

## Two-wattmeter-method, 3-phase Power Calculations with Accurate Line-Line to Line-Neutral Conversion

TECHNICAL BRIEF

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### Summary

The two-wattmeter method reduces from six to four the number of input channels required to measure power on a 3-phase system. With this method, the calculated power values from each line-line voltage and line-neutral current pair are not in phase or balanced, though the total 3-phase power value is correct. However, the Motor Drive Analyzer (MDA) performs a line-to-line to line-neutral conversion and displays accurate and balanced per-phase power values that aid in understanding proper 3-phase system operation.

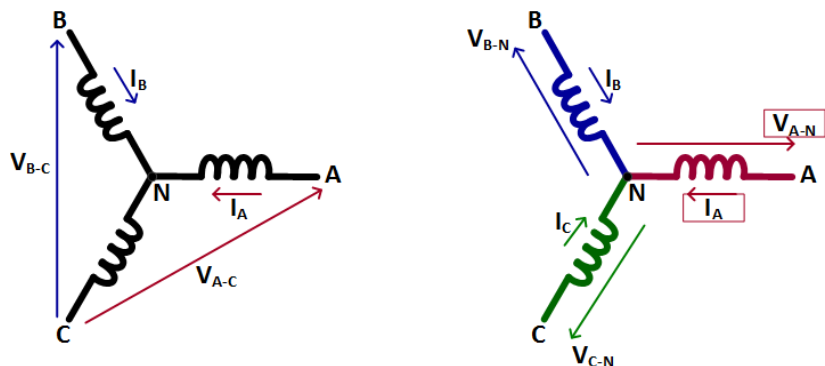
### Introduction

In the example to follow, we will show how to use the Teledyne LeCroy Motor Drive Analyzer to measure voltage, current and power using the two-wattmeter method. This method uses two pairs of line-line voltages and line-neutral currents to calculate total 3-phase power. Additional calculations then show the accurate per-phase power across all three phases as if all three phases were measured directly.

### Blondel's Theorem and Line-Line to Line-Neutral Conversion

There are many readily available references to Blondel's Theorem—it is a proven and accurate method of obtaining 3-phase total power using two wattmeters, including line-line voltage and line current measurements. However, it does not calculate the power in each phase of the winding—understanding the power in each phase calls for a mathematical conversion.

*Figure 1* shows the two measured voltages and currents when using the two-wattmeter method (left) and when using a three-wattmeter method using line-neutral voltage measurements (right).



*Figure 1: Two-wattmeter method voltage and current pairs (left) and three-wattmeter method voltage and current pairs (right)*

The two-wattmeter method uses two voltage measurements referenced to the same phase (line) and the two currents flowing into that phase. The assumption is that the 3-phase system is balanced, i.e., the summation of

all voltages = 0 V and the summation of all currents = 0 A. This is true if there is no leakage current from neutral to ground.

The three-wattmeter method requires voltage measurements from line-neutral. Many motors (and some transformer windings) are connected in either a Delta ( $\Delta$ ) configuration (Figure 2, left) or in a Wye (Y) configuration (Figure 2, right). In the latter case, the neutral is inaccessible.

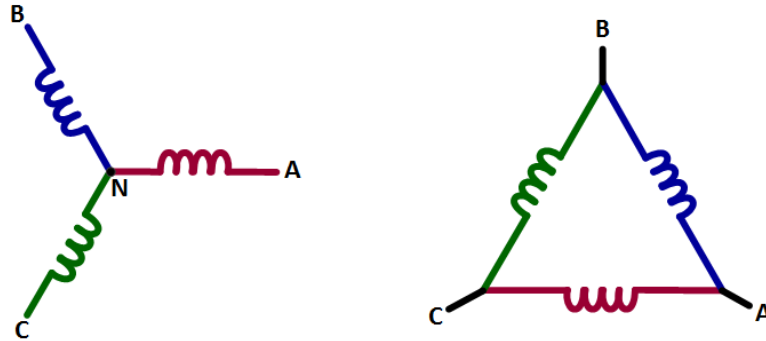


Figure 2: Wye (Y, or Star) winding (left) and Delta ( $\Delta$ ) winding (right).

