356 17-11-23

14
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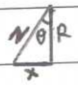
SCHEME OF VALUATION

(Scoring Indicators)

Revision:15 **Course Code: 3033**

Fundamentals of AC Systems

Qn No.	Scoring Indicator	Split up Score	Sub Total	Total
I.1	It is the voltage whose amplitude is changing continuously and changes its direction in a regular interval	2	2	10
2	Impedance $Z=\sqrt{(R^2+X^2)}$. 	2	2	
3	$X_L = X_C$,Resonance frequency $f_r = \dfrac{1}{2\pi\sqrt{LC}}$	1 1	2	
4	A three phase system has only two possible sequences **ABC** and **CBA**. Or **RYB and BYR**	1 1	2	
5	It is the cosine of the angle between voltage and current in a circuit, expressed by $\cos\phi$	2	2	
	Part - B			
II.1	**Advantages of AC System** 1. High voltage generation is easy 2. High power transmission at high voltage is easy 3. The voltage can be stepped up or stepped down 4. AC machines are simpler than DC machine 5. Wireless technology is possible due to AC 6. Transmission cost for long distance is low	1 Mark each	6	
2	**RMS value (Root Mean Square value)/Effective value/Virtual value** The rms value of an AC is given by that DC current which when flowing through a given circuit for a given time produces same amount of heat as produced by the AC when flowing through same circuit for the same time. **Analytical Method** We know the equation of an AC voltage, $v = V_m Sin\theta$. Here we consider only half cycle (0-π). The general formula for rms value, $V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} v^2 d\theta}$ ………(1) Substitute the value of v in equation 1. $V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^{\,2}\sin^2\theta \, d\theta}$ ……….(2)	2		

	We know, $\sin^2\theta = \frac{1-\cos 2\theta}{2}$ Substitute the value of $\sin^2\theta$ in equation 2, $V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^2 \frac{1-\cos 2\theta}{2}\, d\theta}$ $= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi}(1-\cos 2\theta)\, d\theta}$ $= \sqrt{\frac{V_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}}$ $= \sqrt{\frac{V_m^2}{2\pi}\left[\left(\pi - \frac{\sin 2\pi}{2}\right) - (0 - \sin 0)\right]}$ $= \sqrt{\frac{V_m^2}{2\pi}[(\pi - 0) - (0 - 0)]}$ $= \sqrt{\frac{V_m^2}{2\pi} \times \pi} = \sqrt{\frac{V_m^2}{2}}$ $= \frac{V_m}{\sqrt{2}} = 0.707\, V_m$	4	6	
3	Solution L= 10H, C= 15 μ f= 50Hz $X_L = 2\pi fL$, $X_L = 2\pi \times 50 \times 10 = 3141\Omega$ $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 15 \times 10^{-6}} = 212\Omega$ Reactance $X = X_L - X_C$ $= 3141\text{-}212 = 2929\ \Omega$	2 2 2	6	30
4	**Advantages of Poly phase System Over Single Phase System** 1. In a single phase circuit the power delivered is pulsating. While in a polyphase system the total power delivered is constant if loads are balanced 2. The output of the three phase motor is 1.5 times the output of single phase motor for a given size 3. Single phase induction motor are not self-starting, where 3 phase induction motors are self-starting 4. The efficiency of polyphase motors is greater than single phase motor 5. Power factor of polyphase motor is more than the single phase motor for same rating 6. Rotating magnetic field can be set up by polyphase supply	**1 Mark Each (any Six)**	6	

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7. Three phase system requires weight of copper to transmit same power at a given voltage
8. Polyphase system is more reliable
9. Parallel operation of polyphase alternators is simple

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Solution

$Z_{12} = 50\Omega$, $Z_{13} = 20\Omega$, $Z_{23} = 30\Omega$

$$Z_1 = \frac{Z_{12} \times Z_{13}}{Z_{12} + Z_{13} + Z_{23}} = \frac{50 \times 20}{50 + 20 + 30} = 10\Omega$$

$$Z_2 = \frac{Z_{12} \times Z_{23}}{Z_{12} + Z_{13} + Z_{23}} = \frac{50 \times 30}{50 + 20 + 30} = 15\Omega$$

$$Z_2 = \frac{Z_{13} \times Z_{23}}{Z_{12} + Z_{13} + Z_{23}} = \frac{20 \times 30}{50 + 20 + 30} = 6\Omega$$

