

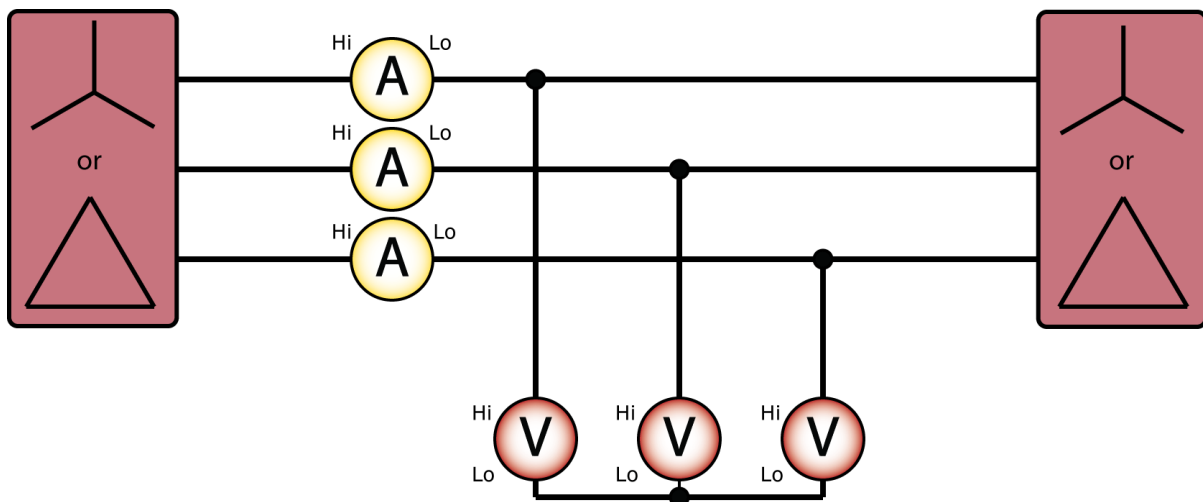
APPLICATION NOTE - 014

3 Phase 2 Wattmeter Power Measurements Explained



For many years the term “3 Phase 3 Wattmeter” and “3 Phase 2 Wattmeter” have been used in the power measurement field of electronics. This application note will explain the difference between the two, where each method can and cannot be used, the advantages of each and describe how the use of two wattmeters will give exactly the same result as three wattmeters under certain conditions.

3 Phase 3 Wattmeter



The above picture illustrates the 3 Phase 3 Wattmeter method of power measurement. This is the easiest to understand as the power analyzer will be taking instantaneous, separate measurements of phases 1, 2 and 3. The sum of the three phase powers will equal the total power.

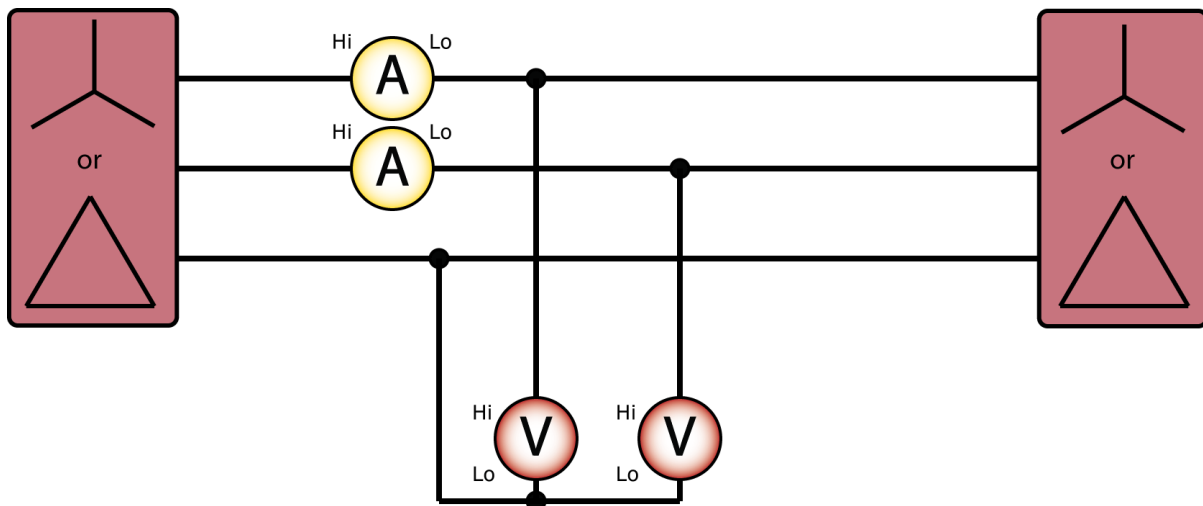
A simplified expression, excluding power factor (both real and fundamental) is below

$$(V_1 \times I_1) + (V_2 \times I_2) + (V_3 \times I_3) = \text{Sum Watts}$$

$$\text{Watts Ph}_1 + \text{Watts Ph}_2 + \text{Watts Ph}_3 = \text{Sum Watts}$$

Note: In a 4-wire system the Star Point/Neutral will be used as the Volts Lo common point.

