

APPLICATION NOTE #106

Understanding AC Power Source Measurements

Programmable AC Power sources are primarily used to provide a low distortion, precisely controlled sinusoidal voltage to a unit under test. Increasing however, the same AC Source is being used to perform measurements as well. The tight integration between AC source (stimulus) and measurements (response) provides several benefits:

- The measurements are optimized for the output range and power level of the AC source providing optimal ranging, which results in better accuracy and resolution.
- The integration of the measurement system into the AC Source eliminates the need for external test equipment in most ATE setups, reducing overall system cost and complexity.
- The internal measurement sense points eliminate the need for external wiring, which is prone to noise pick-up and often results in signal degradation.

Consequently, evaluating the measurement performance of an AC Source can be as important as assessing its ability to provide sufficient power and current. This application note reviews the various aspects of measurement systems as used in AC Power sources and their implementations.

Basic Measurements

Voltage and Current

The most fundamental measurements that can be made at the output of the AC Source are those for voltage and current. Of key importance is that voltage and current measurements are true RMS (Root Mean Squared) values, not average readings. The RMS value of an AC current is equivalent to the DC current that would produce the same amount of power dissipation in a resistor. This can be visualized by breaking up the current waveform in infinitesimally small time slices and determining the power dissipation ($P = I^2 * R$) at each moment in time. The power is equivalent to the sum of all these values divided by the number of time slices. Since the resistance R is presumed constant, it can be taken out of the equation, resulting in the following for-

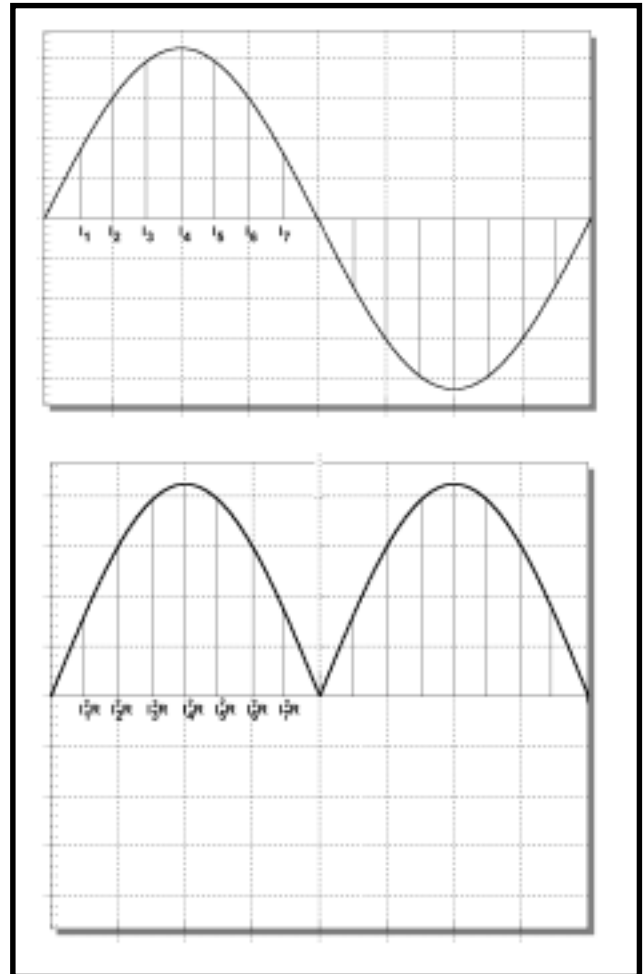


Figure 1: True RMS value of AC current.

mula for the effective current:

$I_{eff} = \sqrt{(I_1^2 + I_2^2 + \dots + I_n^2) / n}$ where n is the number of time slices.

This value is the effective value of the AC current since it is equivalent to a DC current that would produce the same amount of power dissipation in the same resistor. Changing this calculation from a sum to an integration over time (dt) will produce the RMS current value. This value is not the same as the average value which is the sum of the currents divided by the number of time

slices.

