POWER ENGINEERING

#06 THREE-PHASE AC POWER SYSTEMS

POWER MEASUREMENT (1)

2018

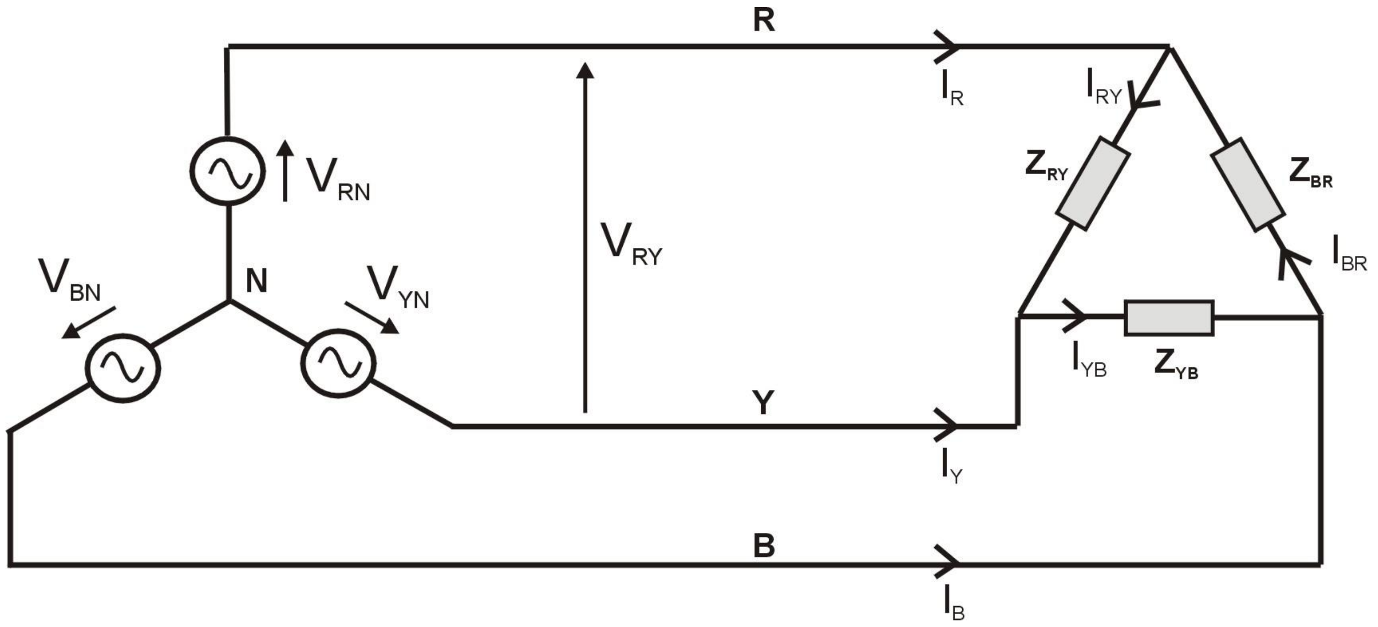
University of Glasgow

Power Measurement in Three Phase AC Systems

Today we will investigate:

- Balanced DELTA connected load (Summary + Example)
- Load Phase power and Supply Power
- Power Measurement #1: 3 Wattmeter Method
- Power Measurement #2: 2 Wattmeter Method
- Unbalanced DELTA connected load

Balanced Delta Connected Load:

