Choosing the Right Power Measurement Instrument

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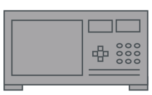
Choosing the Right Power Measurement Instrument

In order to empower development teams to fulfill their objectives across the development cycle, it is important to consider a whole solution approach toward instrument selection. Aside from satisfying unique needs for power accuracy, waveform analysis, or data acquisition, the technology must also be supported by appropriate training, hardware, and software. This maximizes the value of the investment. Regardless of the electromechanical phenomena to be measured, the computation capabilities, the level of accuracy, and measurement technologies must be reliable over the long term. They must offer support in hardware, software, and services in order to help engineers and manufacturers take their products from concept through production with greater quality in shorter time frames.

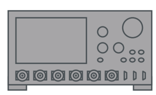
Instruments

There is a variety of instruments on the market that can potentially meet power measurement needs. Depending on the circumstances, one may need the waveform analysis of an oscilloscope, the high accuracy of a power analyzer, or a hybrid combination of the two with the flexibility of a data acquisition added into the mix. There are three main categories of instruments to consider when making power measurements. While there are exceptions, the categories below represent most instruments on the market and their core functionality.



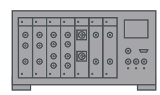
Power Analyzer

- Averaging style measurements
- Designed for accurate power measurements
- Ideal for benchmarking
- Continuous streaming acquisition



Oscilloscope

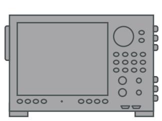
- Raw waveform capture and measurements
- Ideal for debugging
- Designed for flexibility
- Digital storage instrument



Data Acquisition

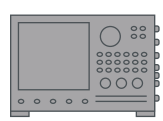
- Raw waveform capture and measurements
- Ideal for datalogging
- Designed for scalability
- Digital storage instrument

Yokogawa has defined two instruments that expand capabilities beyond the standard instruments: Power Scope and the ScopeCorder.



Power Scope

- Raw waveform capture and measurements
- Designed for accurate power analysis
- Ideal for transient analysis and capture
- Continuous streaming acquisition



ScopeCorder

- Raw waveform capture and measurements
- Modular design for flexible I/O
- Ideal for both high and low speed signals
- Continuous streaming and digital storage

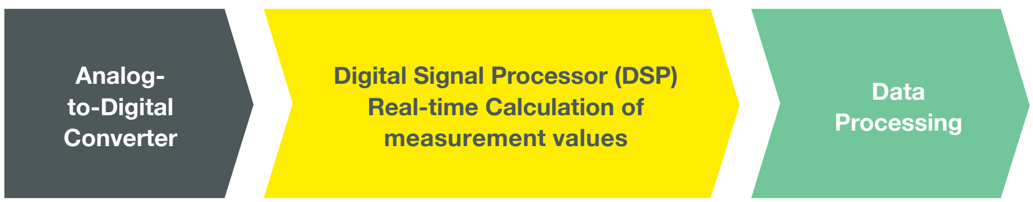
The following will highlight some key considerations to weigh when choosing the best suited instrument.

Measurement Technology

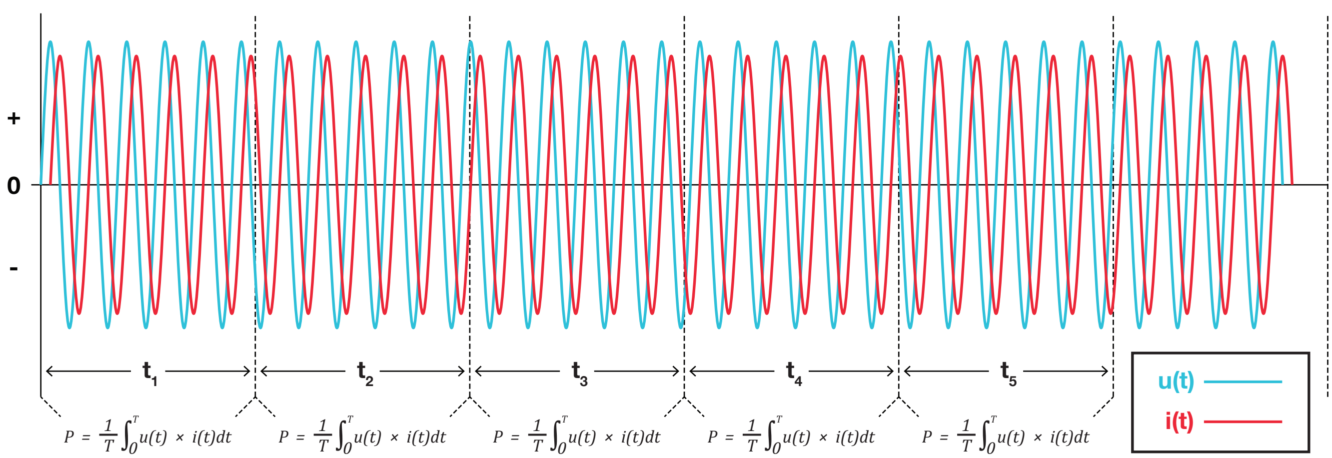
The underlying power measurement principle behind each of these instruments is essentially the same: sampling the voltage and current waveforms simultaneously, multiplying them together after acquisition, integrating the resultant instantaneous power readings over a whole number of fundamental waveform cycles, and then dividing by the time. However, depending on the resolution of the analog-to-digital converter and the sampling rate, there are two broad category types of power measurement instruments: continuous streaming and digital storage.