For the special case of a pure sinusoidal waveform, the average voltage is equivalent to the RMS value divided by a factor of 1.11. As long as the signal to be measured is sinusoidal, this ratio can be used to calculate the RMS value by performing an average voltage measurement. For non-sinusoidal signals however, this fixed ratio no longer applies and there can be a significant difference between the average value times 1.11 and the RMS value. While the output voltage of an AC Source is typically sinusoidal, the current may not be. Many loads these days are non-linear and will draw harmonic currents. To accurately measure current, not only must the measurement system of the AC Source measure true RMS, it must also have sufficient bandwidth to cover higher order harmonics. For many AC power applications, harmonics up to the 40th can be relevant which implies the measurement system bandwidth should be at least 40 times the highest fundamental frequency used.

AC sources with arbitrary waveform generation capabilities like the California Instruments 5001iX must use true RMS measurement for voltage as well as current since either one may not be sinusoidal.

Frequency

Frequency is measured at the output of the AC Source based on the voltage signal. For AC sources that use a direct digital synthesizer to generate the output reference clock, the accuracy with which the voltage is generated often exceeds the accuracy of the frequency measurement.

Real and Apparent Power

Apparent power (VA) can be calculated by multiplying the RMS voltage with the RMS current. Thus, an AC Source that does not offer this function but does measure RMS voltage and current can still provide VA read-

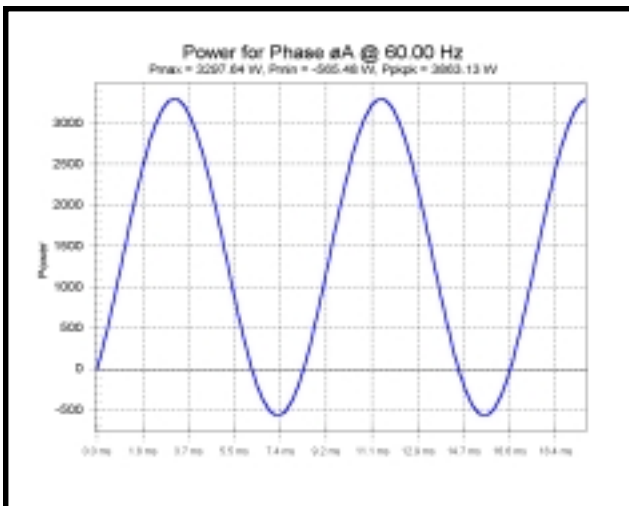
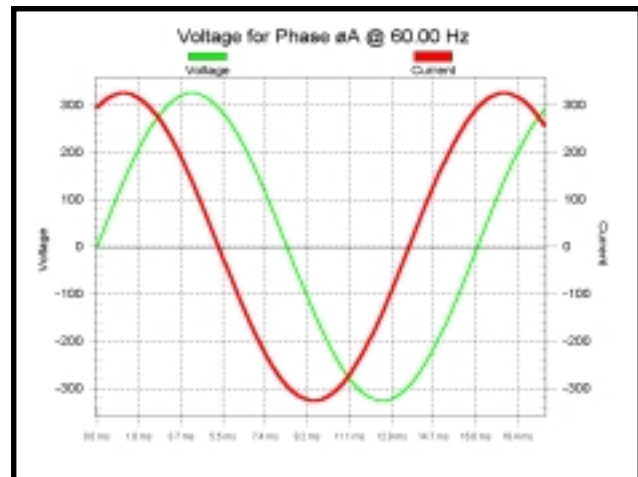


Figure 2: Phase shift between volt and current as shown in figure 3 results in reactive power.

ings when used in a test system. The test program can do the calculation. True Power however is not this simple. Unless the EUT is purely resistive, the voltage and current will not be in phase and the true power is less than the apparent power. Only a true power measurement will provide the correct power dissipation of the EUT. True power measurement requires the integration of the instantaneous voltage and current product over time. The result of this multiplication is shown in Figure 2. Notice that the instantaneous power dips below zero for some period of time. Since many EUT's are not purely resistive, true power is an important measurement function.

