White Paper

Efficiency Testing of Electrical Actuator-Based Systems

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The mechanical world around us is becoming increasingly electrified. This is clearly evident in consumer goods, public transportation, elevators, escalators, vehicles, various pumps, drives and valves used in industrial equipment. In these systems, electrical actuators are rapidly replacing hydraulics power sources or others.

Generally, electric actuators use a single-phase or three-phase electric motor with a gearbox to create the torque required for operating the moving elements. The actuators may be pumping liquids, such as water, pharmaceuticals, chemicals, oil, or natural gas, or merely driving a mechanical system. Such electrical motors sometimes consume 30% of the total energy consumed by a system, when in standby mode. This wasted energy adds up, substantially increasing both the operating costs and maintenance costs of electrically-actuated devices.

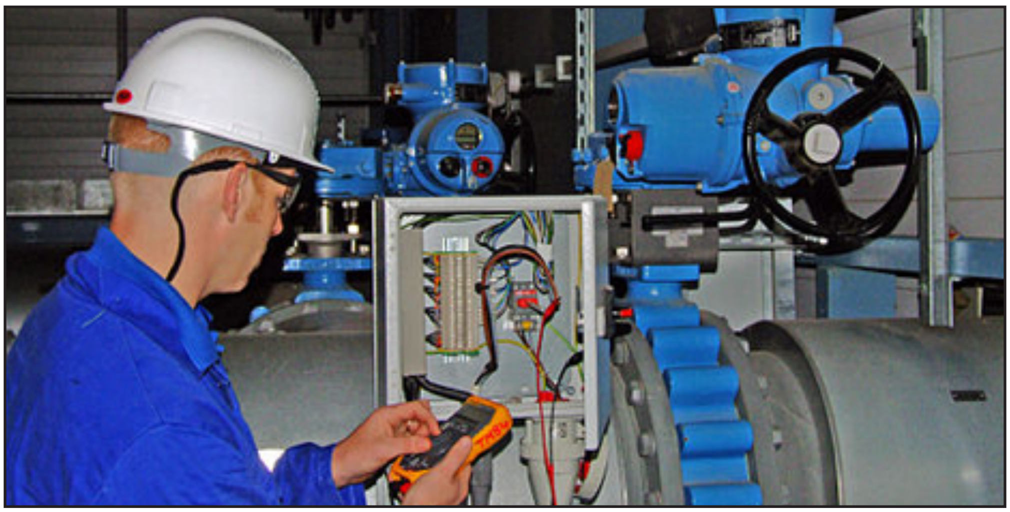

Figure 1. *Three-phase drives, like the one shown here, are taking the place of mechanical actuators in many industrial applications.*

Since 1997, there have been regulations in place that set minimum efficiency standards for general-purpose, three-phase motors rated as low 1 hp and as high as 200 hp. These regulations were updated in 2010, when the Energy Independence and Security Act of 2007 (EISA) went into effect. This legislation raised the minimum efficiency levels of the motors covered by the earlier legislation and extended the regulations to electric motors up to 500 hp as defined in National Electrical Manufacturer's Association (NEMA) Standard MG 1-2011.

The regulations cover all drives sold in the U.S. and motors installed in machinery imported for sale. Canada and Mexico have similar regulations.

In addition to these regulations, the DOE has what's called the Small Motor Rule. This rule applies to general-purpose two-digit NEMA frame (and IEC equivalents), single- and three-phase, 1/4- through 3-horsepower motors in open enclosures. This regulation will go into effect on April 9, 2015. NEMA has published a white paper to help manufacturers and users interpret this rule and meet the requirements (http://www.nema.org/Policy/Documents/EERE2014BTGUID0001%20NEMA%20comments%20DOE%20Small%20Electric%20Motors%20Draft%20Guidance%2012Feb14%20v7_1.pdf).

The Measurement Challenge

In order to determine the efficiency of today's electrically-driven systems accurately, your measurement system must make both electrical voltage and current measurements, calculating power, and with torque and speed the mechanical measurements calculating power simultaneously. Once the data acquisition system has made both the electrical power measurements and the mechanical or hydraulic power measurements, calculating the ratio to determine power efficiency is relatively simple.

In addition to measuring power efficiency, you may also need to make power quality measurements as part of your product design or system testing. Electrical actuators may cause voltage sags or cause excessive harmonic distortion.

