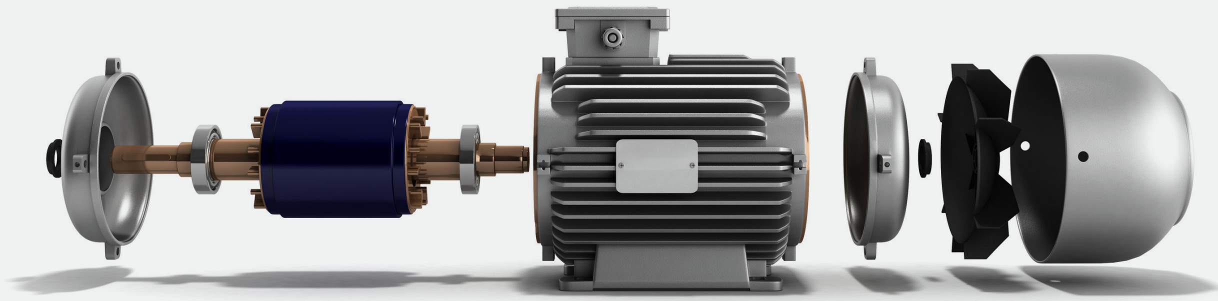


Eight Steps for Electric Motor Power Measurements and Analysis

The Challenge

Energy represents one of the highest costs in modern electromechanical systems, and motors often consume most of the power in applications ranging from consumer appliances and electric vehicles to entire manufacturing facilities. Ensuring that motors are operating optimally is vital to the operating cost of the entire system. By detecting conditions such as a slight wobble in a motor shaft, an accurate power measurement can lead to a significant reduction in energy consumption, improved performance, and an extended lifecycle for the motor.

This document describes the process for measuring and verifying proper motor function using a power analyzer and how to troubleshoot common errors in the measured output.

Necessities

Acquiring measurement of the power and efficiency of motors with the highest fidelity possible requires a high-precision power analyzer with an appropriate number of input elements. For example, six elements allow for the inputs and outputs of a three-phase AC drive system, with two more required to measure torque and speed outputs from the motor. The Yokogawa Test&Measurement solution to this challenge is the WT series of power analyzers.

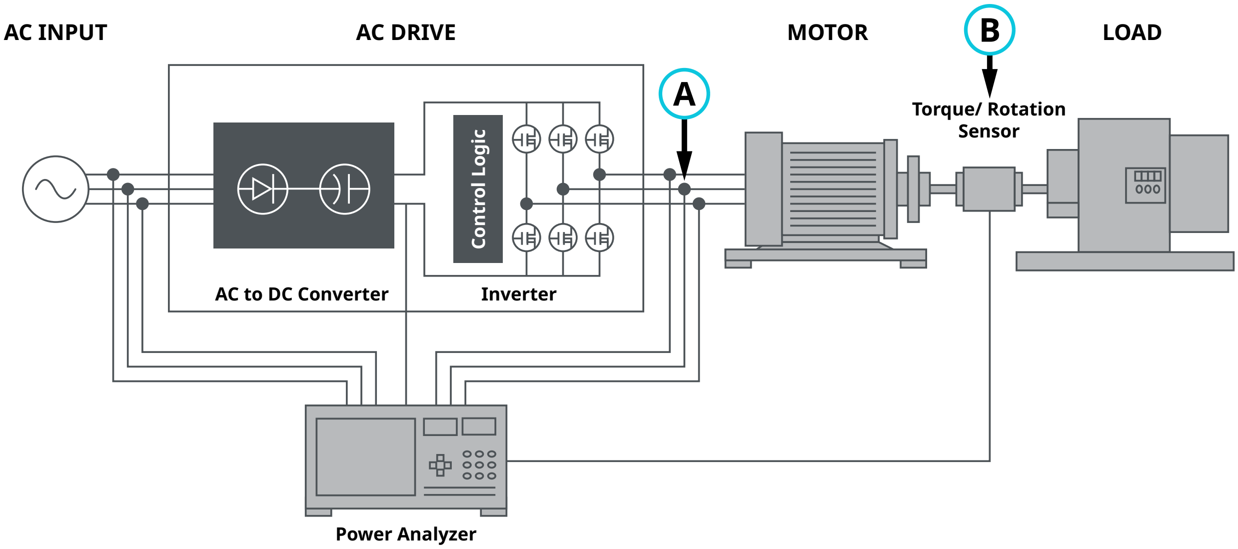


Figure 1. Motor power and efficiency measurements are taken at measurement points A and B.