Power Factor

Power factor is defined as the ratio between true and apparent power. For the special case of sinusoidal voltage and current, the power factor is also equal to the cosine of the phase angle between the voltage and the current. More often that not however, the current contains higher order harmonics and knowing the cosine of the phase angle between the signals does not equate to the power factor. Unless the AC source has the ability to measure RMS voltage, RMS current and true power, it is not possible to obtain accurate power factor readings. As is the case with apparent power, a test program can calculate the power factor as long as the AC source can measure these three parameters. Since the true power can never exceed the apparent power, the Power factor is always less than or equal to one. While the power factor does not provide any information on the phase shift between the voltage and cur-



rent, a sign is often used to indicate leading or lagging current with respect to voltage.

Figure 3: Phase shift between voltage and current results in power factor less than 1.

Note that the power factor is a ratio between two measurements, one of which (VA) is the product of two other measurements. This has an impact on the accuracy with which power factor can be measured. If the power level of the EUT is low, percent of scale errors in the

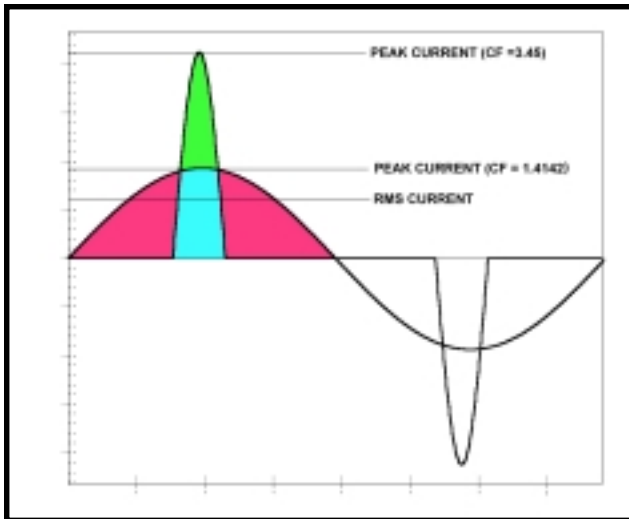


Figure 4: Crest Factor for two AC waveforms with the same RMS values.

current and power measurements will impact the accuracy of the calculated power factor. Published accuracy specifications for power factor measurement may only apply above a certain current or power level.

Crest Factor

Crest Factor is a ratio between the peak current and the RMS current. To measure crest factor, the AC source measurement system must be able to measure the true RMS current as well as the peak current. Some AC Sources such as the 2001RP and the 5001iX offer both single shot peak current and repetitive peak current modes. Single shot peak current mode is more suitable for determining an EUT's inrush current and should not be used to determine crest factor. The repetitive peak current is normally used to calculate the crest factor.

For the special case of a purely sinusoidal current, the crest factor is equal to the square root of two. Any distortion of the AC current will often result in higher crest factors. A high crest factor indicates more stress on the equipment supplying the load as it must provide the large instantaneous currents associated with the distorted current waveform. Most AC Sources have a maximum crest factor specification. The measurement range for crest factor specified generally also applies to the RMS current measurement. Most RMS current measurement systems have a limited crest factor range. This means that the RMS current measurement accuracy specifications may not apply if the current being measured has a crest factor that exceeds this rating.

Power Analysis

Power analysis involves measurement of voltage and current harmonics. This can be done using an analog or a digital measurement system. Modern AC Sources such as the 5001iX use a digital system and Fast Fourier Transform algorithms. Harmonic analysis breaks

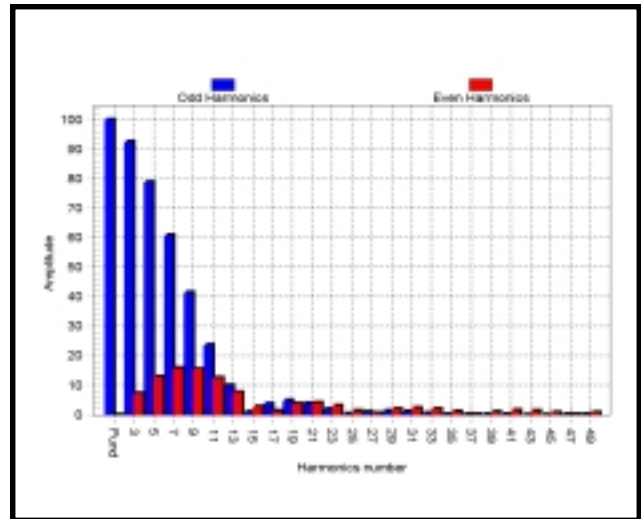


Figure 5: Harmonic analysis result of EUT Current.

down complex voltage and current signals in their harmonic components. This type of measurement also allows calculation of the total harmonic distortion with respect to the fundamental, expressed in percent. Built-in harmonic analysis may be an important feature for EUT power quality testing. A sample data display for the harmonic analysis of a typical EUT current waveform is shown in Figure 5.

