How accurate are your power measurements?

Energy efficiency is the most common discussion point in all forms of sustainable energy, and whenever this topic is discussed the importance of power measurement goes to the top of the priority list. Manufacturers today offer a wide range of power measuring instruments backed up with seemingly impressive specifications, but how do potential users decide which parameters are relevant to their specific application? This article looks at some of the factors that can affect the accuracy of power measurements and shows how users can address the challenges presented by the need for accurate energy-efficiency testing.

Power Accuracy

To increase the energy efficiency of a product - even by a few decimal points - is both an important goal and a major challenge for manufacturers. To validate small improvements in efficiency, R&D teams need to understand the total accuracy or uncertainty of their power analyzers. As a manufacturer, it is important to know all the factors influencing the uncertainty of an instrument. In many cases, for example, customers evaluate power analyzers with respect to voltage and current uncertainty, but what they should really be looking at is the power uncertainty. In addition, when considering power accuracy, the evaluation should considering not just the basic parameters but also other factors such as crest factor, phase angle error, temperature range, warm-up time, stability period and common mode rejection.

Understanding Manufacturers' Specifications

Manufacturers' specifications will often include terms such as "guaranteed" and "typical" values. In fact, Yokogawa is the only manufacturer of power meters that guarantees the power measurement uncertainties published in their data sheets. Some manufacturers use typical values in their published data, which can often mislead customers.

Typical values are usually a reference value based on what a manufacturer expects from their product, but these values are not usually 100% guaranteed. This is the reason why many manufacturers' specifications for typical values are much better than the guaranteed values – and is also why Yokogawa power analyzers, when calibrated, provide accuracies which are five to ten times better than the published specifications.

Measurement Range

Another factor that is often inadequately specified in manufacturers' data is measurement range. Again, Yokogawa is the only power

analyzer manufacturer to specify the measurement range for their products. This is an important point because the uncertainty of a power measurement varies depending on the measurement range, and so the accuracy value should specify the range over which it is valid. For example, the power accuracy of the Yokogawa WT3000 – the world's most accurate power analyzer - is valid from 1% to 130% of the measurement range. Without specifying the measurement range, users will find it difficult to know whether the accuracy values are valid only at a single point or at a few points of measurement range.

High-Precision Harmonics

Harmonic measurement is another area where it is important to specify the accuracy in the context of the application. Every Yokogawa power analyzer has an additional oscillator dedicated to phase-locked loop (PLL) measurement which provides high-precision harmonic measurement. With the help of this dedicated oscillator and powerful digital signal processing, the frequency spectrum can be analyzed up to the 500th order (depending on the instrument) harmonics simultaneously with the normal measurement. In addition, because of this dedicated circuit, it is possible for Yokogawa to specify the accuracy of the harmonic analysis – something that is not the case with many other manufacturers.

The Influence of Crest Factor

For evaluation purpose, accuracy calculations are usually done using sine waves at a frequency of 50-60 Hz and a power factor of one, which means that all the energy supplied by the source is consumed by the load The basic accuracy for voltage, current and power is specified as a percentage of the measured value and a percentage of the measurement range, which can be defined with respect to the peak or RMS values. In order to understand the measurement range error, it is important to understand the effects of the crest factor: defined as the ratio of the peak value to the effective RMS value of the waveform.

For a power meter, crest factor has significance in two ways. One is the specification of the power meter itself as it shows the capability of the instrument to measure correctly, irrespective of how much the waveform is distorted. The other is the measurement of the crest factor of the input voltage or current of an input signal, which provides an indication of the quality of the input signal.

For a measuring instrument, the crest factor expresses the extent of the dynamic range for an input signal. We define the crest factor as the value of the dynamic range based on the rated range value (RMS value). For example, the crest factors of Yokogawa power meters are usually given as three or six. This means that it is possible to measure the input signal with a peak value three or six times larger than that of the rated range value. For example, using 100 V RMS and 1 A RMS ranges, the available input voltage and current signals are as follows:

When CF=3
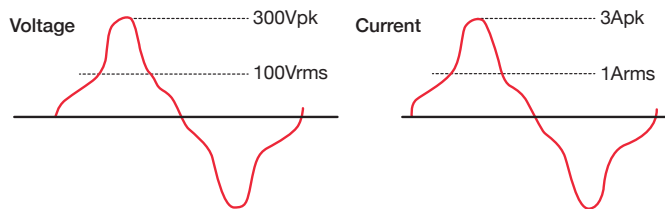
When CF=6
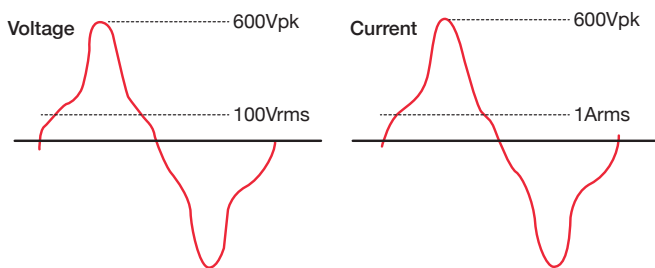
If the input RMS value is lower than the rated range value, the power meter can measure signals with a larger crest factor. The WT series can display values when the signal is more than 0.5% of the rated range value. If the input RMS value is 0.5% of the rated range and input peak value is three times larger than the rated range value, the crest factor becomes 600. If an input exceeding the value shown in the specifications is measured, the peak area of the waveform is clipped to cause an error. Therefore a crest factor of three means that the maximum allowable input is three times the input rated RMS value.