Fortunately, it is simple to measure two voltages and currents (as shown in Figure 1, left), convert the line-line voltages to a line-neutral vector, solve for the “missing” third phase voltage and current vectors, and calculate using a three-wattmeter method. We will show this using the Teledyne LeCroy Motor Drive Analyzer and actual motor drive input and output acquisition data.

### Two-wattmeter Calculation Examples Using the MDA

Figure 3 shows the AC Input setup dialog in the MDA (there is a similar setup for the Drive Output) using a two-wattmeter wiring configuration (3-phase, 3-wire, 2V2A). This matches the example shown in Figure 1.

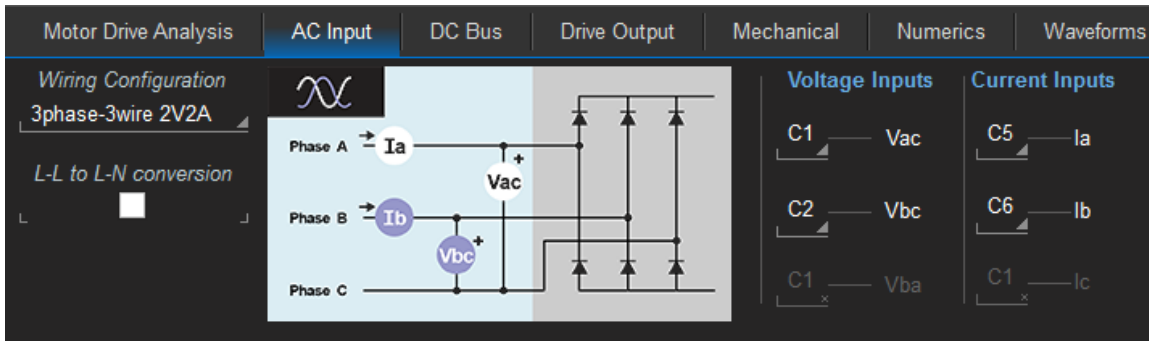


Figure 3: AC Input setup dialog in the MDA showing a two-wattmeter connection.

Figure 4 shows the full set of acquisition data for the AC Input to the motor drive (left grids) and the full set of acquisition data for the Drive Output (right grids). Below that is a Numerics table that displays the mean-value calculated data for each voltage/current pair and the total 3-phase values for both the AC Input and Drive Output. Note that the line-line voltage and line current pairs are not balanced, meaning that the calculated power (real, apparent, and reactive power; power factor; and phase angle) values for the voltage/current pairs are not the

same. This is normal and expected for a two-wattmeter method calculation—the voltage and current pairs are not phase-aligned or directly associated, but the 3-phase total is correct.

