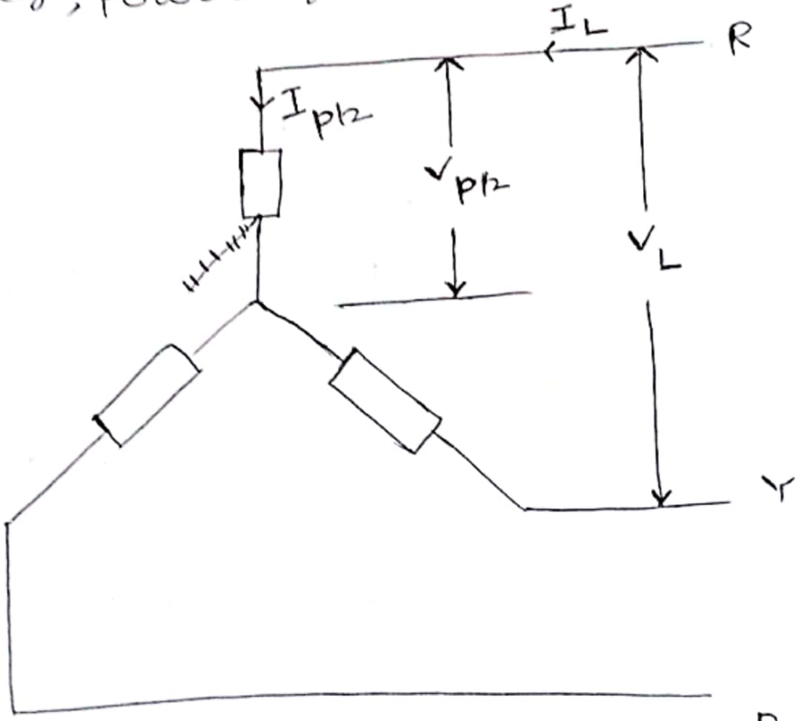
# EEE - unit 3 - Three Phase Balanced Systems & Electrical Installations :-

## Numerical Problems

1) A Balanced 3-phase load consists of 3 coils, each of $4\,\Omega$ resistance and 0.02 H inductance. Determine the total active & reactive power when coils are connected in star, if the supply voltage is 400 V, 50 Hz

Solution :- In three phase systems, by default, the voltages & currents given are line voltage & line current respectively.

Similarly, power given is three phase power by default.




Given :- $V_L = 400\text{ V}$ ; $R = 4\,\Omega$ ; $L = 0.02\text{H}$

$X_L = 2\pi f L = 100\pi(0.02) = 6.28\,\Omega$

$\therefore$ Impedance per phase $= [4 + j6.28]\,\Omega$

$|Z| = \sqrt{4^2 + 6.28^2} = 7.45\,\Omega$ ; $\phi = \tan^{-1}\left[\frac{6.28}{4}\right] = 57.5^\circ$

For star connection :- $V_L = \sqrt{3}\, V_{ph}$

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

$$I_{ph} = \frac{V_{ph}}{|Z|} = \frac{230.94}{7.45} = 31\,A$$

$$\therefore \quad I_L = I_{ph} = 31\,A$$

$$P_{3\text{-phase}} = 3 * V_{ph} * I_{ph} * \cos\phi$$

$$P_{3\text{-phase}} = 3 * 230.94 * 31 * \cos[57.5^\circ]$$

$$\boxed{P_{3\text{-phase}} = 11.54\,KW}$$

$$Q_{3\text{-phase}} = 3 * V_{ph} * I_{ph} * \sin\phi$$

$$= 3 * 230.94 * 31 * \sin(57.5^\circ)$$

$$\boxed{Q_{3\text{-phase}} = 18.11\,KVAR}$$

Note :- Alternate formulas :- 1) $P_{3\text{-phase}} = \sqrt{3}\, V_L I_L \cos\phi$

2) $P_{3\text{-phase}} = 3 * I_{ph}^2 * R$

3) $Q_{3\text{-phase}} = \sqrt{3} * V_L * I_L * \sin\phi$ 4) $Q_{3\text{-phase}} = 3 * I_{ph}^2 * X_L$

2) A balanced $3\phi$, star connected load of 100 KW takes a leading current of 80 A when connected to a $3\phi$, 1.1 KV, 50 HZ supply. Find the resistance, impedance and the capacitance of the load per phase. Also calculate the power factor of the load?

Solution :- $V_L = 1.1\,KV$, 50 HZ ; $I_L = 80\,A$ ; $P_{3\text{-phase}} = 100\,KW$

for star connected system, $I_L = I_{ph} = 80\,A$

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

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{1.1K}{\sqrt{3}} = 635.08\,V$$

Impedance per phase $= Z = \frac{V_{ph}}{I_{ph}} = \frac{635.08}{80}$

$$\boxed{Z = 7.94\,\Omega}$$

$$P_{3\text{-phase}} = 3 * I_{ph}^2 * R$$

$$R = \frac{100 \times 10^3}{3 * 80^2}$$

$$\boxed{R = 5.21\,\Omega}$$

$$Z = \sqrt{R^2 + X_c^2}$$

$$R^2 + X_c^2 = Z^2$$

$$X_c^2 = Z^2 - R^2$$

$$X_c = \sqrt{Z^2 - R^2}$$

$$X_c = \sqrt{7.94^2 - 5.21^2}$$

$$\boxed{X_c = 5.99\,\Omega}$$

Capacitance per phase $= \frac{1}{2\pi f \cdot X_c} = \frac{1}{2\pi \times 50 \times 5.99}$

$$\boxed{C = 531.40\,\mu F}$$

Power factor $= \cos\phi = \frac{R}{Z} = \frac{5.21}{7.94} = 0.656$ lead

3) A balanced delta connected load consumes 2 KW of power when connected to a three phase, 400V, 50 Hz supply. The same load when connected to a three phase 230V, 50 Hz supply, draws a current of 2A at lagging power factor. Determine the load power factor and resistance and inductance per phase?

Solution :- Case 1 - Delta connected load

$V_L = 400\,V$; $f = 50\,Hz$; $P_{3\text{-phase}} = 2\,KW$

$$P_{3\text{-phase}} = 3 * V_{ph} * I_{ph} * \cos\phi$$

$$P_{3\text{-phase}} = 3 * V_{ph} * \frac{V_{ph}}{Z} * \frac{R}{Z}$$

for a ~~star~~ delta connected 3-phase system, $V_{ph} = V_L$

$$\therefore \quad 2000 = 3 \times 400^2 \times \frac{R}{Z^2}$$

$$\Rightarrow \quad \frac{R}{Z^2} = 0.004167 \quad - (1)$$

Case 2) Same delta connected load

$V_L = 230\,V$; $f = 50\,Hz$

$I_L = 2A$

Since same load, $Z$ is same in both cases

for a delta connected 3-phase system $V_{ph} = V_L$

$$I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{2}{\sqrt{3}} = 1.155\,A$$

$$\therefore \quad Z = \frac{V_{ph}}{I_{ph}} = \frac{230}{1.155} = 199.13\,\Omega$$

substituting $Z$ in (1), $R = 0.004167 * 199.13^2$

$R = 165.24\,\Omega$

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{199.13^2 - 165.24^2} = 111.12\,\Omega$$

$$L = \frac{X_L}{\omega} = \frac{111.12}{100\pi} = 0.354\,H$$

$$\cos\phi = \frac{R}{Z} = \frac{165.24}{199.13} = 0.83 \text{ lag}$$

4) The load connected to a three phase supply comprises three similar coils connected in star. The line current is 25A, the real and apparent powers are 11 KW, 20 KVA. Find the line voltage, resistance and reactance of each coil? If the coils are connected in delta, find the ~~[illegible]~~ line current & power taken?