Continuous Streaming Instruments

These include the traditional power meters and power analyzers. Streaming instruments use high resolution on the analog-to-digital conversion stage and instantaneously compute/integrate the voltage, current, and power values in order to achieve continuous measurements and high accuracies. This architecture allows instantaneous computations without deadtime or gaps by continuous flushing of the memory buffer after each acquisition.



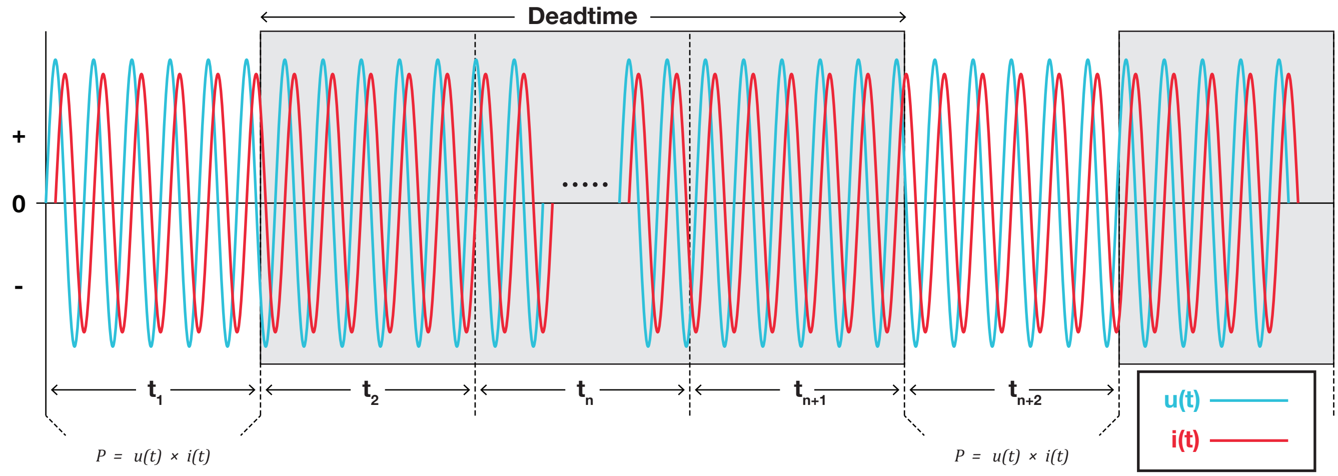
A continuous streaming instrument will acquire every cycle and calculate power based on a time, t, defined by the measurement instrument. This equation is true for any wave shape, including AC, DC, or distorted.



Digital Storage Instruments

A digital storage instrument such as an oscilloscope, acquires data at a high sampling rate, stores it in acquisition memory, and then processes it for output. During processing of the sampled data, there is "dead time" when the instrument is not reading the input waveform, thus missing the data points for continuous measurements.

A digital storage instrument triggers on waveform data used in the power calculation. Because of internal rearm times and data movement to memory, dead times are introduced where the instrument is not recording large portions of data. Since these dead times could easily be greater than 90% of the waveform acquisition time, these instruments are not ideal for power measurements.



The high sampling rate in a digital storage-type instrument allows for a better representation of the input waveform, making it ideal for analyzing single shot or transient events. However, oscilloscopes are not designed for stability and manufacturers do not specify AC uncertainty. Therefore, when high accuracy is needed, particularly in compliance testing, a streaming-type power analyzer is usually the better choice as it can achieve accuracies up to 0.01% of reading. Hybrid instruments such as the Power Scope can combine waveform analysis together with high accuracy measurement, as shown below.