3 Phase 2 Wattmeter



Above is the 3 Phase 2 Watt meter method, this method enables the user to utilise the third phase of a 3 phase power analyzer for a DC bus for example, yet the user is still able to make 3 phase measurements with only the first two channels of the power analyser.

Phase 3 in the above example is used as the reference point. Using phase 3 as a reference the power if a wattmeter were connected to phase 3 would equal zero as $P = IV$. This is because although current will be flowing the voltage would be zero. As we know the Line-Line voltage is $\sqrt{3}$ x Line-Neutral Voltage, even before performing some calculations it may be apparent that the power in the 3rd phase may indeed be included in a 2 wattmeter measurement as we are now measuring Line-Line on the two other phases.

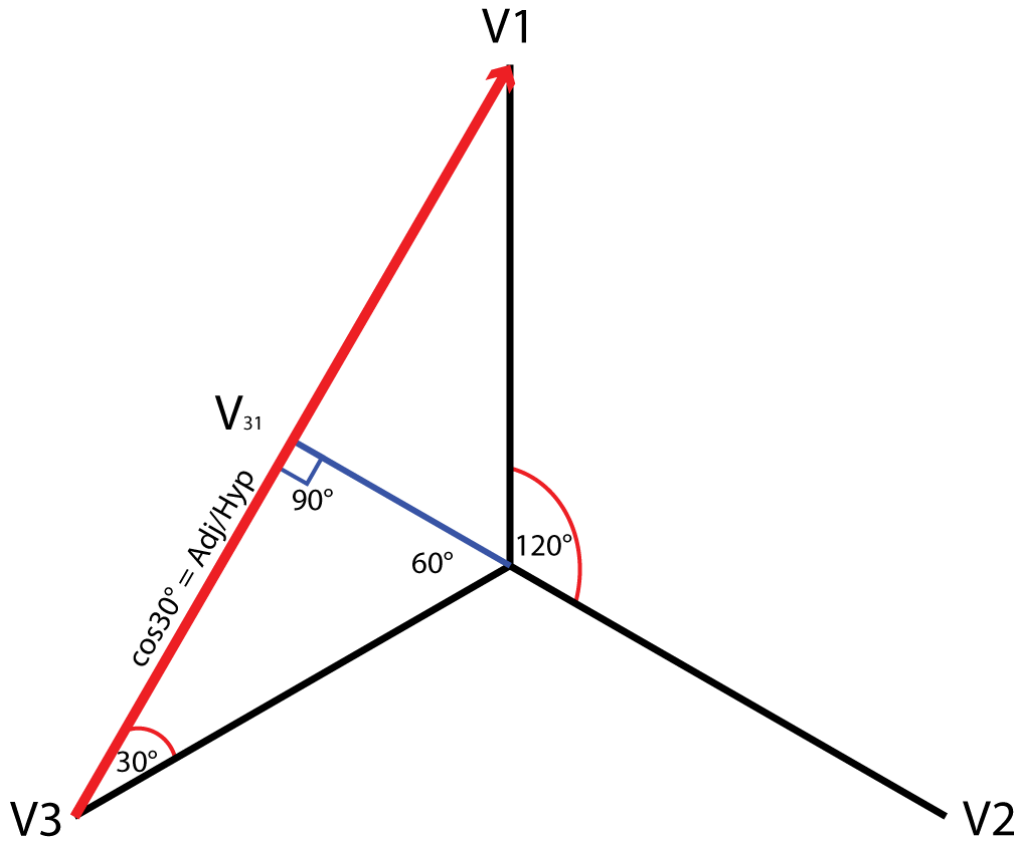
But to prove this is the case, we will now look at the maths whilst inputting some real voltages and currents to examine the 3 Phase 2 Wattmeter method in more depth.

Note: The Newtons4th Power Analyzers will compute the Sum Power from the two wattmeter readings; the following mathematics will illustrate the theory behind 3 Phase 2 Wattmeter measurements. Both wattmeters will not read the same power if the power factors are not unity or the voltages and currents on all phases are not equal. However, the sum of the two wattmeters will be equal to the total power in all cases.

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Line to Neutral or Line to Line?

Below we can see a 3 Phase Star configuration, with 240V line to neutral (UK) being produced, with a 3 Phase 3 Wire configuration, this is the voltage that would be measured. However, with the 3 Phase 2 Wire method the voltage measured is between Phase 1 to Phase 3 and Phase 3 to Phase 2. Here we will look at the voltages in vector form and discuss the mathematics behind the final figures.