**Solution :- case 1 - Balanced star connected load**

Given :- $I_L = 25A$ ; $P_{3-phase} = 11\ KW$ ; $S_{3-phase} = 20 KVA$

$$S_{3-phase} = \sqrt{3} * V_L * I_L$$

$$V_L = \frac{20 \times 10^3}{\sqrt{3} * 25} = 461.88\ V$$

for a star connected load, $I_{ph} = I_L = 25A$ ;

$$V_L = \sqrt{3} \cdot V_{ph} \Rightarrow V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{461.88}{\sqrt{3}}$$

$$\boxed{V_{ph} = 266.66\ V}$$

$$Z = \frac{V_{ph}}{I_{ph}} = \frac{266.66}{25} = 10.66\ \Omega$$

$$P_{3-phase} = 3 * I_{ph}^2 * R$$

$$\Rightarrow R = \frac{11 \times 10^3}{3 * 25^2} = 5.86\ \Omega$$

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{10.66^2 - 5.86^2}$$

$$\boxed{X_L = 8.905\ \Omega}$$

Case 2) Same load reconnected as delta across same supply :-

Since same supply, $V_L$ remains same and since same load, $Z$, $R$ & $L$ in each phase remains same.

for a balanced delta connected load :-

$$V_{ph} = V_L = 461.88\ V$$

$$I_{ph} = \frac{V_{ph}}{Z} = \frac{461.88}{10.66} = 43.33\ A$$

$$I_L = \sqrt{3}\, I_{ph} = \sqrt{3} * 43.33\ A = 75.04\ A$$

$$P_{3-phase} = 3 * I_{ph}^2 * R = 3 * 43.33^2 * 5.86$$

$$\boxed{P_{3-phase} = 33\ KW}$$

$$S_{3-phase} = \sqrt{3} * V_L * I_L = \sqrt{3} * 461.88 * 75.04$$

$$\boxed{S_{3-phase} = 60\ KVA}$$

5) A balanced $3\Phi$ star connected load is supplied from a symmetrical $3\Phi$ 400V system. The current in each phase is $30^\circ$A and lags $30^\circ$ behind the voltage. Find the i) impedance in each phase ii) total power drawn. Draw phasor diagram?

Solution :- $V_L = \sqrt{3} \cdot V_{ph}$ ; $I_L = I_{ph}$

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

$$I_{ph} = 30\angle{-30^\circ}\ A$$

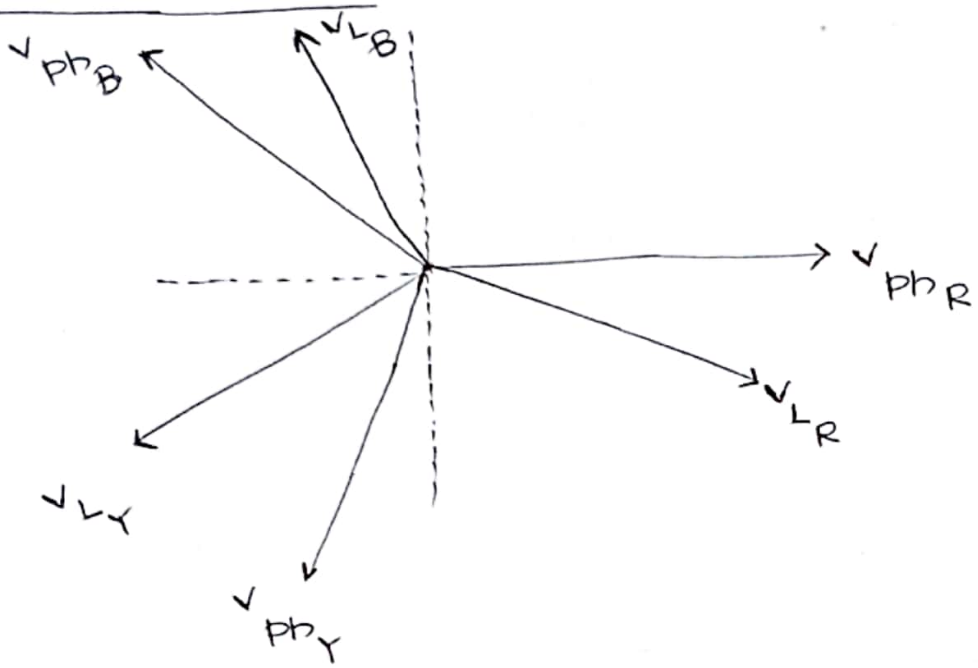
$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{230.94}{30\angle{-30^\circ}} = 7.698\angle{30^\circ}$$

$$\Rightarrow \boxed{Z_{ph} = 6.66 + j\,3.85\,\Omega}$$

$$P_{3\text{-phase}} = 3 \cdot I_{ph}^2 \cdot R = 3 \cdot 30^2 \cdot 6.66$$

$$\boxed{P_{3\text{-phase}} = 17.98 \text{ KW}}$$

Phasor diagram :-




6) A balanced delta connected three phase inductive load draws real and apparent powers of 16 KW and 20 KVA from a balanced three phase 400 V, 50 HZ supply. Determine i) line current ii) Impedance per phase iii) Power factor of the load iv) Resistance & Inductance per phase

Solution :- for delta, $V_L = V_{ph} = 400$ V

$P_{3\text{-phase}} = 16$ KW ; $S_{3\text{-phase}} = 20$ KVA

$S_{3\text{-phase}} = 3 * V_{ph} * I_{ph}$

$P_{3\text{-phase}} = 3 * V_{ph} * I_{ph} * \cos\phi$

$\cos\phi = 0.8$

$\boxed{\phi = 36.86^\circ}$

$$I_{ph} = \frac{20 \times 10^3}{3 * 400}$$

$I_{ph} = 16.67$ A ; $I_L = \sqrt{3} \cdot I_{ph} = 28.86$ A

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400}{I_{ph}} = \frac{400}{16.67\angle -36.86^\circ}$$

$$\boxed{Z_{ph} = 23.99\angle 36.86^\circ = 19.19 + j14.39\ \Omega}$$

(8)

7) A balanced Δ connected 3ϕ load draws reactive and apparent power of 6 KVAR and 10 KVA when connected across balanced 400 V, 50 Hz 3ϕ supply. Determine i) $I_{ph}$ ii) Resistance per phase iii) Reactance per phase

Solution :-

$$V_L = V_{ph} = 400\ V$$

$$Q_{3\text{-phase}} = 6\ KVAR;\ S_{3\text{-phase}} = 10\ KVAR$$

$$Q_{3\text{-phase}} = \underbrace{3 * V_{ph} * I_{ph}}_{S_{3\text{-phase}}} * \sin\phi$$

$$\sin\phi = \frac{6 \times 10^3}{10 \times 10^3}$$

$$\sin\phi = 0.6$$

$$\phi = 36.86°$$

$$\boxed{\cos\phi = 0.8\ lag}$$

$$S_{3\phi} = 3 * V_{ph} * I_{ph}$$

$$I_{ph} = \frac{10 \times 10^3}{3 * 400}$$

$$I_{ph} = 8.33\ A$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400}{8.33 \angle -36.86°}$$