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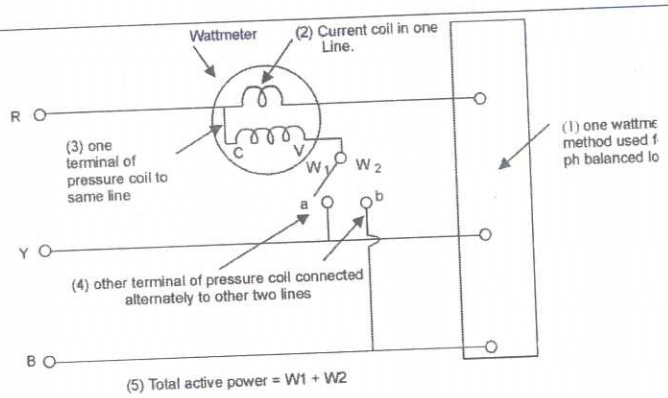

One Wattmeter Method

In this method, it is possible to apply two wattmeter method by means of one wattmeter without breaking the circuit. The current coil is connected in any one line and the pressure coil is connected alternately between this and the other two lines (figure above). The two reading so obtained, for a balanced load, correspond to those obtained by normal two wattmeter method. It should be kept in mind that this method is not of as much universal application as the two wattmeter method because it is restricted to fairly balanced loads only. However it may be conveniently applied, for instance, when it is desired to find the power input to a factory motor in order to check the load upon the motor.

It may be pointed out here that the two wattmeters used in the two wattmeter method are usually combined into a single instrument in the case of switchboard wattmeter which is then known as polyphase wattmeter. The combination is affected by arranging the two sets of coils in such a way as to operate on a single moving system resulting in an indication of the total power on the scale.

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1. **Synchronous Motors(or capacitors)**

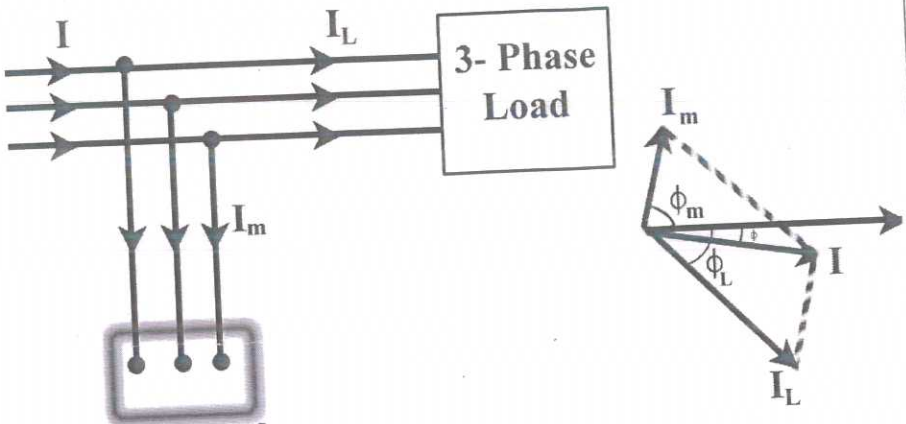


Fig 3

6

A synchronous motor takes a leading current when over-excited and therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser.
When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved. They are employed for correcting power factor in bulk and have the special advantage that the amount of correction can be varied by changing their excitation.
The figure shows the power factor improvement by synchronous condenser method. The 3 load takes current I_L at low power factor cos . The synchronous condenser takes a current I_m which leads the voltage by an angle . The resultant current I is the phasor sum of I_m and IL and lags behind the voltage by an angle . It is clear that is less than . thus the powe4r factor is increased from cos to cos . Synchronous condenser are generally used at major bulk supply substation for power factor improvement.

