Measurement of 3-φ power

By: Er. Pranav Kumar

3-φ circuit:

~~Polyphase system~~

Poly-phase system:- More than one phase.

2, 3, 4, 5, 6, 7, 8, 9 ------ phases.

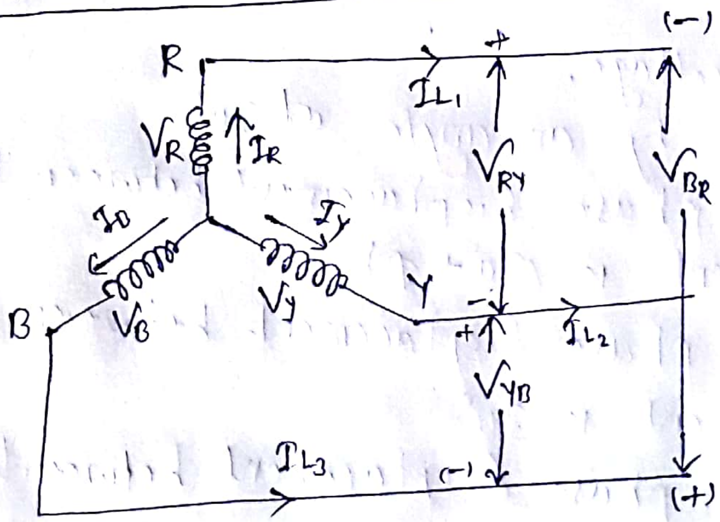
3, 6, 9, 12, ----- phases i-e multiple of 3 are used in industrial applications.

* Main advantages of 3-phase system are.
  - → Smaller in size.
  - → Constant output power
  - → Great output power.
  - → Superior motor performance.
  - → Ease in parallel operation.
  - → Reliability.

Interconnection of system is possible in (Y & Δ)

Mutual phase shift b/w each phase is $\frac{360^\circ}{3} = 120^\circ$

* **STAR Connected Balanced Three phase Supply.**



From the figure,

$$I_{L_1} = I_{L_2} = I_{L_3} = I_R = I_Y = I_B$$

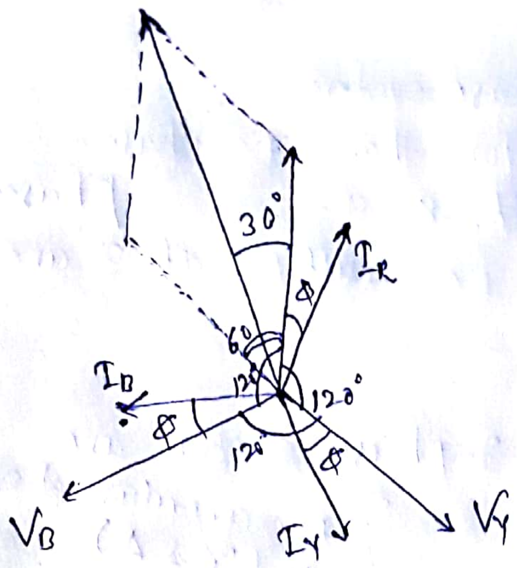
i-e $I_{ph} = I_L$ in Y- connection.

$$V_{RN} = V_{BN} = V_{YN} = V_{ph} \text{ (Phase voltage)}$$

$$V_{RY} = V_{YB} = V_{BR} = V_L \text{ (Line voltage)}$$

$$\therefore V_{RY} = V_R - V_Y \; ; \; V_{YB} = V_Y - V_B \; ; \; V_{BR} = V_B - V_R$$

Phasor diagram considering phase voltages as reference.



[for lagging load]

R
Y (+)ve sequence.
B

$V_R = V_Y = V_B = V_{ph}$

$V_{RY} = V_{YB} = V_{BR} = V_L$

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

With respect to phase voltage,

1. Line voltage is leading by an angle of 30°.
2. For inductive load, phase displacement between line voltage and line current is $(30° + \phi)$
3. For resistive load, phase displacement between line voltage and line current is 30°.
4. For capacitive load, phase displacement between line voltage and line current is $(30° - \phi)$.