$$Z_{ph} = 48.01 \angle 36.86°$$

$$\boxed{Z_{ph} = 38.4 + j28.8\ \Omega}$$

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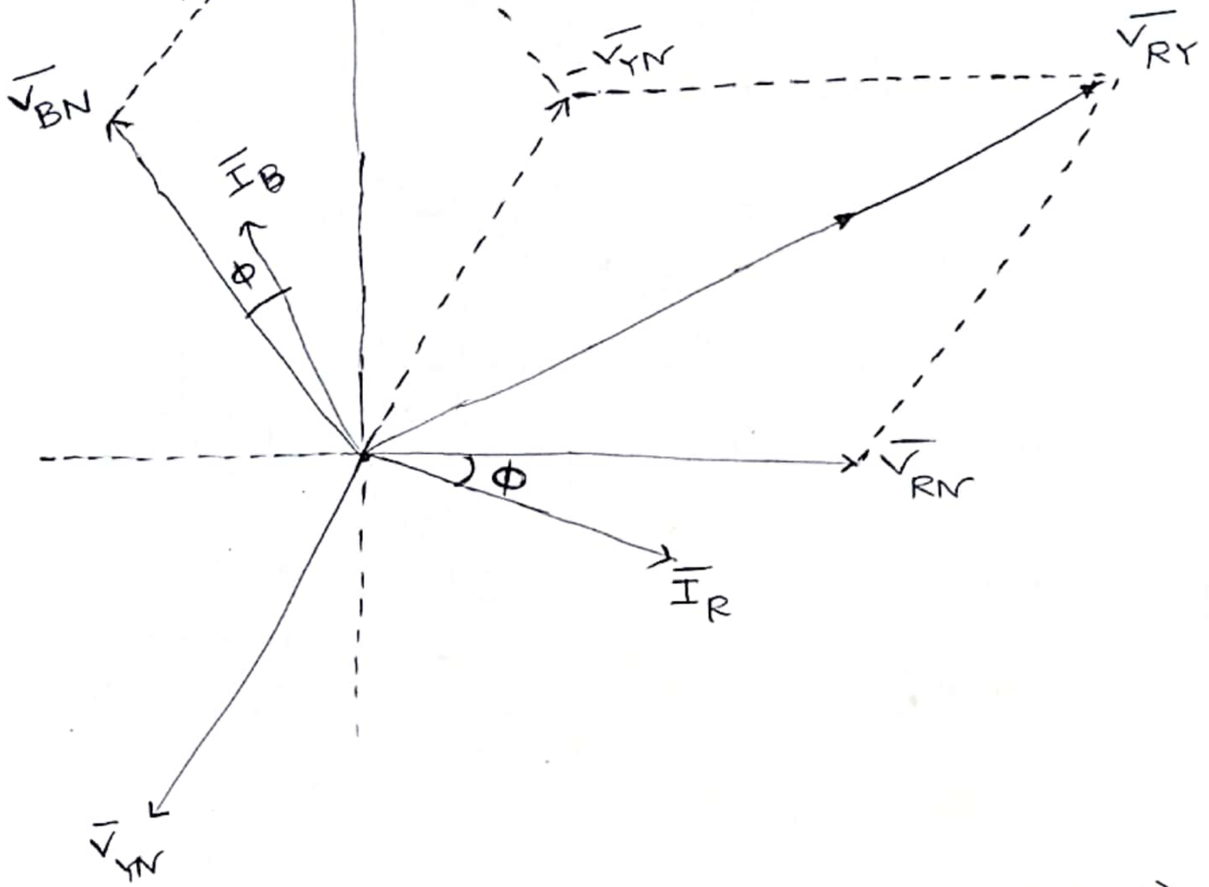
## Two Wattmeter Method - Phasor diagram :- 

$\bar{V}_{RY} = \bar{V}_{RN} - \bar{V}_{YN}$ ; $\bar{V}_{BY} = \bar{V}_{BN} - \bar{V}_{YN}$




$W_1 = V_{RY} * I_R * \cos(30+\phi)$ ; $W_2 = V_{BY} * I_B * \cos(30-\phi)$

$W_1 = V_L * I_L * \cos(30+\phi)$ ; $W_2 = V_L * I_L * \cos(30-\phi)$

$W_1 + W_2 = V_L \cdot I_L \left[\cos(30+\phi) + \cos(30-\phi)\right]$

$$\cos A \cdot \cos B = \frac{\cos(A+B) + \cos(A-B)}{2}$$

$\Rightarrow \cos(A+B) + \cos(A-B) = 2 \cdot \cos A \cdot \cos B$

$= V_L \cdot I_L \left[2 \cdot \cos(30^\circ) \cdot \cos\phi\right]$

$= V_L \cdot I_L \cdot 2 \cdot \sqrt{3}/2 \cdot \cos\phi$

$\Rightarrow W_1 + W_2 = \sqrt{3} * V_L * I_L * \cos\phi = P_{3-\phi}$ - (1)

$W_2 - W_1 = V_L * I_L * \left[\cos(30-\phi) - \cos(30+\phi)\right]$

$= V_L * I_L * 2 \sin(30^\circ) \sin\phi = V_L * I_L * \sin\phi$

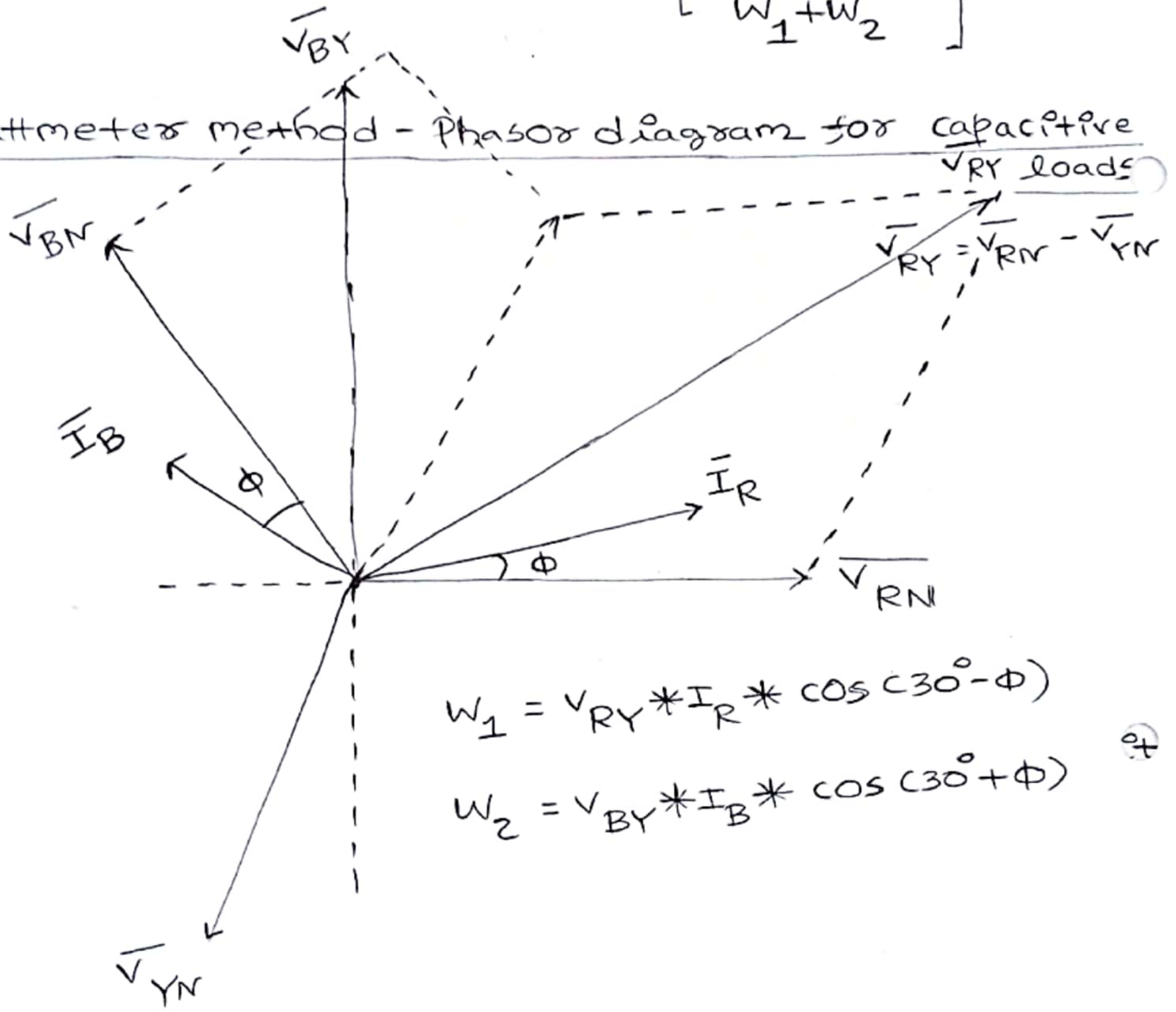
$\therefore \sqrt{3}(W_2 - W_1) = \sqrt{3} * V_L * I_L * \sin\phi = Q_{3-\phi}$ — (2)

$$\therefore \frac{Q_{3-\phi}}{P_{3-\phi}} = \frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2} = \tan\phi$$

$$\Rightarrow \phi = \tan^{-1}\left[\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right]$$

$$\text{Power factor } \cos\phi = \cos\left\{\tan^{-1}\left[\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right]\right\}$$

## Two Wattmeter method - Phasor diagram for capacitive loads




$$W_1 = V_{RY} * I_R * \cos(30^\circ - \phi)$$

$$W_2 = V_{BY} * I_B * \cos(30^\circ + \phi)$$

7) In a two wattmeter method of measuring three phase power, it is observed that the wattmeter readings are in the ratio 3 : 1. Determine the power factor of the load?