3

Part- C

III a **Voltage Equation**

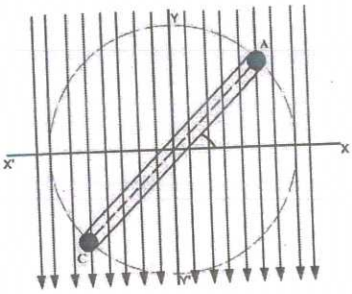


Fig 3

A rectangular coil AC (single turn) rotating in a magnetic field of flux density B webber/m². Let the length of each of its sides A and C be 'l' meters and their peripheral velocity 'v' m/s. let the angle be measured from the horizontal position i.e., from the x-axis. When in horizontal position. The two sides A&C moves parallel to the lines of magnetic flux. Hence no flux is cut and so no emf is generated through the coil. When the coil has turned through angle θ. Its velocity can be resolved into two mutually components. ie, 7

1. Vcos θ Component
2. Vsin θ Component

4

Vcos θ component is parallel to the direction of magnetic flux, so no emf is generated due to this component. Vsin θ component is perpendicular to the direction of magnetic flux. Therefore the emf induced/generated entirely due to Vsin θ. This can be expressed,

The emf generated **e=Blvsin θ**.

If there is N number of conductors equation will be, e = NBlvSin θ

The total emf generated both sides of the coil. Therefore, e = 2BlvSin θ.vdt.

We can write 2BNlv = E_m. So the equation above can be written as

$$\mathbf{e = E_m Sin\ \theta}$$

III b

$$i = 200\,Sin\theta$$

$$75 = 200\,Sin(2\pi ft)$$

$$= 200\,Sin(2\times 180\times 25t)$$

$$= 200\,Sin(9000t)$$

$$\frac{75}{200} = Sin(9000t)$$

4 8

$$9000t = Sin^{-1}(\frac{75}{200})$$

$$9000t = Sin^{-1}(0.375)$$

$$9000t = 22.02$$

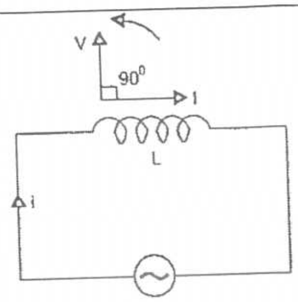
$$t = \frac{22.02}{9000} = 2.44\times 10^{-3}\,s$$

4

$$t = 2.44ms$$

IV a	**Average Value/Mean Value** The average value of an alternating current or voltage is given by that DC current which transfers across any circuit the same amount of charge as is transferred by the that AC during the same time. . For sinusoidal AC, we can use analytical method. We know that instantaneous value of current, i= $I_m Sin\theta$. Integrate the value (instantaneous value) over the limit (0-π) w.r.t θ. $I_{avg} = \frac{1}{\pi}\int_0^{\pi} I_m \mathrm{Sin}\,\theta d\theta$ $= \frac{I_m}{\pi}\int_0^{\pi} \mathrm{Sin}\,\theta d\theta$ $= \frac{I_m}{\pi}[-\cos\theta]_0^{\pi}$ $= \frac{I_m}{\pi}[-\cos\pi + \cos 0]$ $= \frac{I_m}{\pi}[1+1]$ $= \frac{2I_m}{\pi} = 0.637 I_m$ Therefore, $I_{avg} = 0.637 I_m$ Hence proved that the average value of an AC by multiplying the maximum current/voltage with the value of 0.637.	2 5	7	
IV b	$A = 12 + j18,\ B = 3 + j4$ $A + B = 15 + j22$ $A - B = 9 + j14$ Polar Form of A $\sqrt{12^2 + 18^2} = 21.63,\ \tan^{-1}(\frac{18}{12}) = 56.31^0$ $A = 21.63 < 56.31^0$ Polar Form of B $\sqrt{3^2 + 4^2} = 5,\ \tan^{-1}(\frac{4}{3}) = 53.13^0$ $B = 5 < 53.13^0$ $A \times B = (21.63 \times 5) < (56.31^0 + 53.13^0)$ $= 108.15 < 109.44^0$ $A \div B = \left(\frac{21.63}{5}\right) < (56.31^0 - 53.13^0)$ $= 4.33 < 3.18^0$	1 1 1 1 2 2	8	

