

Tools for the Development of Premium Efficiency Motors (IEC 60034)

Accelerate the design, validation and testing of motors and drives

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Standards driving energy efficiency classifications are a driving force behind the development of the next generation of motor and drive technologies. These classifications drive manufacturers to maximize efficiency, requiring a high confidence in energy measurements. The complexity of modern motor control systems present several engineering challenges when integrating the components of the motor and drive system. The use of purpose-built instruments ensures compliance with these standards and furthers the optimization of energy saving technologies.

Standards Demand Precision

In the industrial motor market, IEC 60034-30 specifies energy efficiency classes for induction motors where: IE1 (standard efficiency), IE2 (high efficiency), IE3 (premium efficiency), and IE4 (super premium efficiency). Notably, the efficiency values separating these classifications are often fractions of a percent. Example efficiencies are shown in Table 1.

IE1 (Standard)	IE2 (High)	IE3 (Premium)	IE4 (Super)
94.0%	95.1%	96.0%	96.7%

Table 1 – Minimum efficiency requirements for classes of AC line-operated, 4-pole motors with a 200 kW output.

IEC 60034-30-1 and IEC 60034-30-2 define classifications for line supplied and inverter driven motors. IEC 60034-2-1 is a standard that defines how the efficiency measurement is made for both standards, detailing an “indirect method” and a “direct method.” The “direct method” refers to the actual measurement of mechanical power, while both methods require the measurement of electrical input power to establish efficiency.

Energy Measurement

The measurement of electrical kinetic energy is performed by making voltage and current measurements, computing electrical power, and integrating power over time. Likewise, the measurement of mechanical kinetic energy in a rotating machine is typically performed by making torque and speed measurements, computing mechanical power and integrating power over time. The efficiency of the conversion electrical kinetic energy to mechanical kinetic energy is computed from the ratio of electrical input energy to the mechanical output energy. Power analyzers are often called out in standards documents as the preferred measurement devices for electrical measurements and are regularly found in the engineering laboratories of manufactures and government agencies responsible for ensuring compliance. A power analyzer is a purpose-built instrument intended for making both the electrical and mechanical energy measurements (Figure 1). A power analyzer will provide a highly detailed published accuracy specification with NIST traceability (Figure 2).



Figure 1- Multi-phase power analyzer

Voltage		Current		Power (PF=1)	
DC	±(0.02% of reading + 0.05% of range)	DC	±(0.02% of reading + 0.05% of range)	DC	±(0.02% of reading + 0.05% of range)
0.1 Hz ≤ f < 10 Hz	±(0.03% of reading + 0.05% of range)	0.1 Hz ≤ f < 10 Hz	±(0.03% of reading + 0.05% of range)	0.1 Hz ≤ f < 10 Hz	±(0.08% of reading + 0.1% of range)
10 Hz ≤ f < 45 Hz	±(0.03% of reading + 0.05% of range)	10 Hz ≤ f < 45 Hz	±(0.03% of reading + 0.05% of range)	10 Hz ≤ f < 30 Hz	±(0.08% of reading + 0.1% of range)
45 Hz ≤ f ≤ 66 Hz	±(0.01% of reading + 0.02% of range)	45 Hz ≤ f ≤ 66 Hz	±(0.01% of reading + 0.02% of range)	30 Hz ≤ f < 45 Hz	±(0.05% of reading + 0.05% of range)
66 Hz < f ≤ 1 kHz	±(0.03% of reading + 0.04 of range)		±0.5 μA* *only direct input of 760902	45 Hz ≤ f ≤ 66 Hz	±(0.01% of reading + 0.02% of range)
1 kHz < f ≤ 10 kHz	±(0.1% of reading + 0.05% of range) Add 0.015% × f of reading (lower than 10 V range)	66 Hz < f ≤ 1 kHz	±(0.03% of reading + 0.04 of range)	66 Hz < f ≤ 1 kHz	±(0.05% of reading + 0.05% of range)
10 kHz < f ≤ 50 kHz	±(0.3% of reading + 0.1% of range)	1 kHz < f ≤ 10 kHz	±(0.1% of reading + 0.05% of range)	1 kHz < f ≤ 10 kHz	±(0.15% of reading + 0.1% of range) Add 0.01% × f of reading (lower than 10 V range)
50 kHz < f ≤ 100 kHz	±(0.6% of reading + 0.2% of range)	10 kHz < f ≤ 50 kHz	±(0.3% of reading + 0.1% of range)	10 kHz < f ≤ 50 kHz	±(0.3% of reading + 0.2% of range)
100 kHz < f ≤ 500 kHz	±((0.006 × f)% of reading + 0.5% of range)	50 kHz < f ≤ 100 kHz	±(0.6% of reading + 0.2% of range)	50 kHz < f ≤ 100 kHz	±(0.7% of reading + 0.3% of range)
500 kHz < f ≤ 1 MHz	±((0.022 × f – 8)% of reading + 1% of range)	100 kHz < f ≤ 200 kHz	±((0.00725 × f – 0.125)% of reading + 0.5% of range)	100 kHz < f ≤ 200 kHz	±((0.008 × f)% of reading + 1% of range)
		200 kHz < f ≤ 500 kHz	±((0.00725 × f – 0.125)% of reading + 0.5% of range)	200 kHz < f ≤ 500 kHz	±((0.008 × f)% of reading + 1% of range)
		500 kHz < f ≤ 1 MHz	±((0.022 × f – 8)% of reading + 1% of range)	500 kHz < f ≤ 1 MHz	±((0.048 × f – 20)% of reading + 1% of range)