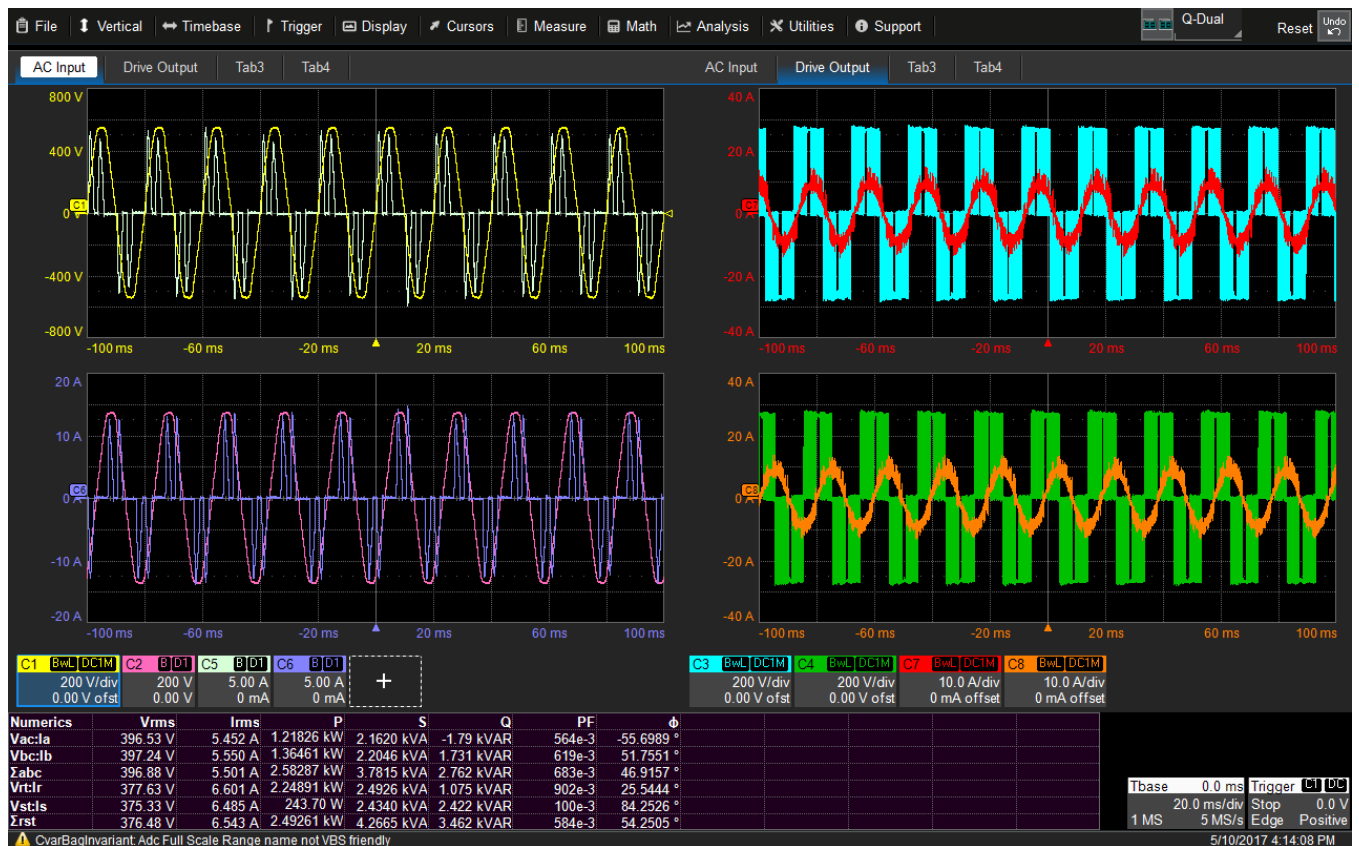


Figure 4: Acquisition data from the motor drive AC input and output with power calculations shown in the Numerics table.

Figure 5 shows a larger view of the Numerics table.

Numerics	Vrms	Irms	P	S	Q	PF	$\phi$
Vac:la	396.53 V	5.452 A	1.21826 kW	2.1620 kVA	-1.79 kVAR	564e-3	-55.6989 °
Vbc:lb	397.24 V	5.550 A	1.36461 kW	2.2046 kVA	1.731 kVAR	619e-3	51.7551 °
$\Sigma$ abc	396.88 V	5.501 A	2.58287 kW	3.7815 kVA	2.762 kVAR	683e-3	46.9157 °
Vrt:lr	377.63 V	6.601 A	2.24891 kW	2.4926 kVA	1.075 kVAR	902e-3	25.5444 °
Vst:ls	375.33 V	6.485 A	243.70 W	2.4340 kVA	2.422 kVAR	100e-3	84.2526 °
$\Sigma$ rst	376.48 V	6.543 A	2.49261 kW	4.2665 kVA	3.462 kVAR	584e-3	54.2505 °

Figure 5: A larger view of the Numerics table shown in Figure 4.

### Line-Line to Line-Neutral Conversion

As seen in Figure 3, the “L-L to L-N conversion” checkbox was unchecked. Checking the box invokes a mathematical vector and value conversion, and the Numerics table data converts to this basis, as shown in Figure 6. Note that voltage values were divided by  $\sim\sqrt{3}$  and the individual phase pairs show power balance (as would be expected). The total 3-phase power values change slightly due to the enforcement of 3-phase system balance (e.g.,  $V_{A-B}+V_{B-C}+V_{C-A} = 0$  and  $I_A+I_B+I_C = 0$ ) in the conversion algorithms.