V
a



v = Vm Sin wt

Fig 2

Consider a circuit containing a coil of pure inductance. This is denoted by *L*. if an alternating current is applied across the inductor in the circuit, a magnetic flux will be set up when the current flows through it. Due to the inference of the magnetic flux an alternating emf is induced in the coil. It is called back emf, and is due to self-induction. The back emf will oppose the rise or fall of current through it, and is equal and opposite to the applied emf.

The instantaneous voltage equation, $v = L.\frac{di}{dt}$ .... (1)

where, $v = V_m \sin \omega t$, L= self-inductance.

Equate both voltage equations,

we get, $L.\frac{di}{dt} = V_m \sin \omega t$ .... (2)

$$di = \frac{V_m}{L} \sin \omega t.dt \quad \text{.................... (3)}$$

5

Integrating both sides, $\int di = \int \frac{V_m}{L} \sin \omega t.dt$ .... (4)

7

$$\int di = \frac{V_m}{L} \int \sin \omega t.dt \quad \text{.................... (5)}$$

$$i = \frac{V_m}{L}\left(\frac{-\cos \omega t}{\omega}\right) \quad \text{........................... (6)}$$

$$i = \frac{V_m}{\omega L}(-\cos \omega t) \quad \text{...................... (7)}$$

$$i = \frac{V_m}{\omega L}(\sin \omega t - 90^0) \quad \text{................. (8)}$$

	Current 'i' is max I_m, when $(\sin\omega t - 90^0)$ is unity. $$I_m = \frac{V_m}{\omega L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$ Substitute eqn 9 in 8 we get, $i = I_m(\sin\omega t - 90^0)$ By analyzing the above equation, we can see that the current lags behind the applied voltage by 90^0 or the phase difference between the two is $\pi/2$ radians as shown in figure above. The quantity ωL is known as inductive reactance and denoted by X_L and is measured in Ω.			
V B	$X_L = 2\pi fL = 2\pi \times 60 \times 0.03 = 11.31\Omega$ $Z = \sqrt{R^2 + X_L^2} = \sqrt{6^2 + 11.31^2} = 12.8\Omega$ **a)** $I = \frac{V}{Z} = \frac{50}{12.8} = 3.906A$ **b)** $\cos\theta = \left(\frac{R}{Z}\right) = \left(\frac{6}{12.8}\right) = 0.468$ **c)** $Phase\ angle = \cos^{-1}\left(\frac{R}{Z}\right) = \cos^{-1}\left(\frac{6}{12.8}\right) = 62.05^0$ **d)** $P = VI\cos\theta = 50 \times 3.906 \times 0.468 = 91.547W$	1 1 1.5 1.5 1.5 1.5	8	60
VI a	$X_L = 2\pi fL = 2\pi \times 50 \times 0.2 = 62.83\Omega$ $X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 20 \times 10^{-6}} = 159.15\Omega$ $X = (X_C - X_L) = (159.15 - 62.83) = 96.32\Omega$ a) $Z = \sqrt{R^2 + X^2} = \sqrt{20^2 + 96.32^2} = 98.37\Omega$ b) $I = \frac{V}{Z} = \frac{200}{98.37} = 2.03A$ c) $PF = \cos\theta = \left(\frac{R}{Z}\right) = \left(\frac{20}{98.37}\right) = 0.203\,leading$ d) $P = VI\cos\theta = 200 \times 2.03 \times 0.203 = 82.418W$	1 1 1 1 1 1 1	7	
VI B	$X_L = 2\pi fL = 2\pi \times 50 \times 0.01 = 3.142\Omega$ Maximum current occurs when, $X_L = X_C$ $\therefore X_C = 3.142\Omega$ $3.142 = \frac{1}{2\pi fC}$	1		

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$$C=\frac{1}{2\pi\times 50\times 3.142}=1013\times10^{-6}\,F$$
$$=1013\mu F$$