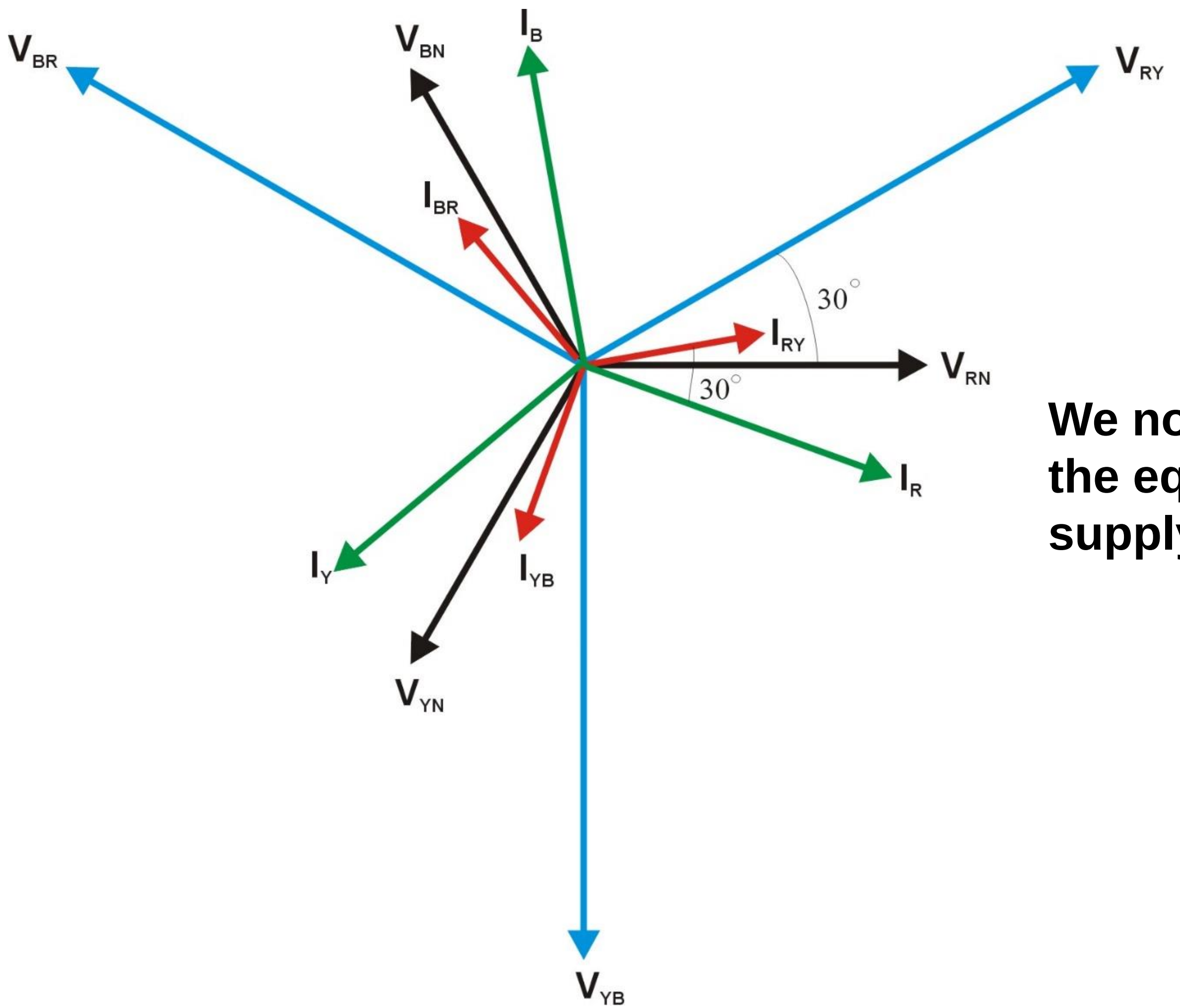


Reminders:

1. Line Voltages (eg V_{RY}) are $\sqrt{3}$x Phase Voltages (eg V_{RN}) and LEAD the phase voltages by 30º

2. Line Currents (eg I_R) are $\sqrt{3}$x Load Phase Currents (eg I_{RY}) and LAG the phase currents by 30º

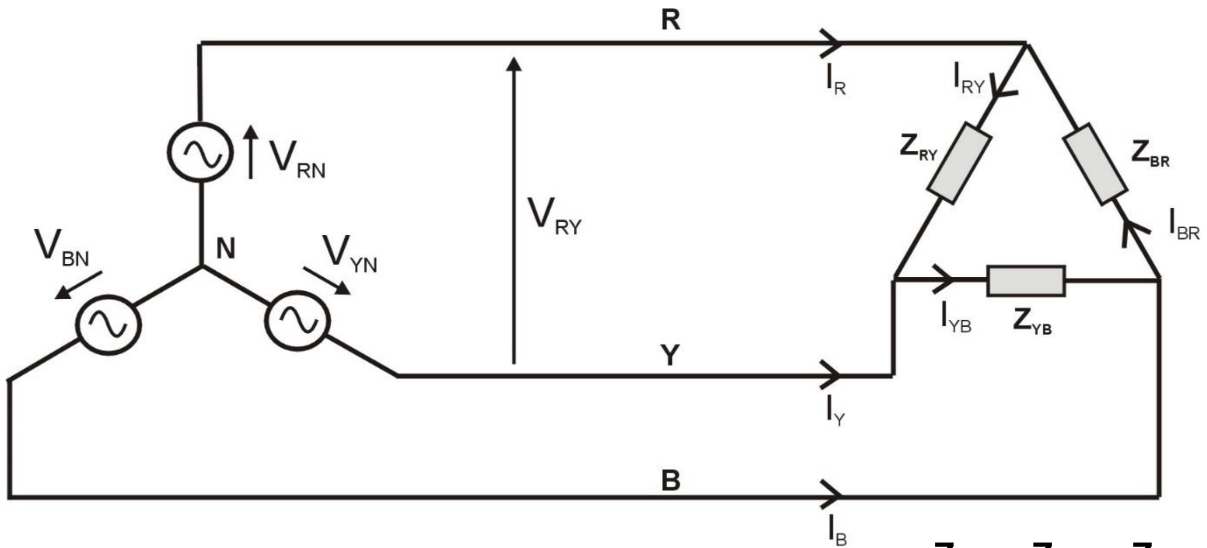
Balanced Delta Connected Load: Phasor Diagram