$V_R = V_{ph} \angle -30°$	$V_{RY} = V_L \angle 0$
$V_Y = V_{ph} \angle -120° - 30°$	$V_{YB} = V_L \angle -120°$
$V_B = V_{ph} \angle +120° - 30°$	$V_{BR} = V_L \angle -240°$ or $V_L \angle +120°$

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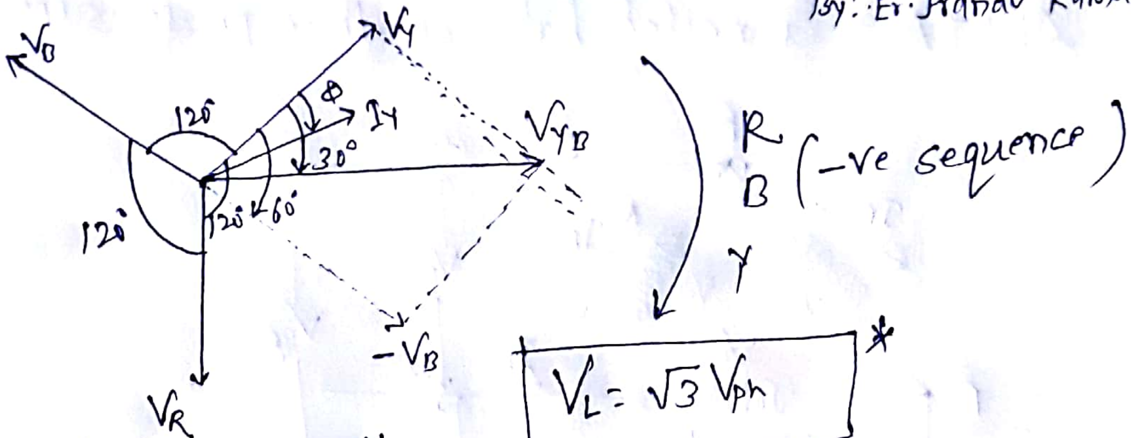


$$V_L = \sqrt{3} V_{ph}$$ *

* With respect to phase voltage
  1. Line voltage is Lagging by an angle of 30°.
  2. For inductive load, phase displacement between line voltage and line current is $(30° - \phi)$
  3. For resistive load, the phase displacement between line voltage and line current is 30°.
  4. For capacitive load, the phase displacement between line voltage line current is $(30° + \phi)$.

$V_{RY} = V_L \angle 0°$

$V_{YB} = V_L \angle +120°$

$V_{BR} = V_L \angle -120°$

(or) $V_L \angle +240°$

$V_R = V_{ph} \angle +30°$

$V_Y = V_{ph} \angle 120° + 30°$

$V_B = V_{ph} \angle -120° + 30°$

* Power in three phase star connected system.

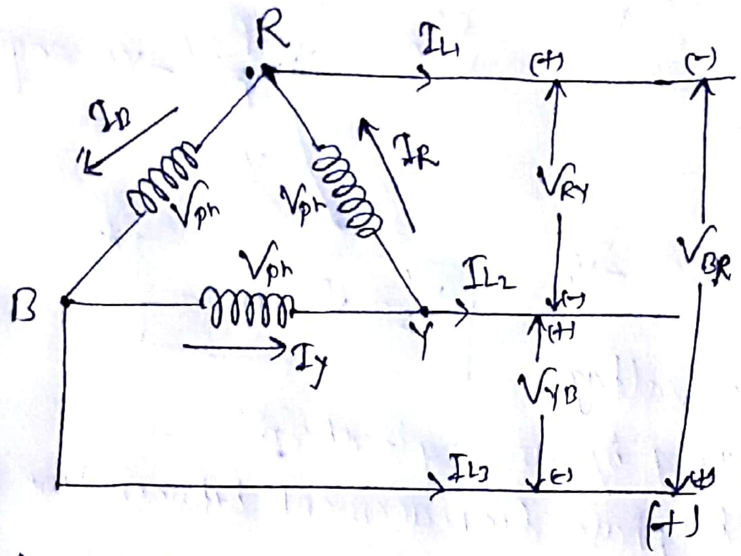
$$S = 3 V_{ph} I_{ph} = 3 \frac{V_L}{\sqrt{3}} I_L$$

