12 Marks

Unit - 3 Three Phase Circuits

* Generation of 3 phase alternating EMF :

• Principle :

R,R', YY', BB' are the Armature windings displaced by 120°

- The single phase supply is generated using a single turn alternator. Thus if armature consists of only one winding, then only one Alternating voltage is produced.
- But if the armature winding is divided into three group which are displaced by 120° from each other then it is possible to generate three alternating v/g.

• Construction :

- As shown in above fig. the armature winding is divided into three groups. The three coils are R-R', Y-Y' & B-B'.
- All these coils are mounted on the same shaft & are physically placed at 120° from each other.
- When these coils rotate in the flux produced by the permanent magnet, emf is induced into these coils.

• Waveforms :

- These emf as shown in fig. are sinusoidal of equal amplitude & equal frequency but they are displaced by 120° from each other.

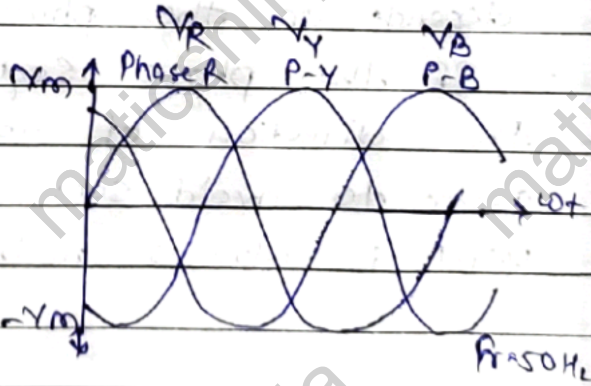


fig. v/g induced in 3 coil

- VR, VY & VB are 3-ph v/g. If VR is considered as reference then VY lag VR by 120° & VB lags VY by 120°.

* Comparison of 1-ph & 3-ph System :

Parameter	1-ph System	3-ph System
① Voltage	Low (230V)	High (415V)
② Transmission η	Low	High
③ Size of m/c to produce same o/p	Larger	Smaller
④ Cross sectional area of conductor	Larger	Small
⑤ Application	Domestic, Small Power application	Industrial, large power application

* Phase Sequence :

- Definition - The phase sequence is defined as the sequence in which the three phases reach their maximum positive values. Normally the phase sequences is R-Y-B. The three phase colours used to denote 3 ph'es are Red, Yellow & Blue.

- Importance of Phase Sequence :

- The direction of rotation of the three phases machine depends on the phase sequence.
- If the phase sequence is changed e.g. R-B-Y then the direction of rotation will be reversed. In order to avoid such things, the phase sequence of R-Y-B is always maintained.

* Types of Three Phase Connection :

1) Star Connection   2) Delta Connection

1) Star Connection (Wye Connection) :

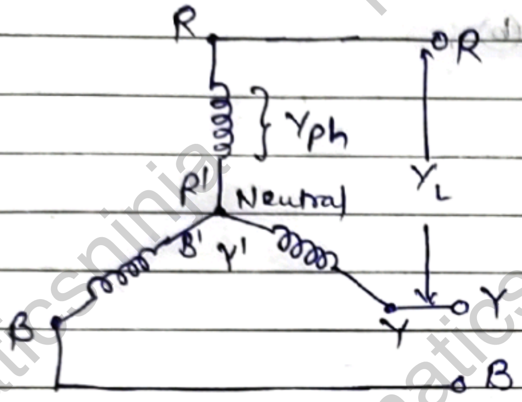


fig. (a) Star Connection

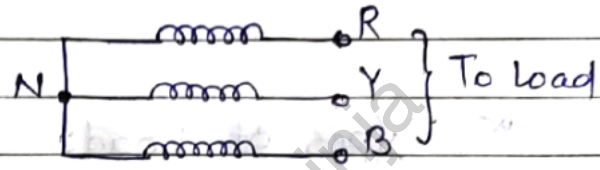


fig. (b) Equivalent circuit

- In above fig. Shows the Star or wye connection of the three alternator winding.
- This configuration is obtained by connecting one end of the three phase winding together
- We can connect either R, Y, B or R', Y', B' together. This common point is called as the Neutral Point & It is denoted by N.
- The three remaining end of the winding are brought out for the external connection. These ends are denoted by R-Y-B as shown in fig. (b).