We now want to determine the equations for load and supply power

Balanced Delta Connected Example

$V_{ph} = 240V$

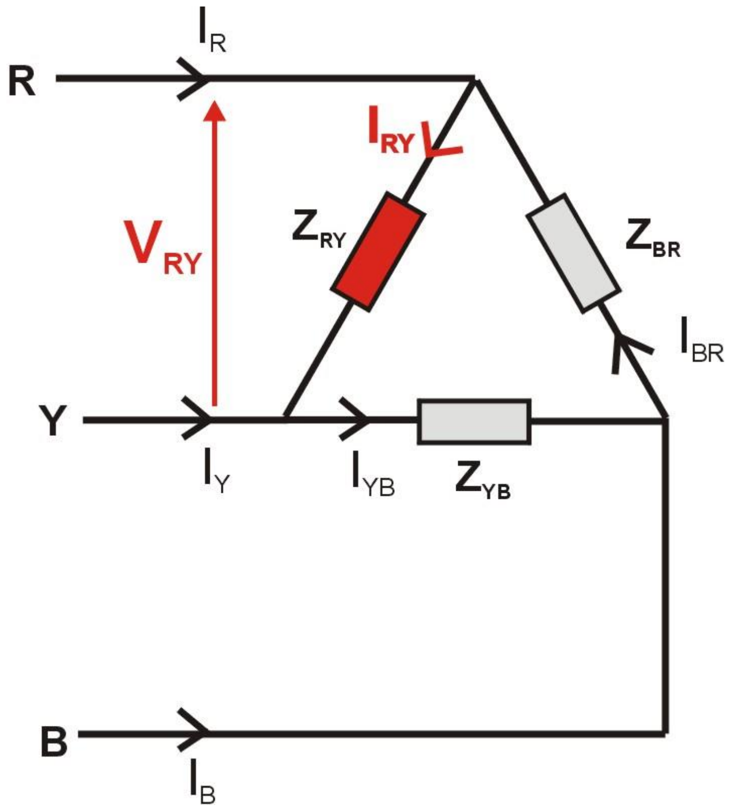


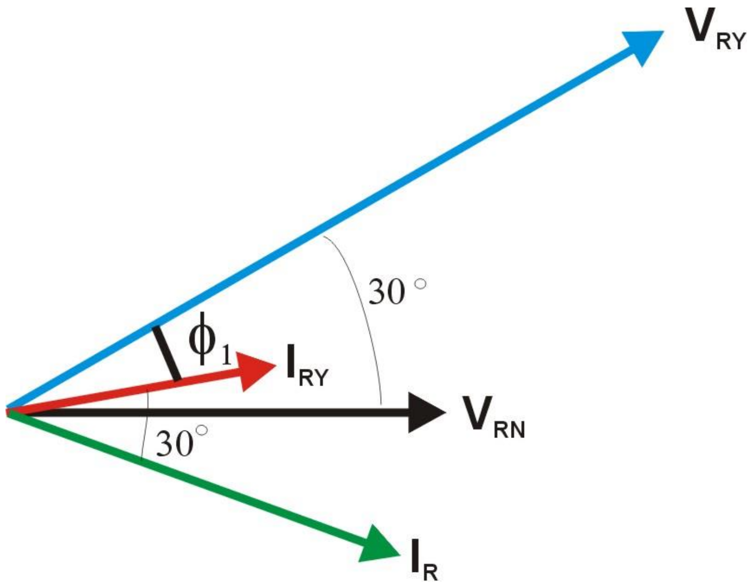
$Z_{RY} = Z_{YB} = Z_{BR} = 5+j2$

For the balanced 3 phase Delta connected load determine the following:

1. **The magnitude of the line voltages**
2. **The line currents I_R, I_Y and I_B**
3. **The phasor diagram showing all currents and voltages**
4. **The TOTAL real power supplied by the 3 phase supply**

Load Phase (Z_{RY}) Real Power (W):

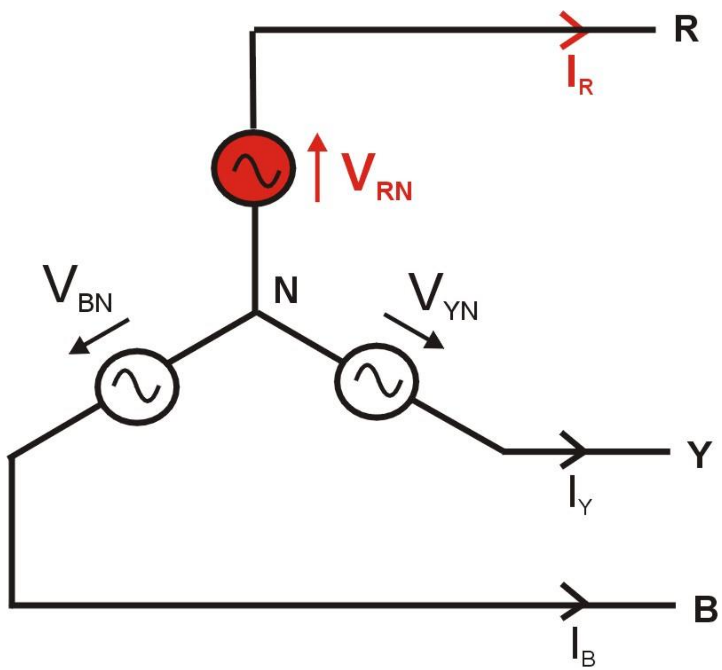


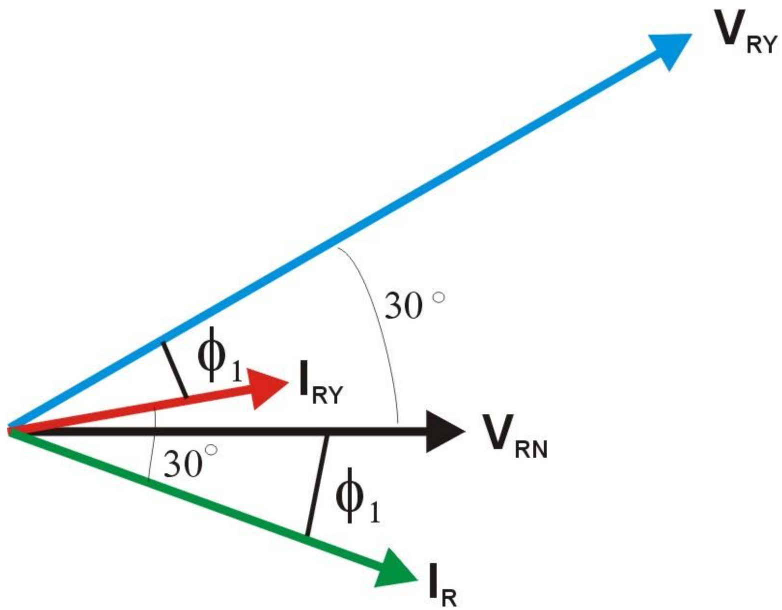


$$P_{RY} = |V_{RY}|.|I_{RY}|.\text{Cos}\Phi_1$$

Remember: the real power (W) output in a complex impedance is equal to the magnitude of the voltage across the impedance multiplied by the magnitude of the current through the impedance multiplied by the Cosine of the angle between that voltage and current (set by the load impedance)

Supply (V_{RN}) Real Power (W):





$$P_{RN} = |V_{RN}|.|I_R|.\cos\Phi_1$$

Now assuming no loss in the transmission lines then the Supply Power should equal the Load Phase Power

Note: Angle between V_{RY} and $I_R = 30^o + \Phi_1$

$$P_{RN} = |V_{RN}|.|I_R|.Cos\Phi_1 \quad = \quad P_{RY} = |V_{RY}|.|I_{RY}|.Cos\Phi_1$$