Keys to Proper Setup

When setting up a motor test, the following settings ensure accurate initial measurements:

1 Wiring – 3V3A

Most motors do not have a neutral connection and require voltmeters to be connected in the delta configuration (3V3A). This means phase voltage cannot be directly measured and voltmeters are instead connected line-to-line (delta). Follow the guidelines below for connecting the power analyzer to the motor in this configuration.

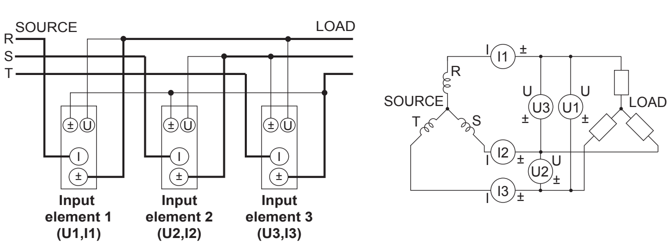


Figure 2. This wiring diagram is specific to the WT5000 precision power analyzer. Users of other instruments need to consult the appropriate manuals for proper configuration.

Once connections are made, users must configure the wiring system in the power analyzer Setup menu. In the case of the WT5000, this is done by tapping the Setup icon or pressing Menu under Setup (Figure 3). Changing Element 1 to 3V3A will change Element 2 and Element 3 to 3V3A as well. Click here for more information on three-phase motor connections.

Figure 3. Wiring configurations are displayed beneath each element in the Setup menu.

2 Voltage Range – Auto

The power analyzer has 12 range settings. Configuring the range improperly can significantly impact the accuracy of the voltage and power readings. The Auto Range setting automatically determines the most appropriate measurement limits to ensure the entire signal is read with optimal accuracy. This includes automatically adjusting the crest factor setting to account for the shape of the input signal (PWM vs. sinusoid, noisy vs. clean, etc.). To change the range setting, return to the Setup menu and press the field for Voltage Range under the elements to find the menu shown below.

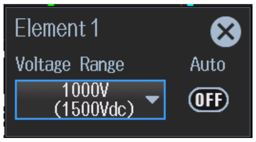


Figure 4. Users can toggle the Auto button to ON for each of the elements.

3 Current Range – Auto

Motor curves are usually developed on a dynamometer by sweeping the motor's speed and torque. Motor current is roughly proportional to the torque delivered. As the torque load on the motor is varied, the Auto Range feature can be used to decide the optimal measurement range. This is typically a wide range when sweeping from no-load conditions to full-load conditions.

Like with voltage range, current range is accessible from the Setup menu by pressing the field labeled Current Range.

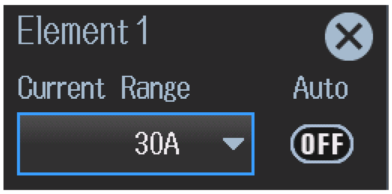


Figure 5. Users can toggle the Auto button to ON for each of the elements.

4 Scaling – Current Transformer (CT) scaling if CTs are used, Voltage Transformer (VT) scaling if VTs are used

For motor currents greater than 50A, it is common to use a CT for safe, galvanically-isolated measurement of high currents. Although not as common, VTs or dividers are also used to step-down a higher voltage to a range that is compatible with the power analyzer. If the measurement setup uses CTs or VTs for this purpose, it is necessary to set the scaling ratio on the power analyzer accordingly. Unless the scaling is set properly in the element menu, power readings will not be accurate. Users can find scaling in the Setup menu under the field labeled Scaling, directly below the Current Range field.

Figure 6. Users can copy the VT and CT ratios to all elements in the selected element's wiring system by pressing Copy Σ, then Copy Exec.

5 Line Filter – Starting at 1MHz

Unwanted, conducted, or radiated electrical noise in signals feeding the power analyzer can be a nuisance to obtaining accurate power readings. One method for determining the presence of these signals and mitigating them is to use the internal line filter of the power analyzer. Since this filter is in series with both the voltage and current measurements, experimenting with its cutoff frequency can help to identify sources of noise in the input signal and remove them.