2) Delta Connection :

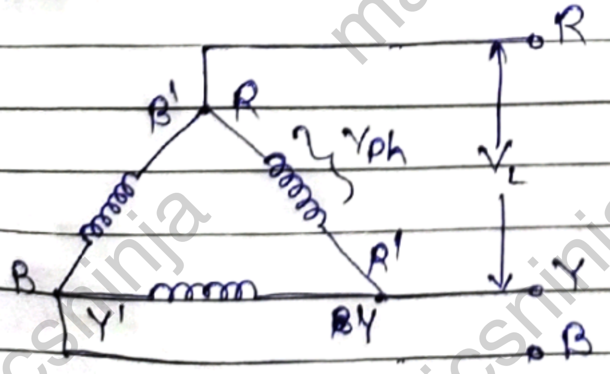


fig (a) Delta or Mesh Connection

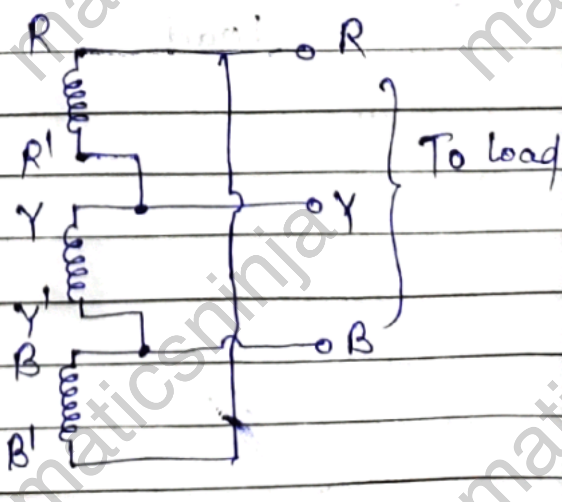


fig (b) Equivalent circuit

- In above fig. Shows the delta connection or mesh conn. of the three alternator winding.
- In delta or mesh configuration is obtained by connection one end of winding to the starting end of the other winding such that it produces a closed loop as shown in fig. (b).

* Types of Loads :

1) Balanced Load
2) Unbalanced Load

1) Balanced Load :

- Defn : A balanced load is that in which magnitude of all impedances connected in the load are equal & the phase angles of them also are equal it is called as balanced load.

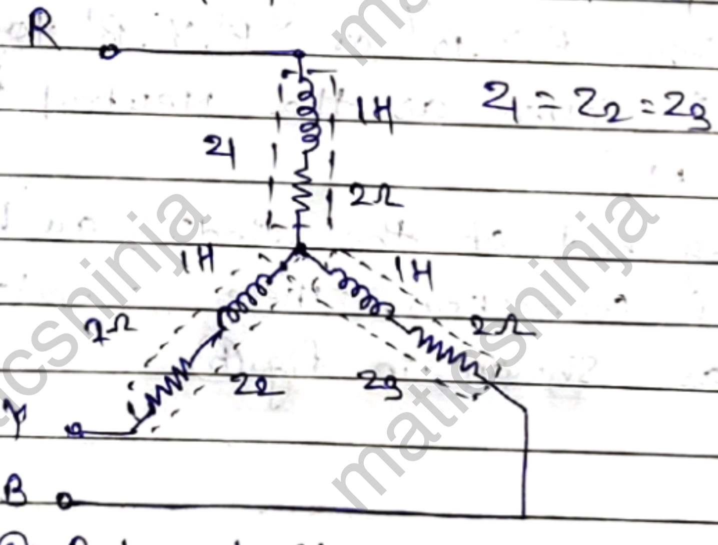


fig. (a) Balanced Star Connected Load

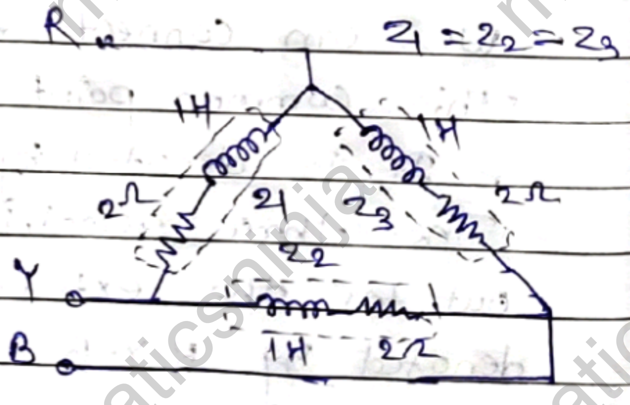


fig. (b) Balanced Delta Connected Load.

