UNIT - 7

POLYPHASE CIRCUIT

☆ **Polyphase System** :- यह दो या दो से अधिक वोल्टेज का combination है जो एक समान magnitude तथा frequency के हों किंतु एक दूसरे के साथ समान phase diffrence में होते हैं। अर्थात यदि 3 voltage हैं तो आपस में 120° electrical angle से displaced रहेंगे।

$$\text{phase diffrence} = \frac{360^\circ \text{ electrical degrees}}{\text{No of phase}}$$

Advantage of 3phase system over 1ϕ system :-

(1) **Constant Power** :- 1ϕ system में power जो deliver होता है वह pulsating होता है जबकि 3ϕ system में power लगभग constant होता है।

(2) **Higher Rating** :- Rating (output) single phase maching की तुलना में ~~लगभग~~ लगभग 1.5 गुणा अधिक होता है जबकि दोनो मशीन का size बराबर हो तो पर भी।

(3) **Power Transmission Economics** :- किसी fixed distance तक एक fixed power को ट्रांसमिट करने में, 1ϕ system में जो conducting material उपयोग होता है, 3ϕ system में केवल उसका 75% conducting material की जरूरत पड़ती है।

(4) **Higher power factor & efficiency** :-

3ϕ system में उपयोग होने वाले मशीनों की efficiency तथा power factor अधिक होती है तथा self start भी होती है।

✡ STAR CONNECTION :-

Que: In a three phase balanced star connected system, find the relation between:-

(a) Line volt. & phase Voltage

(b) Line current & phase current

(c) Total 3Ø power

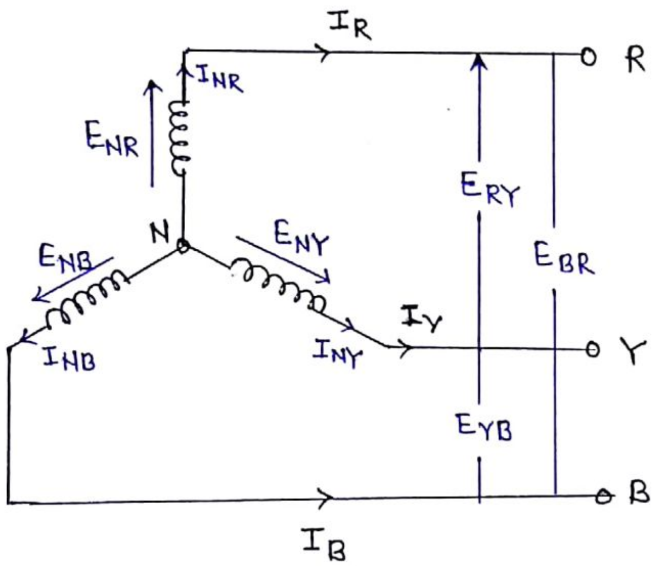
किसी त्रिकलीय समतुल्य स्टार कनेक्शन सिस्टम के लिए निम्न संबंध स्थापित किजिए:-

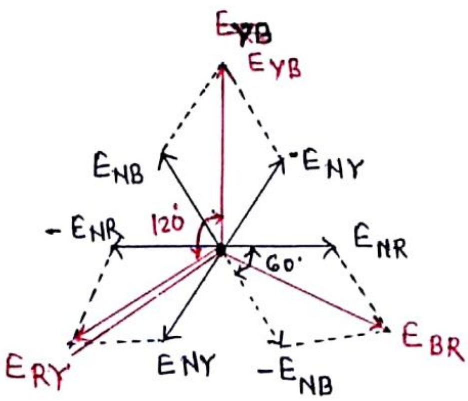
(a) लाइन वोल्टेज व फेज वोल्टेज में।

(b) लाइन करेंट व फेज करेंट में।

(c) कुल त्रिकलीय शक्ति।

Ans:-





phasor diagram.