Implementation.

Measurement systems can be implemented in one of two ways, analog or digital. Analog systems use one or more RMS converters to determine the RMS level of the voltage and current signals. For true power measurement, an analog multiplier is used which multiplies voltage and current and feeds the output into an RMS converter. More often than not, a single RMS converter is used in combination with a multiplexer. The multiplexer routes the required signal to the RMS converter. The RMS converter output is digitized using a high resolution but slow sample rate A/D converter. No high-speed A/D conversion is required with this approach. This significantly reduces cost and required board space. These systems generally offer cost advantages and can be made to provide very accurate readings. The 2001RP is an example of this type of measurement system implementation.

A digital measurement system implementation relies on the digitization of the voltage and current signals in real-time. This requires the use of high-speed A/D converters. For true power measurements, each channel (voltage and current) must either have its own A/D converter or a sample and hold is needed to ensure voltage and time samples are taken at the same moment in time. If not, calculations for power and power factor would be inaccurate.

The output of the A/D converters is stored in digital memory and processed by the AC Source controller to produce TRMS, Power, Power Factor and Crest Factor readings. This type of measurement system benefits from the use of a digital signal processor (DSP). The 5001iX is an example of an AC Source that uses such a measurement system. A pair of 18 bit Sigma-Delta A/D converters are used to digitize voltage and current

While a digital sampling system is generally more expensive to implement, there are some additional capabilities which justify the higher cost. Since the time domain information for the voltage and current is available, the DSP can apply digital filtering and FFT algorithms to provide harmonic analysis of both. In addition to this, the time domain waveforms can be displayed on the front panel of the AC Source or on a PC, providing the operator with more details on the voltage and current than would be possible using an analog measurement system.

Accuracy and Resolution

Regardless of the implementation, most measurement systems use an A/D converter to allow processing and display of measurement data. This limits the resolution of the measured value to number of counts the A/D can produce or the number of bits. Resolution is not to be confused with accuracy however. Increasing the number of bits of the A/D may yield higher resolution, it will not improve accuracy. It would mean more meaningless digits are added behind the decimal point. As a rule, the resolution of the measurement should be better than the accuracy, say 2 to 10 times better. If not, it is not possible to take full advantage of the available accuracy of the measurement system. For example, if the resolution of the current measurement function is 1 mA but the accuracy is only 100 mA, the last two digits of any current reading are meaningless. Vice versa, if the accuracy is 1 mA but the resolution is only 100 mA, there is little benefit from the 1 mA accuracy.

Comparing Specifications

Measurement accuracy specifications are not always directly comparable between manufacturers. They can be provided in % of reading and % of full scale or as an absolute error. An example of a this first specification method is:

Current Measurement Accuracy:	0.3 % of FS + 0.5 % of reading.
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Assuming the full-scale current measurement is 40 A and we are measuring a load that draws 10 A current, the measurement uncertainty would be $0.003 * 40 + 0.005 * 10 = 0.17$ or 170 mA.

An example of an absolute error specification is:

Current Measurement Accuracy:	50 mA
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Given the same 40 A range and 10 A measurement, the measurement on this unit would be more accurate.

Three Phase Sources

If the AC Source has three-phase output capability, the measurement system must be capable of providing measurement data on all phases. This can be accomplished by multiplexing the same measurement hardware between the three phase outputs or providing individual measurement hardware for each phase. If properly implemented, the measurements will include phase angle between voltage and current as well as between output voltages on each phase with respect to phase A.

Summary

While the output capability of an AC Source remains of key importance to the selection process - refer to application note #105 - the measurement functions provided by the AC Source can add significantly to its usefulness and cost effectiveness.

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