2) Unbalanced Load :

- **Defⁿ** : If a load does not satisfy the condition of balanced, then its called as the Unbalanced load.
  - If the magnitude & phase angle of the three impedances Z_1, Z_2 & Z_3 diff. from each other, then the load is said to be unbalanced.

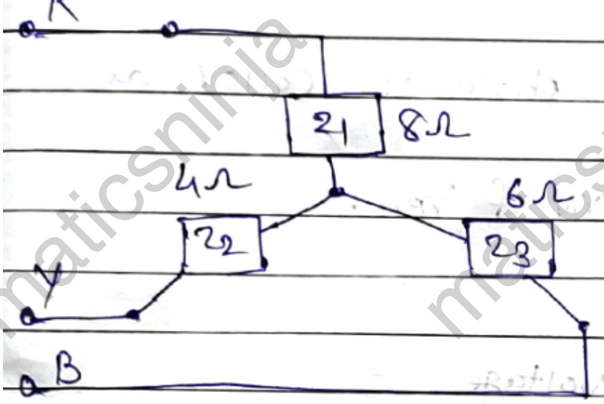


fig. (a) Unbalanced Star load

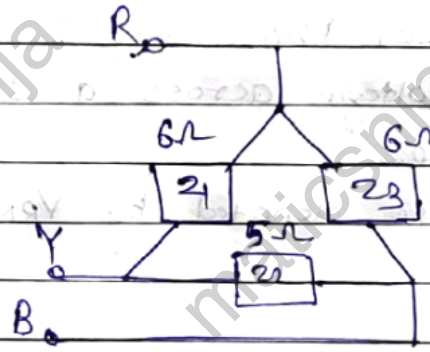


fig. (b) Unbalanced delta Load

- In fig. (b) $Z_1 = Z_3 = 6\Omega$ still this is an unbalanced delta connection because all the impedances are not equal.

✱ Three Phase Balanced Star Load :

- Line Voltage & Phase Voltage for Star Connected Supply :

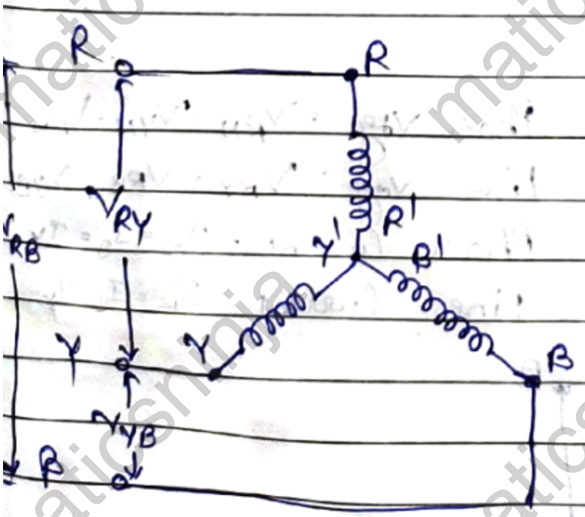


fig. (a) Line voltage

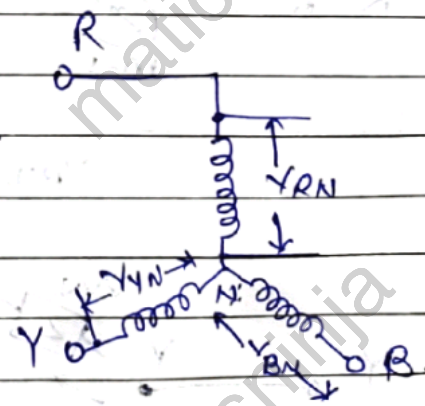


fig. (b) Phase voltage

- Definition of line vtg :
  - If R, Y & B are called as supply lines, then the potential difference betn any two lines is known as the line vtg.
  - V_{RY}, V_{RB}, V_{YB}, V_{YR}, V_{BR} & V_{BY} are six possible line voltages.

- Definition of Phase vtg :
  - The voltage across a single phase is called as phase voltage.
  - They are denoted by V_{RN}, V_{YN} & V_{BN}.