At resonance Z=R

$$I=\frac{V}{R}=\frac{200}{2}=100A$$
$$V_C=IX_C=100\times3.142=314.2V$$
$$Q\,Factor=\frac{1}{R}\sqrt{\frac{L}{C}}=\frac{1}{2}\sqrt{\frac{0.01}{1013\times10^{-6}}}=1.57$$

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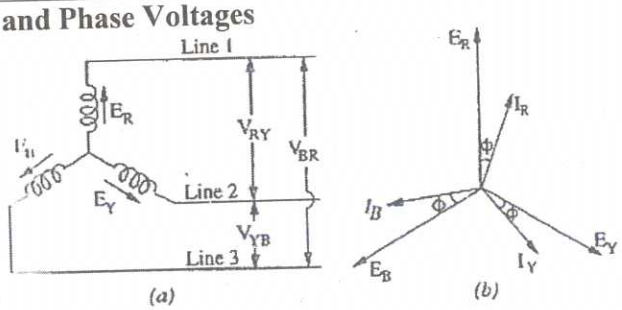
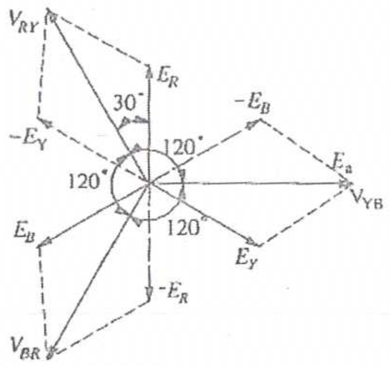
Line Voltages and Phase Voltages



The p.d. between lines 1 and 2 is $V_{RY}=V_R-V_Y$ (vector difference)

Hence, V_{RY} is found by compounding V_R and V_Y reversed and its value is given by the diagonal of the parallelogram of figure. Obviously, the angle between V_R and V_Y reversed is 60^0. Hence if $E_{RY}=E_R-E_Y=E_{ph}$ - the phase emf., then

$$V_{RY}=2\times E_{ph}\times\cos(60/2)$$



$$V_{RY}=2\times E_{ph}\times\cos30=V_{RY}=2\times E_{ph}\times\frac{\sqrt{3}}{2}=\sqrt{3}E_{ph}$$

Similarly, $V_{YB}=E_Y-E_B=\sqrt{3}E_{ph}$

$V_{BR}=E_B-E_R=\sqrt{3}E_{ph}$

Now, V_{RY}=V_{YB}=V_{BR}= Line voltage, say, V_L. Hence, in star connection $V_L=\sqrt{3}E_{ph}$.