$$\therefore S = \sqrt{3} V_L I_L \quad \text{VA's}$$

$$P = \sqrt{3} V_L I_L \cos\phi \quad \text{Watts.}$$

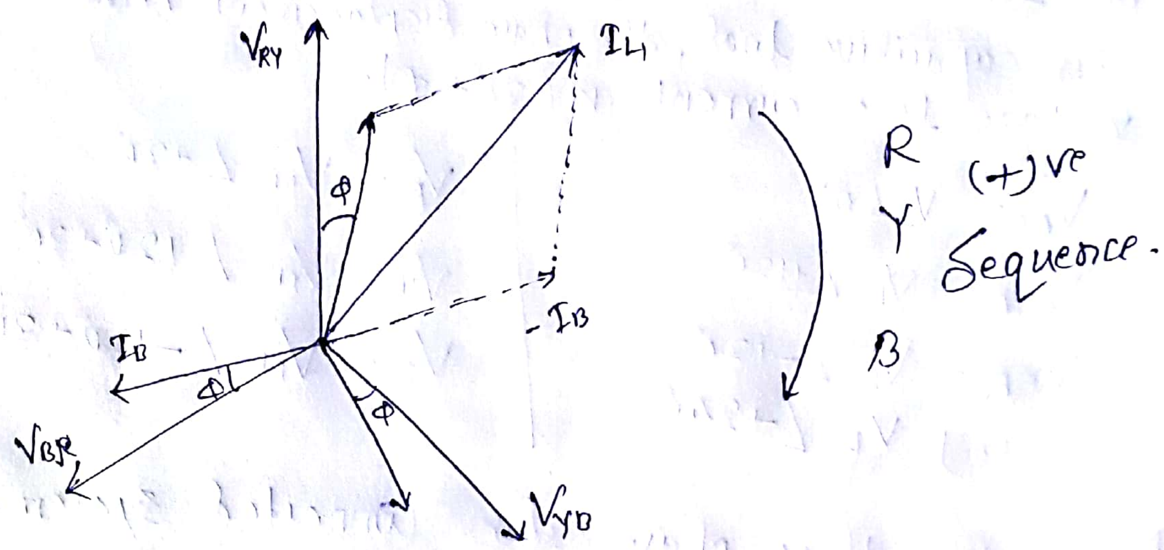
$$Q = \sqrt{3} V_L I_L \sin\phi \quad \text{VAR's}$$

DELTA Connected balanced three phase supply.



$V_{RY} = V_{YB} = V_{BR} = V_L$ } $I_{L_1} = I_R - I_B$; $I_{L_2} = I_Y - I_R$;

$\Rightarrow$ $\boxed{V_L = V_{ph}}$ $I_{L_3} = I_B - I_Y$;



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

(1.) In +ve phase sequence of Δ- connected system with respect to phase current, line current Lag by an angle 30°.

(2.) In (+)ve phase sequence of Δ- connection system with respect to phase currents, line current Lead by 30°.

(3.) In (+)ve phase sequence, the phase displacement between line voltage and line current is L → (30° + φ)

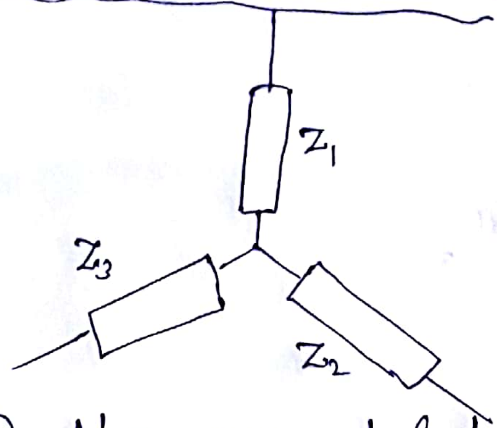
R → 30°, C → (30° − φ)

(4) In (−)ve phase sequence, the phase displacement between line voltage and line current is L → 30° − φ, R → 30°

C → 30° + φ

* Types of load and interconnection of three phase circuits.

