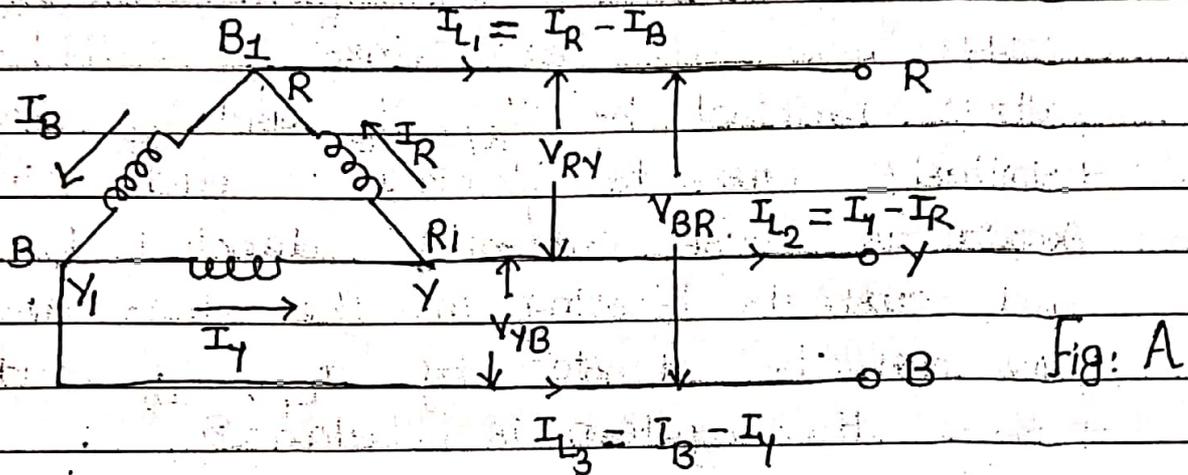


Fig: A

- In other words, the three windings are connected in series to form a closed path or mesh.
- Three leads are taken out from the three junctions to form the three lines.
- In this method, there is no neutral wire and so it is called as 3-phase, 3-wire system.
- The algebraic sum of the voltages around a closed path is zero i.e. at a given instant the emf in one phase is equal and opposite to the resultant of the emfs in the other two phases.

* Voltage and Current relations in Delta connection system:

- Fig: A shows 3-phase, 3-wire delta connected system.

- The emf across each winding is called the phase voltage denoted by E_R , E_Y and E_B and voltage betⁿ any two lines is called the line voltage denoted by V_{RY} , V_{YB} and V_{BR} respectively.

- Similarly, currents flowing in each winding are known as phase currents denoted by I_R , I_Y and I_B and currents flowing in the lines are called line currents denoted by I_{L1} , I_{L2} and I_{L3} .

- Since the system is balanced

$$I_R = I_Y = I_B = I_{ph}$$

$$I_{L1} = I_{L2} = I_{L3} = I_L$$

$$E_R = E_Y = E_B = E_{ph}$$

$$V_{RY} = V_{YB} = V_{BR} = V_L$$

⇒ Relation betⁿ line voltage & phase voltage:

From fig, it is clear that

$$E_R = V_{RY} \rightarrow E_{ph} = V_L$$

$$E_Y = V_{YB} \rightarrow E_{ph} = V_L$$

$$E_B = V_{BR} \rightarrow E_{ph} = V_L$$

Thus in delta connection,

$$\text{Line voltage } V_L = \text{Phase voltage } E_{ph}$$

⇒ Relation between line current and phase current:

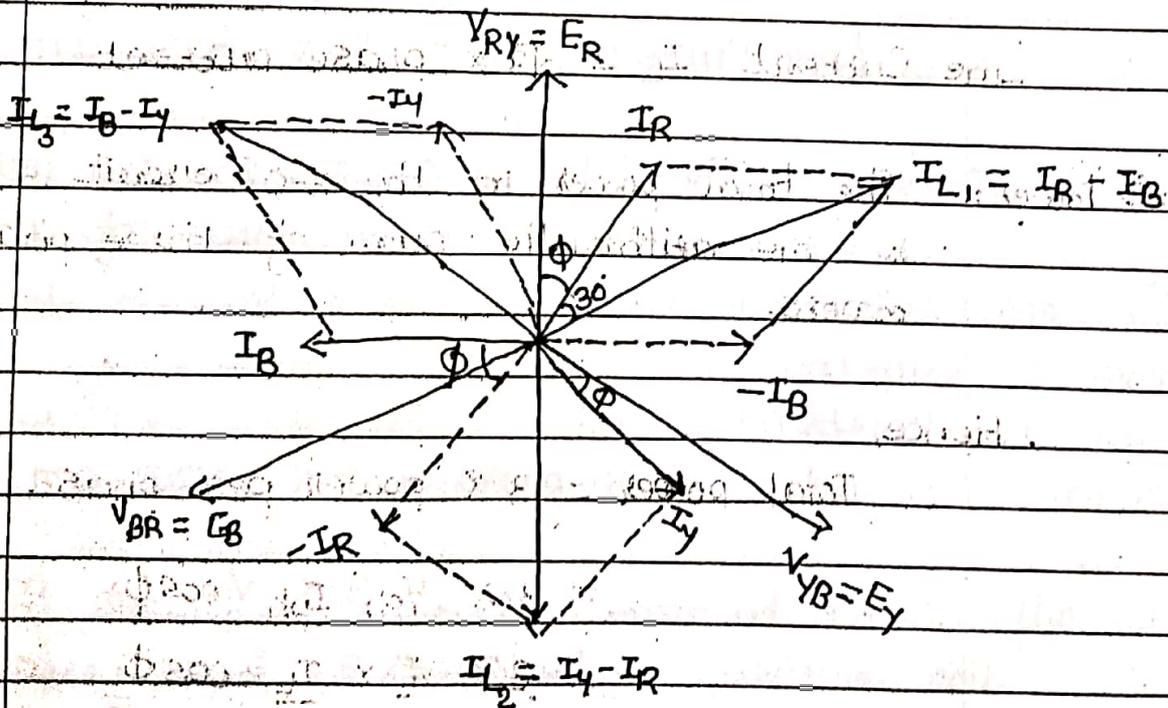
From fig A it is clear that current flowing in each line is the vector difference of the two phase currents.

Current in line 1, $I_{L1} = I_R - I_B$

Current in line 2, $I_{L2} = I_Y - I_R$

Current in line 3, $I_{L3} = I_B - I_Y$

- Current in line 1 can be found as the vector difference of the two corresponding phase currents.
- This is shown in fig. below.



For example, I_{L1} can be obtained by adding I_R and I_B reversed and its value is given by the diagonal of the parallelogram as shown in fig. above.

- since the sides of parallelogram are equal magnitude and the angle between them is 60° the resultant current or the line current is given as

$$I_{L1} = I_R - I_B \quad \text{Cvector difference}$$

$$= 2 \times I_{ph} \cos \frac{60^\circ}{2}$$

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

$$I_{L1} = \sqrt{3} I_{ph}$$

Similarly: $I_{L2} = I_{L3} = \sqrt{3} I_{ph} = I_L$

Thus, in delta connection,

$$\text{Line Current } I_L = \sqrt{3} \times \text{phase current}$$

⇒ Power: The total power in the 3- ϕ circuit is equal to the arithmetic sum of three phase powers.

Hence,

$$\text{Total power} = 3 \times \text{power per phase}$$

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

$$= 3 \times V_L \times \frac{I_L}{\sqrt{3}} \cos \phi$$

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

✓ * Advantages of 3-phase supply system over single-phase supply system:

- (i) Three phase currents produce rotating magnetic field.
- (ii) Power factor of a 3-phase motor is higher than that of a single phase motor.
- (iii) To transmit a certain amount of power 3-phase system requires three-fourth the weight of copper as compared to single phase supply system.
- (iv) Single phase motors are not self-starting while 3-phase motors are self-starting.
- (v) For a given frame size, output of 3-phase motor is more than that of a single phase motor.