① Relation b/w V_{ph} & V_L:

प्रत्येक phase में (winding) में वोल्टेज को phase voltage कहते हैं तथा Line conductor के across voltage को Line voltage (V_L) कहते हैं।

Now $E_{NR} = E_{NY} = E_{NB} = E_{ph}$ (phase voltage)

LOOP NRYN से $\bar{E}_{NR} + \bar{E}_{RY} - \bar{E}_{NY} = 0$

$$\bar{E}_{RY} = \bar{E}_{NY} - \bar{E}_{NR} \text{ (vector diffrence)}$$

$$E_{RY} = \sqrt{E_{NY}^2 + E_{NR}^2 + 2E_{NY}E_{NR}\cos 60^\circ}$$

$$E_L = \sqrt{E_{ph}^2 + E_{ph}^2 + 2E_{ph} \cdot E_{ph} \times 0.5}$$

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

$$\boxed{E_L = \sqrt{3}E_{ph}}$$

where $E_{RY} = E_{YB} = E_{BR} = E_L$ (line voltage)

अतः star connection में

लाइन वोल्टेज $= \sqrt{3} \times$ फेज वोल्टेज

② Relation b/w I_L & I_{ph} :-

चित्र से स्पष्ट है कि phase winding तथा line conductor में same current flow होगा क्योंकि आपस में series में जुड़े हैं।

अर्थात $I_R = I_{NR}$

$I_Y = I_{NY}$

$I_B = I_{NB}$

$I_{NR} = I_{NY} = I_{NB} =$ (phase current) I_{ph}

and $I_R = I_Y = I_B =$ (line current) I_L

अतः स्टार कनेक्शन में (I_L) Line current = Phase current (I_{ph})

(3) Power

Power $= 3VI\cos\phi$ (जहां पर Volt. & current, phase Volt & phase current है)

Line Power $(P_L) = 3V_{ph}I_{ph}\cos\phi$

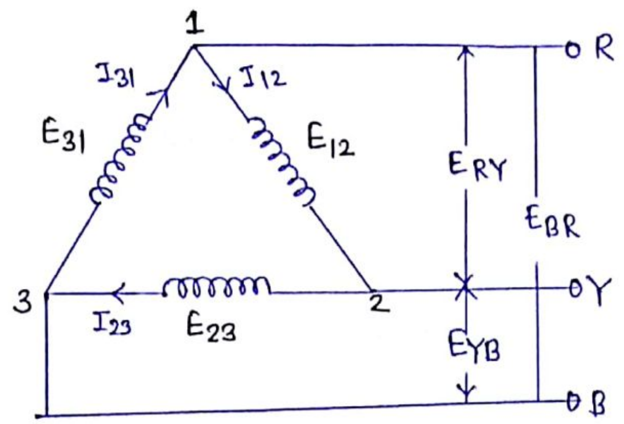
$(P_{ph}) = 3$ since $V_{ph} = \frac{V_L}{\sqrt{3}}$ तथा $I_{ph} = I_L$

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

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

✡ DELTA CONNECTION :-

Q:- In 3ϕ balanced delta connected system, find relation between (a) V_L and V_{ph} (b) I_L and I_{ph} (c) Total 3ϕ power



(a) Relation b/w V_{ph} and V_L

चित्र से स्पष्ट है कि Terminal 1 & 2 के across जो voltage होगा वह E_{RY} के बराबर होगा क्योंकि parallel में वोल्टेज same होगा।

$$\therefore \quad E_{12} = E_{RY}$$

इसी प्रकार $E_{23} = E_{YB}$

तथा $E_{31} = E_{BR}$

जहां पर $E_{12} = E_{23} = E_{31} = E_{ph}$ = (Phase Voltage)

तथा $E_{RY} = E_{YB} = E_{BR} = E_L$ = (line Voltage)