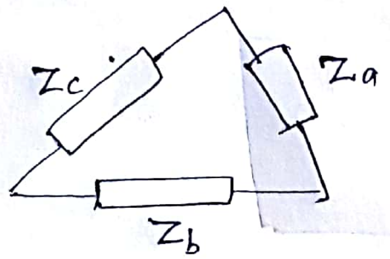
Star connected load:



$Z_1 = Z_2 = Z_3 \Rightarrow$ Balanced

$Z_1 \neq Z_2 \neq Z_3 \Rightarrow$ Unbalanced.

Delta connected load:



$Z_a = Z_b = Z_c \Rightarrow$ Balanced

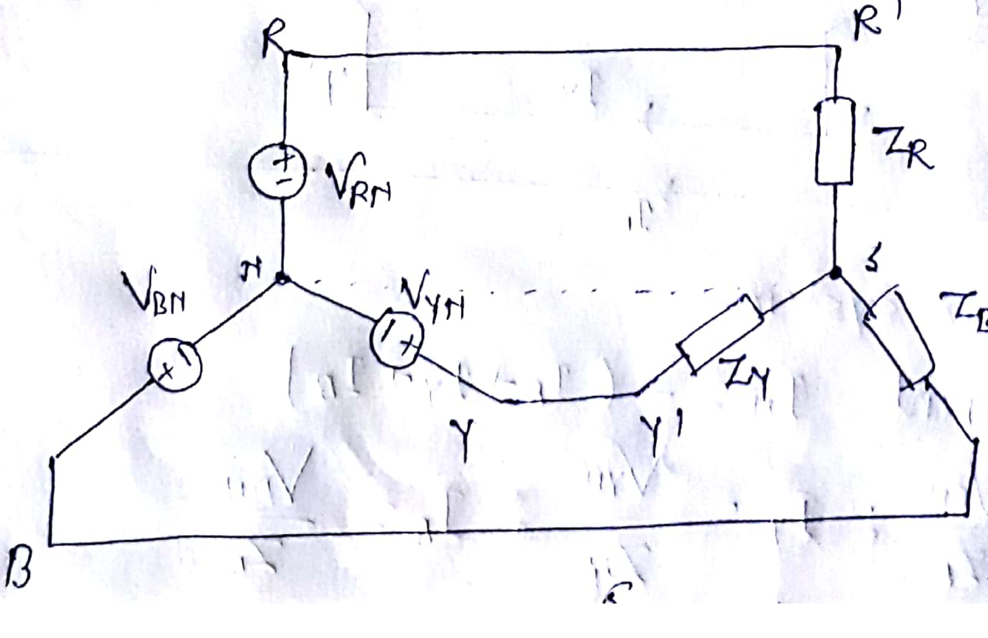
$Z_a \neq Z_b \neq Z_c \Rightarrow$ Unbalanced.

* Interconnection between source - load.

Source	Load
Y	Y
Y	Δ
Δ	Y
Δ	Δ

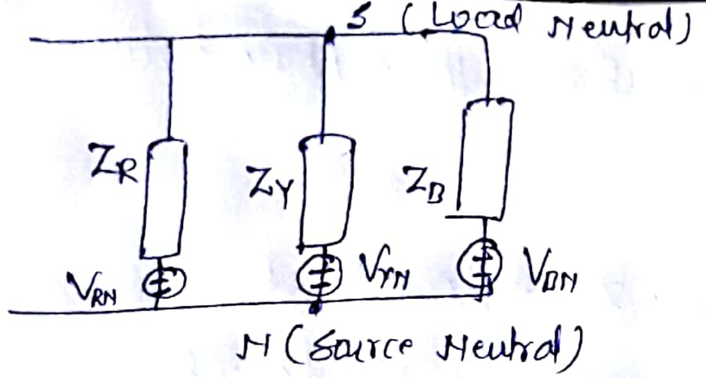
* System source is always balanced
* Potential at neutral point of source is always zero whether the load balanced (or) unbalanced.
* Load neutral is considered as floating point neutral with respect to unbalanced load.