Proof:

$$V_{RN}.I_R.Cos\phi_1 = \frac{V_{RY}}{\sqrt{3}}.\sqrt{3}.I_{RY}.Cos\phi_1$$

$$V_{RN}.I_R.Cos\phi_1 = V_{RY}.I_{RY}.Cos\phi_1$$

Total Real Power in Balanced 3 Phase System:

$$P_T = 3.|V_{ph}|.|I_L|.Cos\Phi$$

Where Φ is angle between phase voltage and respective line current

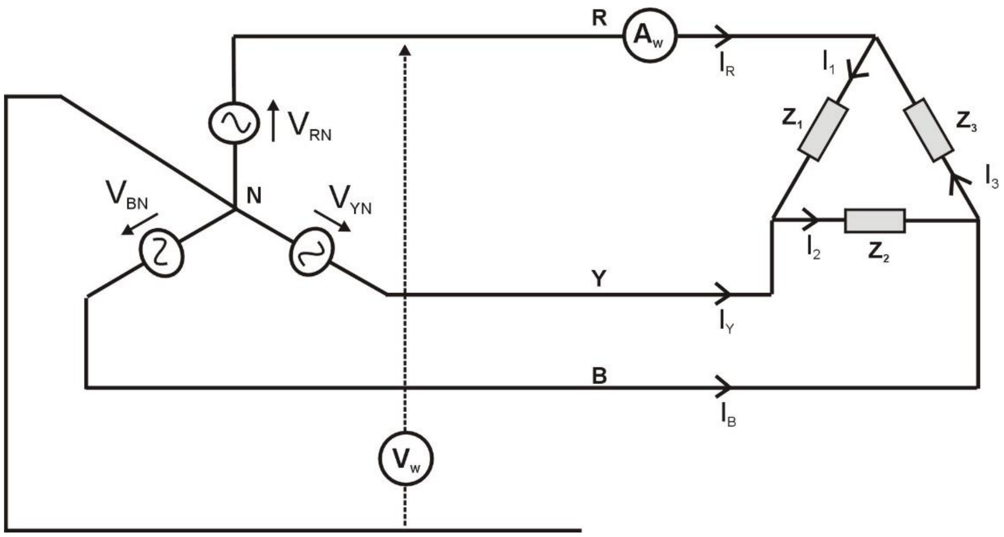
or

$$P_T = 3.|V_L|.|I_{ph}|.Cos\Phi$$

Where Φ is angle between line voltage and respective load phase current

Where I_L and V_L are line current and voltage respectively

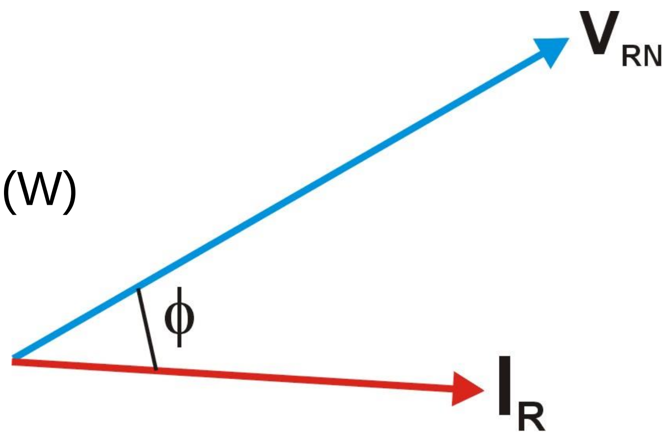
Power Measurements in 3 Phase Systems:



'Classic' Wattmeter Measures:

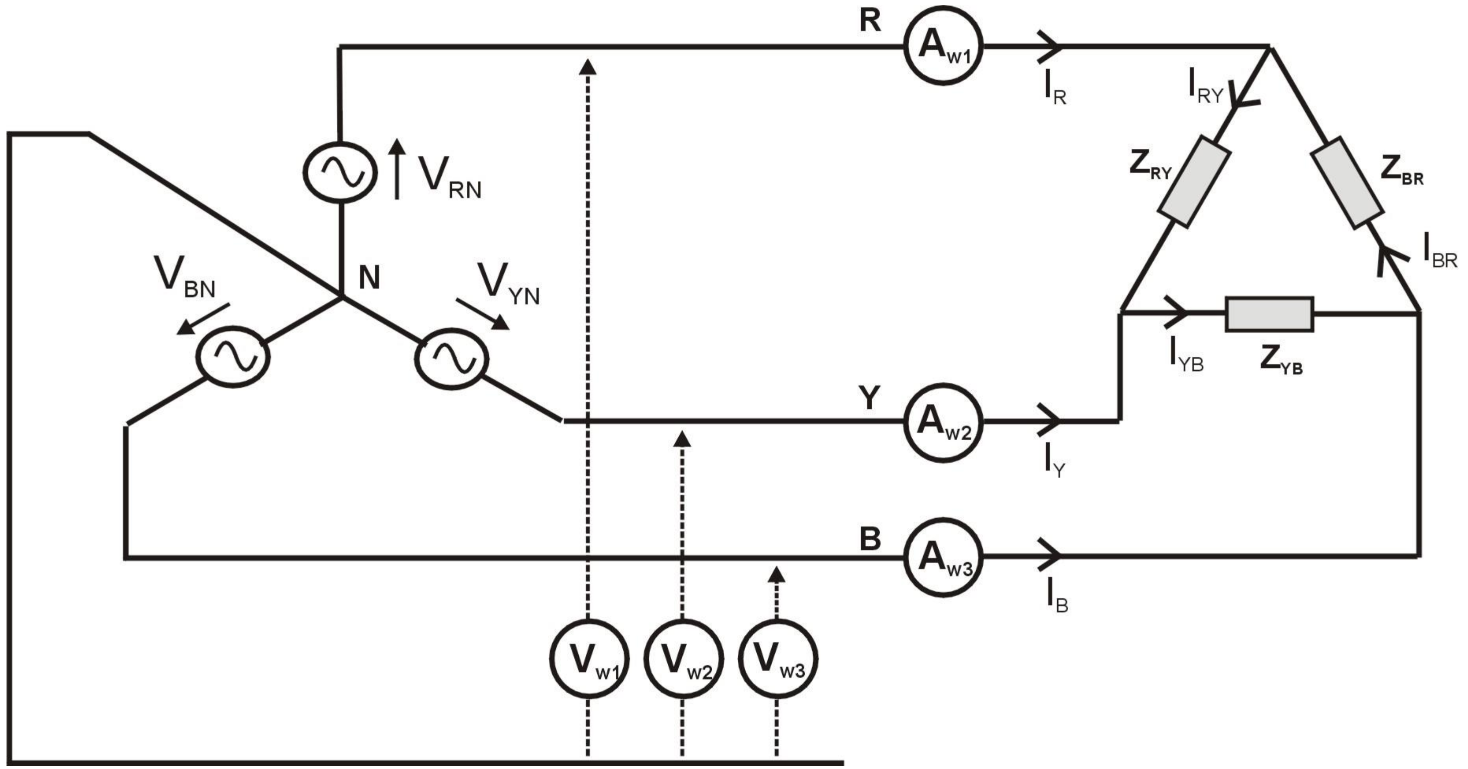
- Voltage (V)
- Current (A)
- Power Factor (angle between voltage and current)