Hence in delta connection

$$\boxed{V_{ph} = V_L \text{ OR } E_{ph} = E_L}$$

② Relation b/w I_{ph} and I_L

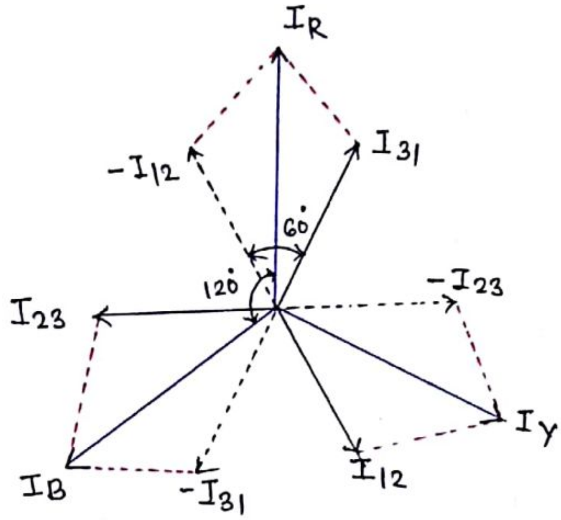


Fig: phasor diagram

$I_{12} = I_{23} = I_{31} = I_{ph} =$ (phase current)

Junction 1 में KCL लगाने पर

$$\bar{I}_{31} = \bar{I}_R + \bar{I}_{12}$$

OR $\bar{I}_R = \bar{I}_{31} - \bar{I}_{12}$ (vector diffrence) — ①

इसी तरह Junction 2 पर

$$\bar{I}_Y = \bar{I}_{12} - \bar{I}_{23}$$

तथा Junction 3 पर

$$I_B = \bar{I}_{23} - \bar{I}_{31}$$

$$I_R = \sqrt{I_{31}^2 + I_{12}^2 + 2 I_{31} I_{12} \cos 60^\circ}$$

$$I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2 I_{ph} \cdot I_{ph} \cos 60^\circ}$$ ($\because I_R = I_L =$ line current)

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

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

similarly $\quad \bar{I}_Y = \bar{I}_{12} - \bar{I}_{23}$ or $I_L = \sqrt{3}\, I_{ph}$

$\bar{I}_B = \bar{I}_{23} - \bar{I}_{31}$ or $I_L = \sqrt{3}\, I_{ph}$

अत: delta connection में

Line current = $\sqrt{3}$ x phase current

(3) Power:-

1ϕ system में power = $VI\cos\phi$

जहां पर $\quad V$ = वोल्टेज of 1ϕ i.e. V_{ph}

I = 1ϕ में current i.e. I_{ph}

अत: 3ϕ system के लिए

$$\boxed{P = 3 V_{ph} I_{ph} \cos\phi} \quad \text{——— (2)}$$

अत: Δ connection के लिए

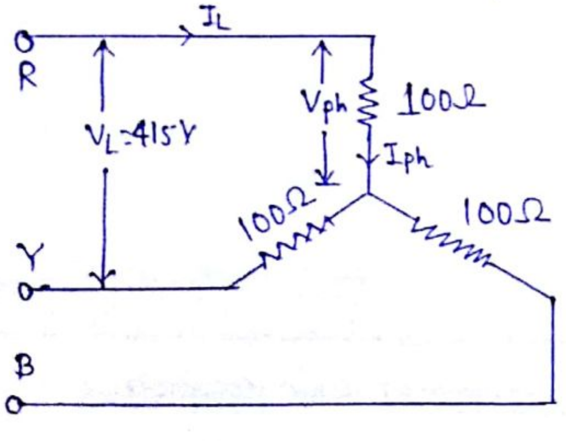
$V_{ph} = V_L$ तथा $I_{ph} = \frac{I_L}{\sqrt{3}}$

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

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

Que: Three $100\,\Omega$ resistors are connected first in star and then in delta across 415V, 3ϕ supply. Calculate the line & phase current in each and also power taken from source.

solution:-



जब Resistor star Y में जुड़ा है

phase volt $V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{415}{\sqrt{3}} = 239.6V$

phase current $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{415}{100} = 2.396 A$