The ideal cutoff frequency also depends on other factors for a test's specific measurement conditions. For example, when measuring a DC bus, it may be appropriate to set a low cutoff frequency that is close to that of an expected DC ripple (or lower if the ripple's impact is being excluded). Likewise, when using an external current measurement device, it makes sense to set a line filter close to the cutoff frequency for that device, since any power delivered above that frequency would be noise (e.g., LEM CT's have a bandwidth in the 100kHz's region). The Filter menu can be found by navigating to the Setup menu and pressing the Filter icon.

Figure 7. In the Filter menu, line filters and frequency filters for each element can be enabled and adjusted.

6 Frequency Filter

For the best possible power accuracy, the power analyzer requires a precise measurement of the waveform's cycle period. The power analyzer uses the current and voltage measurements over this measurement period to calculate power, rms values, harmonic distortion, and many other values that depend on a time integration or frequency reading. For instance, in the case of synchronous permanent magnet motors, the frequency measurement is proportional to the speed of the motor.

In order to accurately identify the cycle period's zero-crossing events, the signal measurement should be clean enough to avoid crossing zero more than once per rising/falling edge. The frequency filter ensures that noise will not affect the zero-crossing detection of the period measurement process.

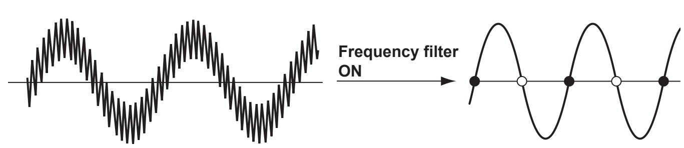


Figure 8. Enabling the frequency filter removes any high-frequency noise that could affect your period measurement.

The frequency filter should be set according to the following table:

Input Signal Frequency	Cutoff Frequency
100 Hz or less	0.1 kHz
1 kHz or less	1 kHz
100 kHz or less	100 kHz

Figure 9. To enable the frequency filter, press the Filter icon from the Setup menu and toggle the ON button under the input elements.

7 Sync Source – I1 (or the first element's current of the multi-phase motor connection)

The signal on which the measurement period is made is referred to as the sync source. This signal is generally chosen to be the cleanest sinusoidal waveform available in the motor system. In the case of sinusoidally-wound and commutated PWM motors, the inductance of the stator windings smooths out the modulated voltage signals to produce a sinusoidal current waveform.

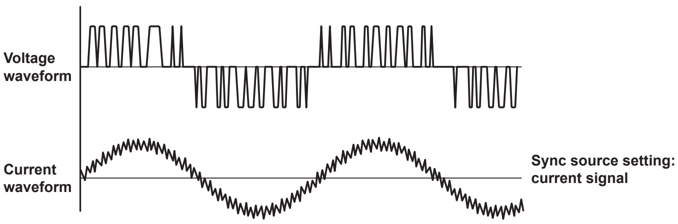


Figure 10. The motor's inductive behavior creates a mostly sinusoidal current waveform in response to the PWM voltage input.

Using the current waveform for the synchronization source provides a relatively clean sinusoidal signal that makes it easier to precisely identify zero-crossings and obtain an accurate period measurement.

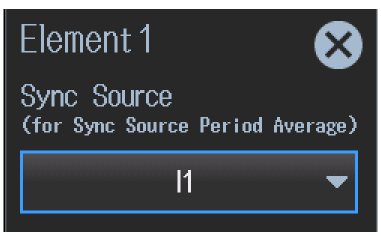


Figure 11. To change the sync source, navigate to the Setup menu and press the Sync Source button under the elements in the motor's wiring group, then choose the proper signal from the drop-down.

8 Motor/Aux – Motor speed and torque analysis (optional)

Measuring the efficiency of electrical motor systems requires capturing the mechanical output power produced at the rotor shaft. The power analyzer calculates this mechanical power using outputs from torque and speed sensors. This output power is then used to calculate electromechanical efficiency of the motor, giving users access to full system efficiencies in one instrument.