* Power Measurement in 3-phase circuits:-

- The standard instrument for measuring power in an electric circuit is wattmeter.
- A single phase wattmeter contains two coils, one fixed and other moving coil carrying a pointer.
- The fixed coil is known as current coil and is connected in series with the line and carries the line current.
- The moving coil is connected across the line and is called pressure coil or potential coil.
- It reads average power in the circuit.
- Measurement of power in a 3-phase system depends on whether the load connected across it is balanced or unbalanced, star connected or delta connected.

(i) One wattmeter method:

- Power can be measured by connecting a single wattmeter in the circuit.

- Its current coil is connected in one line and the pressure coil between line and the neutral point as shown in fig.

The reading of the wattmeter gives power per phase

$$\text{Total power} = 3 \times \text{power per phase}$$

$$= 3 \times \text{Wattmeter reading}$$

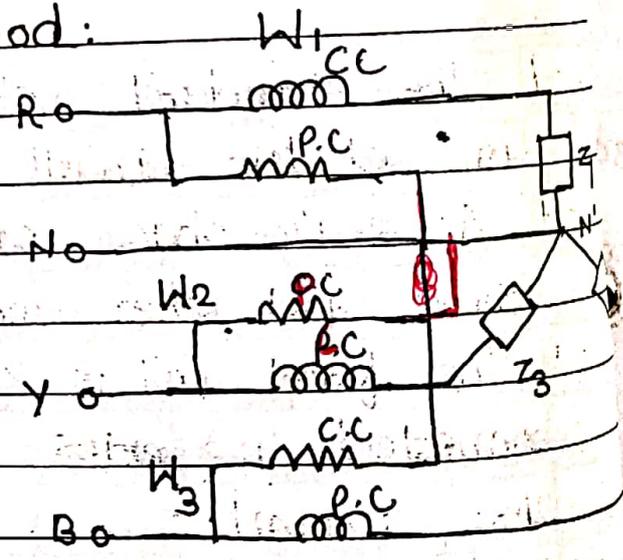
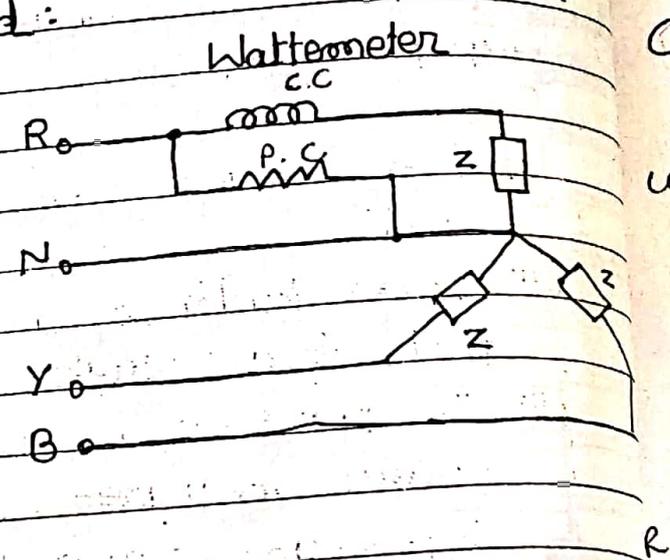
(ii) Three wattmeter method:

- In this method three wattmeters are connected to measure the power of each phase separately as shown in fig.

The algebraic sum of

three watt meter readings gives the total power.

The difficulty with this method is that sometimes it is not possible to have access to the neutral point in the star connection. The main drawback of this method is the requirements of three wattmeters.



Wattmeter
Current
Voltage
wattmeter
reading
Sin
 i_R
 i_B
 i_Y