→ Real Power (W)



Power Measurement #1: 3 Wattmeter Method

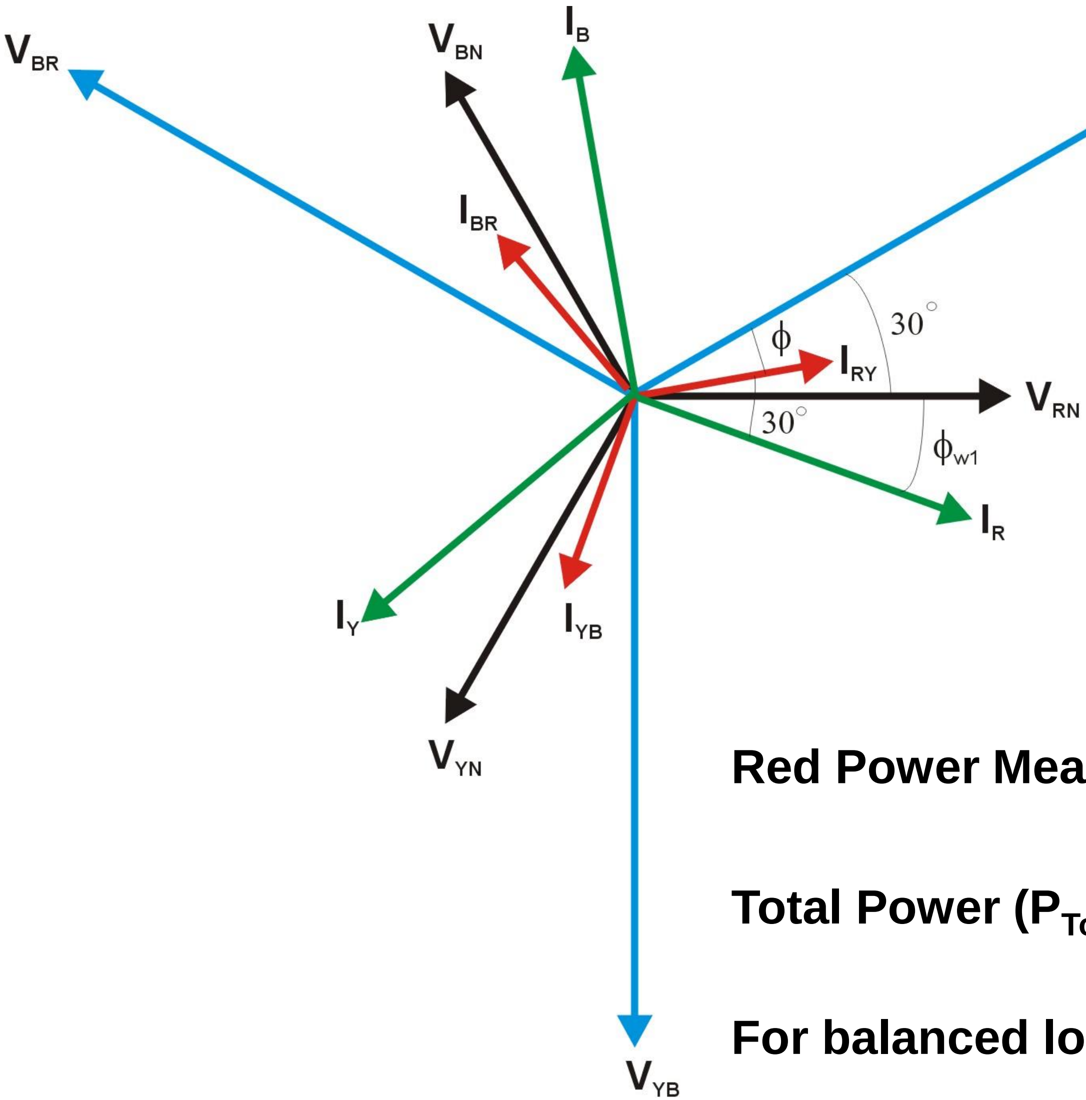
3-phase 3-wire



Wattmeter 1: V_{W1} , A_{W1} , & Φ_{W1}

Wattmeter 2: V_{W2} , A_{W2} , & Φ_{W2}

Wattmeter 3: V_{W3} , A_{W3} & Φ_{W3}



From Phasor Diagram: $\Phi_{W1} = \Phi$

Red Power Measurement (P_{W1}) = $|V_{RN}|.|I_R|.\text{Cos}\Phi$