If Voltage was 1V on all phases we can calculate a ratio metric relationship between line to neutral and line to line.

To Calculate $V_3 - V_1$ we first create a right-angled triangle between the star point, V_3 and mid-point between V_1 and V_3

Therefore

$$\cos 30^\circ = (\frac{1}{2} V_1 - V_3) / 1$$

$$\cos 30^\circ = \frac{1}{2} V_1 - V_3$$

$$2 \times \cos 30^\circ = V_1 - V_3$$

$$V_3 - V_1 = 1.73205$$

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Note: $1.73205^2 = 3$

Therefore:

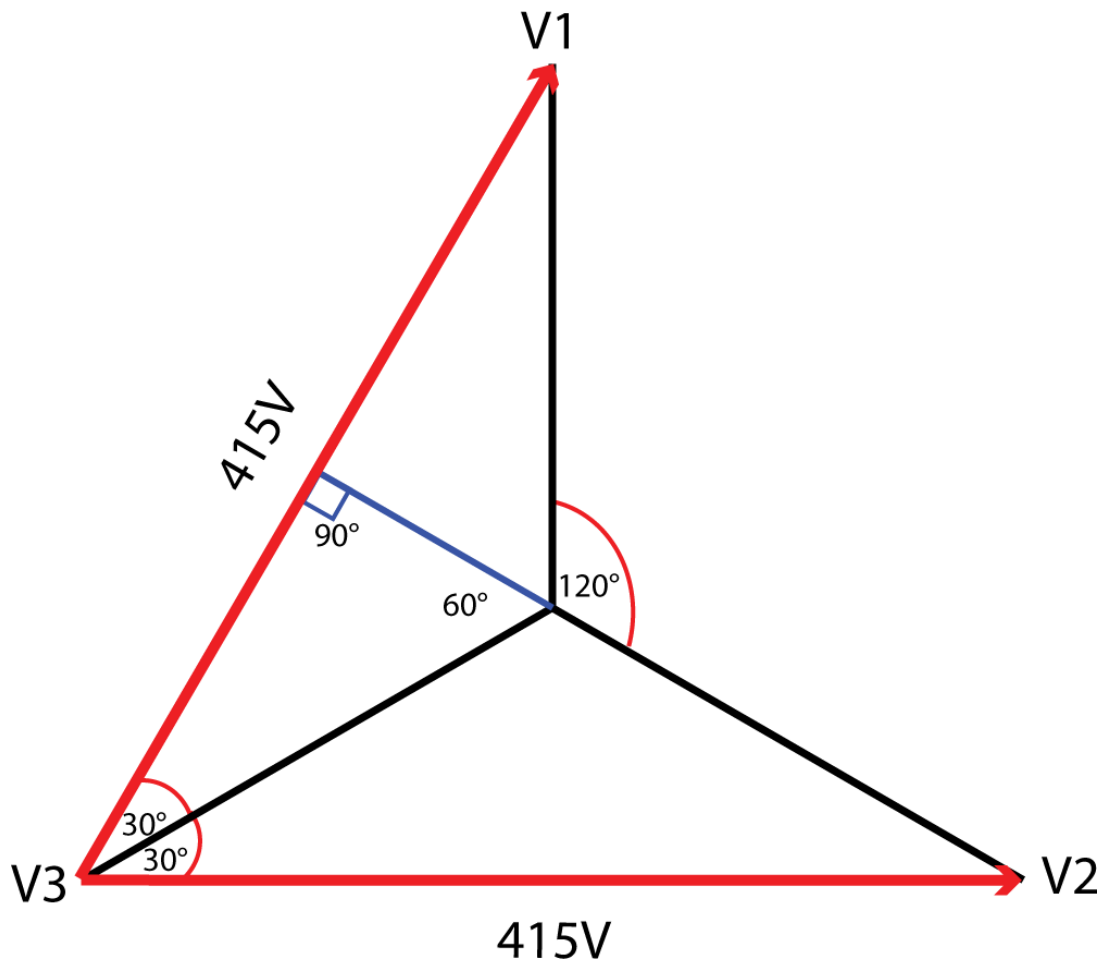
$$V_3 - V_1 = V_3 \times \sqrt{3}$$

This will be more obvious if we use some real values for the Voltage of V_1 and V_3

Line to Neutral = 240V (UK Standard Voltage)

