USE OF A SINGLE ELEMENT WATTMETER OR WATT TRANSDUCER ON A BALANCED THREE-PHASE THREE-WIRE LOAD WILL NOT WORK. HERE'S WHY.

INTRODUCTION

Frequently customers wish to save money by monitoring a three-phase, three-wire connected motor with a single element (one multiplier) watt (power) transducer. This will not work.

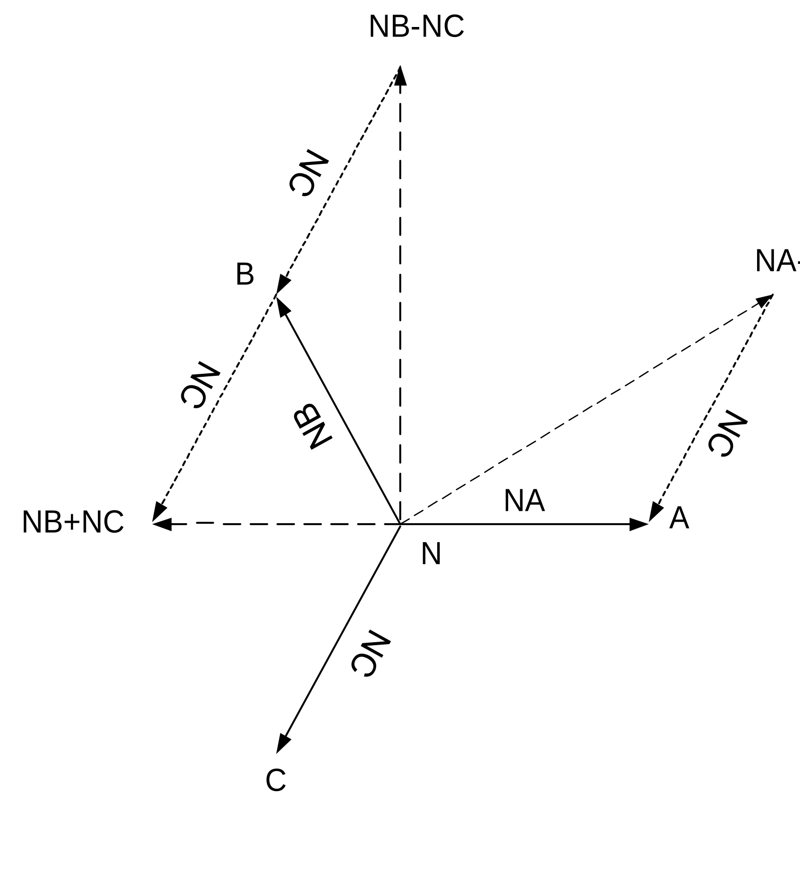
The voltage as measured from line to line in a three-phase circuit is 30º out of phase with the current as measured on one of the those two phase lines at unity power factor. If one has a wattmeter or watt transducer connected between phase lines A and C, the power registered is equal to the product of RMS voltage, RMS current, and the cosine of the phase angle shift + 30º. However if one has a second wattmeter or watt transducer connected between phase lines B and C, the power registered is equal to the product of the RMS voltage, RMS current and the cosine of the phase angle shift - 30º. Only when the phase angle shift equals zero degrees (0º) will the two read the same. The sum of the two will always be the total power.

SOME EXPLANATION

The following arithmetic is done using the software package Mathcad™. In doing these calculations Mathcad™ uses radians. There are 2π radians (360º) in a complete circle or in one cycle. For calculating power, we are interested in the range of –90º to 0° to +90º or from $-\pi/2$ to 0 to $+\pi/2$ in radians.

In order to graph the three power curves I will let the phase angle displacement between the voltage and current in radians vary from $-\pi/2$ to 0 to $+\pi/2$ (-90º to 0º to +90º). We will step the iteration by 5º by saying let θ range from –90 to +90 multiply the result by π and divide it by 180.

On the next page is a vector diagram illustrating the relationship of the three voltages and the potential difference as measured between phases A and C and between B and C.