Total Power (P_{Total}) = $P_{W1} + P_{W2} + P_{W3}$

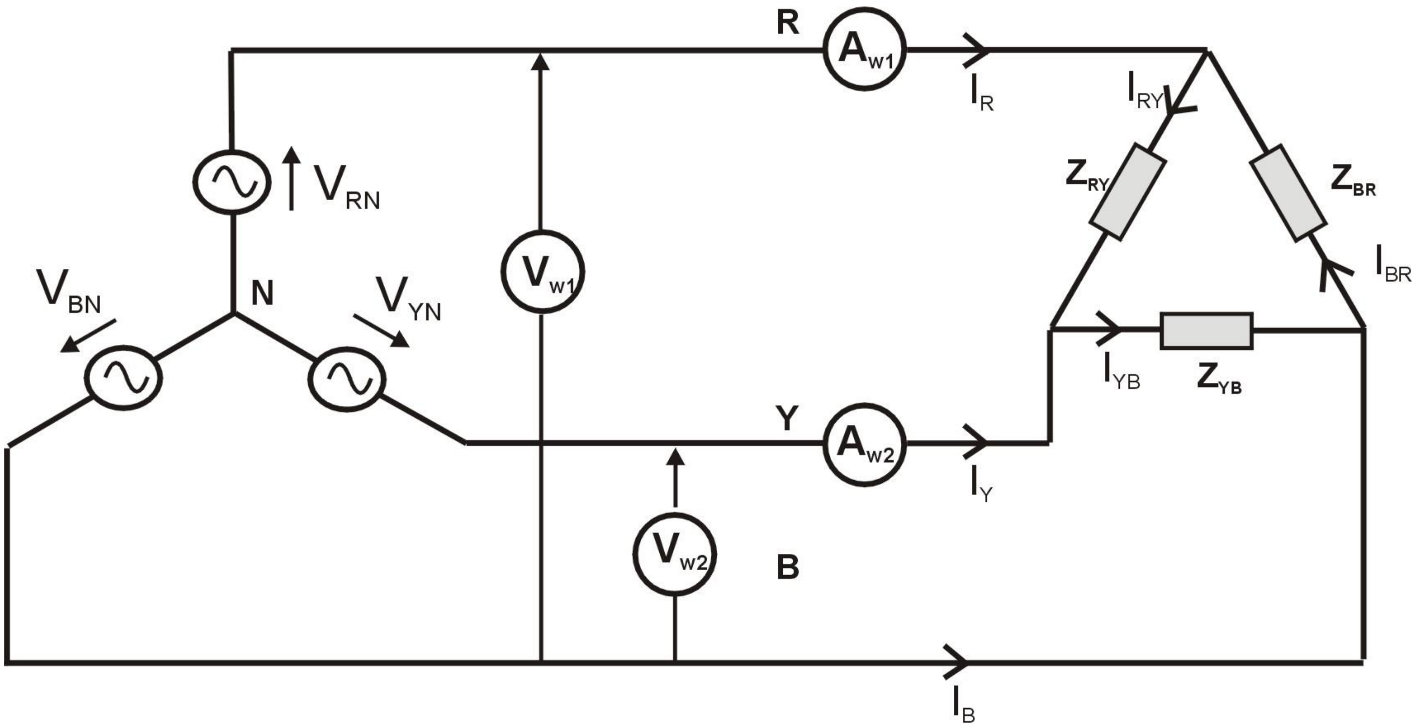
For balanced load:

Total Power (P_{Total}) = $3.|V_{ph}|.|I_L|.\text{Cos}\Phi$

Note: Φ set by load impedance

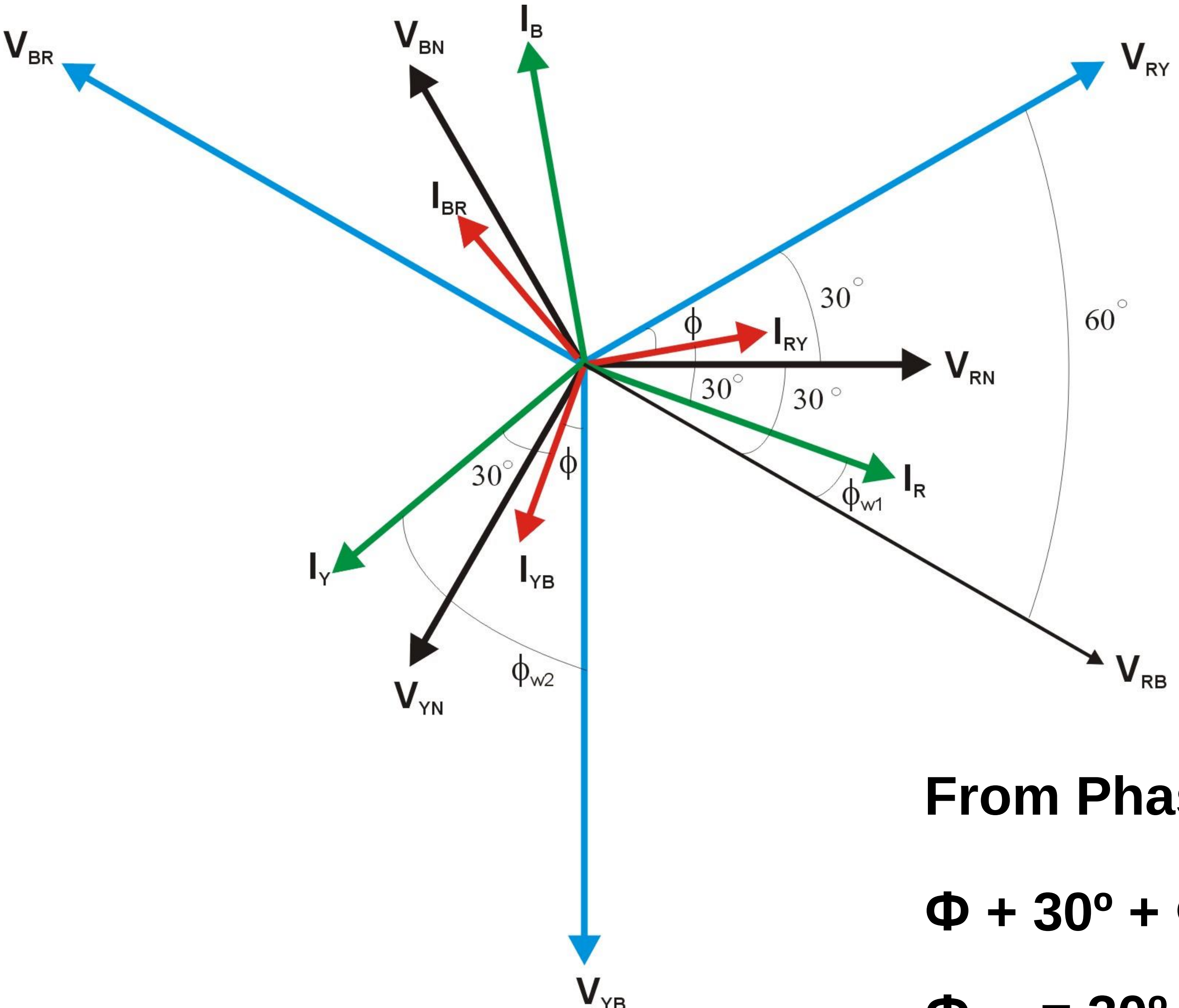
Power Measurement #2: 2 Wattmeter Method