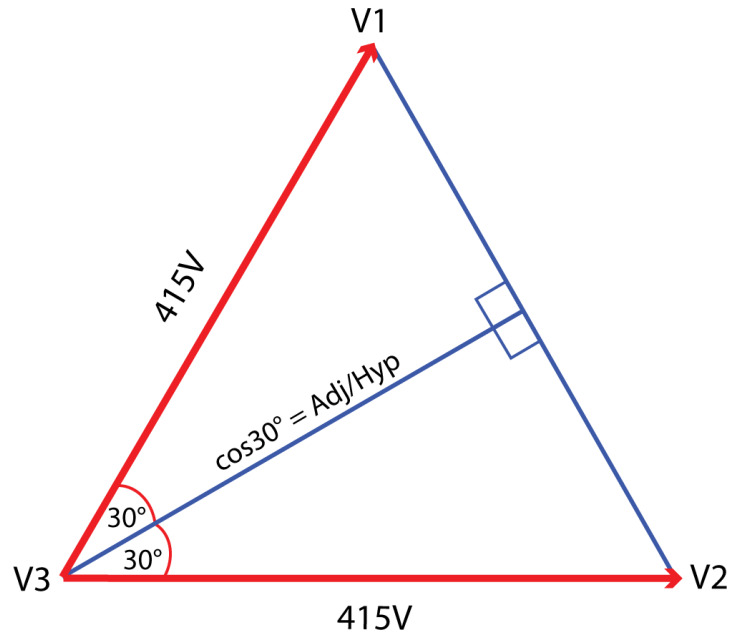
$$\text{Line to Line} = 240V \times \sqrt{3} = 415V$$

It follows that this is the same case with the voltage between Phase 3 and Phase 2



If we now look at the two voltage vectors we are measuring with 3 Phase 2 wattmeter on their own, we can calculate the total voltage by adding the vectors.

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Therefore,

$$\text{Adj} = 415\cos 30^\circ$$

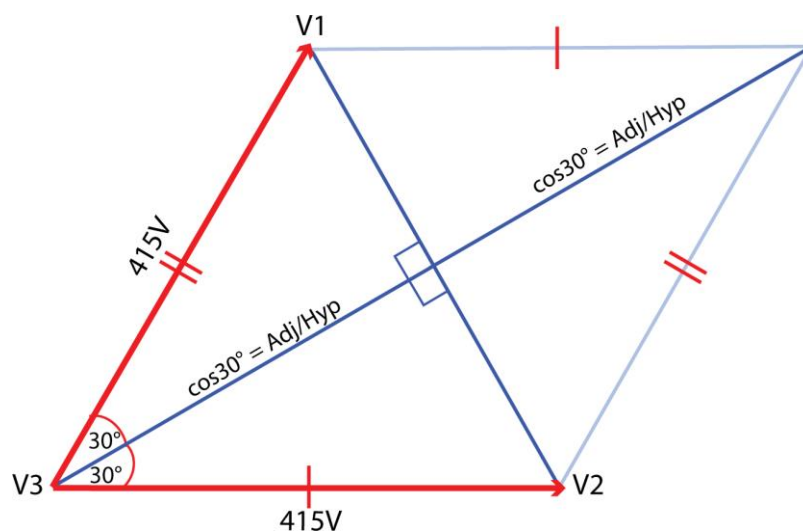
$$(V_3 - V_1) + (V_3 - V_2) = 2 \times (415\cos 30^\circ)$$

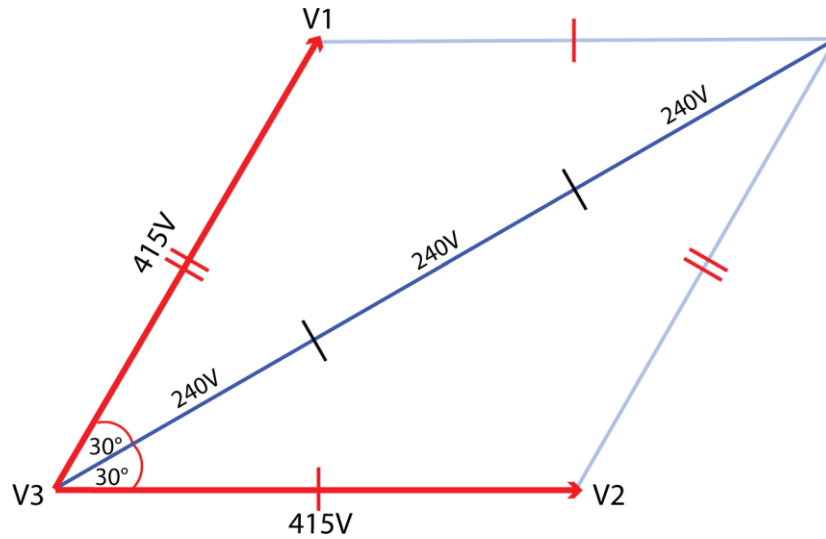
$$(V_3 - V_1) + (V_3 - V_2) = 2 \times 359.4$$