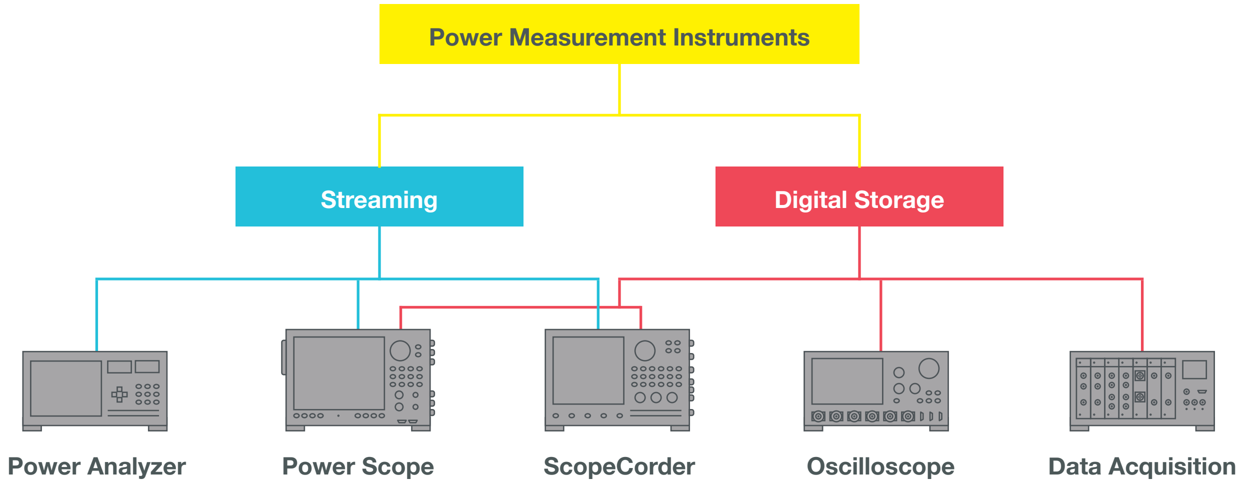
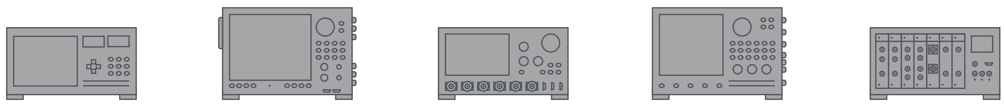


Figure 1. A power analyzer, Power Scope, and ScopeCorder can stream data continuously while oscilloscopes and data acquisition products are subject to large dead times.

Key Considerations

Job Functions

The various stages of product development each demand different capabilities and levels of accuracy. For example, isolated tests of individual components in early development stages may only need waveform analysis at limited accuracy, but when a multicomponent system needs to be tested, the objective is to optimize the system rather than a single component. This calls for sophisticated multichannel, multi-parameter measurements. Requirements for compliance and adherence to standards become stricter as the project nears production testing. Given the diverse operating conditions and objectives among development phases, one needs to be mindful that measurement needs can vary or evolve across the development cycle.



	Power Analyzer	Power Scope	Oscilloscope	ScopeCorder	Data Acquisition
Design	●	● ● ●	● ● ●	● ●	
Validation/Verification	● ● ●	● ● ●	●	● ●	
Compliance/Certification Testing	● ● ●	● ●		●	
Production/Manufacturing/Test	● ● ●	● ● ●	●	● ●	●
Field		● ●		● ● ●	●

● ● ● Best ● ● Better ● Good

Design

During this stage, individual components may need to be measured. Engineers must deal with fast switching speeds (in inverters, power supplies, and electronic circuitry), dynamic behaviors at high frequencies, and frequent overshoots on pulses. High sampling rates are, therefore, needed to capture waveforms faithfully, making the oscilloscope the go-to instrument for such scenarios. Oscilloscopes offer automated measurement of voltage and current waveforms providing peak, average, and root mean square (rms).

Validation and Verification

As control systems become more sophisticated, measurements are no longer limited to optimizing individual components. More I/O signals are needed and, consequently, faster sampling and higher bandwidth to circumvent noise from inverters or power supplies. More channels are needed to capture the dynamic behaviors of each component as part of an overall system. In an automotive powertrain, for example, together with the electrical parameters, physical parameters such as rotational speed, fuel injector pulse time, and crank angles are measured from sensor signals, rotary encoders, etc. For such multichannel measurements of dynamic system behavior, the combined features of an oscilloscope and a data-acquisition recorder are needed.

