EXPERIMENT NUMBER: 5

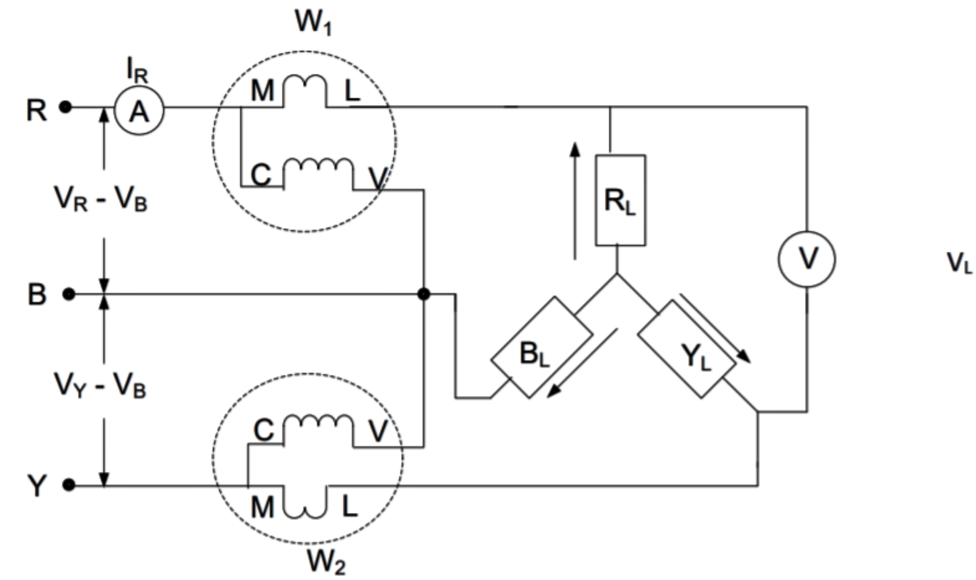
AIM OF THE EXPERIMENT: Measurement power in a three-phase circuit

OBJECTIVE: To measure power in a three-phase load by two wattmeter methods.

APPARATUS REQUIRED:

Sl. No.	Instrument Name	Specification	Quantity
1	A.C. Wattmeter	0-600V, 750W	2
2	A.C. Voltmeter	0-600V	1
3	A.C. Ammeter	0-5 A	1
4	Resistors	25,50 Ω	3
5	Inductance	0.27566 H, 0.437274 H, 0.5 H, 0.37 H	3
6	A.C Voltage Source	440 V (peak), 50 Hz	1

Circuit diagram:



Circuit diagram of Power measurement by two wattmeter method

<u>OBSERVATION TABLE</u>:

1. **Balanced Load:**

SL. NO.	LINE CURRENT (I_L) in Amp	LINE VOLTAGE (V_L) in Volt	1st Wattmeter reading (W_1) in Watt	2nd Wattmeter reading (W_2) in Watt	POWER = $W_1 + W_2$	$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$ (In degrees)	$\mathbf{P.F.} = \cos\phi$
1	5.081	440	1936	1936	3872	0	1
2	2.54	440	0.05042	968	968.05042	-59.997	0.500
3	1.738	440	-132.7	585.7	453	-69.996	0.342
4	2.818	440	-297.8	893.5	595.7	-73.897	0.277
5	1.597	440	-251.3	442.6	191.3	-80.956	0.157
6	2.317	440	-288.3	630.7	342.4	-77.860	0.210

2. **Unbalanced Load:**

SL. NO.	LINE CURRENT (I_L) in Amp	LINE VOLTAGE (V_L) in Volt	1st Wattmeter reading (W_1) in Watt	2nd Wattmeter reading (W_2) in watt	POWER = $W_1 + W_2$
1	3.811	440	1452	1936	3388
2	2.324	440	135.1	89.2	224.3
3	1.664	440	-52.47	555.7	503.23

<u>CALCULATIONS</u>:

Reading 1:

$$\text{First Wattmeter reading } = W_1 = 1936\ W$$

$$\text{Second Wattmeter reading } = W_2 = 1936\ W$$

$$\text{Total Power } = W_1 + W_2 = 3872\ W$$

$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(1936 - 1936)}{3872} = 0°$$

$$\text{Power factor} = cos\,\phi = cos\,0° = 1$$

Reading 2:

$$\text{First Wattmeter reading } = W_1 = 0.05042\ W$$

$$\text{Second Wattmeter reading } = W_2 = 968\ W$$

$$\text{Total Power } = W_1 + W_2 = 968.05942\ W$$

$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(0.05042 - 968)}{968.05042} = -59.997°$$

$$\text{Power factor} = cos\,\phi = cos(-59.997°) = 0.500$$

Reading 3:

$$\text{First Wattmeter reading } = W_1 = -132.7\ W$$

$$\text{Second Wattmeter reading } = W_2 = 585.7\ W$$

$$\text{Total Power } = W_1 + W_2 = 453\ W$$

$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(-132.7 - 585.7)}{453} = -69.996°$$