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<td>Fig 1.5

Fig 1.5

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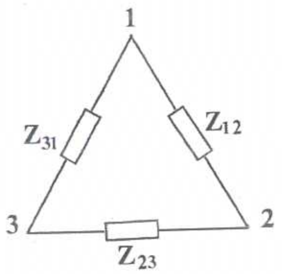
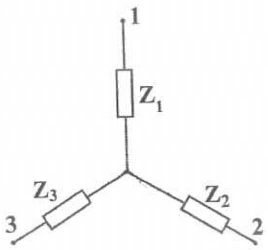
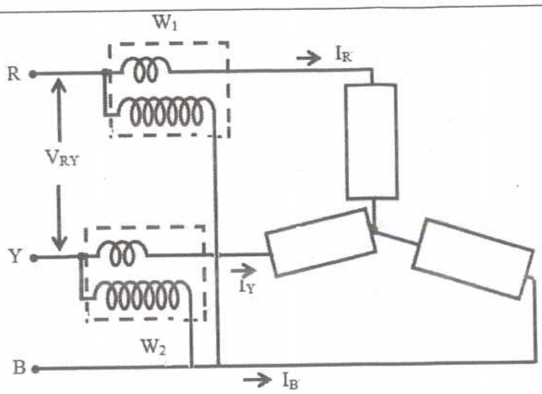
VII b	$E_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230V$	1	
	Impedance per phase $Z_{ph} = \sqrt{R_{ph}^2 + X_{ph}^2} = \sqrt{12^2 + 9^2} = 15\Omega$	1	
	Current per phase, $I_{ph} = \frac{E_{ph}}{Z_{ph}} = \frac{230}{15} = 15.33\,A$		
	In a star connected load, line current = Phase current, $I_L = I_{ph}$ (a) $I_L = 15.33\,A$ $\cos\phi = \frac{R_{ph}}{Z_{ph}} = \frac{12}{15} = 0.8$	2	8
	(b) $Active\ Power = \sqrt{3} V_L I_L \cos\phi$ $= \sqrt{3} \times 400 \times 15.33 \times 0.8 = 4905.6W$ $= 4.9kW \simeq 5kW$	2	
	$\phi = \cos^{-1} 0.8 = 36.87^0$ (c) $\mathrm{Re}active\ Power = \sqrt{3} V_L I_L Sin\phi$ $= \sqrt{3} \times 400 \times 15.33 \times Sin 36.87$ $= 6732.56\,\mathrm{VAR}$ or $6.73kVAR$	2	
VIII a	**Delta/ Star Conversion**		
	 	Fig 2	
	For Y- load, total impedance between terminals 1 and 2 is Z_1+Z_2 Considering terminals 1 and 2 of delta load, we find that there are two parallel paths having impedances of Z_{12} and $(Z_{31}+Z_{23})$. Hence, the equivalent impedance between terminals 1 and 2 is given by $\frac{1}{Z} = \frac{1}{Z_{12}} + \frac{1}{Z_{13}+Z_{23}}$ or $Z = \frac{Z_{12}(Z_{13}+Z_{23})}{Z_{12}+Z_{13}+Z_{23}}$. Therefore, for equivalence between the two systems $Z_1 + Z_2 = \frac{Z_{12}(Z_{13}+Z_{23})}{Z_{12}+Z_{13}+Z_{23}}$		

	Similarly, $Z_2 + Z_3 = \dfrac{Z_{23}(Z_{13}+Z_{12})}{Z_{12}+Z_{13}+Z_{23}}$, ...2 $Z_3 + Z_1 = \dfrac{Z_{31}(Z_{23}+Z_{12})}{Z_{12}+Z_{13}+Z_{23}}$ ....3 Adding equation 3 to 1 and subtracting equation 2, we get $2Z_1 = \dfrac{Z_{12}(Z_{13}+Z_{23})+Z_{31}(Z_{12}+Z_{23})-Z_{23}(Z_{12}+Z_{13})}{Z_{12}+Z_{13}+Z_{23}}$ $= \dfrac{2Z_{12}Z_{13}}{Z_{12}+Z_{13}+Z_{23}}$ $\therefore Z_1 = \dfrac{Z_{12}Z_{13}}{Z_{12}+Z_{13}+Z_{23}}$ ....4 $\therefore Z_2 = \dfrac{Z_{12}Z_{23}}{Z_{12}+Z_{13}+Z_{23}}$ ....5 $\therefore Z_3 = \dfrac{Z_{13}Z_{23}}{Z_{12}+Z_{13}+Z_{23}}$ 6	5	7	
VIII b	$X_L = 2\pi fL = 2\pi \times 50 \times 0.2 = 62.8\Omega$ a) Impedance, $Z_{ph} = \sqrt{R_{ph}^2 + X_{ph}^2} = \sqrt{45^2 + 62.8^2} = 77.23\Omega$ b) Current in each coil, $I_{ph} = \dfrac{E_{ph}}{Z_{ph}} = \dfrac{415}{77.23} = 5.37A$ $I_L = \sqrt{3}I_{ph} = \sqrt{3}\times 5.37 = 9.3A$ c) $\text{PF}, \cos\phi = \dfrac{R_{ph}}{Z_{ph}} = \dfrac{45}{77.23} = 0.582$ d) Total power consumed $P = \sqrt{3}\times V \times I_L \times \cos\phi$ $= \sqrt{3}\times 415 \times 9.3 \times 0.582 = 3895W$ $= 3.895kW$	2 2 1 3	8	