Figure 2 – Example power analyzer accuracy specifications

Benchmarking Efficiency

Motor and drive systems are often comprised of multiple stages, each component in the stage contributing to the overall system efficiency. Figure 3 shows an example motor and drive system comprised of a 3-phase AC input, AC to DC converter, variable speed 3-phase inverter, and a variable speed motor.

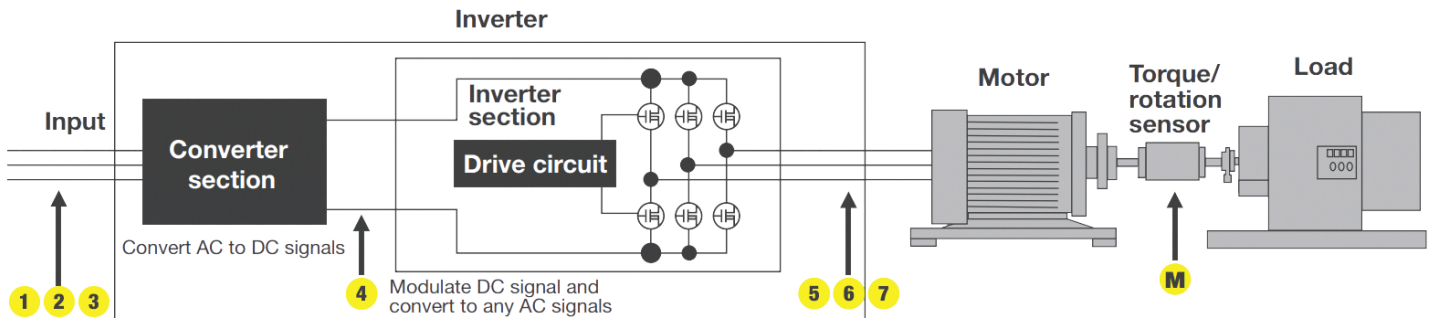


Figure 3 – Example motor and drive system

Measurement points 1-7 denote the points of electrical power measurement in the system, with point M denoting the measurement of mechanical output power. Power analyzers allow engineers to make high confidence measurements at one of these stages, quantifying the efficiency of each component in the system (converter, inverter, motor) and enabling the maximization of overall efficiency.