Compliance Testing

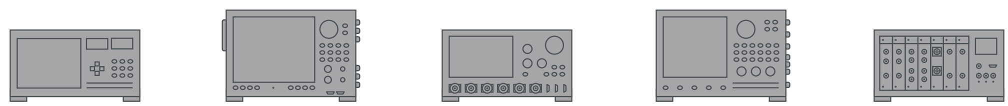
Industries today must meet several governmental and regulatory standards to ensure product efficiency, safety, comfort, and productivity for homes and businesses. Compliance to standards for standby power consumption (EN 50564 and IEC 62301) or harmonics and flicker (IEC/EN 61000-3-2 and IEC 61000-4-7) for different classes of electrical and electronic equipment affects both market validation (fit-for-use) and product differentiation for competitive advantage. A power analyzer that can guarantee its accuracy over specified operating conditions is the ideal solution for this stage. Oscilloscopes and data acquisition instruments are not rated highly for compliance testing due to the lack of guaranteed AC accuracy over the bandwidth of the instrument.

Production and Field Testing

Measurements in production line and field testing have different sets of requirements. It may be necessary to measure energy generated, converted, or consumed along with the effects of harmonics. It may also be required to troubleshoot power consumption in startup, standby, or operation modes, or use high crest factors at every measurement range for capturing inrush currents. This would be best served by power analyzers calibrated to minimize uncertainty within the specified operating ranges. ScopeCorders and DAQ may be useful in this stage if there is a need for collecting data over extended and unattended periods.

Measurements

Power measurements across instrument types can vary with internal architecture and signal processing capabilities. Choosing the best instrument can depend on the actual measurement(s) required. One consideration is connection to the signal under test. Instruments such as oscilloscopes require a probe for voltage and current connection, which adds additional impairments due to loading. Other instruments such as power analyzers and power scopes have direct connections for voltage and current, allowing for compensation due to thermal drift.



	Power Analyzer	Power Scope	Oscilloscope	ScopeCorder	Data Acquisition
Efficiency	● ● ●	● ●		● ●	●
Voltage	● ● ●	● ●		● ●	● ●
Current	● ● ●	● ●		● ●	●
Power	● ● ●	● ●		● ●	
Switching Loss/SOA			● ● ●	●	
Harmonics/THD	● ● ●	● ● ●	●	● ●	●
Mechanical	● ● ●	● ●		● ● ●	●

● ● ● Best ● ● Better ● Good

Efficiency

Efficiency measurements involve a comparison of the input to output power of a device. This is more complicated if the input and/or output have more than one phase. Efficiency is a comparison measurement and to detect the smallest differences requires the most accurate measurement device possible. The power analyzer is the best instrument for this measurement because of the rated accuracy and the guaranteed accuracy over the entire bandwidth range. Additionally, if the output is mechanical power, the power analyzer includes motor inputs to measure a resolver or encoder with high precision.

To read an example of measuring inverter efficiency, click here.

Voltage

Voltage measurements are impacted by the method of connecting the signal to the measurement device. High voltage signals may be connected directly with safety rated cables, or by using a voltage probe, either single ended or differential. The best probe is one with infinite loading and unlimited bandwidth. It imparts the least amount of attenuation to the actual signal under test. While this probe does not exist, it is important to consider the bandwidth and loading effects of any probe or instrument front end.

A power analyzer, Power Scope, and ScopeCorder have direct connections into the front end of the instrument, typically rated to 1000V to eliminate the need to add a probe. Oscilloscopes and data acquisition instruments require the use of passive or active voltage probes, which can impact the magnitude and shape of the voltage waveform being digitized.

Current

Current is typically calculated by measuring the voltage dropped across a shunt resistor. Power analyzers and Power Scopes include integrated shunts for the most accurate current measurements. An internal integrated shunt allows for temperature compensation due to thermal effects.

Other common current measurement solutions include Hall effect clamps, external shunt resistors, Rogowski coils, AC transformer clamps, AC transformers, and fluxgate transformers. Each of these is an external device that can impair the accuracy of the current measurement. The high current measurement application guide highlights the tradeoffs with each solution. For details on using a fluxgate current transformer, click here.

Power

Power measurements are best made with an instrument with the highest resolution, lowest phase error, and guaranteed accuracy. There are some tradeoffs when measuring power with an oscilloscope due to the nature of the sampling architecture. Yokogawa uses the equation below to calculate real or true power by integrating the instantaneous voltage times the instantaneous current over time, T.

The phase relationships of the voltage and current waveforms are very important to capture accurately for the most precise power measurements. The instruments with high scores have integrated de-skew functions to eliminate skew inherent to external probes and long cable lengths. For more details on how a power analyzer calculates power, read the white paper Fundamentals of Electric Power Measurements.

$$P = \frac{1}{T}\int_0^T u(t) \times i(t)dt$$

Harmonics

Harmonic measurement is another area in which it is important to specify the accuracy in the context of the application. When left unaccounted for, harmonics can cause capacitance losses, undesired vibrations in motors, transformer losses in no-load conditions, heating losses in conductors at higher frequencies, premature melting of fuses when electronic breakers do not respond at designed levels, and many more. It is vital to equip an engineer with the ability to detect harmonics and assess their effects on components, systems, and subsystems within an application. When measuring harmonics, it is important to ensure the harmonic measurements have a guaranteed accuracy. Additionally, the technique to determine zero crossing and duty cycle is important since many instruments use incomplete cycle data in their harmonic calculations, resulting in spectral leakage. A technique using a phase-locked loop (PLL) can ensure proper zero crossing is used in the harmonic's calculation. Highly accurate instruments can measure harmonics upwards of the 500th order.