3-Φ, 3-wire



By applying Millman's theorem the above circuit can be simplified to

≡



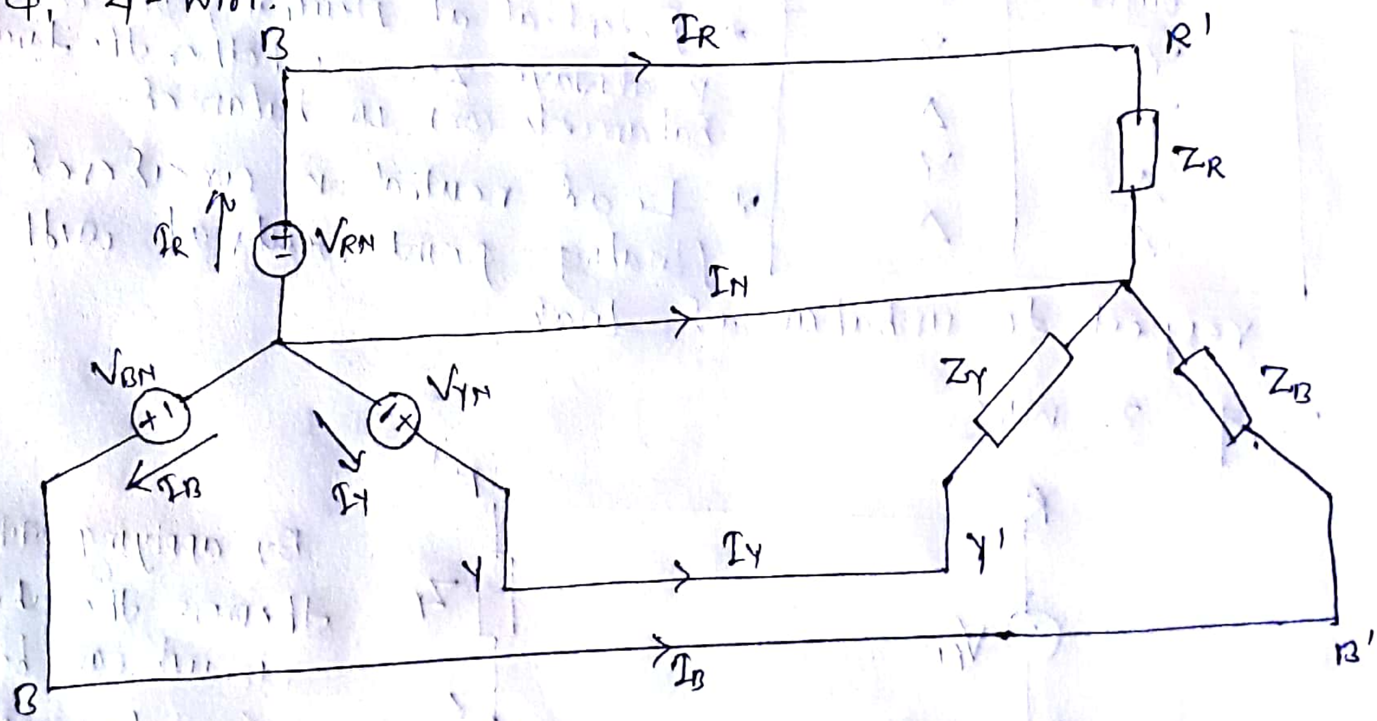
Potential difference between source neutral and load neutral(s) is V_{SN} :

$$V_{SN} = \frac{\frac{V_{RN}}{Z_R} + \frac{V_{YN}}{Z_Y} + \frac{V_{BN}}{Z_B}}{\frac{1}{Z_R} + \frac{1}{Z_Y} + \frac{1}{Z_B}}$$

$$V_{SN} = \frac{V_{RN} \cdot Y_R + V_{YN} \cdot Y_Y + V_{BN} \cdot Y_B}{Y_R + Y_Y + V_B}$$

$$V_{NS} = -V_{SN}$$

3-Φ, 4-wire.