To enable motor evaluation, navigate to Setup, Input (Advanced/Options), and then Motor/Aux. In this menu, make appropriate selections for the number of motor measurements, the type of speed input, and the electrical angle measurement settings.

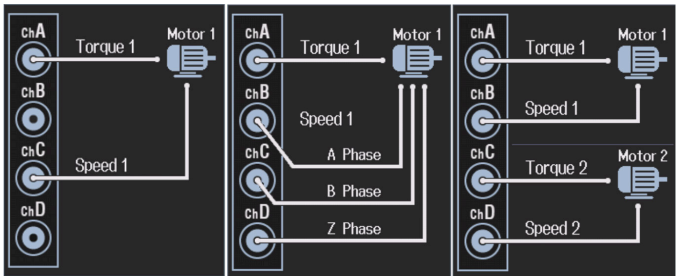


Figure 12. With the MTR1 option, one motor can be evaluated with an analog or ABZ speed encoder, whereas two motors can be evaluated with analog/pulse signals for speed.

The motor analysis function allows detailed configuration of the settings for torque and speed inputs through the Ch Settings button. For analog torque signals, Analog Range and Auto-Range settings are available, and linear scaling/offset can be calculated and set within the Ch Settings menu.

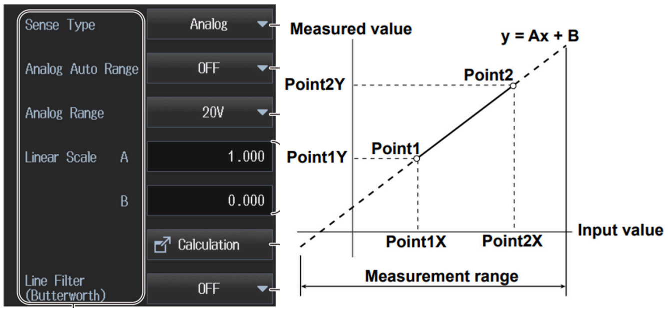


Figure 13. When Sense Type is set to Analog, the linear scaling values for slope (A) and intercept (B) can be adjusted. For simpler calculation of slope and intercept, two ordered pairs of voltage and torque can be input in the Calculation window.

When Torque Type is set to Pulse, upper and lower settings for Pulse Range, Rated Torque, and Rated Frequency can be adjusted manually. The Pulse Range setting controls the upper and lower bounds of torque when the signal is output from the power analyzer's D/A converter and may differ from the rated upper/lower torque values.

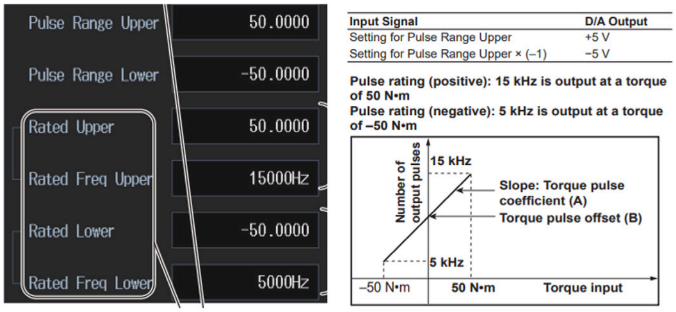


Figure 14. When Sense Type is set to Pulse, ordered pairs of pulse frequency and rated torque are used for calculation of torque measurement. Pulse Range Upper corresponds to the +5V and -5V of the D/A converter in the power analyzer.

To ensure proper speed measurements, it's necessary to enter the Pulse N of the motor.

Figure 15. Set the number of pulses per revolution (1 to 9999) of the revolution signal during Pulse speed mode, which is used to compute synchronous speed.

What to Expect

The specifics of an application determine what to expect from the measurement results. In order to determine what is acceptable on a test, use the expected performance curves to look at anticipated torque, speed, power factor, and current and voltage efficiency. From there, investigate an operating point to test against.