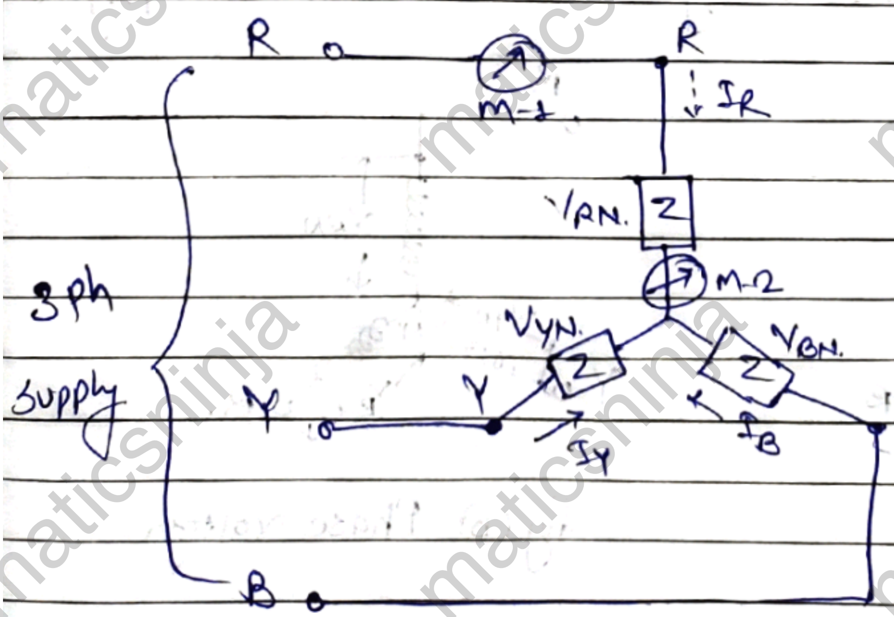
* Relation betn Phase & Line Voltage :

  - For a star connected load, the magnitude of line vtg is $\sqrt{3}$ times higher than that of a phase vtg.

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

* ~~Relation betn Phase & line Current~~ :

* Line & Phase Current for Star Connected Supply :



Phase vtg = V_{RN} = V_{YN} = V_{BN}.
Line vtg : V_{RY} = V_{RB} = V_{YB}.
Phase Current = I_R = I_B = I_Y.
Line Current : I_R = I_B = I_Y

- **Definition of Phase Current :**

- The current passing through any branch of the Star connected load is called as phase current.
- I_R, I_Y & I_B are the phase currents.
- Meter - 2 measures the phase current I_R.

- **Definition of Line Current :**

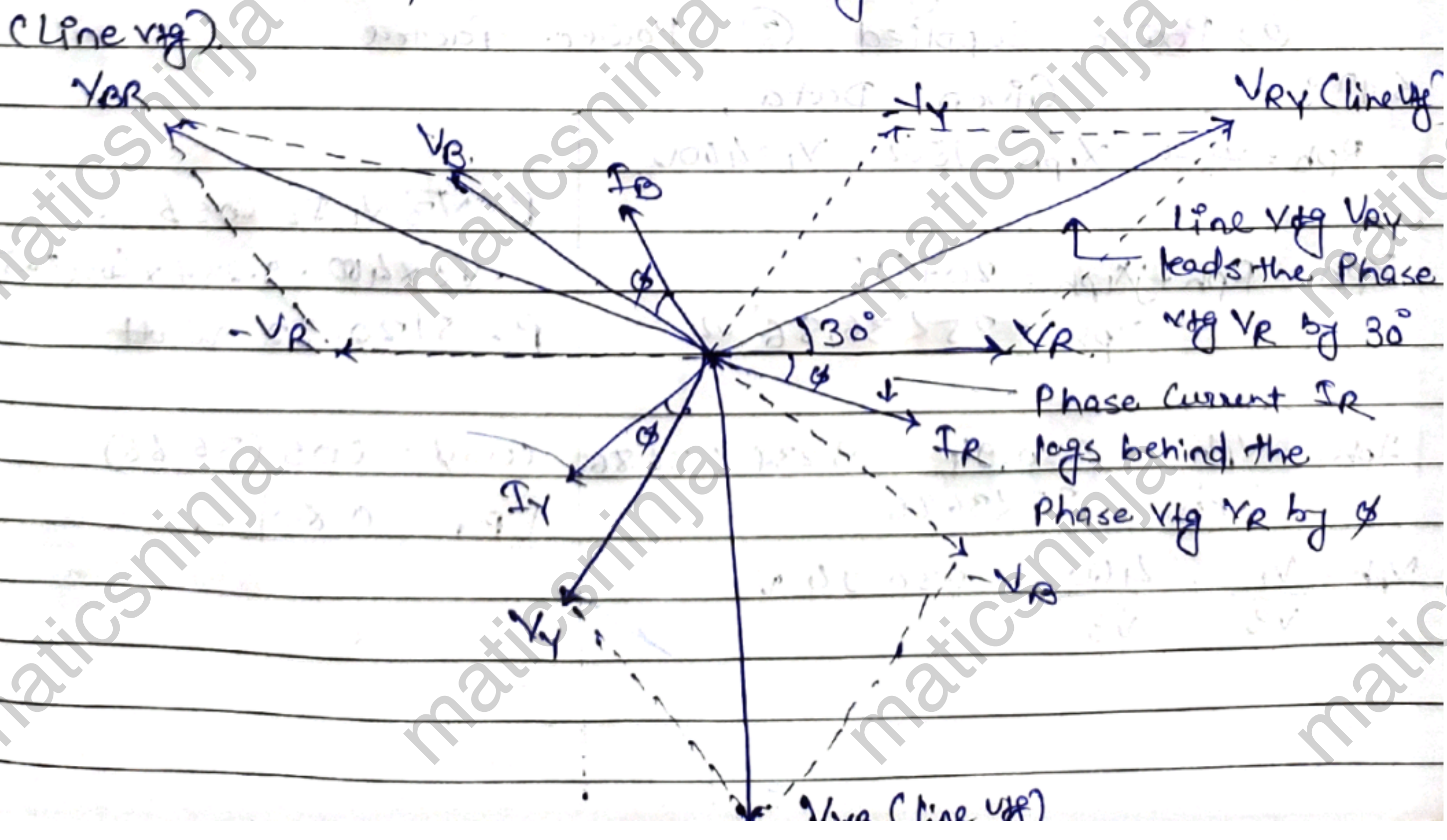
- The current passing through any line R, Y, B is called as line current.
- Meter - 1 measured the line current.
- It is denoted by I_L.