Mechanical

Mechanical power is measured as the motor speed times the motor torque. Speed and torque sensors should be fitted to the motor dynamometer and integrated into the test system. These sensors typically provide an analog voltage output or a frequency style output. Modern power analyzers can accommodate both types and provide support for rotational position sensors such as encoders. The ScopeCorder can calculate the angle of rotation from a resolver.

Signal Type

Testing a device such as a motor powertrain could require measurement of a broad variety of inputs such as a combination of repetitive signals of voltage and current that are input into an inverter, high speed switching signals, control signals for the AC drive, temperature signals from the drive, and mechanical signals from the motor output. Capturing all signals with one instrument can be difficult.

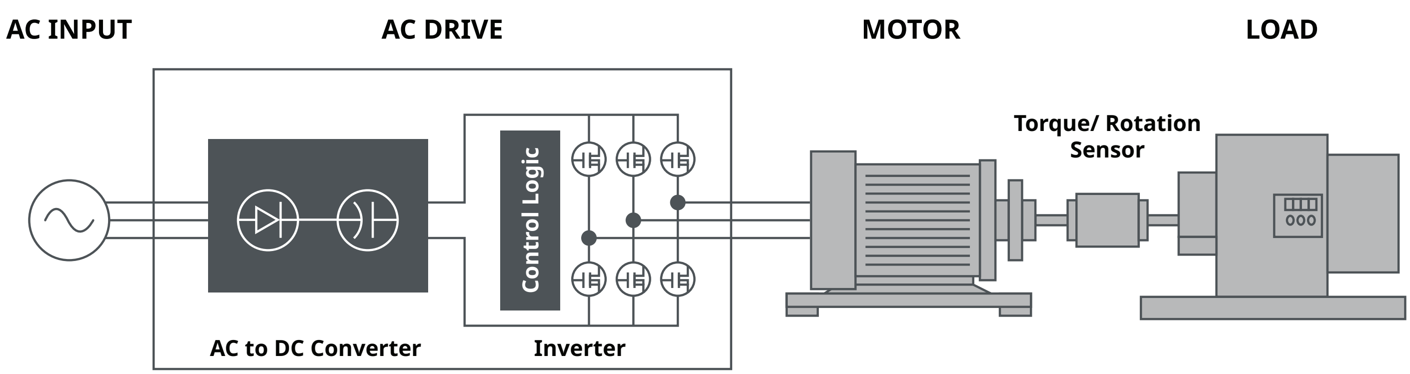
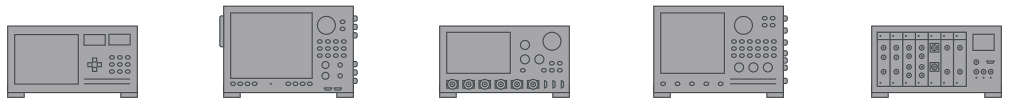


Figure 2. A motor powertrain has many different test points with various signal characteristics that can make the use of one measurement instrument difficult.



	Power Analyzer	Power Scope	Oscilloscope	ScopeCorder	Data Acquisition
Repetitive/Steady State	● ● ●	● ●	●	● ●	●
Single Shot/Transient	● ●	● ● ●	● ● ●	● ● ●	●
Serial/Automotive Bus			● ● ●	● ● ●	
Switching Devices			● ● ●		
Torque/Speed	● ● ●	● ● ●		● ●	
Sensor: Temp/flow/pressure		●		● ● ●	● ● ●

● ● ● Best ● ● Better ● Good

Repetitive vs. Transient

The high sampling rate in a digital storage-type instrument allows for a better representation of the input waveform. It is ideal for analyzing single shot events. However, oscilloscopes are not designed for stability and manufacturers do not specify AC uncertainty. When high accuracy is needed, particularly in compliance testing, a streaming or averaging-type power analyzer is usually a better choice as they can achieve accuracies up to 0.01% of reading. Hybrid instruments like the Power Scope, however, can combine waveform analysis together with high accuracy measurement.