$$\text{Power factor} = cos\,\phi = cos(-69.996°) = 0.342$$

Reading 4:

$$\text{First Wattmeter reading } = W_1 = -297.8\ W$$

$$\text{Second Wattmeter reading } = W_2 = 893.5\ W$$

$$\text{Total Power } = W_1 + W_2 = 595.7\ W$$

$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(-297.8 - 893.5)}{595.7} = -73.897°$$

$$\text{Power factor} = cos\,\phi = cos(-73.897°) = 0.277$$

Reading 5:

$$\text{First Wattmeter reading } = W_1 = -251.3\ W$$

$$\text{Second Wattmeter reading } = W_2 = 442.6\ W$$

$$\text{Total Power } = W_1 + W_2 = 191.3\ W$$

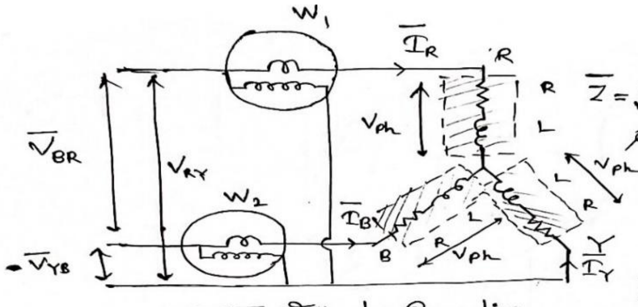
$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(-251.3 - 442.6)}{191.3} = -80.956°$$

$$\text{Power factor} = cos\,\phi = cos(-80.956°) = 0.157$$

Reading 6:

$$\text{First Wattmeter reading } = W_1 = -288.3\,W$$
$$\text{Second Wattmeter reading } = W_2 = 630.7\,W$$
$$\text{Total Power } = W_1 + W_2 = 342.4\,W$$
$$\phi = tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \tan^{-1}\frac{\sqrt{3}(-288.3 - 630.7)}{342.4} = -77.860°$$
$$\text{Power factor} = cos\,\phi = cos(-77.860°) = 0.210$$

PHASOR DIAGRAM:



$$\overline{Z} = \sqrt{R^2 + (\omega L)^2} \angle \tan^{-1}\left(\frac{\omega L}{R}\right)$$
$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$
$$\overline{I}_R = \frac{(\overline{V}_{ph})_R}{\overline{Z}}, \quad \overline{I}_B = \frac{(\overline{V}_{ph})_B}{\overline{Z}}, \quad \overline{I}_Y = \frac{(\overline{V}_{ph})_Y}{\overline{Z}}$$

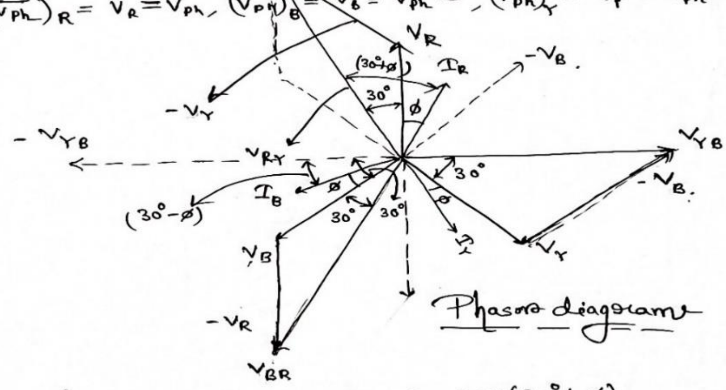
Two Wattmeter Connection

Phase sequence is RYB.

$\overline{V}_R = V_{ph} \angle 0°$, $\overline{V}_Y = V_{ph} \angle -120°$, $\overline{V}_B = V_{ph} \angle +120°$

Now, $\angle -120° = \omega^2$, $\angle +120° = \omega$.

$\therefore (\overline{V}_{ph})_R = \overline{V}_R = V_{ph}$, $(V_{ph})_B = \overline{V}_B = V_{ph}\,\omega$, $(V_{ph})_Y = \overline{V}_Y = V_{ph}\,\omega^2$.



Phasor diagram

Now, for W_1, $P_1(W_1) = I_R V_{RY} \cos(30° + \phi)$

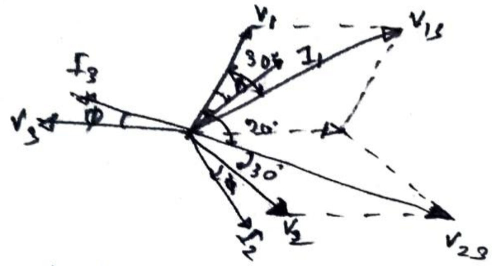
and for W_2, $P_2(W_2) = I_B(-V_{YB}) \cos(30° - \phi) = I_B V_{BY} \cos(30° - \phi)$