- **Relation betn Phase & Line Current :**

- As the current flowing through each branch line is equal to the current flowing through the corresponding branch, the line current is equal to the phase current.

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

*** The Complete Phasor diagram :**



Numerical on Star Load :

① A 3-ph Star Connected load has a resistance of 16Ω & an inductive reactance of 12Ω in each branch. It is supplied from 3 ph 400V, 50 Hz supply. Calculate line & Phase current & Power input in Watt.

Solⁿ : Given Data,

$R_{ph} = 16\Omega$, $X_{Lph} = 12\Omega$, $f = 50Hz$, $V_L = 400V$.

in star $I_L = I_{ph}$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230.94}{20\angle 36.86} = 11.547\angle -36.86^\circ A$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94V$$

$$Z_{ph} = R_{ph} + jX_{Lph} = 16 + j12 = 20\angle 36.86^\circ$$

$$I_L = I_{ph} = 11.547\angle -36.86^\circ A \quad \ldots \text{Ans}$$

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

$$P = \sqrt{3} \times 400 \times 11.547 \times \cos(-36.86)$$

$$P = 6400.82 \text{ Watt} \quad \ldots \text{Ans}$$

② Three Coil each having a resistance of 20Ω & reactance of 15Ω are connected in star to a 400V, 3ph, 50Hz supply. Calculate : ① Line Current ② Power supplied ③ Power factor.

Solⁿ : Given Data

$R_{ph} = 20\Omega$, $X_{Lph} = 15\Omega$, $V_L = 400V$,

$$Z_{ph} = R_{ph} + jX_{Lph} = 20 + j15$$

$$Z_{ph} = 25\angle 36.86^\circ \Omega$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230.94}{25\angle 36.86} = 9.237\angle -36.86$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94V$$

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

$$= \sqrt{3} \times 400 \times 9.237 \times \cos(36.86)$$

$$P = 5120.32 \text{ Watt}$$

$$\cos\phi = \cos(36.86)$$

$$\boxed{P.f = 0.80}$$

③ Three Coil each with a resistance of 10Ω & inductance of 0.35 mH are connected in star to a 3ph - 400V, 50Hz supply. Calculate line current & total power consumed.

Soln: Given Data, star load.