Serial / Automotive Bus (I2C, SPI, CAN)

While all these instruments can capture the signals for common serial buses, a combination of analog and digital channels, decode packages with built-in intelligence of the signal parameters, advanced triggers, and search capabilities make one better suited to the task. The oscilloscopes and ScopeCorder products are best suited to capturing and analyzing serial bus signals.

Figure 3. Typical oscilloscopes can display and decode multiple bus types.

Torque/Speed

Mechanical power is measured as the motor speed times the motor torque. There are many different types of speed and torque sensors that can allow integration into a dynamometer. These sensors can provide the speed and torque measurements necessary to calculate the mechanical power in the power analyzer. Calculations of motor speed and torque can be made directly on a power analyzer. The wiring for this measurement depends on the signal type for speed and torque, output as either a pulse or analog signal, or a three-phase encoder pulse represented by phases A, B, and Z. Additionally, the ScopeCorder can calculate the angle of rotation from a resolver.

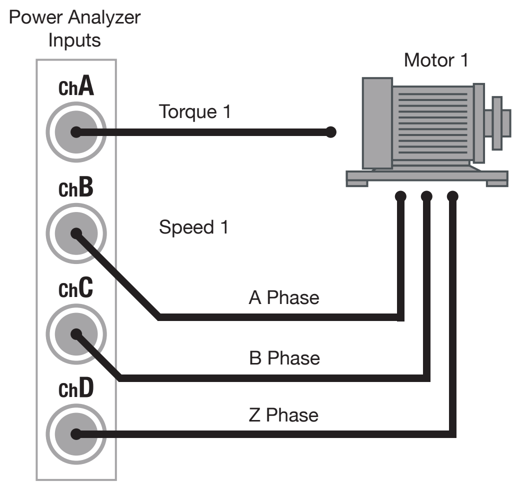


Figure 4. Torque and motor wiring for a three-phase encoder on a power analyzer

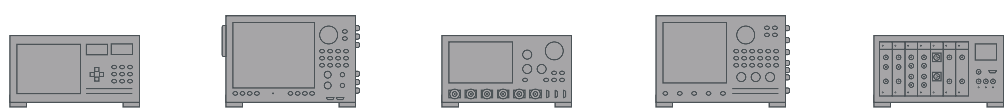
Sensors: Temp/Pressure/Flow

There are many sensors on a motor drive train, and it is not always cost effective to monitor them with an oscilloscope. A DAQ device will properly measure the sensor output, including thermocouples or thermistors for temperature. These systems will scale to the input requirements for a smaller investment than a new oscilloscope. A ScopeCorder and DAQ device will provide the most flexibility for these measurements.

Power Accuracy

Every measurement device has some degree of uncertainty, which is why accuracy is normally expressed as a range. Within this range, engineers consider power accuracy as the primary indicator of uncertainty for basic measurement parameters such as voltage, current, phase angle, and power (watts). These parameters may be presented using terms such as "guaranteed accuracy" and "typical accuracy."

To learn more, please refer to "Accuracy Specifications: Reading it Right with Range."



	Power Analyzer	Power Scope	Oscilloscope	ScopeCorder	Data Acquisition
DC	Guaranteed	Guaranteed	Guaranteed	Guaranteed	Guaranteed
AC	Guaranteed	Guaranteed	Typical	Typical*	Typical
ADC resolution	• • •	• •	•	• •	•
Isolation	Yes	Yes	No	Yes	No
CMRR	• • •	• • •	•	• •	•

• • • Best • • Better • Good

*The ScopeCorder has one module that has guaranteed AC accuracy, while the Yokogawa power analyzer and Power Scope has guaranteed accuracy over the entire bandwidth.

Guaranteed vs. Typical

What does “typical” mean in this context in terms of watts? The term often is misleading. A typical value is usually a reference value based on a manufacturer’s expectation from its product. In practice, it can be translated as “usually but not always,” “maybe,” “perhaps,” or “possibly.” It is deliberately vague because typical accuracies are neither guaranteed nor traceable to a national calibration standard or accredited calibration laboratory standard. When selecting a power measurement instrument, the prospective user should be sure that the published accuracies are guaranteed rather than typical values.

AC Accuracy

In power measurement, not enough emphasis is placed on AC accuracy. Often, instruments will guarantee AC accuracy at 50-60 Hz, but more power applications measure signal content outside the 50-60 Hz range due to fundamental frequencies changing per application, and harmonic content at multiples of those frequencies. The ideal instrument will have AC accuracy specified through the entire bandwidth range.