System Complexity

Power analyzers provide a concrete measure of efficiency throughout the system; however, each individual component carries its own complexity. Each sub-component presents unique engineering challenges to optimization and integration. A new motor control algorithm in the inverter might require the use of a positional feedback sensor such as Hall-effect, encoder, or resolver (test point M). As shown in Figure 4, the feedback from these signals are often high-speed, multi-channel, and require complex mathematics to decode position, direction, and speed.

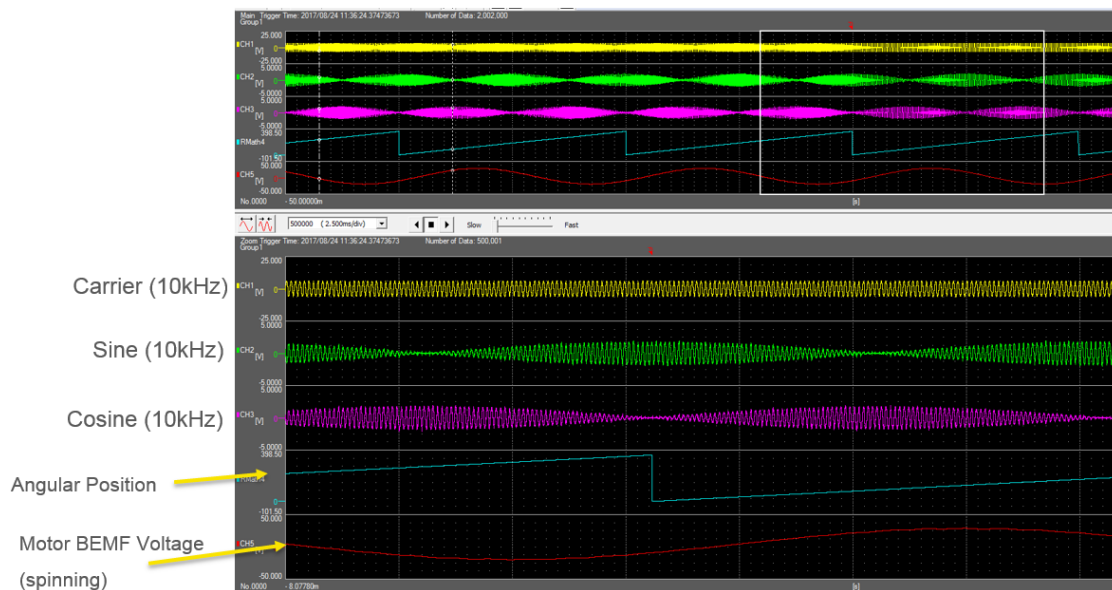


Figure 4 – Example resolver signal and position (carrier, sine, cosine)

Figure 5 shows an example output of an AC inverter (test points 5,6,7). Modern inverters use high-speed pulsed power electronics (PWM), resulting in complex high-voltage, high-frequency output waveforms of voltage and current. These signals present several engineering challenges such as harmonics, electromagnetic interference, and the ability to make high-voltage measurements in a safe manner.

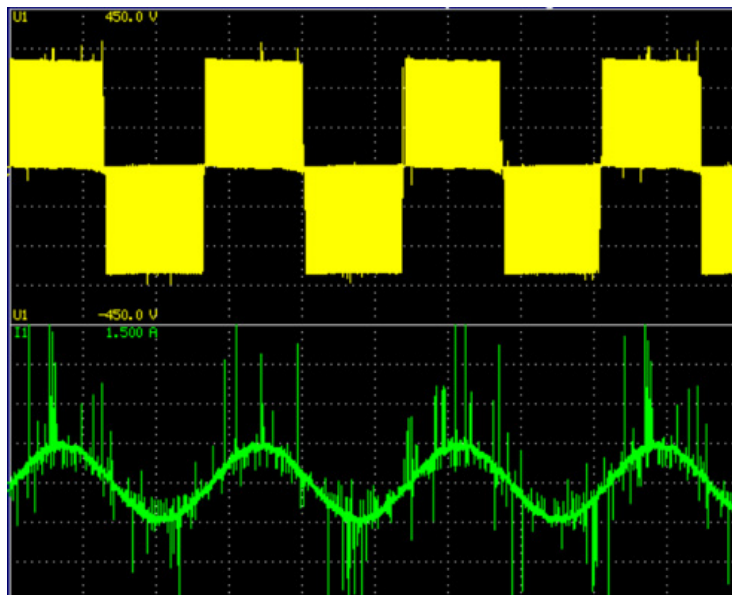


Figure 5 – AC Inverter output voltage and current waveforms

Modern embedded control systems employ digital communication networks such as CAN FD to communicate between inverters, electronic control modules, and other sensors in the system (Figure 6). These signals require decoding and debugging for troubleshooting at the systems level.