Solution :- Given $W_1 : W_2 = 3 : 1$

$$\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}\,(W_2 - W_1)}{W_1 + W_2}\right]\right]$$

$$= \cos\left[\tan^{-1}\sqrt{3}\ \cancel{3}\left[\frac{W_2 - 3W_2}{4W_2}\right]\right]$$

$$= \cos\left[\tan^{-1}\sqrt{3}\left[-1/2\right]\right]$$

$$= \cos\left[\tan^{-1}\left[-\sqrt{3}/2\right]\right]$$

$$\boxed{\cos\phi = 0.756}$$

8) Two wattmeters are connected to measure input to a balanced three phase circuit indicate 2000 W and 500 W respectively. Find the power factor when

i) Both readings are positive

ii) Latter reading is obtained after reversing its cc

Solution :- Case 1 - $W_1 = 2000\ W$ & $W_2 = 500\ W$

$$\cos\phi = \cos\left[\tan^{-1}\sqrt{3}\left(\frac{W_2 - W_1}{W_1 + W_2}\right)\right]$$

$$\cos\phi = \cos\left[\tan^{-1}\sqrt{3}\left(\frac{1500}{2500}\right)\right]$$

$$\boxed{\cos\phi = 0.693}$$

Case 2 :- $W_1 = 2000\ W$ ; $W_2 = -500\ W$

$$\cos\phi = \cos\left[\tan^{-1}\sqrt{3}\left[\frac{W_2 - W_1}{W_1 + W_2}\right]\right]$$

$$\cos\phi = \cos\left[\tan^{-1}\sqrt{3}\left[\frac{-2500}{1500}\right]\right]$$

$$\boxed{\cos\phi = 0.327}$$

9) Three coils each having a resistance of 20Ω and a reactance of 15Ω are connected in star across a 3φ 400V, 50 HZ supply. calculate the readings of the two wattmeters connected to measure the power input. If these coils are now connected in delta across the same supply, calculate the new wattmeter readings?

Solution :- Case 1 - Balanced star connected load :-

$V_L = 400\ V$ ; $R = 20\Omega$ ; $X_L = 15\Omega$

$\therefore\ Z = [20 + j15]\Omega$

$$|Z| = \sqrt{20^2 + 15^2} = 25\Omega ; \phi = \tan^{-1}\left[\frac{15}{20}\right] = 36.87^\circ$$

for star :- $V_L = \sqrt{3}\cdot V_{ph}$

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

$$I_{ph} = \frac{V_{ph}}{|Z|} = \frac{230.94}{25} = 9.24\ A$$

for star ⇒ $I_L = I_{ph} = 9.24\ A$

$$W_1 = V_L I_L \cos(30 + \phi)$$

$$= 400 * 9.24 * \cos(30 + 36.87^\circ)$$

$$\boxed{W_1 = 1.451\ KW}$$

$W_2 = V_L + I_L * \cos(30° - \phi)$

$W_2 = 400 * 9.24 \cos(-6.87°)$

$\boxed{W_2 = 3.67 KW}$

Case 2) Same load connected as delta connected load :-

since same supply, $V_L$ remains same and since same load, Z remains same :-

$V_{ph} = 400 V = V_L$

$I_{ph} = \frac{V_{ph}}{|Z|} = \frac{400}{25} = 16 A$

$I_L = \sqrt{3} * I_{ph} = \sqrt{3} * 16 = 27.71 A$

$\therefore W_1 = V_L * I_L * \cos(30° + \phi)$

$W_1 = 400 * 27.71 * \cos(66.87°) = 4.354 KW$

$W_2 = V_L * I_L * \cos(30° - \phi)$

$W_2 = 400 * 27.71 * \cos(-6.87°) = 11 KW$

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10) Two wattmeters are connected to measure power in a three phase circuit. The readings of one of the wattmeters is 5KW when the load power factor is unity. If the power factor of the load is changed to 0.707 lag without changing the total input power, calculate the new readings of the wattmeters?

Solution :- case 1 :- Load power factor is unity

$W_1 = 5 KW$; for load power factor unity ⇒

$W_1 = W_2$; $\therefore P_{3-\phi} = W_1 + W_2 = 10 KW$;

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Case 2) Load power factor is changed to 0.707 lag with total input power unchanged

Since total input power is same, $P_{3\phi} = W_1 + W_2$
$= 10\ kW$ — ①

$$\cos\phi = \cos\left[\tan^{-1}\sqrt{3}\left[\frac{W_2 - W_1}{W_1 + W_2}\right]\right] = 0.707$$

$$\tan^{-1}\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2} = \cos^{-1}[0.707]$$

$$\tan^{-1}\sqrt{3}\left[\frac{W_2 - W_1}{W_1 + W_2}\right] = 45^\circ$$

$$\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2} = \tan(45^\circ)$$

$$\sqrt{3}(W_2 - W_1) = 10\ kW$$

$$W_2 - W_1 = 5.77\ kW$$

$$W_2 + W_1 = 10\ kW$$

$$\Rightarrow \boxed{W_2 = 7.88\ kW}$$

$$\boxed{W_1 = 2.12\ kW}$$

11) Two wattmeters connected to measure three phase power for star connected load read 3 kW and 1 kW respectively. The line current is 10 A. Calculate a) Line & phase voltage b) Resistance & Reactance per phase

Solution: Given star connected load,

$W_1 = 3\ kW$ ; $W_2 = 1\ kW$ ; $I_L = 10\ A$

$$\text{Power factor} = \cos\phi = \cos \tan^{-1}\left[\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right]$$

$$= \cos\left[\tan^{-1}\sqrt{3}\left[\frac{-2}{4}\right]\right]$$

$$= \cos \tan^{-1}\left[\frac{-\sqrt{3}}{2}\right]$$

$$= \cos(-40^\circ)$$

$$\boxed{\cos\phi = 0.756}$$

$$P_{3-\phi} = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos\phi$$

$$V_L = \frac{4 \times 10^3}{\sqrt{3} * 10 * 0.756}$$

$$\boxed{V_L = 305.48\,V}$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = 176.37\,V$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{176.37}{10} = 17.64\,\Omega$$

$$R = Z * \cos\phi = 13.33\,\Omega$$

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{17.64^2 - 13.33^2}$$

$$\boxed{X_L = 11.55\,\Omega}$$

12) A three phase balanced load connected across a 3-$\phi$ 400V ac supply draws a line current of 10 A. Two wattmeters are used to measure input power. The ratio of two wattmeter readings is 2:1. Find the readings of the two wattmeters.

(15)

Solution :- $V_L = 400V$; $I_L = 10A$; $\frac{W_1}{W_2} = \frac{2}{1}$

If $W_1 > W_2 \Rightarrow W_1 = V_L \cdot I_L \cdot \cos(30 - \phi)$

$$W_2 = V_L \cdot I_L \cdot \cos(30 + \phi)$$

$$\phi = \tan^{-1} \sqrt{3} \left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$= \tan^{-1} \sqrt{3} \left[\frac{W_2}{3W_2}\right]$$

$$\phi = \tan^{-1}\left[1/\sqrt{3}\right] = 30^\circ$$

$$\boxed{\cos\phi = 0.866}$$

$$W_1 = 400 \times 10 \times 1 = 4\,KW$$

$$W_2 = 400 \times 10 \times \frac{1}{2} = 2\,KW$$

13) Calculate the readings of the two wattmeters connected to measure the total power for a balanced delta connected load, fed from a three phase, 200 V balanced supply with phase sequence as R-Y-B. The load impedance per phase is $[14 - j14]\Omega$. Also find the line & phase currents, power factor, total power, total reactive VA and total VA?