3-phase 3-wire



$P_{W1} = |V_{RB}|.|I_R|.\text{Cos}\Phi_{W1}$ **Where Φ_{W1} = angle between V_{RB} and I_R**

$P_{W2} = |V_{YB}|.|I_Y|.\text{Cos}\Phi_{W2}$ **Where Φ_{W2} = angle between V_{YB} and I_Y**



From Phasor Diagram:

$$\Phi + 30^o + \Phi_{W1} = 60^o$$

$$\Phi_{W2} = 30^o + \Phi$$

Note: Φ set by load impedance and CosΦ = PF

$$P_{Total} = P_{W1} + P_{W2} = |V_{RB}|.|I_R|.\text{Cos}\Phi_{W1} + |V_{YB}|.|I_Y|.\text{Cos}\Phi_{W2}$$

Substitute for Φ_{W1} and Φ_{W2} and solve:

Equations solved on whiteboard

Result (for a balanced load):

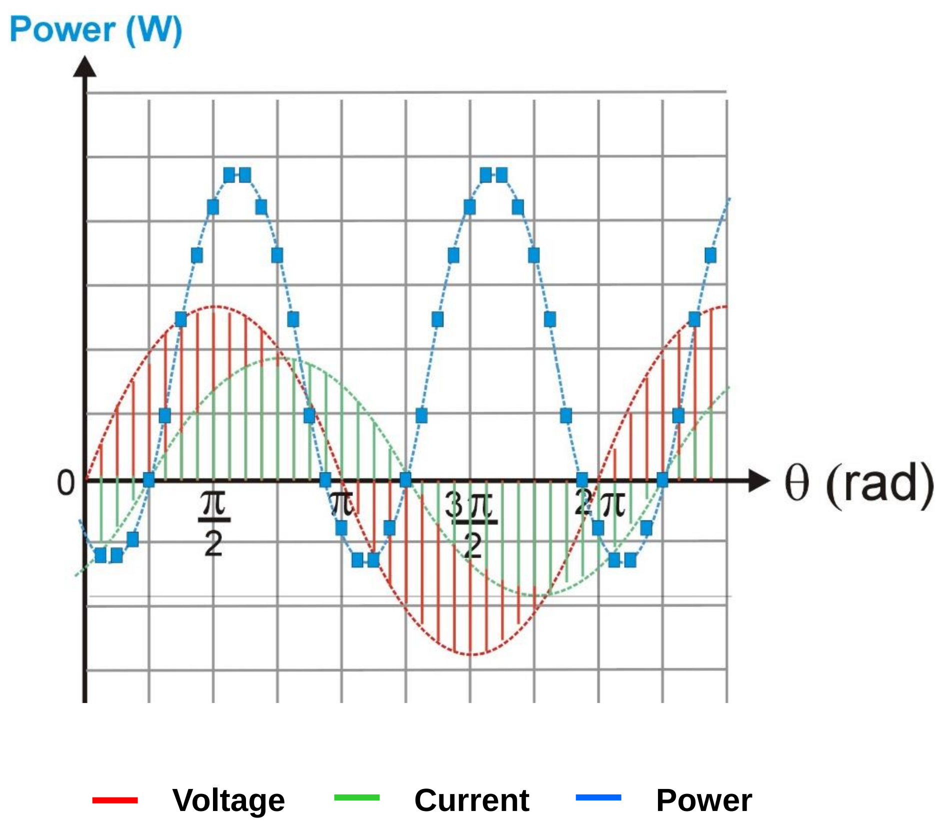
$$\boxed{P_{Total} = 3.|V_{ph}|.|I_L|.\text{Cos}\Phi}$$

Note: You will get the chance to prove the application of the 2 Wattmeter method to a balanced STAR connected load as part of the 3 Phase Tutorial.

Note: Φ set by load impedance

Modern Digital Sampling Power Meters/Analysers:

Manufacturers:
Voltech
Fluke
Yokagawa



$$Power(W) = \frac{1}{N}\sum_{0}^{N} v.i$$

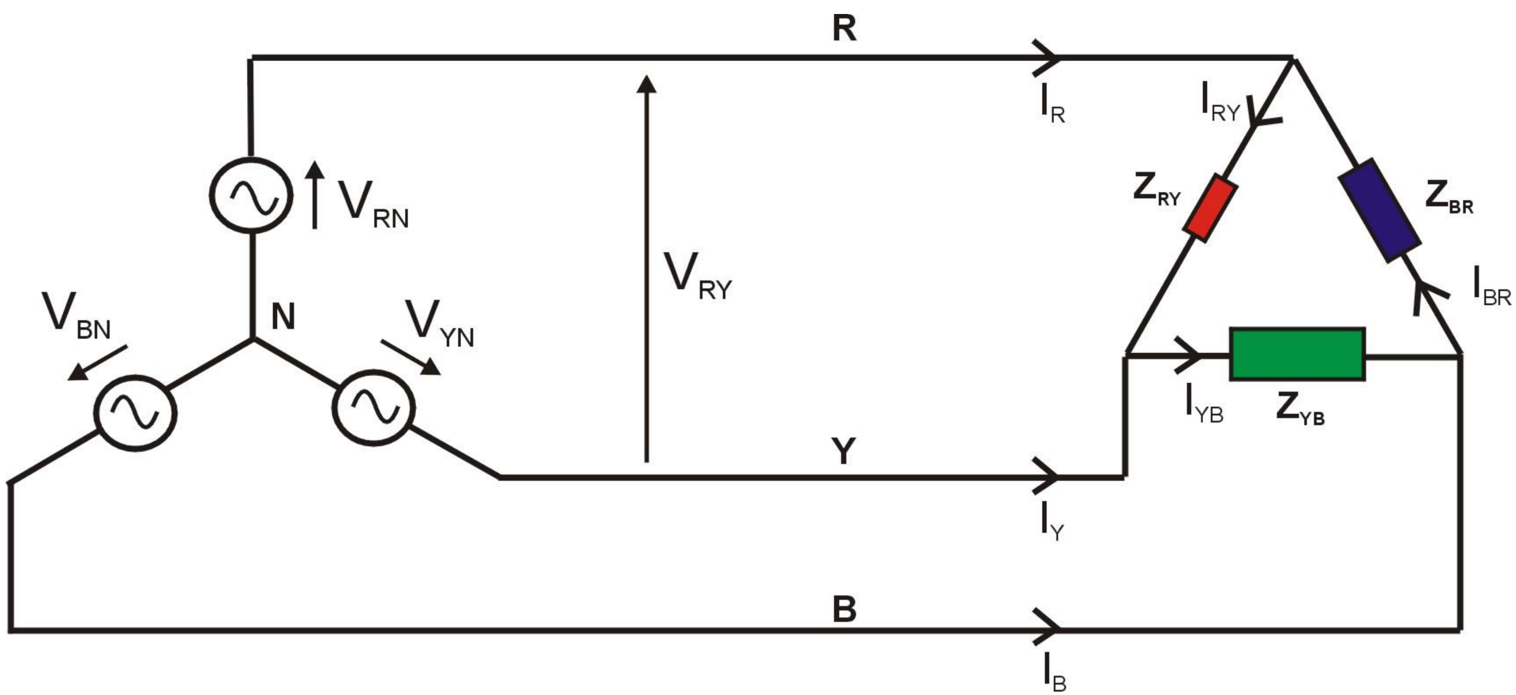
where N is the number of samples in a period