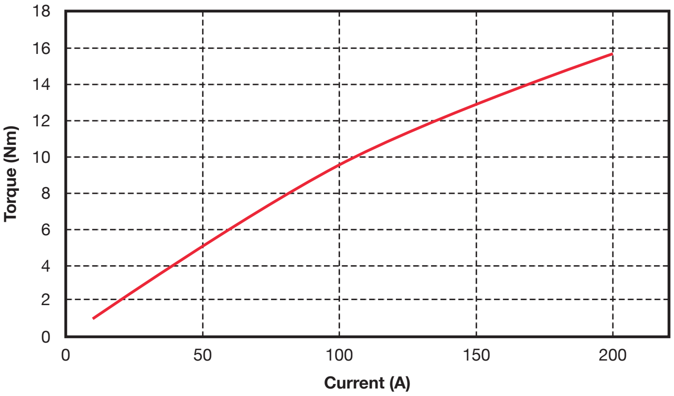


Figure 16. This torque-current curve represents one example for which a test of proper operation could be performed.

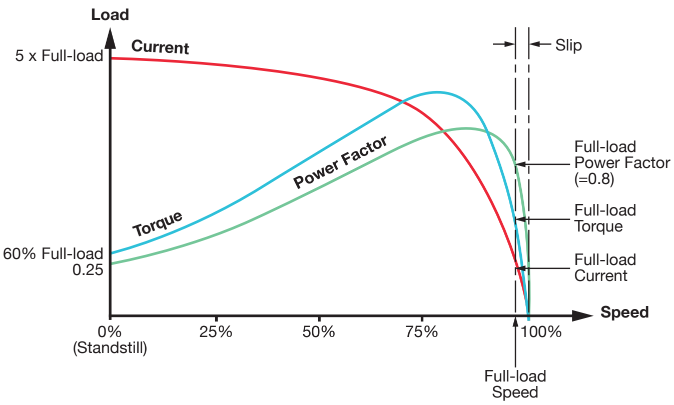
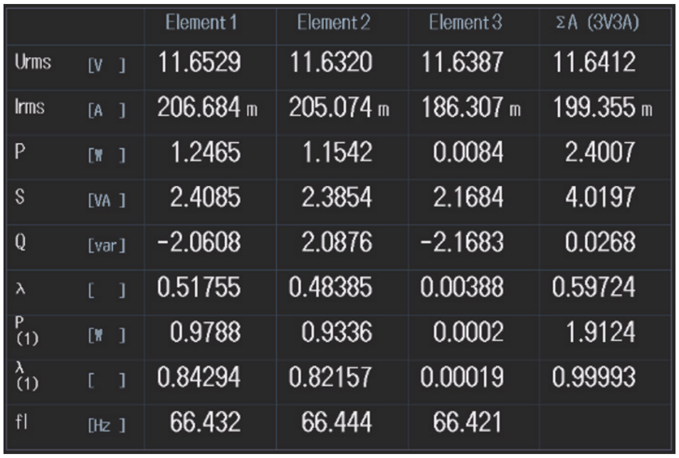


Figure 17. This torque-speed curve represents the expected behavior of current, torque, and power factor as motor speed is adjusted.

Be sure to drive the motor with sufficient load such that it is well within its designed steady-state operating region. This is important so that the true power, apparent power, reactive power, vector diagram, power factor, and efficiency numbers are sufficiently high enough to reasonably fit expected performance curves. Typically, a 30-80% load point will result in a power factor of 0.4-0.8 and greater than 80% efficiencies.



		Element 1	Element 2	Element 3	ΣA (3V3A)
Urms	[V]	11.6529	11.6320	11.6387	11.6412
Irms	[A]	206.684 m	205.074 m	186.307 m	199.355 m
P	[W]	1.2465	1.1542	0.0084	2.4007
S	[VA]	2.4085	2.3854	2.1684	4.0197
Q	[var]	-2.0608	2.0876	-2.1683	0.0268
λ	[ ]	0.51755	0.48385	0.00388	0.59724
P(1)	[W]	0.9788	0.9336	0.0002	1.9124
λ(1)	[ ]	0.84294	0.82157	0.00019	0.99993
fI	[Hz]	66.432	66.444	66.421	

Figure 18. The numeric display values anticipated in a low-power motor example. Measurement items followed by (1) indicate measurement of the signals' fundamental frequency.