When making power quality measurements, it is important to make them with high accuracy and best possible resolution. Many power analyzers available today typically make 16-bit measurements with an accuracy of 0.1%. This may be insufficient for some applications, but modern data acquisition systems can provide much higher accuracy (typically 0.05%) at 24 bits of resolution. These more accurate measurements can help you find problems earlier or as service job. And because these data acquisitions systems also do acquire sensor signals from torque, speed, displacement, flow, pressure, temperature and humidity, it may be easier to determine the cause of a power quality problem.

Another advantage in using a single data-acquisition system in comparison to a collection of special-purpose standalone instruments or handhelds is that you'll save time processing the test data. Many standalone instruments don't have the ability to stream and store raw signals. The raw data is very helpful when trying to analyze overall load situation and special conditions or detect an anomaly. Although some instruments have an option to interface with mechanical measurement devices, they can be expensive and lack seamless integration thereby leaving the end user as a do it yourself task.

Case Study: Measuring the Efficiency of a Three-Phase Motor

For most industrial applications, engineers use three-phase motors. One of the reasons for this is that a three-phase motor is typically 50% more efficient than a comparable single-phase motor.

Another reason to use three-phase motors is that they are self-starting. Single phase induction motors have no starting torque, so you must provide an auxiliary means of starting them. Single-phase motors also vibrate more than three-phase motors. This can lead to premature failure of the motor or the machine that it is powering.

Isolating the data acquisition system from these hazardous voltages and their transients are very important. Most inputs of data acquisition systems are not isolated and may be not safe enough for the user and not able to handle transient voltages. Must have information before using a modern instrument is the so called measurement category according to IEC 61010 from II to IV. Without this and on just a datasheet entry about isolation it can cause the device to fail or users to be seriously injured.

Buying a data acquisition system with a CAT II or CAT III safety rating reduces the risks of working in these high voltage domains. One such system is the QuantumX data acquisition system from HBM. In addition to isolation the new QuantumX MX403B amplifier can measure low or high voltages at high electrical potential.

Figure 2. *the scalable QuantumX MX403B data acquisition system.*

The low voltage input can be used as current measurement input by a resistive shunt or burden resistor for example. They some along with 1 or 2.5 or 10 Ω and a precision of 0.02% and an outstanding minimum temperature drift. Connection can be done via 4 mm standardized safety banana directly to MX403B.

In addition to that, one can add more channels for mechanical and temperature measurements.

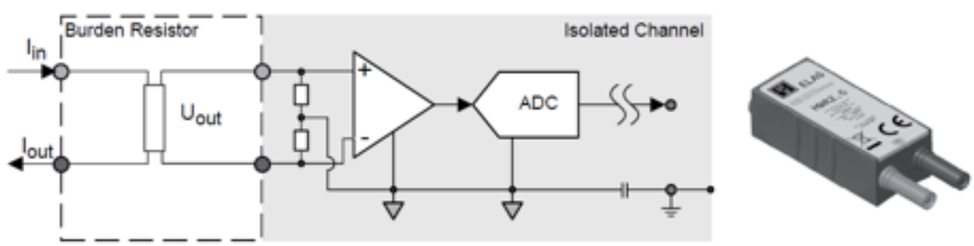

Figure 3. *current measurement with a burden resistor*

The two most common ways to connect three-phase electric induction motors in industrial applications are the Wye, or star, configuration (shown in Figure 2) and the Delta configuration, (shown in Figure 3). In each of these configurations, there are three voltages —L1, L2, and L3—and three currents, all sinusoidal waveforms, each with a phase difference of 120°.

In the Y configuration, the voltage across the loads is equal to the line voltage, whereas in the delta configuration, the voltage across each load is instead the line-to-line. In either case, the voltages and currents should be balanced. The line voltages should all be equal to one another and 120° out of phase with one another.