$$(V_3 - V_1) + (V_3 - V_2) = 718.8$$

This is equal to the sum of all of the voltages; we have 3 phase voltage now. If we divide by 3 we should get the individual Phase – Neutral Voltage

$$718.8 / 3 = 240V$$



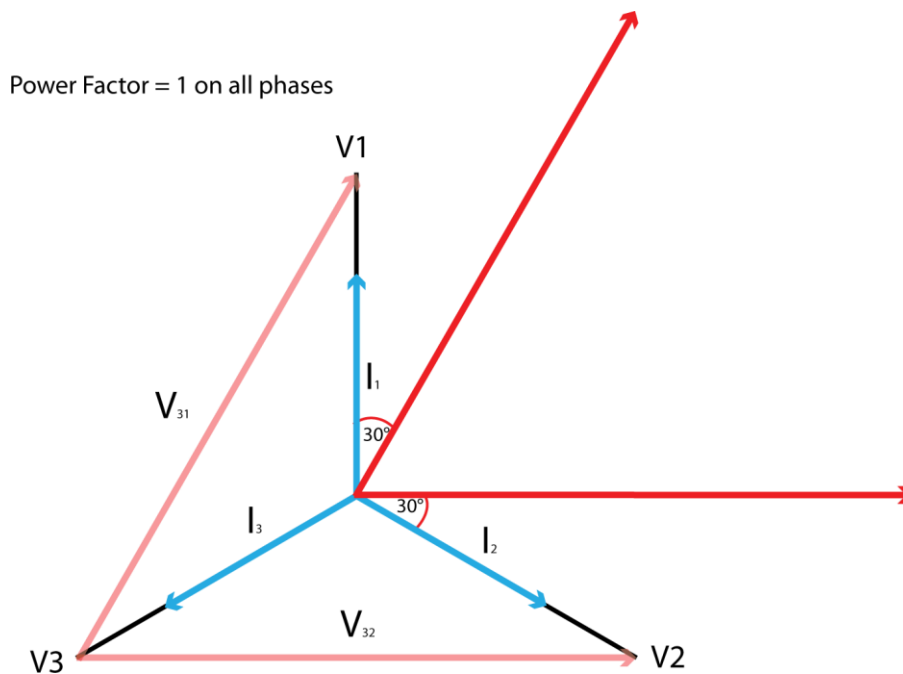


This should give indication that using the 2-wattmeter method would indeed result in the same total voltage being measured vectorially.

Note: The two voltages measured now only have a 60° phase to phase relationship, not 120°

So when the wattmeters are connected to Phase 1 and Phase 2 the following calculation is true for instantaneous voltage and current readings

The phase relationship between the Line to Line voltages will be 30° out of phase with the Line to Neutral Voltages on each wattmeter



Considering the 30° phase difference between Line to Line voltage and a unity power factor load on every phase, we have to apply this phase difference when computing watts on each wattmeter.

In this case we have current sensing on phase 1 and phase 2, we have used phase 3 as the reference to measure voltage.

With a 240V Line to Neutral, 415V Line to Line system we can compute the readings we would get on a 3 Phase 2 Wattmeter arrangement

$W_1 = \text{Wattmeter 1 (Current Phase 1, Voltage Ph3 to Ph1)}$

$W_2 = \text{Wattmeter 2 (Current phase 2, Voltage Ph3 to Ph2)}$

$P = W_1 + W_2$

$W_1 = V_{31} * I_1 * \cos \Phi A$

$\Phi A = \text{Phase angle between } V_{31} \text{ to } I_1$

$W_2 = V_{32} * I_2 * \cos \Phi C$

$\Phi C = \text{Phase angle between } V_{32} \text{ to } I_2$

Note: ΦA and ΦC are 30 degrees +/- Phase lag/lead of current from their respective Line-Neutral voltage vectors.