Solution :- Given $V_L = 200V$; $Z = [14 - j14]\Omega$

To find $I_L, I_{ph}, PF, P_{3-\phi}, Q_{3-\phi}, S_{3-\phi}$ :-

for delta connected load :- $V_L = V_{ph} = 200V$

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

$$|Z| = \sqrt{14^2 + 14^2} = 19.79\Omega; \quad \phi = \tan^{-1}(-1) = -45^\circ$$

$$I_{ph} = \frac{V_{ph}}{|Z|} = \frac{200}{19.79} = 10.106\ A$$

$$I_L = \sqrt{3} \cdot I_{ph} = \sqrt{3} \cdot 10.106 = 17.504\ A$$

$$W_1 = V_L \cdot I_L \cdot \cos(30^\circ - \phi)$$

$$W_1 = 200 \times 17.504 \times \cos(75^\circ)$$

$$\boxed{W_1 = 906\ W}$$

$$W_2 = V_L \cdot I_L \cdot \cos(30^\circ + \phi)$$

$$W_2 = 200 \times 17.504 \cdot \cos(-15^\circ)$$

$$\boxed{W_2 = 3.38\ kW}$$

$$\cos\phi = \cos \tan^{-1}\left[\frac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right]$$

$$\cos\phi = \cos \tan^{-1} \frac{\sqrt{3}(3.38k - 906)}{3.38k + 0.906k}$$

$$\boxed{\cos\phi = 0.707}$$

$$P_{3-\phi} = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos\phi$$

$$= \sqrt{3} \cdot 200 \cdot 17 \cdot 0.707$$

$$\boxed{P_{3-\phi} = 4.28\ kW}$$

$$Q_{3-\phi} = \sqrt{3} \cdot V_L \cdot I_L \cdot \sin\phi$$

$$Q_{3-\phi} = \sqrt{3} * 200 * 17.504 * \sin(-45^\circ)$$

$$\boxed{Q_{3-\phi} = -4.28\ kVAR}$$

$$S_{3-\phi} = \sqrt{3} \cdot V_L \cdot I_L = 6.063\ kW$$

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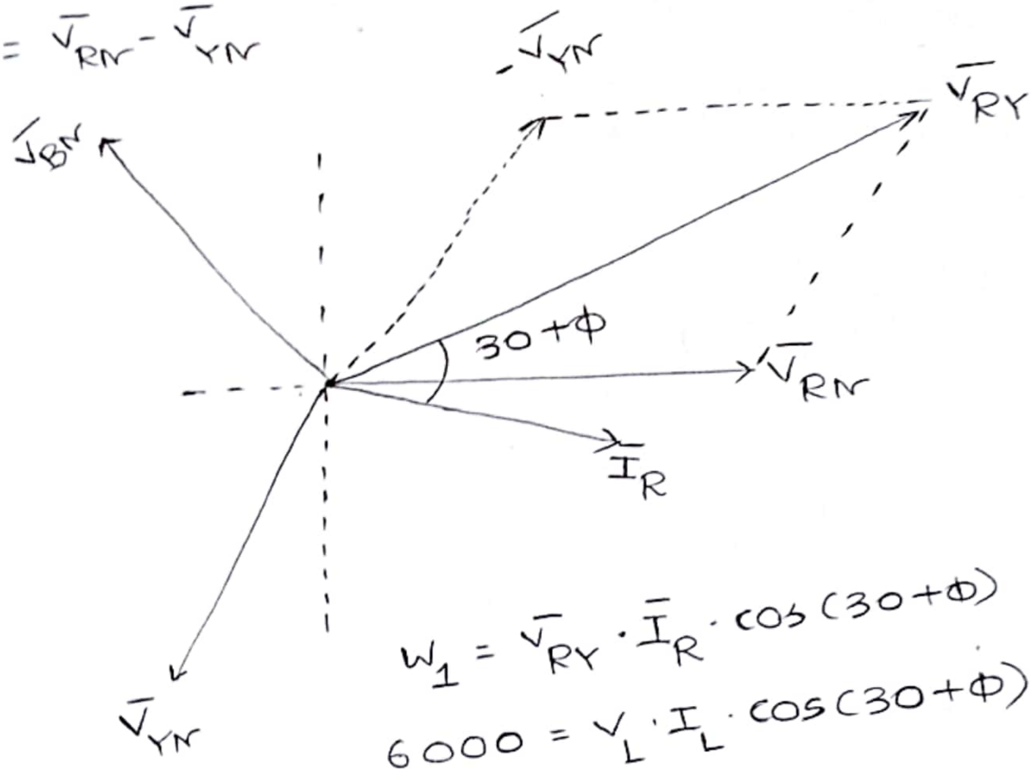
14) A 3-$\phi$, Y-connected, balanced load with a lagging power factor is supplied at 400 V. A wattmeter when connected with its current coil in the R-coil and voltage coil between R & Y lines gives a reading of 6 kW. When the same terminals of the voltage coil are switched over to Y- and B-lines, the current coil connections remaining the same; the readings of the wattmeter remains unchanged. Calculate the line current & power factor of the load. Phase sequence is RYB.

Solution :- Case 1 :- CC in R-line and PC between R & Y lines

$\bar{V}_{RY} = \bar{V}_{RN} - \bar{V}_{YN}$



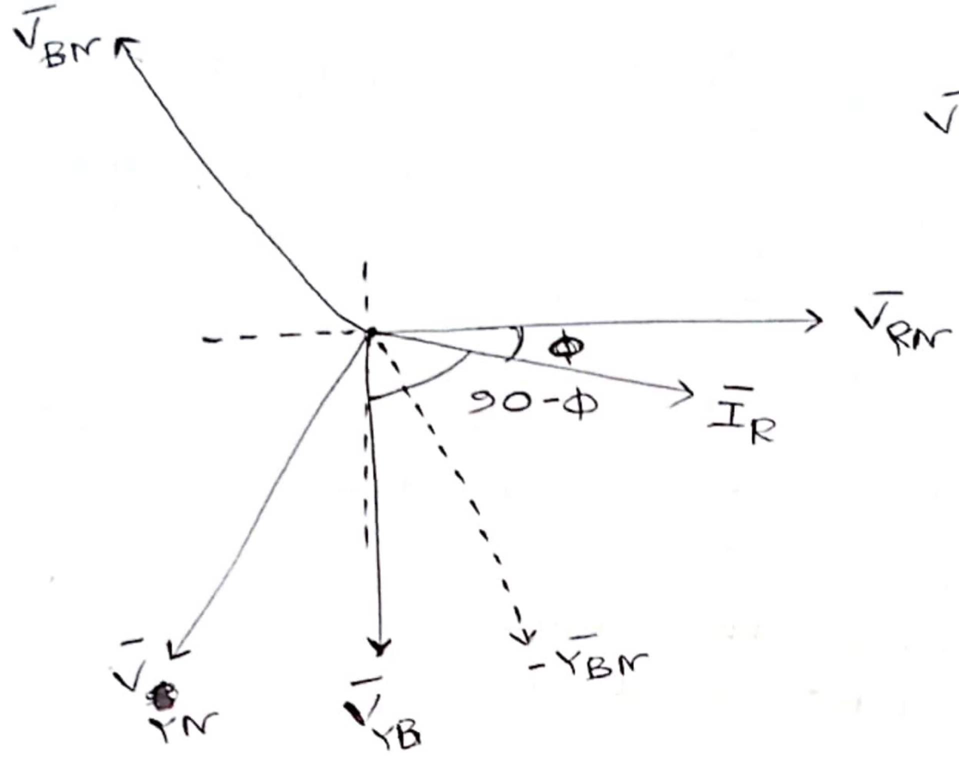

$W_1 = \bar{V}_{RY} \cdot \bar{I}_R \cdot \cos(30+\phi)$

$6000 = V_L \cdot I_L \cdot \cos(30+\phi)$

Case 2 :- CC in R-line & PC between Y & B lines

$W_2 = \bar{V}_{YB} \cdot \bar{I}_R \cdot \cos \angle V_{YB}, I_R$

$$\bar{V}_{YB} = \bar{V}_{YN} - \bar{V}_{BN}$$




$\therefore \quad W_2 = V_L \cdot I_L \cdot \cos(90-\phi)$

The two wattmeter readings are equal :-

$$6000 = V_L \cdot I_L \cdot \cos(30+\phi)$$

$$\Rightarrow \cancel{V_L} \cancel{I_L} \cos(30+\phi) = \cancel{V_L} \cdot I_L \cdot \cos(90-\phi)$$

$$30+\phi = 90-\phi$$

$$\Rightarrow \phi = 30^\circ$$

$$6000 = V_L \cdot I_L \cdot \cos(30^\circ + 30^\circ)$$

$$I_L = \frac{6000 \times 2}{400}$$

$$\boxed{I_L = 30A}$$

15) A 3-$\phi$ motor operating on a 400 V supply is developing an output power of 25 HP at an efficiency of 87% and power factor of 0.82. Calculate a) the line current b) the phase current, if the windings are delta?