$R_{ph} = 10\Omega$, $L = 0.35mH$, $V_L = 400V$, $f = 50Hz$

Find: I_L & P

$X_{Lph} = 2\pi f L_{ph} = 2 \times 3.14 \times 50 \times 0.35 = 109.9\Omega$

$Z_{ph} = \sqrt{(R)^2 + (X_L)^2} = \sqrt{(10)^2 + (109.9)^2} = 110.35\angle 84.8^\circ$

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94V$

$\therefore I_{ph} = I_L = \frac{V_{ph}}{Z_{ph}} = \frac{230.94}{110.35\angle 84.8} = 2.09\angle -84.8^\circ A$

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

$= \sqrt{3} \times 400 \times 2.09 \times \cos(84.8)$

$P = 131.23$ Watt

* Three Phase Balanced Delta Load :

• Line vtg & Phase vtg for Delta Connected Supply :

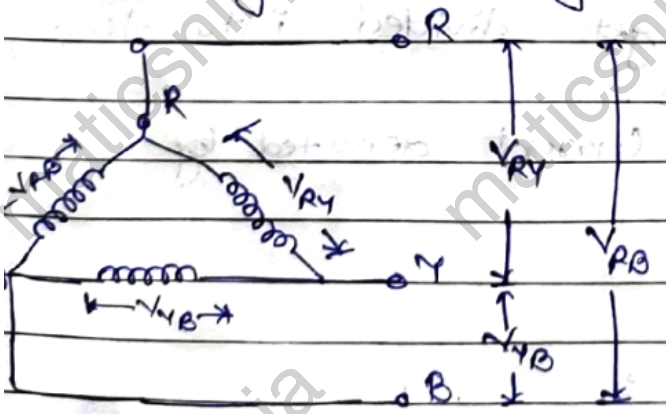


fig. Delta Connection

• Line vtg : The line vtg is defined as the potential diff. betn two line. So V_{RY}, V_{YB} & V_{RB} are the line vtg.

• Phase vtg : The vtg measured across a single winding is called as the phase vtg.

- Note that V_{RY}, V_{YB} & V_{RB} which are same as line vtg. Thus for delta connected supply, the phase vtg are same as line vtg.

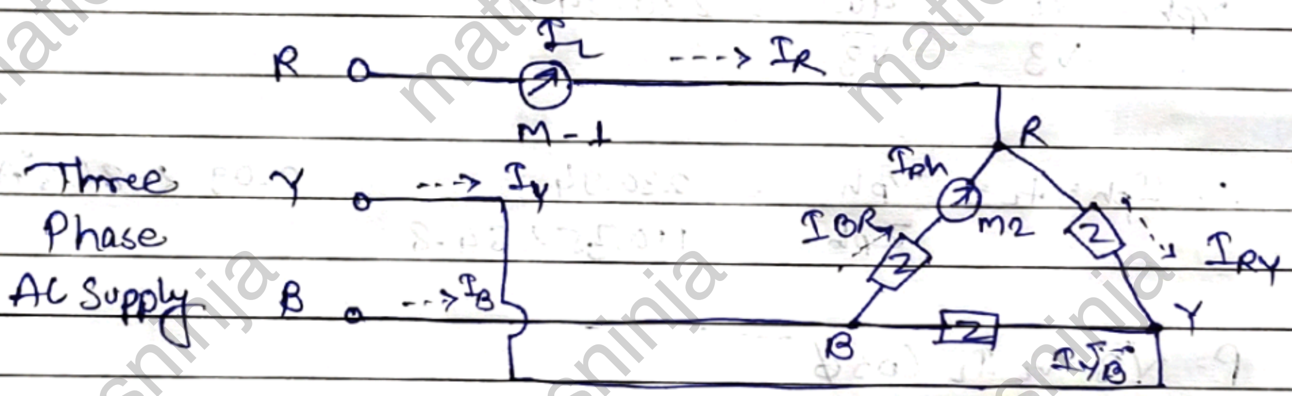
Relation betn Phase & line vtg :

- For delta connected supply the phase vtg V_{RY}, V_{YB} & V_{RB} ~~are~~ ~~same~~ and line voltage also are V_{RY}, V_{YB} & V_{RB}.

$$\therefore V_{ph} = V_L = V_{RY}, V_{RB}, V_{YB}$$

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

Line & Phase Current for Delta Connection :