Analog-to-Digital Converter (ADC) Resolution

In measurement terms, resolution is the smallest increment that the instrument can indicate or display. The more resolution an instrument has, the more it can resolve differences or details on waveforms. It can be expressed in a few different ways. Since we are working with time domain instruments, the most common is the number of bits. If the frequency domain is used for a Fast Fourier Transformation (FFT) for harmonics, the resolution can be expressed as signal-to-noise ratio (SNR). This number of bits is often provided by the manufacturer of the ADC. In an ideal condition, an instrument would have the resolution of the ADC, but noise and distortion will reduce the real resolution of the instrument. To account for this, instrument manufacturers use the term ENOB (effective number of bits) or SINAD (signal plus noise and distortion) to represent the resolution of the system. These are recommended metrics when determining the real resolution. Filters or techniques such as averaging can improve resolution, as well, but come at a tradeoff.

A power analyzer will provide the greatest resolution among measurement instruments at 18-bits, followed by the ScopeCorder at 16-bits. When power measurements require the best accuracy, a power analyzer is recommended.

Isolation

Isolating functional sections of electrical systems prevents current flow by removing a direct conduction path and eliminating ground loops. Isolation is used where two or more electrical circuits must communicate, but their grounds may be at different potentials. Benefits of isolation include signal-to-noise reduction and improved noise immunity.

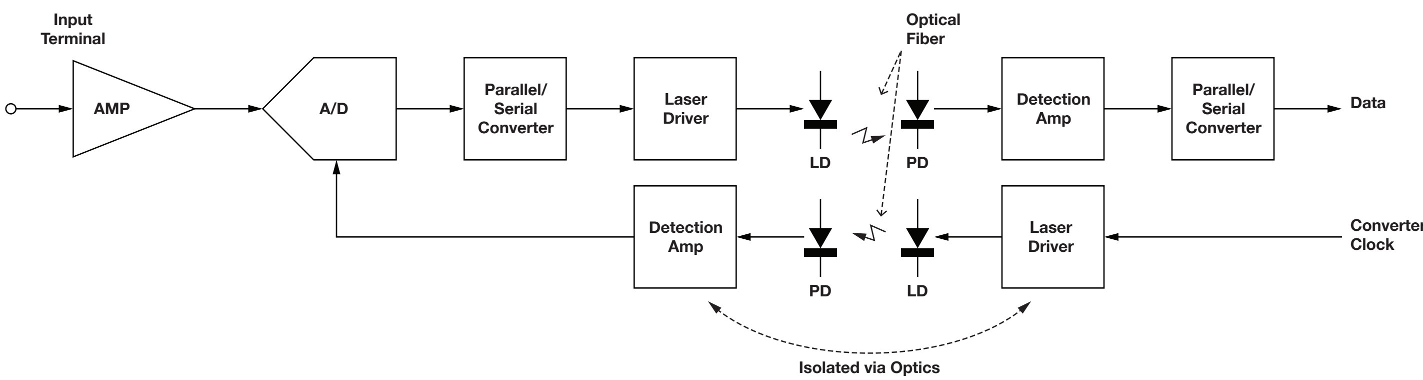


Figure 5. Yokogawa's IsoPRO™ uses optical isolation in their power analyzers, PowerScope, and ScopeCorder

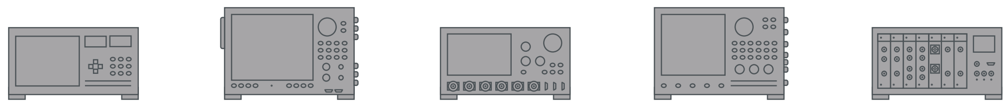
Common-Mode Rejection Ratio (CMRR)

The common-mode rejection ratio (CMRR) is the rejection by the device of unwanted input signals common to both leads of the voltage input. When two input terminals are connected to each other; the reference point is the device ground. Ideally, this should have no influence on the measurement result, but, in fact, leakage causes an interference voltage as a function of the symmetry of the input circuit. In practical terms, the noise voltage superimposed on the signal to be measured leads to measurement errors. It is important for the customer to consider this error in uncertainty calculations. Common-mode noise is especially present in inverter style applications because of the presence of high voltage potentials with high-frequency components to ground. Yokogawa specifies CMRR for power analyzers. The figure can be used while calculating uncertainties.

For instruments with poor CMRR, a differential probe can be used. With any probe, an additional network is placed in line between the device under test (DUT) and the measurement instrument. The resulting resistive and capacitive loading and potential bandwidth limiting introduce sources of uncertainty.

Banner Specifications

Banner specifications are important to understand how well your test instrument can meet the basic setup requirements needed on a test stand. The most important specifications to note are bandwidth and input channels.



	Power Analyzer	Power Scope	Oscilloscope	ScopeCorder	Data Acquisition
Bandwidth	●	● ●	● ● ●	●	
Analog Channels	●	●	●	● ●	● ● ●
Digital Channels			● ● ●	● ● ●	● ●

● ● ● Best   ● ● Better   ● Good

Bandwidth

Bandwidth is defined as the frequency at which the amplitude of the observed signal drops by -3dB, as shown in figure 6.