To take into account phase lag on respective phases the equations is expanded

$W_1 = V_{31} * I_1 * \cos (30^\circ - \Phi)$

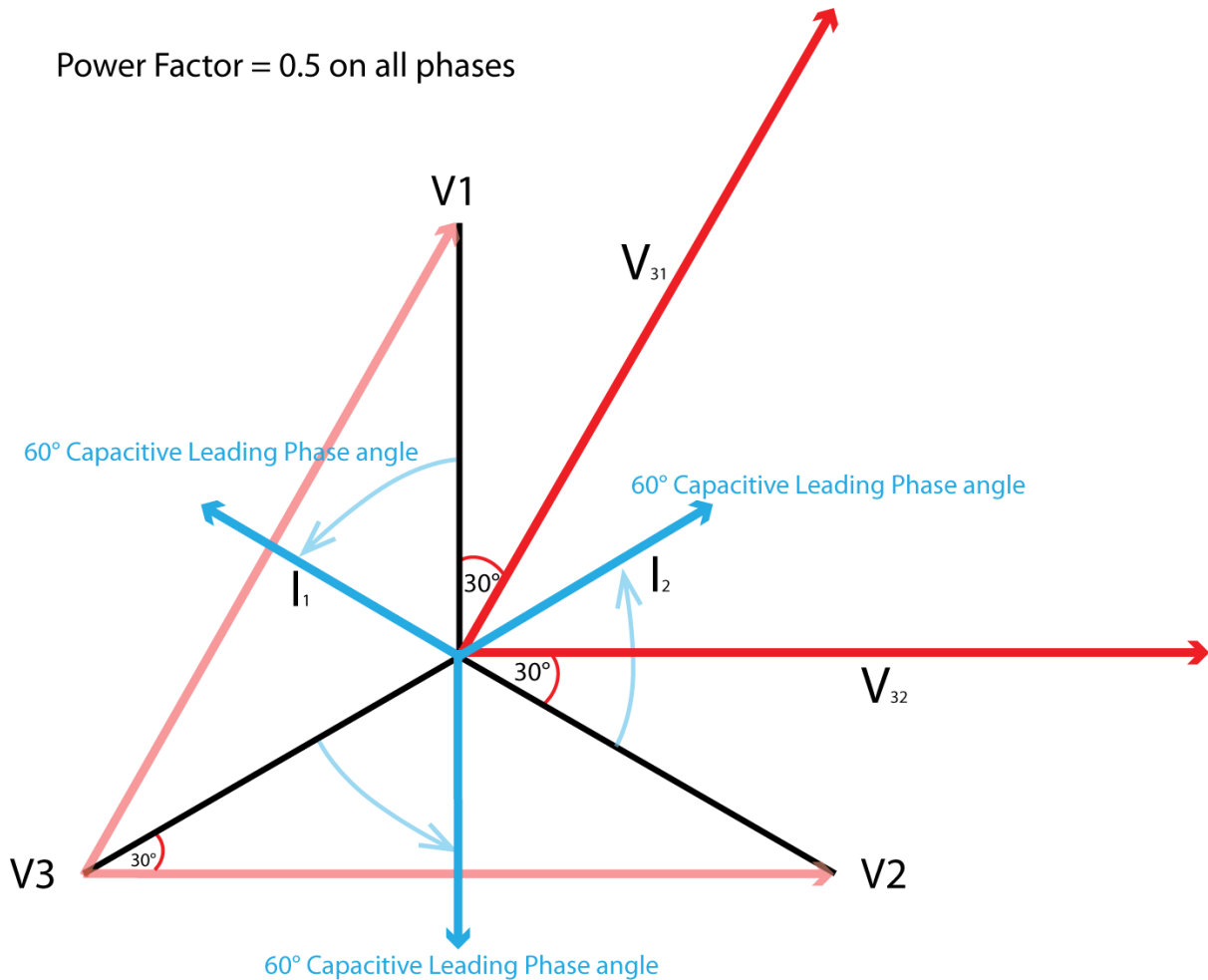
$W_2 = V_{32} * I_2 * \cos (30^\circ + \Phi)$

The above equation correlates to the vector diagram, as for an inductive (positive) phase angle where voltage is leading current, as the phase angle tends towards 60° Wattmeter 1 will read closer to Zero watts until eventually as the phase angle hits 60° Wattmeter 1 will read Zero and wattmeter 2 will read Sum power.

Total Power (Watts) = $[V_{31} * I_1 * \cos (30^\circ - \Phi)] + [V_{32} * I_2 * \cos (30^\circ + \Phi)]$

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Power Factor = 0.5 on all phases



Capacitive phase angles will now be put into the equation

Using 415V Line to Line, 5A per Phase, -60° Capacitive phase angle

3 Phase 2 Wattmeter

$$\text{Total Power (Watts)} = [415 * 5 * \cos (30^\circ - -60^\circ)] + [415 * 5 * \cos (30^\circ + -60^\circ)]$$

$$\text{Total Power (Watts)} = [2075 \cos 90^\circ] + [2075 \cos -30^\circ]$$

$$\text{Total Power (Watts)} = [2075 * 0] + [2075 * 0.866]$$

$$\text{Total Power (Watts)} = 1797 \text{ Watts}$$

$$\text{Wattmeter 1 Reading} = 0 \text{ Watts}$$

$$\text{Wattmeter 2 Reading} = 1797 \text{ Watts}$$

Here it is evident that the effective power factor on Wattmeter 1 is Zero, therefore all power is measured on Wattmeter 2.