Phase Currents I_{RY}, I_{YB}, I_{BR}
Line Currents I_R, I_Y, I_B

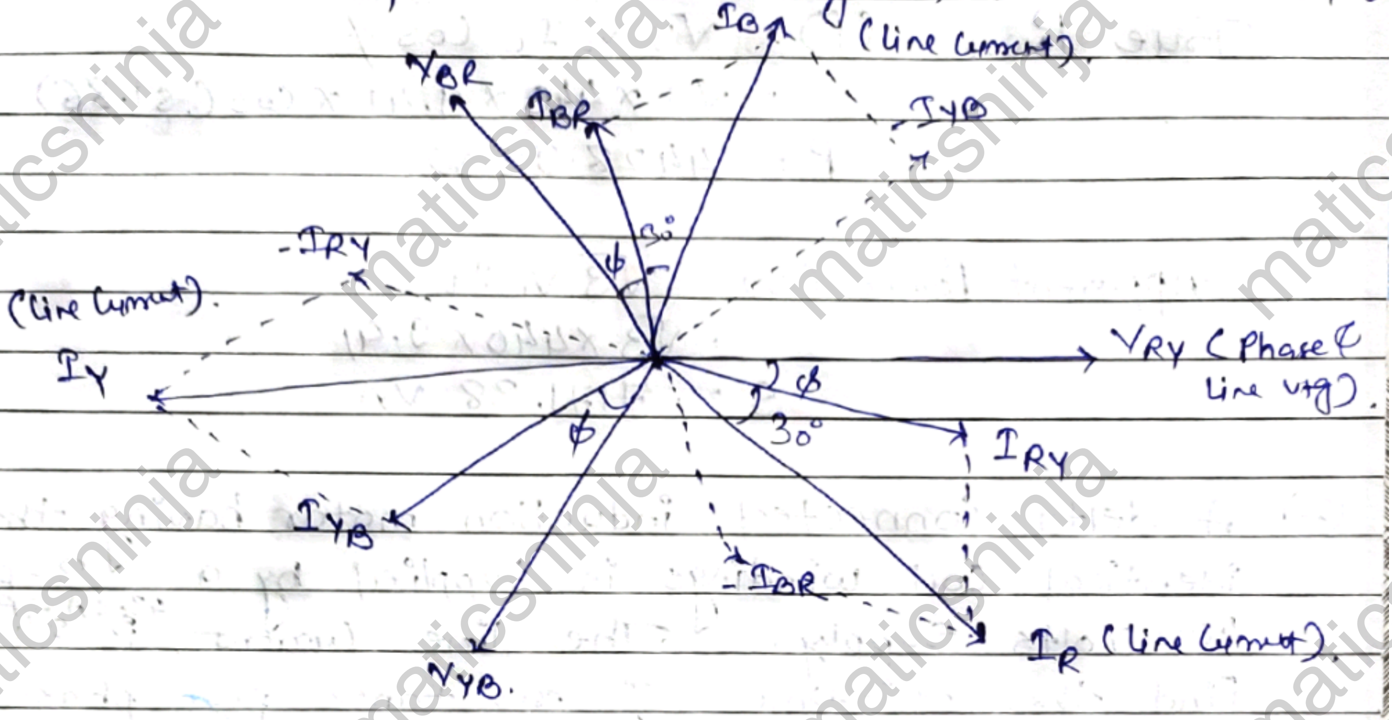
- Line Current : It is denoted by I_R, I_Y & I_B
- ~~Phase Current~~ : - The line current is higher than the phase current. This is because at node R, the line current I_R gets divided into two phase current I_{RY} & I_{RB}.
- So that the phase current denoted by I_{RY}, I_{YB}, & I_{RB}.

Relation betn I_L & I_{ph} :

- The relation betn line current & Phase current for a delta connected balanced load is as follow :

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

* The Complete Phasor diagram for Delta Load :



* Numerical on Delta Connected Load (Balanced) :

① A Three-phase delta Connected balanced load having a resistance of 50 Ω / Phase & Capacitance of 50 μF / Phase, is supplied by 440V, 3φ, 50 Hz AC Supply. Determine : ① Line Current ② Phase Current ③ True Power ④ Apparent P/w.

Soln : Given Data,

$R = 50\,\Omega/ph$, $C = 50\,\mu F/Phase$, $V_L = V_{ph} = 440V$, 3ϕ, $f = 50\,Hz$.

$I_L = \sqrt{3}\, I_{ph} = \sqrt{3} \times$ ~~4.94~~ 5.43 $=$ ~~8.55~~ 9.41 A.

$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{440}{80.97} =$ ~~4.94 A~~. 5.43

$Z_{ph} = \sqrt{R^2 + X_C^2} = \sqrt{(50)^2 + (63.69)^2} = 80.97 \angle 51.86°\,\Omega$

$X_C = \frac{1}{2\pi FC} = \frac{1}{2 \times 3.14 \times 50 \times 50 \times 10^{-6}} = 63.69\,\Omega$

True Power (P) $= \sqrt{3} V_L I_L \cos\phi$

$= \sqrt{3} \times 440 \times 9.41 \times \cos(51.86)$

$P = 4428.93\ W$

Apparent Power (S) $= \sqrt{3} V_L I_L$

$= \sqrt{3} \times 440 \times 9.41$

$S = 7171.38\ VA$

② A delta connected induction motor having three identical coil windings is supplied by a 3-ph 400 Volts supply. The line current is 43.3 A & Power is 24 kW. Find the resistance & reactance per phase of the winding.