Solution:- for a delta connected 3$\phi$ system,

$V_L = V_{ph} = 400\ V$

convert HP to KW

$1\ HP = 0.746\ KW$

$P = 25 \times 0.746\ KW$

$\boxed{P = 18.65\ KW}$

$\eta = 0.87 ;\ \cos\phi = 0.82$

$$\eta = \frac{P_o}{P_i} \Rightarrow P_i = \frac{18.65 \times 10^3}{0.87}$$

$\boxed{P_i = 21.43\ KW}$

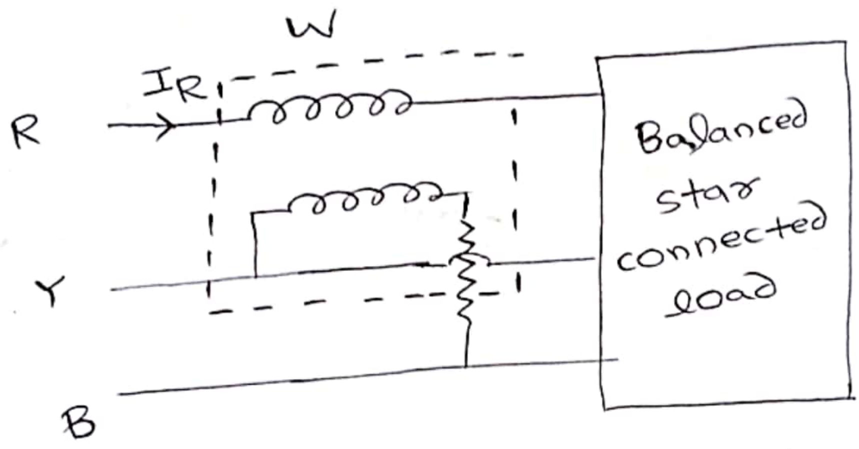
$P_{3-\phi} = V_L \cdot I_L \cdot \sqrt{3} \cdot \cos\phi$

$21.43 \times 10^3 = 400 \times I_L \times \sqrt{3} \times 0.82$

$\boxed{I_L = 37.72\ A}$

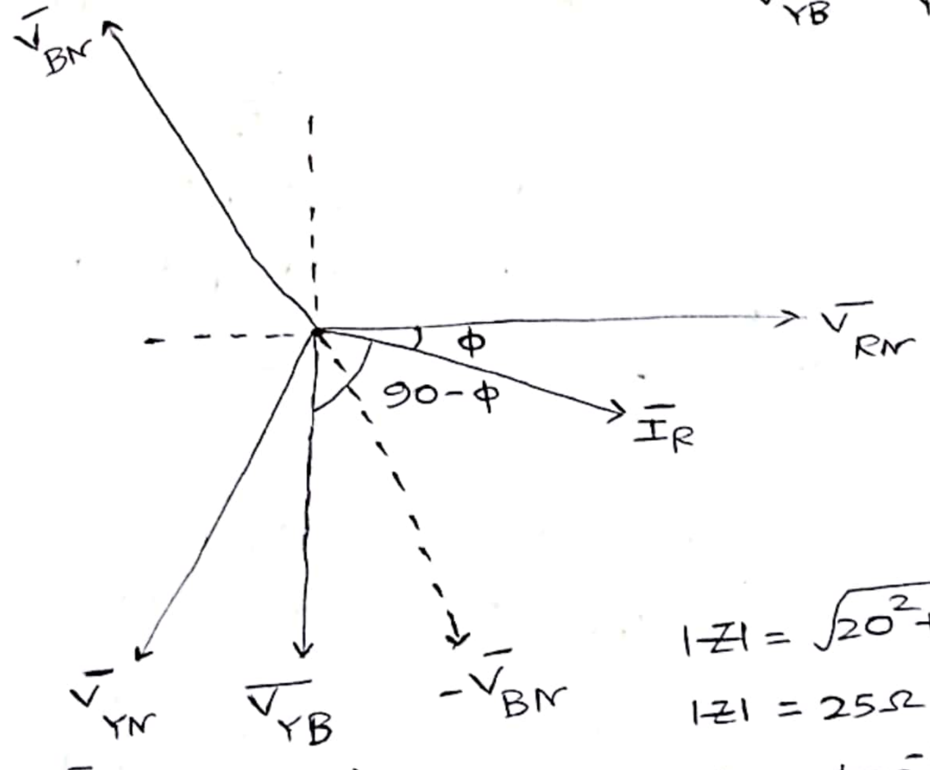
$$I_{ph} = \frac{I_L}{\sqrt{3}} = 21.77\ A$$

16) Calculate the reading of the wattmeter (W) as connected in figure below. The load is a balanced star connected one, with impedance of $[20+j15]\Omega$ per phase, fed from a 3-$\phi$, 400 V, balanced supply, with phase sequence as R-Y-B ?