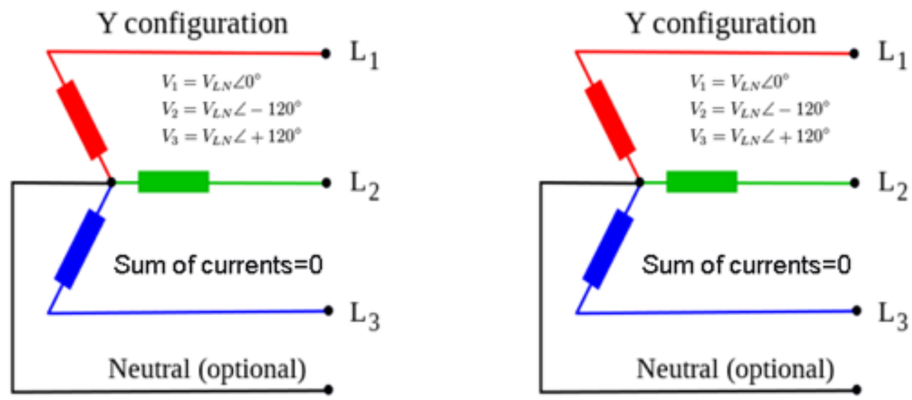

Figure 4. *Y and Delta configuration in 3 phase networks.*

In the Y configuration, the return path for the current in a particular phase conductor is the other two phase conductors. When properly balanced, the neutral conductor carries little or no current, and in some systems may even be optional. Properly balancing the voltages and currents also helps to reduce vibrations.

To calculate the consumed electric power, the data acquisition system has to measure the voltage and current of each phase. To do this, you'll need a data acquisition system with at least six channels, three to measure the phase voltages and three to measure the phase currents, as shown in Figure 4. While you can connect the three voltages directly to the data acquisition system, you may not be able to measure the current quite so directly. In many cases, if the current is high, you will need external current sensors, such as a resistive shunt or an inductive current clamp meter, and read an output voltage from them.

When using a clamp meter, be sure to compensate for any phase error or voltage attenuation as part of the measurement calibration process. Sometimes, the meter manufacturer will include the calibration data in the sensor data sheet. If, however, this information is not present, it is easy to determine these values. All you have to do is to measure the current through a resistive load using the selected clamp meter and determine the phase shift.

You can then use this value when measuring the power consumption of the motor. This ensures that the measured voltages and currents have the appropriate phase relationship and the power measurement is accurate. Making this calculation is very easy to do with a data acquisition system, and because of this, you can choose a current sensor that has the appropriate size, accuracy, bandwidth, and frequency range.

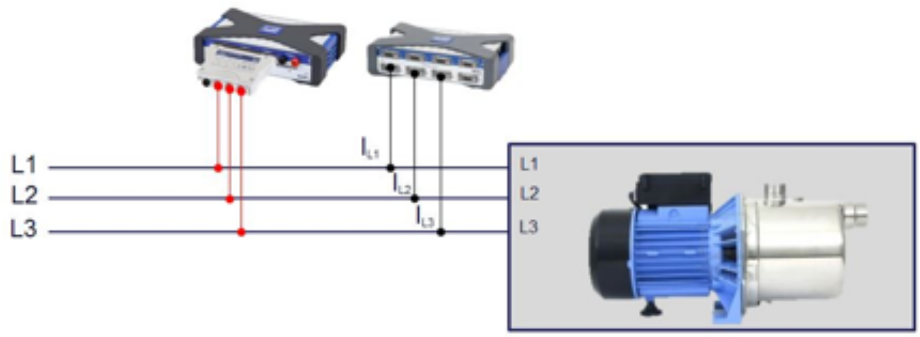

Figure 5. *To measure the power input to a three-phase motor, you need six channels, three to measure the voltage and three to measure the current.*

With accurate voltage and current measurements, you can then calculate the rms voltage and current and the power factor. The power factor is a measure of how much the current leads or lags the applied voltage. Mathematically, the power factor is the cosine of phase angle between the voltage and the current during the measurement process. The AC power consumed, also known as active power, is the product of the rms voltage, rms current, and power factor.

Some of the applied power is reflected back (or lost) due to energy stored in the load, or due to a non-linear load that distorts the wave shape of the current drawn from the source. This is called reactive power. A motor with a low power factor draws more current than a motor with a high power factor for the same amount of useful power transferred. The higher currents increases the energy lost in the system. As such electric motors with a high power factor are more desirable than motors with a low power factor.

By modulating the phase and amplitude of applied voltage to the motor, one can minimize the contribution of reactive power, thereby making the system a lot more energy efficient. A variable frequency drive or inverter based drive makes that possible. It simply takes a sine wave input and load feedback from the motor and in turn outputs a pulse width modulated sinusoidal waveform instead of a smooth sine wave. The motor basically sees this as a sine wave with a ripple, and because motor windings are inductive, filters out any high frequency component. This type of closed-loop control allows the motors to operate a lot more efficiently.