Voltage relationships in a three-phase system at a selected point in time.

Points A, B, & C rotate with time but maintain the same angular displacement from each other.

The vector diagram above illustrates the phase relationship in a three-phase system. Note the following:

- The three phases A, B and C are mutually 120º apart.
- The voltage as measured from phase C to phase A leads the current on phase A by thirty degrees. Or put another way, the current on phase A lags the voltage as measured from C to A by 30º.
- The voltage as measured from phase C to phase B lags the current on phase B by thirty degrees. Or put another way, the current on phase B leads the voltage as measured from C to B by 30º.

The arithmetic of this situation is on the next page. (If you are not interested in the arithmetic, skip ahead to page 4.)

THE ARITHMETIC

For practical reasons assume that all three line to line voltages are the same (balanced) and that all three phase currents are the same. The apparent power (RMS line to line voltage multiplied by RMS current) is set as follows so that the total power can be expressed as a percent of maximum power.

$$VA := 50 \cdot \left(\frac{2}{\sqrt{3}}\right)$$

The power is evaluated over the range of -90 through 0 to +90 degrees (-π/2 to +π/2) in steps of 5 degrees.

$$\theta := -90, -85 .. 90$$

Let P1 be the power measured between phases A and C.

Let P2 be the power measured between phases B and C.

PT = P1 + P2 where PT is the total power.

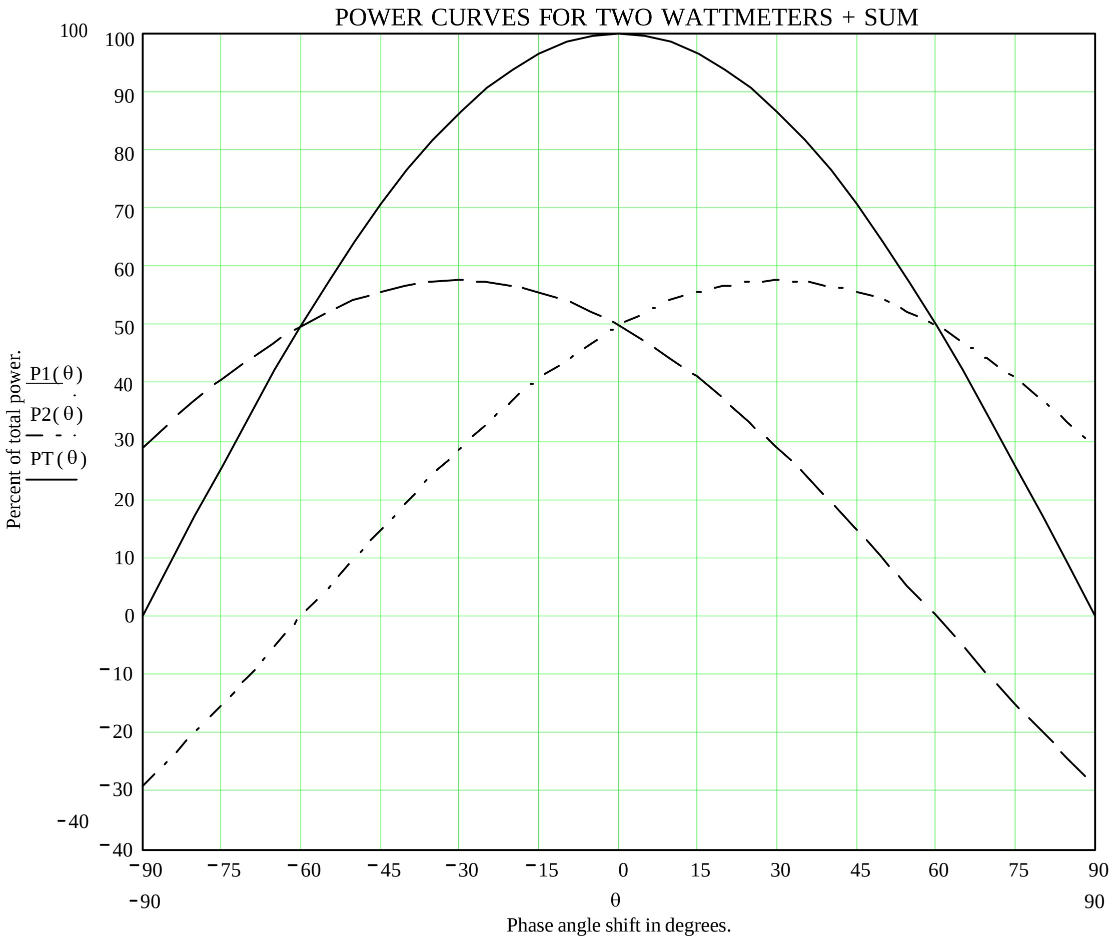
$$P1(\theta) := VA \cdot \cos\left(\theta \cdot \frac{\pi}{180} + \frac{\pi}{6}\right)$$