$$\therefore W_1 + W_2 = I_R V_{RY} \cos(30° + \phi) + I_B V_{BY} \cos(30° - \phi)$$
$$= I_L V_{LL} \{\cos(30° + \phi) + \cos(30° - \phi)\}$$
$$= V_{LL} I_L \left\{2 \cos\left\{\frac{30° + \cancel{\phi} + 30° - \cancel{\phi}}{2}\right\} \cos\left\{\frac{\cancel{30°} + \phi - \cancel{30°} + \phi}{2}\right\}\right\}$$
$$= \frac{\sqrt{3}}{\cancel{2}} \times \cancel{2}\, V_{LL} I_L \cos\phi = \sqrt{3} V_{LL} I_L \cos\phi.$$

$$W_1 - W_2 = V_{LL} I_L \sin\phi, \quad \therefore \frac{W_1 - W_2}{W_1 + W_2} = \frac{1}{\sqrt{3}}\tan\phi, \quad \phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right].$$

QUESTIONS:

- Establish that power factor may also be estimated from two wattmeter readings.



Let V_1, V_2, V_3 be the rms values of phase voltage and I_1, I_2, I_3 be the rms values of phase currents

The total load is balanced therefore,

Phase Voltages, $V_1 = V_2 = V_3 = V$ (say)

Line Voltages, $V_{13} = V_{23} = V_{12} = \sqrt{3}V$

Phase Currents, $I_1 = I_2 = I_3 = I$ (say)

Line Currents, $I_1 = I_2 = I_3 = I$

Power factor $= \cos\phi$

The phase currents lag the corresponding phasor voltages by an angle ϕ.

The current through wattmeter P_1 is I_1 and voltage across its pressure coil is V_{13}. I_1 leads V_{13} by an angle $(30° - \phi)$

$\therefore$ Reading of P_1 wattmeter, $P_1 = V_{13} I_1 \cos(30-\phi) = \sqrt{3}VI\cos(30-\phi)$

The current through wattmeter P_2 is I_2 and voltage across its pressure coil is V_{23}. I_2 lags V_{23} by an angle $(30+\phi)$

$\therefore$ Reading of P_2 wattmeter, $P_2 = V_{23} I_2 \cos(30+\phi) = \sqrt{3}VI\cos(30+\phi)$

Sum of reading of two wattmeters, $P_1 + P_2$

$$= \sqrt{3}VI[\cos(30-\phi) - \cos(30+\phi)]$$
$$= 3VI\cos\phi$$

This is the total power consumed by the load $P = P_1 + P_2$

$\therefore$ Difference of readings of two wattmeters

$$P_1 - P_2 = \sqrt{3}VI[\cos(30-\phi) - \cos(30+\phi)]$$
$$= \sqrt{3}VI\sin\phi$$

$$\frac{P_1 - P_2}{P_1 + P_2} = \frac{\sqrt{3}VI\sin\phi}{3VI\cos\phi} = \frac{\tan\phi}{\sqrt{3}} \text{ or } \tan^{-1}\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}$$

$$\therefore \text{Power factor, } \cos\phi = \cos\left(\tan^{-1}\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}\right)$$

Therefore established power factor can be measured by two wattmeter method.

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- Explain why the wattmeter will give (a) zero reading (b) negative reading.

  The reading of a wattmeter is proportional to (current through the current coil) x (voltage across the pressure coil) x Cosine (angle between this current and this voltage). Depending on the value of the cosine the wattmeter reading can be zero or negative. For a three-phase balanced load the two wattmeter readings will be, $W_1 = V_{ab} \cdot I_a \cdot \cos(30° + \phi)$ and $W_2 = V_{cb} \cdot I_c \cdot \cos(30° - \phi)$.

  a) When this angle becomes equal to 90 degrees the reading of the wattmeter will be zero. So, if $\phi = 60°$ (P.F. equal to 0.5), a zero reading will be obtained for the first wattmeter.

  b) When this angle becomes more than 90 degrees the reading of the wattmeter will be negative. For a three-phase balanced load when $\phi > 60°$ (P.F. less than 0.5), a negative reading will be obtained for the first wattmeter (W_1). In this case, the voltage-coil connections must be reversed in order that the instrument may give a positive or forward reading.

CONCLUSION:

- With this method we can measure power in a phase three wire system with unbalanced or balance load. The load may be star or delta connected; in this experiment we have used star connected load.
- Reading of wattmeter W_1 is zero when the load power factor is 0.5 lagging i.e., $\phi = 60°$.
- Reading of wattmeter W_1 is negative for $\phi > 60°$. In this case, we reverse the connections to the pressure coil in order to measure power registered by wattmeter W_1. However, the reading thus obtained must be taken as negative while calculating total power and power factor.
- The reading of W_1 is positive when $\phi < 60°$.
- Both the wattmeters indicate the same readings when power factor of load is unity.
- All our calculations match with these observations and the experiment thus was successful.