The three-phase readings in the rows in Figure 18 for power (P), power factor (λ), and current frequency (fI) are critical for comparison with the desired motor performance curves. When observing the individual phase powers in 3V3A configuration, a low or even negative power reading on Element 3, and similar power readings on Element 1 and Element 2, would be expected. This tends to deviate at lower power factors. A negative power reading on Element 3 should not be cause for alarm as it is not included in the calculation of total power. The current waveforms are expected to be roughly sinusoidal and phase-shifted by approximately 120°, while the voltage waveforms appear as PWM signals. However, since the voltage inputs are line-to-line, they have a phase shift of roughly 60° between them, instead of 120 degrees for the current signals.

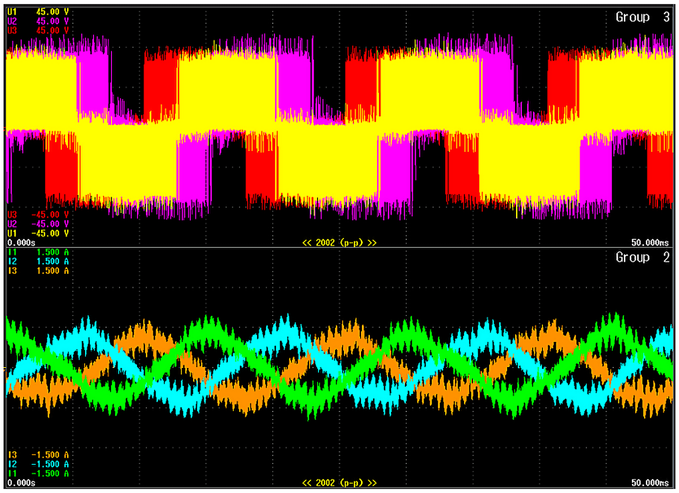


Figure 19. An example of the waveform display of the motor input voltage and current.

The power analyzer includes a vector display form to show relative phase angles and magnitudes for the wiring system's voltage and current inputs. In a 3V3A configuration, the delta is formed by the line-to-line voltages while the star is formed by phase currents. Due to the motor's behavior as an inductive load, a counterclockwise rotation of the delta at lower power factors is expected.

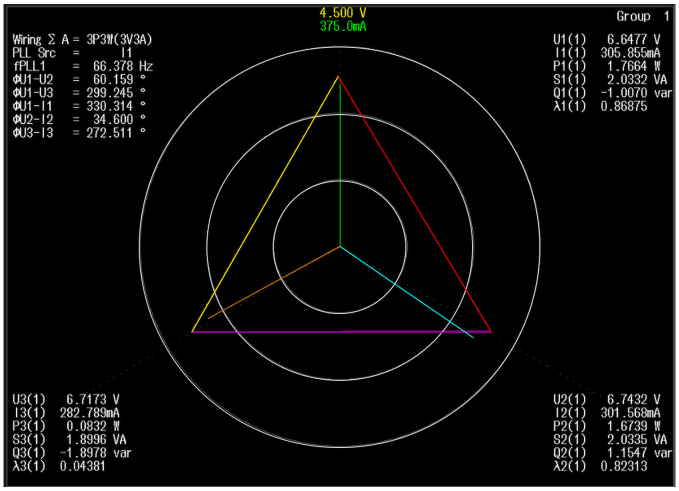


Figure 20. When the 3V3A wiring is properly connected, the vector graph should appear similar to this image.

Troubleshooting

If there is significant error in power readings, check the current transformer settings. Work through the CT ratios and effective measurement range of the meter itself to understand the expected performance and ensure CT ratings are not sized too large for the actual current being measured, then match an input element to the output of the CT signal. Since most CTs output less than five amps, a lower-rated element will provide more accuracy (For more information, please see the Yokogawa Test&Measurement High Current Measurement Guide). Observe the vector diagram to verify wiring is correct and phases are matched. If the diagram is significantly different from the expected form, a wiring error may be present.

If there is negative total power, check to see if P1 and P2 are negative. The wiring for current is likely swapped on the current measurement. Negative power can also mean the motor is in generation mode and sending energy back to the source instead of motoring and consuming power. This is normal operation and power factor will also indicate a negative value.

For more troubleshooting, please visit the Yokogawa Test&Measurement FAQ page or contact a member of the Yokogawa suppor team.

Learn more about Yokogawa Test&Measurement power analyzer solutions.