IX **a**	 In this method the current coils of the two wattmeters are inserted in any two lines and the potential coil of each joined to the third line. It can be proved that the sum of the instantaneous power indicated by W_1 and W_2 give the instantaneous power absorbed by the three loads L_1, L_2 and L_3. A star-connected loads because a Delta connected load can always be replaced by an equivalent Star-connected load. Let, Instantaneous current through W_1 $= i_R$ PD across $W_1 = e_{RB}$ $= e_R - e_B$ power read by W_1 $= i_R(e_R - e_B)$ Instantaneous current through W_2 $= i_Y$ Instantaneous PD across $W_2 = e_{YB}$ $= e_Y - e_B$ Instantaneous power read by W_2 $= i_Y(e_Y - e_B)$ Total power = W_1+W_2 $= i_R(e_R - e_B) + i_Y(e_Y - e_B)$ $= i_R e_R + i_Y e_Y - e_B(i_R + i_Y)$ According to Kirchhoff's current law, $(i_R + i_Y + i_B) = 0$ $\therefore (i_R + i_Y) = -i_B$ Substitute the value of $i_R + i_Y$ in the above equation W_1+W_2 $= i_R e_R + i_Y e_Y - e_B(-i_B)$ $= i_R e_R + i_Y e_Y + e_B i_B$ $= p_1 + p_2 + p_3$ Where, p_1, p_2 and p_3 are the power absorbed by the loads L_1, L_2 and L_3 respectively. $\therefore$ **W_1+W_2 = Total power absorbed**	**Fig 2** **5**	**7**	
IX **b**	a) Input power , $P = W_1 + W_2 = 300 + 100 = 400\text{kW}$ $\phi = \tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)$	**1**		

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$$= \tan^{-1}\left(\frac{\sqrt{3}(300-100)}{300+100}\right) = \tan^{-1} 0.866 = 40.9^0$$

b) PF, $\cos\phi = \cos(40.9) = 0.756\, lag$

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

c) Line current , $I_L = \dfrac{P}{\sqrt{3} \times V_L \times \cos\phi} = \dfrac{400 \times 10^3}{\sqrt{3} \times 1000 \times 0.756} = 305.48A$

d)

$$\text{Power output} = \text{input power} \times \eta$$
$$= 400 \times 10^3 \times 0.9 = 360 \times 10^3 W$$

e) $HP\, output = \dfrac{Power\ output}{735.5} = \dfrac{360 \times 10^3}{735.5}$
$$= 490\, metric$$
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Balanced Load	Unbalanced Load
All 3 phases carry same current	Each phases carries different current depending upon load
Neutral current is zero	Nuetral current exists
No need of neutral wire	Neutral wire is must
No need of special attention	Need special attention that one or two phase is overloaded or zero load

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Motor output= 100×735.5=73550W

Motor input= $\dfrac{Motor\ output}{\eta} = \dfrac{73550}{0.9} = 81722W = W_1 + W_2$

$Phase\ angle, \phi = \cos^{-1} 0.9 = 25.84^0$

$\tan\phi = \tan 25.84 = 0.484$

$$\tan\phi = \left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)$$
$$0.484 = \left(\frac{\sqrt{3}(W_1 - W_2)}{81722}\right)$$

$$W_1 - W_2 = \frac{0.484 \times 81722}{\sqrt{3}} = 22836W$$
$$W_1 + W_2 = 81722$$
$$W_1 - W_2 = 22836$$
$$2W_1 = 104558$$
$$W_1 = 52279W$$
$$52279 + W_2 = 81722$$
$$W_2 = 81722 - 52279 = 29443W$$
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</table>

	(a) *Wattmeter readings*, $W_1 = 52279W$ $W_2 = 29443W$	**3**		
	(b)Line current, $I_L = \frac{P}{\sqrt{3} \times V_L \times \cos\phi} = \frac{81722}{\sqrt{3} \times 400 \times 0.9} = 131.07A$	**1**		
	(c)Phase current, $I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{131.07}{\sqrt{3}} = 75.67A$	**1**		