Numerics		Vrms	Irms	P	S	Q	PF	$\phi$
Va:la	LL to LN	229.43 V	5.452 A	854.06 W	1.2510 kVA	-914.06 VAR	683e-3	-46.9514 °
Vb:lb	LL to LN	229.83 V	5.550 A	866.82 W	1.2756 kVA	-935.80 VAR	679e-3	-47.1982 °
Vc:lc	LL to LN	228.89 V	5.432 A	862.01 W	1.2435 kVA	-896.27 VAR	693e-3	-46.1175 °
$\Sigma abc$	LL to LN	229.38 V	5.478 A	2.58288 kW	3.7702 kVA	2.74636 kVAR	685e-3	46.7564 °
Vr:lr	LL to LN	218.01 V	6.601 A	819.84 W	1.4390 kVA	1.18257 kVAR	570e-3	55.2684 °
Vs:ls	LL to LN	216.64 V	6.485 A	823.91 W	1.4049 kVA	1.13780 kVAR	586e-3	54.0899 °
Vt:lt	LL to LN	217.35 V	6.664 A	849.05 W	1.4484 kVA	1.17340 kVAR	586e-3	54.1138 °
$\Sigma rst$	LL to LN	217.33 V	6.583 A	2.49280 kW	4.2923 kVA	3.49408 kVAR	581e-3	54.4958 °

Figure 6: Numerics table after the L-L to L-N conversion is performed.

### Why Do Some Instruments Not Show Balance After L-L to L-N Conversion?

A common confusion among power analyzer users is why their instruments never show complete per-phase balance after a line-line to line-neutral (sometimes called a delta-star) conversion. More than likely, it is because the instrument uses a two-wattmeter-method wiring configuration even when the user has opted to use three line-line voltages and three line currents.

See Figure 7 (left) for the connection of the two voltages and two currents for two-wattmeter measurement and Figure 7 (right) for a three-wattmeter measurement using three line-line voltages. Note that the polarity of the  $V_{A-C}$  measurement differs between the two. If the power analyzer requires no change in connection when switching from a two-voltage to a three-voltage method, power is measured using a two-wattmeter method even if the user has made another selection. A conversion algorithm may provide correct, balanced results for real power (P) across phases, but the incorrect voltage and current vector pairs will often result in inaccurate per-phase reactive power (Q), apparent power (S), power factor, and phase angle calculations.

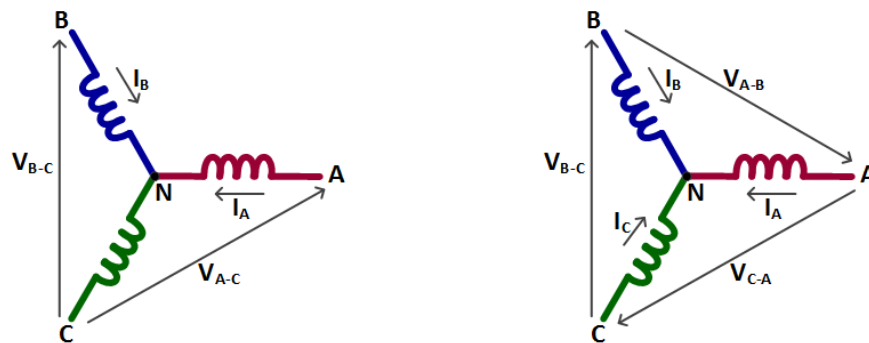


Figure 7: Two-wattmeter wiring configuration (left) and typical measurement of three line-line voltages and currents.

### Conclusion

The Teledyne LeCroy Motor Drive Analyzer accurately measures 3-phase power using two line-line voltages and two line currents. It also performs line-line to line-neutral voltage vector conversions and 3-phase power calculations from the converted voltage vectors and acquired line currents. The resulting per-phase calculations balance across all three windings, as would be expected, for debugging of per-phase power behaviors.