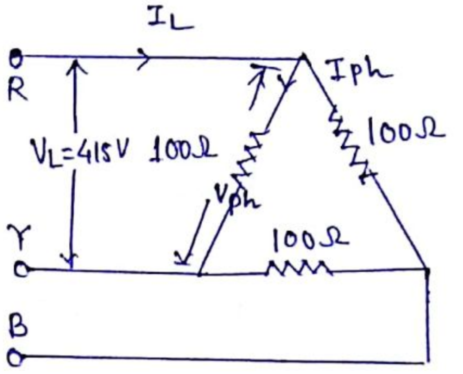
Line current $I_L = I_{ph} = 2.396 A$

Power drawn, $P = 3 I_{ph}^2 R_{ph}$

$= 3 \times (2.396)^2 \times 100$

$= 1722 W$

② जब Resistor Δ में जुड़ा है



$V_{ph} = V_L = 415V$

$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{415}{100} = 4.15 A$

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

$= \sqrt{3} \times 4.15 = 7.188 A$

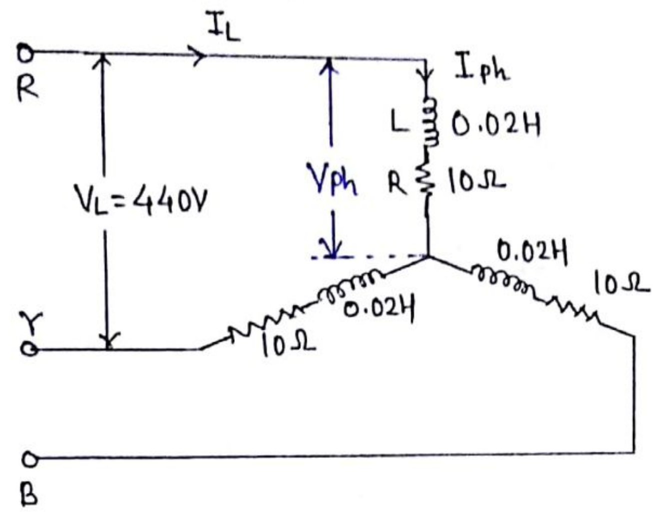
Power drawn $P = 3 I_{ph}^2 \cdot R_{ph}$

$= 3 \times (4.15)^2 \times 100$

$= 5166 W$

Que: Three coils each having resistance of 10Ω and inductance of 0.02H are connected in star across 440V, 50HZ, 3ø supply Calculate line current and total power consumed.

Solution:-



Inductive Reactance $X_L = 2\pi f L$

$= 2\pi \times 50 \times 0.02$

$= 6.283\Omega$

Impedance per phase $Z_{ph} = \sqrt{(10)^2 + (6.283)^2}$ $\therefore Z = \sqrt{R^2 + X_L^2}$

$= 11.81\Omega$

phase voltage $= V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}} = 254.03V$

phase current $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{254.03}{11.81} = 21.51A$

line current $I_L = I_{ph} = 21.51A$

power factor, $\cos\phi = \frac{R_{ph}}{Z_{ph}} = \frac{10}{11.81} = 0.8467$ Lag.

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

$= \sqrt{3} \times 440 \times 21.51 \times 0.8467$

$= 13880W$

$= 13.88kW$

Que: Three equal impedance each having a resistance of 8Ω and inductive reactance of 6Ω are connected in (a) star (b) delta across 3ϕ 440V system. Find:-
(a) phase current (b) line current (c) Total power consumed

Solution: (a) Star connection

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}} = 254V$$

$$Z_{ph} = \sqrt{R^2 + X_L^2} = \sqrt{(8)^2 + (6)^2}$$
$$= 10\Omega$$

(1) $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{254}{10} = 25.4\,A$

(2) $I_{ph} = I_L = 25.4\,A$

(3) Power factor $\cos\phi = \frac{R}{Z} = \frac{8}{10} = 0.8$ Lagging

(4) Power $= \sqrt{3}\, V_L I_L \cos\phi$
$= \sqrt{3} \times 440 \times 25.4 \times 0.8$
$= 15.488\,kW$

(B) Delta connection:-

$V_{ph} = V_L = 440V$

$Z_{ph} = 10\Omega$

$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{440}{10} = 44\,A$

$I_L = \sqrt{3}\, I_{ph} = \sqrt{3} \times 44 = 76.21\,A$

$\cos\phi = R/Z = 0.8$ Lagg.