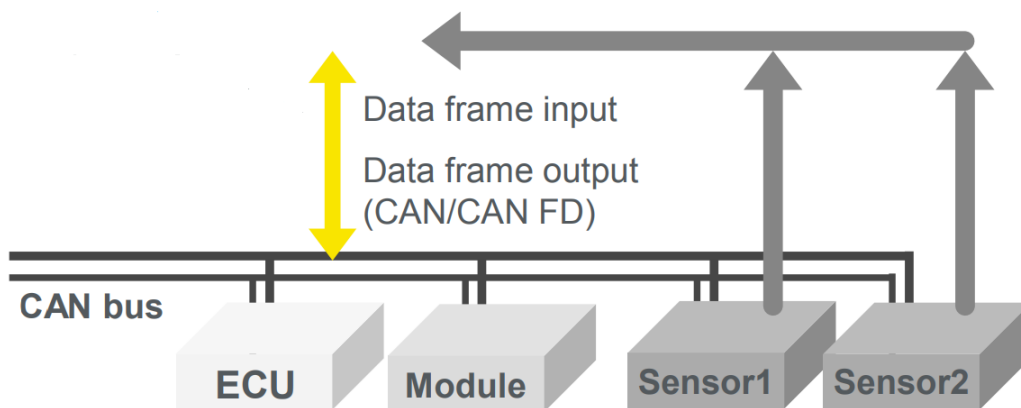


Figure 6 – Example communications network

Understanding how each of these subsystems are interacting and determining proper operation is key to optimizing the efficiency at each stage. Design, validation, and test engineers are faced with challenging questions when trying to understand the performance of the entire system. Examples of these challenges include:

- Did the new motor control algorithm make a difference?
- Is the motor feedback signal working properly?
- Is the inverter properly communicating to the supervisory and control system?
- Is there EMI causing a fault somewhere in the system?

Tackling Complexity

Optimization and integration of the individual components of a complex motor and drive system requires instrumentation that is flexible enough to handle a wide range of signals not found in conventional oscilloscopes or data acquisition systems. A ScopeCorder is a purpose-built instrument for the development for electromechanical systems such as motors and drives. A modular design enables the evolution of the instrument as the engineering needs change. A unique array of digital and analog input modules combined with real-time math enable the decoding of complex sensor data such as encoders and resolvers. High-voltage, high-sample rate modules offer isolated inputs up to 1000V allowing safe measurements on complex pulsed power signals. Communication modules such as CAN/FD decode digital bus signals into engineering units for correlation with the rest of the system IO. Figure 7 shows the array of input modules including voltage, temperature, strain, frequency, acceleration, logic, and various digital communications.



Figure 7 – ScopeCorder system with array of input modules

A Comprehensive Measurement Solution

Standards such as IEC 60034 establish classifications and test methods that provide parity in the market as government agencies attempt to steer manufacturers toward more energy efficient motor and drive systems. Precision power analyzers are a purpose-built tool for providing reliable mechanical and electrical energy measurements allowing manufacturers to confidently comply with efficiency standards. The complexity of highly-efficient modern motor and drive systems challenges engineers with a multitude of signals that conventional instrumentation does not easily accommodate. ScopeCorders provide a unique solution to mechatronic measurements and allow engineers to answer challenging questions they are faced with when analyzing the entire system. Yokogawa Test and Measurement is an industry leader in providing a full range of instruments for power analysis and mechatronics development including power analyzers and ScopeCorders.