In 3-Φ, 4-wire system.

Neutral current $I_N = -(I_R + I_Y + I_B)$

$$I_R = \frac{V_{RN}}{Z_R} \; ; \; I_Y = \frac{V_{YN}}{Z_Y} \; ; \; I_B = \frac{V_{BN}}{Z_B}$$

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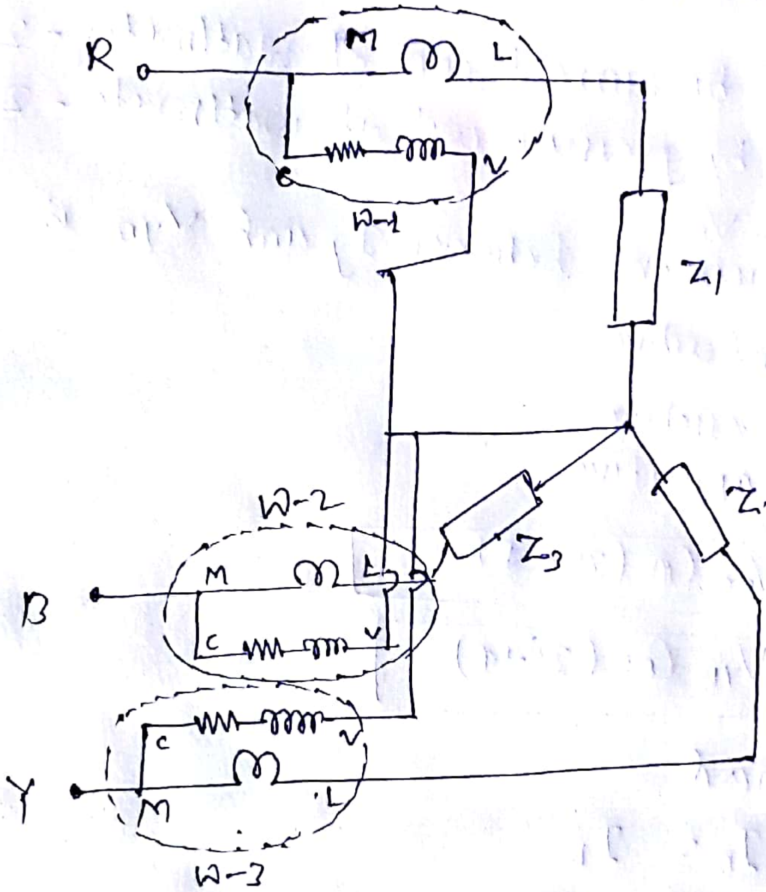
* Measurement of 3-Φ power

→ 3- wattmeter method used for balanced or Unbalanced loads.
→ 2- wattmeter method used for balanced or Unbalanced loads
→ 1. wattmeter method used for balanced load only.

3-Φ, 3- wattmeter method :

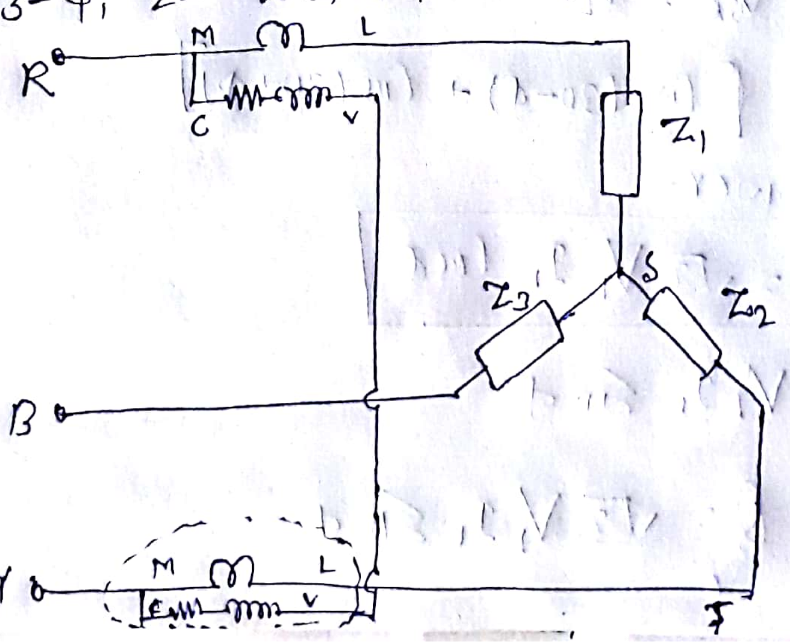
In a commercial wattmeter we can identify the terminal connections are.