Power $= \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3} \times 440 \times 76.21 \times 0.8 = 46.464\,kW$

Q. A balanced star-connected load of $(8+j6)\,\Omega$ per phase is connected to a 3ϕ, 230V supply. Find line current, power and power factor.

Solution :-

$$\bar{Z}_{ph} = 8+j6$$

$$= \sqrt{(8)^2+(6)^2}\,\angle \tan^{-1}(6/8)$$

$$= 10\angle 36.87^\circ$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{230}{\sqrt{3}} = 132.79\,V$$

① $$I_L = I_{ph} = \frac{\bar{V}_{ph}}{\bar{Z}_{ph}} = \frac{132.79}{10\angle 36.87} = 13.279\angle -36.87^\circ\,A$$

② Power factor, $\cos\phi = \cos 36.87$

$$= 0.8\ \text{lag}$$ — Ans.

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

$$= \sqrt{3} \times 230 \times 13.279 \times 0.8$$

$$= 4232\ W$$ — Ans.

✡ POWER MEASURMENT IN 3Ø CIRCUITS

A.C. Circuit में Wattmeter के द्वारा Power का measurment किया जाता है। Wattmeter एक ऐसा device है जिसमें दो coil होता है जिसे current coil तथा potential coil कहते हैं। current coil जिसमें low resistance होता है उसे लोड के साथ series में लगाते हैं। तथा Potential coil जिसमें High resistance होता है उसे लोड के across लगाते हैं।

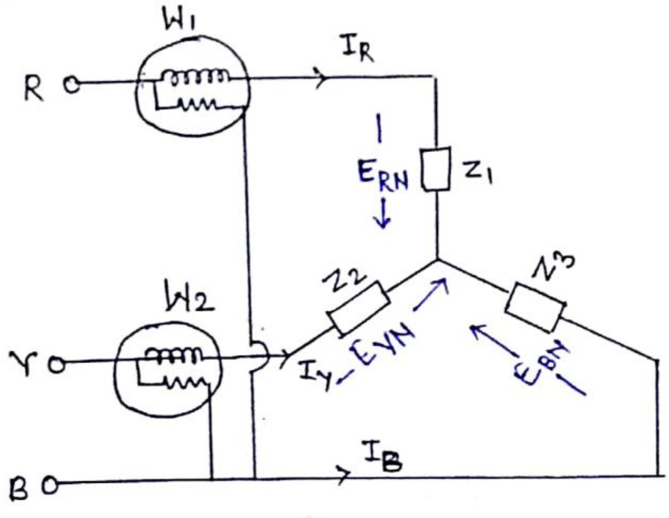
BLONDEL'S THEOREM:-

Blondel's के अनुसार जब K wire में power supply हो रही है तो, इसमें Total Wattmeter की आवश्यकता Total wire से 1 कम के बराबर होगी चाहे लोड ballanced हो या unbalanced.

No of wattmeter required = (K−1)
" " " = (No. of wire − 1)

अर्थात 3Ø, 4 wire system में (4−1) अर्थात 3 Wattmeter की आवश्यकता होगी तथा 3Ø, 3 wire system में (3−1) अर्थात 2 Wattmeter की आवश्यकता होगी।

✡ TWO WATTMETER METHOD FOR POWER MEASURMENT :



Consider Star connection:-

चित्र के अनुसार Two wattmeter method को star connection में जोड़ा गया है।

Instantaneous current through current coil of W_1 = I_R

W_1 के current coil में Instanteneous current = I_R

W_1 के Potential coil में instanteneous voltage = $E_{RN} - E_{BN}$

अतः W_1 में instanteneous power = $I_R(E_{RN} - E_{BN})$

W_2 के current coil में instanteneous current = I_Y

W_2 के Potential coil में instanteneous Voltage = $E_{YN} - E_{BN}$

अतः W_2 में Instanteneous power = $I_Y(E_{YN} - E_{BN})$

$$\therefore \quad W_1 + W_2 = I_R(E_{RN} - E_{BN}) + I_Y(E_{YN} - E_{BN})$$

$$= I_R \cdot E_{RN} - I_R \cdot E_{BN} + I_Y \cdot E_{YN} - I_Y \cdot E_{BN}$$

$$= I_R \cdot E_{RN} + I_Y \cdot E_{YN} - E_{BN}(I_R + I_Y)$$

$$\therefore (I_R + I_Y + I_B = 0)$$

$$= I_R \cdot E_{RN} + I_Y \cdot E_{YN} - E_{BN}(-I_B)$$

$$= I_R \cdot E_{RN} + I_Y \cdot E_{YN} + I_B \cdot E_{BN}$$

= Total power absorbed by three load

$$W_1 + W_2 = P$$

TWO WATTMETER METHOD (BALANCED LOAD)