Sol^n: Given Data,

$I_L = 43.3\ A$, $P = 24\ kW$, $V_L = 400V$

for delta connection, $V_L = V_{ph} = 400V$.

$I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{43.3}{\sqrt{3}} = 25\ A$

$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400}{25} = 16\Omega$

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

$24 \times 10^3 = \sqrt{3} \times 400 \times 43.3 \times \cos\phi$

$\cos\phi = \frac{24 \times 10^3}{\sqrt{3} \times 400 \times 43.3} = 0.8$

$\cos\phi = \frac{R_{ph}}{Z_{ph}}$

$R_{ph} = Z_{ph} \cos\phi = 16 \times 0.8 = 12.8\ \Omega$

$\sin\phi = \frac{X_{ph}}{Z_{ph}}$

$X_{ph} = Z_{ph} \sin\phi = 16 \times \sin(36.86) = 9.59\ \Omega$

③ A delta Connected load having phase impedance of $(8+j6)\,\Omega$ Supplied by a star connected alternator, having line voltage of 230V. Determine :
① Phase Current ② Line Current ③ Power factor ④ R.P/(Q)

Soln: Given Data,

$Z_{ph} = (8+j6)\,\Omega$, $V_L = V_{ph} = 230V$

$$Z_{ph} = \sqrt{R^2+X^2} = \sqrt{8^2+6^2} = 10\,\Omega$$

$$P.f = \cos\phi = \frac{R}{Z_{ph}} = \frac{8}{10} = 0.8$$

$$\sin\phi = \frac{X}{Z} = \frac{6}{10} = 0.6$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{230}{10} = 23\ A.$$

$$I_L = \sqrt{3}\, I_{ph} = \sqrt{3} \times 23 = 39.83\ A.$$

Reactive Power $(Q) = \sqrt{3}\, V_L I_L \sin\phi$

$= \sqrt{3} \times 230 \times 39.83 \times 0.6$

$= 9522\ VA = 9.522\ kVA$

④ A Three phase System supplied a load of 30kW at a P.f of 0.8. The line vtg is 250V. If the load is connected in ① Star ② Delta. Then Calculate line Current & Phase Current.

Soln: Given Data,

$P = 30kW$, $P.f = \cos\phi = 0.8$, $V_L = 250V.$

• for Star Connected Load :

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{250}{\sqrt{3}} = 144.33V.$$

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

$$I_L = \frac{30 \times 10^3}{\sqrt{3} \times V_L(250) \times 0.8} = 86.6\ A$$

$I_L = I_{ph} = 86.6\ A$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{144.33}{86.6} = 1.66\ \Omega$$

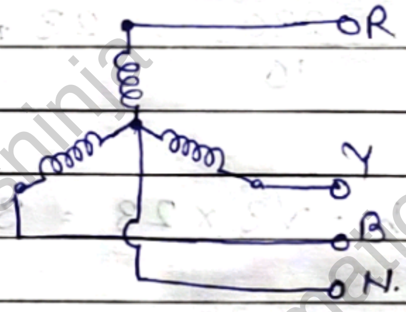
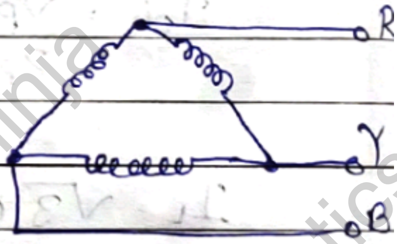
- For Delta Connected Load :

$$V_L = V_{ph} = 250\ V.$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{250}{1.66} = 150.6\ A.$$

$$I_L = \sqrt{3}\, I_{ph} = \sqrt{3} \times 150.6 = 260.84\ A.$$

* Comparison of Star & Delta Connection :

Sr. No.	Parameter	Star Connection	Delta Connection
1	Way of Connection		
2	Voltage Relationship	$V_L = \sqrt{3}\, V_{ph}$	$V_L = V_{ph}$
3	Current Relationship	$I_L = I_{ph}$ $I_{ph} = V_{ph}/Z_{ph}$	$I_L = \sqrt{3}\, I_{ph}$
4	Neutral wire	Can be Connected	Not necessary

Subject I/C
Mr. Bhosiwale. G.H