**Solution:-** $V_L = 400\,V$ ; $R = 20\,\Omega$ ; $X_L = 15\,\Omega$

$\bar{V}_{YB} = \bar{V}_{YN} - \bar{V}_{BN}$




$|Z| = \sqrt{20^2 + 15^2}$

$|Z| = 25\,\Omega$

$\phi = \tan^{-1}\left[\frac{15}{20}\right] = 36.86^\circ$

$W_1 = \bar{V}_{YB} \cdot \bar{I}_R \cdot \cos(90-\phi)$

$W_1 = V_L \cdot I_L \cdot \sin(\phi)$

$\therefore\ W_1 = 400 \times 9.24 \times \sin(36.86)$

$\boxed{W_1 = 2.2\,kW}$

**for star:-**

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

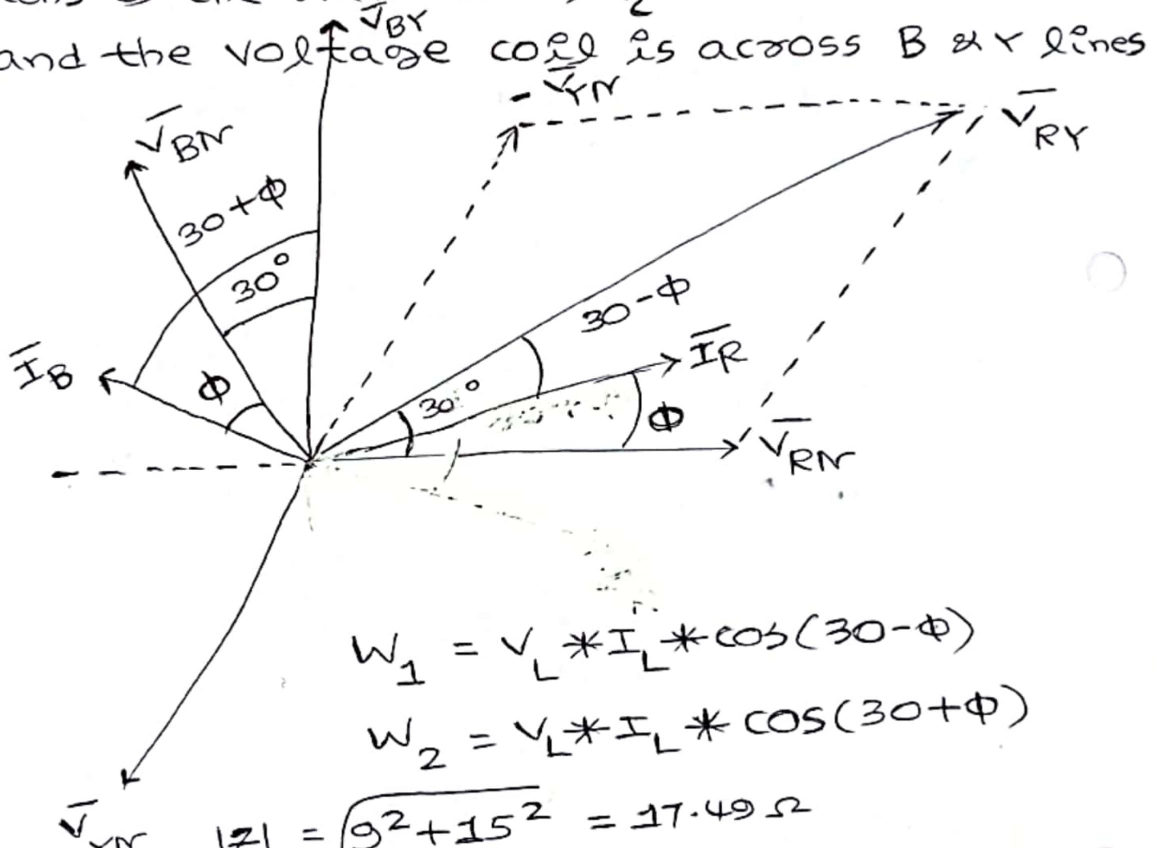
$\Rightarrow V_{ph} = \frac{400}{\sqrt{3}} = 230.94\,V$

$I_{ph} = \frac{V_{ph}}{|Z|} = 9.24\,A = I_L$

(21)

17) Calculate the reading of the two watt-meters $W_1$ and $W_2$ connected to measure the power for a balanced 3-phase load. The supply voltage is 200 V for a star connected load with $[9-j15]\,\Omega$ per phase. The connections of the wattmeter, $W_1$ - current coil is in R-line, and the voltage is across R & Y lines. The connections of the wattmeter, $W_2$ - current coil is in B line, and the voltage coil is across B & Y lines

Solution :-




$$W_1 = V_L * I_L * \cos(30-\phi)$$

$$W_2 = V_L * I_L * \cos(30+\phi)$$

$$|Z| = \sqrt{9^2+15^2} = 17.49\,\Omega$$

$$\phi = \tan^{-1}[-5/9] = -29.05°$$

for star connected $3\phi$ system, $V_L = \sqrt{3}\cdot V_{ph}$

$$V_{ph} = \frac{200}{\sqrt{3}} = 115.47\text{ V}$$

$$I_L = I_{ph}; \quad I_{ph} = \frac{V_{ph}}{|Z|} = 6.602\text{ A}$$

$$\Rightarrow I_L = 6.602\text{ A}$$

$$W_1 = 200 * 6.602 * \cos(59.05°) = 679.06\text{ W}$$

$$W_2 = 200 * 6.602 * \cos(0.95°) = 1320.2\text{ W}$$

18) Consider the Table below :-

| SL.NO | Name of the Appliance | Wattage | Average consumption hours per day |
|---|---|---|---|
| 1 | Four Incandescent bulbs | 60W per bulb | 10 hrs each |
| 2 | Four ceiling fans | 75W per fan | 12 hrs each |
| 3 | Geyser | 1 kW | 1 hr |
| 4 | Refrigerator | 100 W | 16 hours |
| 5 | Television | 50 W | 10 hours |
| 6 | Mixer Grinder | 750 W | 1 hour |

consider a 30 day month, Determine

i) the total number of units consumed in a month

ii) monthly bill for the above consumption units considering a domestic connection of 3 kW sanctioned load and with the tariff details listed in a table below :-

| | | |
|---|---|---|
| 1) | Fixed charges for sanctioned load | 50/- for first kW<br>60/- for every additional kW |
| 2) | Energy consumption charges | 0 to 30 units - Rs 3.50 per unit<br>31 to 100 units - Rs. 4.95 per unit<br>101 to 200 units - Rs. 6.50 per unit<br>201 to 300 units - Rs. 7.55 per unit<br>301 to 400 units - Rs. 7.60 per unit<br>Above 400 units - Rs. 7.65 per unit |

consider a tax of 7.3 % on total charges. Neglect any other charges.

(23)

## Solution :-

Total units consumed per day

1) Four bulbs → $4 \times 60 \times 10 = 2400$ Whrs $= 2.4$ kWhr
$= 2.4$ units

2) Four ceiling fans → $4 \times 75 \times 12 = 3600$ Whr $= 3.6$ kWhr
$= 3.6$ units

3) Geyser → 1 kWhr → 1 unit

4) Refrigerator → $100\,W \times 16$ → 1600 Whr → 1.6 kWhr
→ 1.6 units

5) Television → $50 \times 10$ → 500 Whr → 0.5 kWhr → 0.5 units

6) Mixer Grinder → $750 \times 1$ → 750 Whr → 0.75 kWhr → 0.75 units

Total units consumed per day → 9.85 units

Total units consumed per month → 295.5 units

1) Fixed charges → $(1 \times 50) + (2 \times 60) =$ RS. 170/-

2) Energy consumption charges →

0 to 30 → $3.50 \times 30$

31 to 100 → $4.95 \times 70$

101 to 200 → $6.50 \times 100$

201 to 300 → $7.55 \times 96$

∴ Total energy consumption charges = Rs. 1862.3/-

3) Tax of 7.3% on total charges

Total charges = RS. 1,996.3/-

Tax = RS. 145.73/-

4) Total Bill = RS. 2,178.03/-

19) For Question, refer Lecture 55 - slide 3

Total units consumed per day :-

1) $8 \times 20 \times 10 \rightarrow 1600$ Whr $\rightarrow 1.6$ KWhr $\rightarrow 1.6$ units
2) $80 \times 10 \times 2 \rightarrow 1600$ Whr $\rightarrow 1.6$ units
3) $3 \times 1$ KW $\times 1 \rightarrow 3$ kWhr $\rightarrow 3$ units
4) $250 \times 24 \rightarrow 6000$ Whr $\rightarrow 6$ units
5) $60 \times 6 \rightarrow 360$ Whr $\rightarrow 0.36$ units
6) $800 \times \frac{30}{60} \rightarrow 400$ Whr $\rightarrow 0.4$ units
7) $900 \times \frac{40}{60} \rightarrow 600$ Whr $\rightarrow 0.6$ units

$\therefore$ Total units consumed per day $= 13.56$ units

Total units consumed per month $= 420.36$ units

1) Fixed charges $= (1 \times 60) + (5 \times 75) =$ Rs. 435/-

2) Energy consumption charges $= (4.5 \times 50) + (5.95 \times 50) + (7.5 \times 100) + (8.55 \times 100) + (8.6 \times 100) + 9 \times 20$

$=$ Rs. 3,167.50/-

3) Fuel adjustment charges $= 0.20 \times 420.36 =$ Rs. 84.072/-

4) Tax of 9.5 % on energy consumption only $=$ Rs. 300.9125/-

Total Bill $=$ Rs. 3987.4845/-

25

20)

| SL.NO | Name of the Appliance | Wattage | Average consumption in hrs/day | units consumed per day |
|---|---|---|---|---|
| 1 | 4 LED bulbs | 15W each | 10 hrs | $4 \times 15 \times 10$ = 600 Whr = 0.6 KWhr = 0.6 units |
| 2 | Four ceiling fans | 75W each | 12 hrs | $4 \times 75 \times 12$ = 3600 Whr = 3.6 KWhr = 3.6 units |
| 3. | Geyser | 1KW | 1hr | 1 KWhr = 1 unit |
| 4. | Refrigerator | 100W | 24hrs | $100 \times 24$ = 2400 Whr = 2.4 units |
| 5. | Television | 50W | 8 hrs | $50 \times 8$ = 400 Whr = 0.4 unit |
| 6. | Mixer Grinder | 750W | 15 mins | $750 \times \frac{15}{60}$ = 187.5 Whrs = 0.1875 units |
| 7. | Water pump | 750W | 30 minutes | $\frac{750 \times 30}{60}$ = 375 Whrs = 0.375 units |