HBM's QuantumX Provides the Perfect Measurement Solution

HBM's QuantumX data acquisition system provides an easy to use approach for measuring the efficiency of electrical motors and other electrically-actuated systems. Connectivity is simply plug and play with provided adapters and data can be acquired immediately with no programming needed. Overall, the QuantumX data acquisition system provides the best in class accuracy of 0.05% and a best in class resolution at 24 bits.

The MX403B module can make all the voltage measurements, and when paired with another module such as MX840B or MX1609KB, one can measure a variety of mechanical parameters including speed, torque, pressure, flow, displacement, vibration, stress, temperature and so forth, etc.

HBM's QuantumX can acquire data up to 100 kS/sec and can stream the acquired raw data to a computer for online analysis, using HBM's Test & Measurement software catman. This includes calculating input power and efficiency in real time and displaying the results. Figure 5 is an example of how catman can display power data.

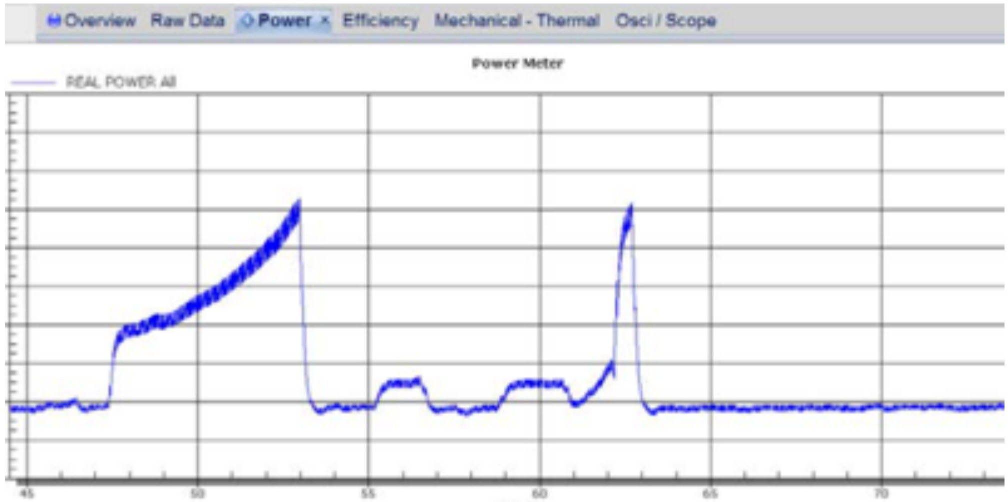

Figure 6. *This display shows how active power varies with time during an efficiency test. When correlated with mechanical measurements, users can determine whether the spikes are the result of normal operation or the result of a fault.*

Users can define custom triggers to help them troubleshoot problems. For example, they may set a trigger to be taking measurements when a system that normally consumes 500 W suddenly spikes to over 1,000 W. Because the QuantumX is measuring both electrical input power and mechanical output power, they have the data they need to figure out what caused the electrical spike.

To aid with further investigation, catman software can also perform a Fast Fourier Transformation (FFT) on the raw data, so that users can determine harmonics of the signal. Voltage harmonics are mostly caused by current harmonics which in turn is caused by non-linear loads.

Making power efficiency measurements will not only help you comply with DOE mandates, but help you save money as well. By analyzing and calculating your system under typical load and operating conditions, you can now determine how much power your system is consuming on average, when power consumption peaks, and take appropriate steps to reduce that consumption.

About HBM, Inc.

For more than 65 years, the name HBM has stood for reliability, precision and innovation all over the world. HBM offers products and services for an extensive range of measurement applications in many industries. Users worldwide rely on the perfectly matched components of the measurement chain that guarantees maximum accuracy of measurement results and enables optimization of the complete product life cycle, from the development through the testing stages, as well as in manufacturing and production. Their product range covers sensors, transducers, gauges, amplifiers and data acquisition systems as well as software for structural durability investigations, tests and analysis. The potential fields of application can be found in every branch of engineering in both virtual and physical test and measurement.

HBM has 27 subsidiaries and sales offices in Europe, America and Asia. HBM also has representatives in another 40 countries around the world. In addition to headquarters in Darmstadt, Germany, other HBM production facilities are located in Marlboro, Massachusetts, and Suzhou, China.