3 Phase 3 Wattmeter

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With a wattmeter on each phase the individual phase watts readings sum to equal the total power.

Now we measure Line to Neutral (239.6V), Current remains 5A per phase

$$\text{Total Power (Watts)} = [V_1 * I_1 * \cos(\Phi)] + [V_2 * I_2 * \cos(\Phi)] + [V_3 * I_3 * \cos(\Phi)]$$

$$\text{Total Power (Watts)} = [239.6 * 5 * \cos(60^\circ)] + [239.6 * 5 * \cos(60^\circ)] + [239.6 * 5 * \cos(60^\circ)]$$

$$\text{Total Power (Watts)} = [1198 * 0.5] + [1198 * 0.5] + [1198 * 0.5]$$

$$\text{Total Power (Watts)} = [599] + [599] + [599]$$

$$\underline{\text{Total Power (Watts)} = 1797 \text{ Watts}}$$

Here we can see the 3 Phase 2 Wattmeter measurements are the same as 3 Phase 3 Wattmeter measurements for sum power.

Negative Readings?

For power factors less than 0.5 one wattmeter will read negative values for watts, the difference between the two wattmeters in these instances will equal the total power.

Example: For Line to Line Voltages of 415V, Phase Current of 5A, Phase angles of 80° capacitive

3 Phase 2 Wattmeter

$$\text{Total Power (Watts)} = [415 * 5 * \cos(30^\circ - -80^\circ)] + [415 * 5 * \cos(30^\circ + -80^\circ)]$$

$$\text{Total Power (Watts)} = [2075 * \cos(110^\circ)] + [2075 * \cos(-50^\circ)]$$

$$\text{Total Power (Watts)} = [2075 * -0.34] + [2075 * 0.64279]$$

$$\text{Total Power (Watts)} = [-709.69] + [1333.78]$$

$$\text{Wattmeter 1 Reading} = -709.69 \text{ Watts}$$

$$\text{Wattmeter 2 Reading} = 1333.78 \text{ Watts}$$

$$\underline{\text{Total Power (Watts)} = 624.09 \text{ Watts}}$$

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3 Phase 3 Wattmeter

$$\text{Total Power (Watts)} = [239.6 * 5 * \cos(80^\circ)] + [239.6 * 5 * \cos(80^\circ)] + [239.6 * 5 * \cos(80^\circ)]$$

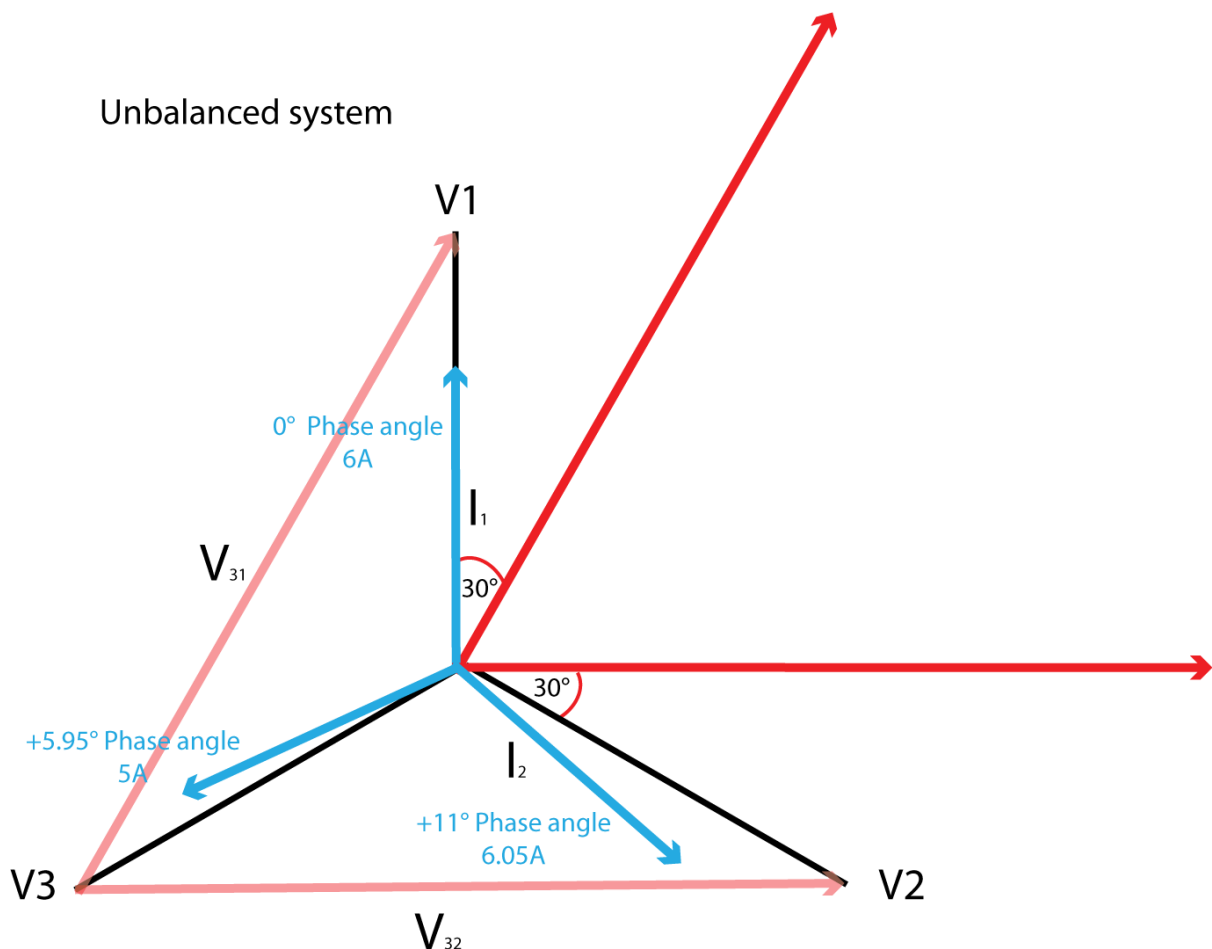
$$\text{Total Power (Watts)} = [208.03] + [208.03] + [208.03]$$