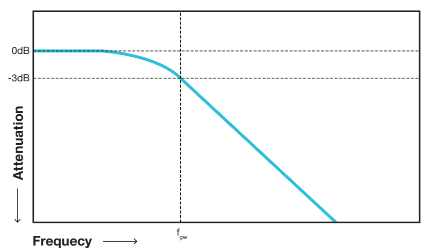


Figure 6. Bandwidth is defined as the frequency at which amplitude of the observed signal drops by -3dB.

Using bandwidth to select the proper instrument can be tricky because the recommendations of guidelines can depend on the signal under test, measurements being made, and other criteria.

Here are a few considerations:

- Nyquist rate: In general, half of the sampling rate will define the maximum frequency signal that can be properly digitized without aliasing. For example, an instrument with 10MS/s should not be rated with a bandwidth higher than 5 MHz for time domain applications.
- 5x Rule: For digital signals, oscilloscopes should have enough bandwidth to capture up to the 5th harmonic to adequately show proper waveform details. Poor results lead to a slower rise time / slew rate, filtering out of high frequency details, and possibly distorted amplitude.
- Rise time: If a measurement goal is to properly digitize a fast rise time, the equation of Bandwidth= (rise time)/k where the constant k is generally 0.35 for oscilloscopes with bandwidths lower than 1 GHz.
- Harmonics: Most power applications require a THD measurement or the acquisition of n number of harmonic orders. The proper method to determine adequate bandwidth is to multiple the fundamental frequency of the signal times the harmonic order. For example, if a PWM signal has a fundamental frequency of 60 Hz and 100 orders of harmonics are required, then the bandwidth should be > than 60 * 100 = 6 kHz.

Analog / Digital Channels

Input channel types are important to understand when selecting the best instrument. A combination of analog and digital channels is often required. For example, a motor test can require measurements of 3 phase AC channels, 1 channel for DC, inputs for a motor resolver, and digital channels for CANbus.

Analog Channels: Generally the more channels the better, but they come at a cost. Some architectures such as the power analyzer, are modular so more input channels mean more capital cost. Other instruments like an oscilloscope are generally offered in 4 and 8 channel models.

Mixed Signal: For applications requiring the acquisition of both analog and digital channels may prefer the use of a mixed signal oscilloscope to show time correlated waveforms.

Motor Input Channels: Some instruments measure more than just electrical parameters. The motor input channels enable measurements of rotational speed and direction, synchronous speed, slip, torque, mechanical power, electrical angle and motor efficiency from an analog or pulse output of torque sensors or pulse outputs of rotation sensors.

Is there one instrument that will satisfy all my measurements needs?

The answer depends entirely upon the needs of the application across its development stages. With oscilloscopes focusing on waveform analysis, power analyzers on accuracy, and hybrids extending that to time domain measurements or flexible data acquisition, adopting a single instrument may call for a compromise on capabilities. That could be easier in some industries or applications than others. If more than one instrument is required, an integrated software experience to simplify measurement collection correlation and storage is a very important consideration.

Conclusion

On today's market is a variety of instruments that can potentially meet power measurement requirements. Depending on the circumstances, one may need the waveform analysis of an oscilloscope, the high accuracy of a power analyzer, or a hybrid combination of the two with flexible data acquisition added into the mix.

Next Steps

For more information on Yokogawa Power Analyzers and related software, click here.

For more information on Yokogawa Power Scopes and related software, click here.

For more information on Yokogawa Oscilloscopes and related software, click here.

For more information on Yokogawa ScopeCorders and related software, click here.

For more information on Yokogawa data acquisition products and related software, click here.

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Still not sure which instrument(s) is best for your measurement needs, speak with a precision maker by submitting an inquiry here.

Yokogawa has been developing measurement solutions for 100 years, consistently finding new ways to give R&D teams the tools they need to gain the best insights from their measurement strategies. The company has pioneered accurate power measurement throughout its history, and is the market leader in digital power analyzers.

Yokogawa instruments are renowned for maintaining high levels of precision and for continuing to deliver value for far longer than the typical shelf-life of such equipment. Yokogawa believes that precise and effective measurement lies at the heart of successful innovation - and has focused its own R&D on providing the tools that researchers and engineers need to address challenges great and small.

Yokogawa takes pride in its reputation for quality, both in the products it delivers - often adding new features in response to specific client requests - and the level of service and advice provided to clients, helping to devise measurement strategies for even the most challenging environments.

Meet the Precision Makers at
tmi.yokogawa.com