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

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

दोनो Wattmeter reading को जोड़ने पर

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

$$= V_L I_L [\cos(30 - \phi) + \cos(30 + \phi)]$$

$$W_1 + W_2 = V_L I_L [\cos 30 \cos\phi + \sin 30 \sin\phi + \cos 30 \cos\phi - \sin 30 \sin\phi]$$

$$= V_L I_L [2 \cos 30 \cos\phi]$$

$$= V_L I_L \left(2 \times \frac{\sqrt{3}}{2} \cos\phi\right)$$

$$W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi \quad \text{—— (1)}$$

$W_1 + W_2 = P$ (Total power absorbed by 3ϕ ballanced Load)

तथा

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

$$= V_L I_L [\cos(30 - \phi) - \cos(30 + \phi)]$$

$$= V_L I_L [\cos 30 \cos\phi + \sin 30 \sin\phi - (\cos 30 \cos\phi - \sin 30 \sin\phi)]$$

$$= V_L I_L [2 \sin 30 \sin\phi]$$

$$= V_L I_L \left[2 \times \frac{1}{2} \sin\phi\right]$$

$$W_1 - W_2 = V_L I_L \sin\phi \quad \text{—— (2)}$$

समी० (2) को समी० (1) से भाग देने पर

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi}$$

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

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

Que: A balanced 3ϕ star connected load draws power from a 440V supply. The two wattmeter connected indicate $W_1 = 4.2$ kW and $W_2 = 0.8$ kW. calculate power, p.f & current drawn from circuit.

Solution: $W_1 = 4.2$ kW

$W_2 = 0.8$ kW

$\therefore$ Total power $P = W_1 + W_2$

$= 4.2 + 0.8$

$= 5.0$ kW

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

$= \sqrt{3}\left(\frac{4.2 - 0.8}{4.2 + 0.8}\right)$

$\tan\phi = 1.17$

$\phi = \tan^{-1}(1.17)$

$= 49.47^\circ$

(2) Power factor $\cos\phi = \cos(49.47) = 0.6472$

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

$5 \times 1000 = \sqrt{3} \times 440 \times I_L \times 0.6472$

$I_L = 10.137$ A

Que: Two wattmeters are used to measure the power in 3-phase balanced system. What is power factor (1) when both the meter read equal (2) both the meter read equal but one is negative (3) one reads twice the other.

Solution: case I: When both meter read equal, i.e. $W_1 = W_2$

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

$$= \sqrt{3}\left(\frac{W_1 - W_1}{W_1 + W_1}\right)$$

$$\tan\phi = 0$$

$$\phi = \tan^{-1}(0) = 0°$$

Power factor $= \cos\phi = \cos 0 = 1$ — Ans.

case II: जब दो reading समान है किंतु एक –ve है: अर्थात

$$W_1 = -W_2$$

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

$$\tan\phi = \infty$$

$$\phi = \tan^{-1}\infty = 90°$$

Power factor $= \cos\phi = \cos 90° = 0$ — Ans.

case III: जब एक मीटर का reading दूसरे से double हो

$$W_1 = 2W_2$$

$$\tan\phi = \sqrt{3}\left(\frac{2W_2 - W_2}{2W_2 + W_2}\right)$$

$$= \sqrt{3} \times \frac{1}{3}$$

$$\tan\phi = \frac{1}{\sqrt{3}} \qquad \phi = \tan^{-1}(1/\sqrt{3}) = 30°$$

Power factor $= \cos\phi = \cos 30 = 0.866$ — Ans.