RMS vs. Peak Value for Crest Factor Evaluation

The measuring ranges of Yokogawa power meters are defined with respect to the RMS value, which means that the crest factor of the power analyzers is three or six. If the range was defined using the peak value like other manufacturers, the maximum crest factor of Yokogawa power analyzers would be 300. For example in the range 100 V RMS with the crest factor set to three, peaks of ±300 V could be easily detected. By using the crest-factor formula, we get 300 V peak divided by 1 V RMS, giving the result as 300. Note that this is 1% of the range and therefore the accuracy specification is also still valid (as previously mentioned).

Peak and RMS measurement

Some power meters use RMS measurement ranges and others use peak measurement ranges. Relating the accuracy information to peak values looks impressive at first sight, but in

reality it is not. For example, the accuracy value of 0.1% from the peak measurement range corresponds to 0.3% of the RMS measurement range at a crest factor of three. For active power calculation, the multiplication of voltage and current (and power factor) will enhance the effect dramatically.

Yokogawa uses RMS values for both measurement range setting and tolerance calculation.

Zero-Crossing Detection

For accurate power measurement, it is necessary for the power analyzer to have accurate zero-crossing detection. Yokogawa power analyzers have frequency-measuring hardware for zerocrossing detection which identifies the fundamental frequencies in the pulse-width-modulated (PWM) signals. This is achieved by using a synchronization technique known as "average for the synchronous source period" (ASSP).
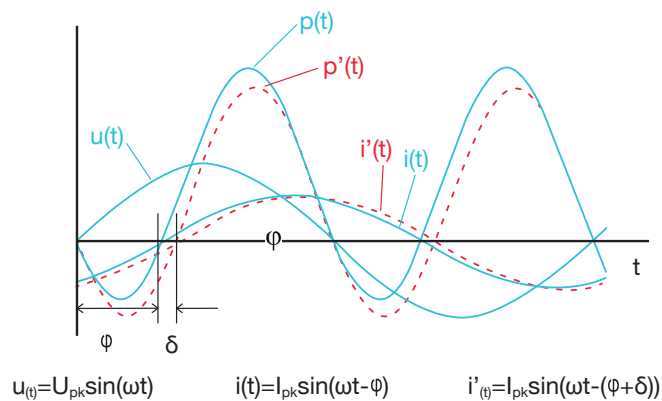
For complex PWM signals which have many harmonics, alternative measurement methods that determine the zero crossing by means of software cannot achieve high measurement accuracy for current, voltage and active power. In order to get precise measurements of the effective power, it is essential to ensure that the current and voltage samples are synchronized, especially when low power factors and/or high frequencies are involved. The instantaneous values of power are then integrated within the defined measurement interval to get the effective electrical power which can be displayed as a waveform or numeric depending on the customer's preference.

Phase Error

Every power meter has a phase error associated with it which cannot be ignored in the uncertainty calculations. The voltage and current inputs fed to the A/D converters are not normally in phase, resulting in a phase error which is represented in the simple active power formula for pure sine waveforms as:

$P = (Vrms) * (IRMS) * \cos (\phi \pm \delta)$ where δ the phase error.

$u_{(t)}=U_{pk}\sin(\omega t)$ $i(t)=I_{pk}\sin(\omega t-\varphi)$ $i'_{(t)}=I_{pk}\sin(\omega t-(\varphi+\delta))$

Phase angle error δ

Challenges in Current Measurement

One of the key challenges in current measurement occurs when a current shunt is used. The current shunt is a relatively large component with low inductance and parasitic capacitances. This causes a small phase shift and therefore the current undergoes an additional time delay. The transition of this process into the digital world requires perfect hardware design. While it has no effect on the RMS voltage or current or the apparent power, it does influence the measurement of active power; hence the power factor. A power factor of 0.1 causes a phase error of 0.1° and an additional active power error of 1.6%. This phase shift must be specified by the manufacturers of power analyzers. Yokogawa specifications consider all possible boundary conditions that can lead to a phase angle error or measurement error, and are included in the calculations.

Common-Mode Rejection Ratio (CMRR)

The common-mode rejection ratio (CMRR) is the rejection by the device of unwanted input signals common to both input leads of the voltage input. Here, the 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. Therefore it is important for the customer to take into account this error in their 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 power analyzers have their CMRR specified and can be used while calculating the uncertainties.

Temperature Effects

Another factor that affects the accuracy of a power analyzer is the effect of temperature. Yokogawa uncertainty specifications are specified at 23°C ± 5°C. In some cases manufacturers indicate different temperature ranges: for example, only 23°C ±2°C: a much lower figure which adds significant uncertainty.

The Importance of Calibration

As this article has illustrated, in order to understand the true accuracy of a power analyzer, it is important for the customer to understand all the key influencing factors. In addition, it is always recommended to have the unit calibrated at regular intervals.

Yokogawa is the only industrial (i.e. non-government or national) organization to offer traceability up to 100 kHz, and is the only power-meter manufacturer which can directly prove the performance of its own instruments.

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