$$\text{Total Power (Watts)} = 624.09 \text{ Watts}$$

As calculated the sum of Wattmeter 1 + Wattmeter 2 will be to the total power.

Unbalanced Systems

Unbalanced 3 phase systems are still able to measure sum power with only two wattmeter's, here we have phase 1 purely resistive, phase 2 and phase 3 inductive, all with different phase angles and currents.



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3 Phase 2 Wattmeter

$$\text{Total Power (Watts)} = [415 * 6 * \cos (30^\circ - 0^\circ)] + [415 * 6.05 * \cos (30^\circ + (+11^\circ))]$$

$$\text{Total Power (Watts)} = [2490 * \cos (30^\circ)] + [2510.75 * \cos (41^\circ)]$$

$$\text{Total Power (Watts)} = [2156.40] + [1894.90]$$

$$\text{Wattmeter 1 Reading} = 2156.40 \text{ Watts}$$

$$\text{Wattmeter 2 Reading} = 1894.90 \text{ Watts}$$

$$\text{Total Power (Watts)} = 4052 \text{ Watts}$$

3 Phase 3 Wattmeter

$$\text{Total Power (Watts)} = [239.6 * 6 * \cos (0^\circ)] + [239.6 * 5 * \cos (5.95^\circ)] + [239.6 * 6.05 * \cos (11^\circ)]$$

$$\text{Total Power (Watts)} = [1437.6] + [1191.55] + [1422.95]$$

$$\text{Total Power (Watts)} = 4052 \text{ Watts}$$

This implies that for 3 Wire systems, only 2 wattmeters are required. The PPA15xx, PPA25/26xx and PPA55xx series power analyzers from Newtons4th have the option for a separate channel 3 configuration. This enables the measurement of a DC bus or a different frequency single phase input on channel 3, i.e. 4 phase measurement using 3 wattmeters.

$$\text{Number of wattmeter's needed} = \text{Number of wires} - 1$$

Conclusion

3 Phase 2 Wattmeter measurements can cater for both balanced and unbalanced loads, the method is proven when considering Kirchhoff's laws.

Kirchhoff's Laws

1. At any given time the sum of all currents in a network connecting at a node will algebraically equal zero
2. At any given time the sum of all voltages in a network connecting at a node will algebraically equal zero.

This indicates that as long as the current and voltage of two of the three phases are known, the third phase will be the value to algebraically equal zero when the third phase is added to the first two, balanced or unbalanced – it does not matter. Both wattmeters will not equal the same value under all conditions. One Wattmeter will read negative watts if the power factor goes below 0.5

The phase related data measured in 3 Phase 2 wattmeter mode is only useful for Sum power, if individual impedance and phase data is required for individual phases 3 Phase 3 Wattmeter must be used.

Note: With applications featuring 4 wire systems with a neutral return, the 3 Phase 2 Wattmeter readings will only be correct if the system is balanced; if the system is unbalanced 3 Phase 3 Wattmeter must be used in order to calculate the neutral return current.

The Newtons4th Power Analyzer range can be set up to perform both 3 Phase 3 Wattmeter and 3 Phase 2 Wattmeter modes, for more information and contact details for a distributor in your territory please visit <http://www.newtons4th.com/products/power-analyzers>

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