$$P2(\theta) := VA \cdot \cos\left(\theta \cdot \frac{\pi}{180} \quad \frac{\pi}{6}\right)$$

$$PT(\theta) := P2(\theta) + P1(\theta)$$

The power curves are graphed on the next page.

THE GRAPH



In the graph above the solid line represents total power. The dashed line represents the power as measured from phase A to phase C. The dash-dot line represents the power as measured from phase B to phase C. Some things to note:

- At 0º phase shift the two phase to phase power curves cross. At unity power factor the two are equal and each represents 50% of the total power.
- At -90º phase shift the power as measured from B to C is –29% and the power as measured from A to C is +29%. The total is 0 – exactly what is expected with a -90º phase angle shift.
- At +90º phase shift the power as measured from B to C is +29% and the power as measured from A to C is -29%. The total is 0 – exactly what is expected with a +90º phase angle shift.
- At +30° phase shift the power as measured from B to C is exactly double the power as measured from A to C.
- At +60° phase shift the power as measured from B to C is the total power while the power as measured from A to C is exactly zero.

CONCLUSION

Use of a single element watt transducer measuring the power between two phases of a three phase connected system does not work except at unity power factor (phase angle shift of 0°).

Because a typical motor load operates with a power factor varying with the load, a single element watt transducer connected between two phase lines will give an output that is meaningless. For the typical motor that runs with a power factor of 0.9 and less, the results will be either too high or too low depending on which pair of phase lines are used.

For a lightly loaded motor the output of a single element watt transducer connected between phase lines A and C will go negative below a power factor of 0.5.

THE EXCEPTION

Take a close look at the vector diagram on page 2 of appendix D. If one measures the **voltage difference** between two phase lines and **the current difference** between those same two phase lines, the two resultant vectors are in the same direction.

Measuring the voltage difference between two phases is easy – just connect the two phase lines to the potential input of a wattmeter or watt transducer. How can one measure the current difference?

1. Run the phase lines through a single current transformer in opposite directions.
2. Put current transformers on the two phase lines and connect both current transformers to a wattmeter or watt transducer in parallel but opposite in polarity.

The resultant current will be larger than the phase current by a factor of the square root of 3 (1.732…). The voltage difference between two phase lines is greater than the line to neutral voltage by a factor of the square root of 3 (1.732…). Therefore, the single element watt transducer will provide an output that is already scaled correctly – one only needs to multiply by the current transformer ratio and (if used) the potential transformer ratio. This works for a balanced load on balanced voltage only.

Why would one do this?

1. Someone goofed by ordering single element transducers to monitor a balance three-phase motor load, the transducers are already installed, providing incorrect information, and the situation needs to be corrected without exchanging the transducers. (All too common!)

2. A high voltage motor is to be monitored and the instrument grade potential transformers are far more expensive than the watt transducer. The user wants to save money.

For this second situation buy a 1 ½ element transducer already connected internally to read the voltage between two phases and the current on those same two phases.