M → Mains, L → Loads, C → Common. V → Voltage.



Total three phase power = $W_1 + W_2 + W_3$

3-Φ, 2- wattmeter method :



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Wattmeter W_1 :

(i) Current measured by current coil of wattmeter -1 = I_R

(ii) Voltage measured by pressure coil of wattmeter -1

$$V_{RB} = V_R - V_B.$$

(iii) The phase displacement between 'I_R' and 'V_{RB}' is equal to.

$(30° - \phi) \rightarrow$ Inductive

$30° \rightarrow$ Resistive

$(30° + \phi) \rightarrow$ Capacitive.

Wattmeter W_2 :-

(i) Current measured by current coil of wattmeter-2 is = I_Y

(ii) Voltage measured by pressure coil of wattmeter-2

$$V_{YB} = V_Y - V_B$$

(iii) The phase displacement between I_Y and V_{YB} is

$(30° + \phi) \rightarrow$ Inductive

$30° \rightarrow$ Resistive

$(30° - \phi) \rightarrow$ Capacitive.

So

$$W_1 = I_R V_{RB} \cos(30° - \phi)$$

$$W_2 = I_Y V_{YB} \cos(30° + \phi)$$

For balanced load

$$I_R = I_Y = I_B = I_L$$

$$V_{RY} = V_{YB} = V_{BR} = V_L$$

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

So, total active power.

$$P = W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi$$

Also $W_1 - W_2 = V_L I_L \sin\phi$

But reactive power $Q = \sqrt{3} V_L I_L \sin\phi$

$$\therefore \boxed{Q = \sqrt{3}(W_1 - W_2)}$$

$$\Rightarrow \frac{Q}{P} = \frac{\sqrt{3} V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi} = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

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

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

Effect of power factor on wattmeter Reading.

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

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

Case (i) If $\phi = 0$,

$$W_1 = V_L I_L \cos 30^\circ \text{ and } W_2 = V_L I_L \cos 30^\circ$$

$\therefore \boxed{W_1 = W_2}$ → If power factor angle is 0° both wattmeter reading is equal.

Case (ii) :- If $\phi = 30^\circ$

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

$$W_2 = V_L I_L \cos(30^\circ + 30^\circ) = \frac{V_L I_L}{2}$$

$$\therefore \boxed{W_2 = \frac{W_1}{2}}$$

If power factor angle is 30° one wattmeter readings is half of the other.

Case (iii) If $\phi = 60^\circ$

$$W_1 = V_L I_L \cos(30^\circ - 60^\circ) = \frac{\sqrt{3}}{2} V_L I_L$$

$$W_2 = V_L I_L \cos(30^\circ + 60^\circ) = 0$$

If power factor angle is 60°, one of the wattmeter reading is zero.

Case (iv) If $\phi = 90^\circ$

$$W_1 = V_L I_L \cos(30^\circ - 90^\circ) = \frac{V_L I_L}{2}$$

$$W_2 = V_L I_L \cdot \cos(30^\circ + 120^\circ) = -\frac{V_L I_L}{2}$$

$$\boxed{W_2 = -W_1}$$

If power factor angle is 90° one wattmeter reading is negative.