We now need to turn our attention to **UNBALANCED** Load Conditions:

- Unbalanced DELTA connected load
- Unbalanced 3 wire STAR connected load
- Unbalanced 4 wire STAR connected load

The plan is to outline the necessary steps to solve for each of the unbalanced conditions and then to highlight these with some examples (this and next lecture)

Unbalanced DELTA Connected Load:



For the Unbalanced load: $Z_{RY} \neq Z_{YB} \neq Z_{BR}$

Therefore: $I_{RY} \neq I_{YB} \neq I_{BR}$ & $I_R \neq I_Y \neq I_B$

Solution:

Step 1: Calculate individual load phase currents:

$$\boxed{I_{RY} = \frac{V_{RY}}{Z_{RY}}} \quad \boxed{I_{YB} = \frac{V_{YB}}{Z_{YB}}} \quad \boxed{I_{BR} = \frac{V_{BR}}{Z_{BR}}}$$

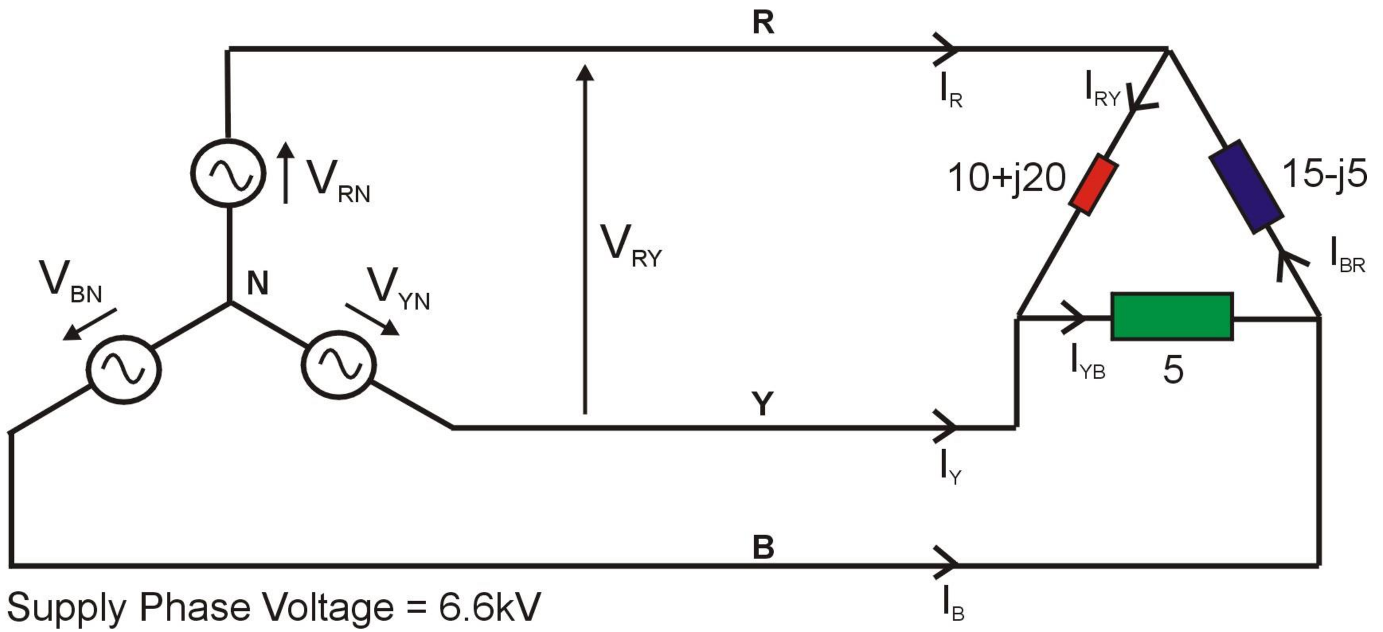
Step 2: Calculate individual line currents:

$$\boxed{I_R = I_{RY} - I_{BR}} \quad \boxed{I_Y = I_{YB} - I_{RY}} \quad \boxed{I_B = I_{BR} - I_{YB}}$$

Step 3: Calculate Total Real Power:

$$\boxed{P_T = |V_{RY}|.|I_{RY}|.\mathrm{Cos}\Phi_{RY} + |V_{YB}|.|I_{YB}|.\mathrm{Cos}\Phi_{YB} + |V_{BR}|.|I_{BR}|.\mathrm{Cos}\Phi_{BR}}$$

Unbalanced Delta connected load example:



Determine:

1] All the load phase currents
2] Draw a phasor diagram (to scale) showing all line voltages and load phase currents. From this estimate the line currents.
3] The total 3 phase power (W) at the load

Solution done on Whiteboard