Total units consumed per day = 8.5625 units per day

Total units consumed per month = 256.875 units per month [for 30 days]

1) Fixed charges for 5 KW sanctioned load :-

Rs.50/- for first KW and Rs.60/- for every additional KW $\Rightarrow (1\times50)+(4\times60) = $ Rs.290/-

2) Energy consumption charges for 256.875 units

0 to 30 units $\rightarrow 3.5\times30$

31 to 100 units $\rightarrow 4.95\times70$

101 to 200 units $\rightarrow 6.5\times100$

201 to 256.875 units $\rightarrow 7.55\times56.875$

$\therefore$ Total energy consumption charges = Rs.1530.906/-

3) Fuel Adjustmeter charges $\rightarrow$ 14 ~~paisa~~ paisa per unit consumed

= Rs.35.962/-

4) Overall tax = 9% on above charges $= 0.09[1856.866]$

= Rs.167.117/-

$\therefore$ Total Bill = 2023.985/-

21) The list of loads and average consumption hours per day of a typical household is given below:-

| SL-NO | Name of the appliance | Wattage | Average consumption hours per day |
|---|---|---|---|
| 1 | 6 Bulbs | 25W each | 12 hours |
| 2 | 3 ceiling fans | 85W each | 10 hours |
| 3 | 2 Geysers | 1 KW | 1 hour |
| 4 | Refrigerator | 150 W | 24 hours |
| 5 | Television | 50 W | 8 hours |
| 6 | Mixer Grinder | 850 W | 20 minutes |
| 7 | Water pump | 800W | 45 minutes |

Considering a 31 day month, Determine

i) Total number of units consumed in a month

ii) Monthly bill for the above consumption units considering a domestic connection of 6 KW sanctioned load with the tariff details given below:-

| SL-NO | Type of charges | Tariff Details |
|---|---|---|
| 1 | Fixed charges for the sanctioned load | RS.60/- for first KW<br>RS.75/- for every additional KW |
| 2. | Energy consumption charges | 0 to 50 units @RS.4.5/unit<br>51 to 100 units @5.95/unit<br>101 to 200 units @7.5/unit<br>201 to 300 units @8.55/unit<br>301 to 400 units @8.6/unit |

Above 400 units @ RS 9.0 per unit

3) Fuel Adjustment charges @ 20 paise per unit consumed

4) Tax on Energy consumption charges only - 9.5 %

Solution Fixed charges = $(1 \times 60) + (5 \times 75)$

Units consumed

1) $6 \times 25 \times 12 = 1800$ Whr $= 1.8$ kWhr $= 1.8$ units
2) $3 \times 85 \times 10 = 2550$ Whr $= 2.55$ kWhr $= 2.55$ units
3) $2 \times 1$ kW $\times 1$ hr $= 2$ kWhr $= 2$ units
4) $150 \times 24 = 3600$ Whr $= 3.6$ kWhr $= 3.6$ units
5) $50 \times 8 = 400$ Whr $= 0.4$ kWhr $= 0.4$ units
6) $850 \times \frac{20}{60} = 283.33$ Whr $= 0.28$ kWhr $= 0.28$ units
7) $800 \times \frac{45}{60} = 600$ Whr $= 0.6$ kWhr $= 0.6$ units

## Additional Problems - unit 3

1) A balanced star connected load consumes a power of 3 KW at a lagging power factor of 0.8 when connected to a three-phase supply. If the line current is 12.5A, calculate the resistance and reactance in each branch of the load. What will be the line current and power consumed, if the same load is connected in delta, to the same supply?

**Solution :-** $P = 3\,KW;\ \cos\phi = 0.8;\ I_L = 12.5A$

For star connected $3\phi$ system, $I_L = I_{ph}$

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

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

$$V_L = \frac{3\times10^3}{\sqrt{3}\times12.5\times0.8} = 173.20\,V$$

$$\cos\phi = 0.8 \Rightarrow \phi = \cos^{-1}0.8 =$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{173.20/\sqrt{3}}{12.5}$$

$$Z_{ph} = 8\angle36.86^\circ\,\Omega = [6.4 + j\,4.79]\,\Omega$$

$$R_{ph} = 6.4\,\Omega \;\&\; X_{L_{ph}} = 4.79\,\Omega$$

**For Delta connected load :-**

$$I_L = \sqrt{3}\cdot I_{ph};\ V_L = V_{ph}$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = 21.65\,A$$

$$I_L = \sqrt{3}\times I_{ph} = \sqrt{3}\times21.65$$

$$I_L = 37.498\,A$$

$$P_\Delta = 3\cdot P_Y = 9\,KW$$

2) What are the components of an earthing System? Mention the methods of earthing?

Solution :- An earthing system consists of the following basic components - 1) Earth continuity indicator 2) Earthing lead 3) Earthing electrode

Methods of Earthing - 1) Plate earthing 2) pipe earthing 3) Rod earthing 4) strip Earthing.

3) The list of ~~[illegible]~~ loads and average consumption hours per day of a typical household is given below :-

| SL.NO | Name of the Appliance | Wattage | Average consumption hours per day |
|---|---|---|---|
| 1 | Five LED bulbs | 12 W each | 14 hours each |
| 2 | Four ceiling fans | 90 W each | 12 hours each |
| 3 | Geyser | 1 KW | 2 hours |
| 4 | Refrigerator | 100 W | 24 hours |
| 5 | Television | 48 W | 8 hours |

considering a 30-day month, Determine

1. Total number of units consumed in a month
2. Monthly bill for the above consumption units considering a domestic connection of 4 KW sanctioned load with the tariff details given below :-

| SL.NO | Type of charges | Tariff Details |
|---|---|---|
| 1 | Fixed charges for the sanctioned load | 110/- for first KW<br>120/- for every additional KW |
| 2 | Energy consumption charges | 0-50 units @ 4.15/- per unit<br>51-100 units @ 5.6/- Per unit<br>101-200 units @ 7.15/- per unit<br>Above 200 units @ 8.2/- per unit |
| 3. | Fuel Adjustment charges | @ 0 paise per unit consumed |
| 4 | Tax applicable only for units consumed | @ 9% [Note: Only for units consumed and not for fixed charges and fuel adjustment charges] |

Solution :-

| SL.NO | Name of the appliance | Wattage | Avg consumption hrs/day | Units consumed per day |
|---|---|---|---|---|
| 1 | Five LED bulbs | 12W each | 14 hrs | 5×12×14 = 0.840 KWhr = 0.840 units |
| 2 | Four ceiling fans | 90W each | 12 hrs | 4×90×12 = 4320 Whr = 4.32 units |
| 3 | Geyser | 1 kW | 2 hrs | 1kW × 2hr = 2 units |
| 4 | Refrigerator | 100 W | 24 hours | 100 W * 24 hrs = 2400 Whr = 2.4 units |
| 5 | Television | 48 W | 8 hours | 48×8 = 384 Whr = 0.384 units |

3M

Total units consumed per day = 9.944 units per day

Total units consumed per month = 30×9.944 = 298.32 units per month

≃ 298 units

1M

Tariff Details and calculations :-

1) Fixed charges → (110×1)+(120×3) = 470.00/-

2) Energy consumption charges :- (50×4.15)+(50×5.6)+(100×7.15) +(98×8.2) = 2006.10/-

3) Fuel Adjustment charges @ 0 ~~Rs~~ paise per unit consumed = 0.00/-

4) Tax applicable only for units consumed - 9% on 298 units - 0.09 × 2006.10 = 180.549/-

3M

Monthly bill = 470 + 2006.10 + 180.459 = 2656.64 ≃ RS. 2657/-

1M