

Power Supply Measurements

Application Note



Application Note

Table of Contents

1.	1. Measuring Power Supplies			
	1.1. Critical Power Measurements	3		
2.	The Key to Measuring Volts, Amps and Watts	4		
	2.1. RMS (Root Mean Squared Value)	5		
	2.2. Average Value	6		
	2.3. Real and Apparent Power (W & VA)	7		
	2.4. Power Factor	9		
	2.5. Crest Factor	10		
	2.6. Harmonics Distortion	10		
	2.7. Standby Power	11		
3.	What Types of Power Supply	11		
4.	Conclusion	11		
5.	5. Reference11			

1. Measuring Power Supplies

Power supplies are power electronics systems that convert electrical energy from one voltage and frequency to another. Typically, they convert the AC line (110 / 220V 50/60Hz) into low voltage (12, 5, 3V) DC and provide safety isolation and control features.

Power supply designers strive to improve the efficiency of designs while maintaining specified performance over a range of input and load conditions and complying with international regulations for safety and EMC.

A power analyzer is the tool used to make measurements of:

- Power and EfficiencyOutput power as percentage of input power
- Power Factor
 Confirming the operation of power factor correction circuits
- Standby Power
 - Including compliance to ENERGY STAR and IEC62310 Ed.2
- Load and line regulation
- Current harmonics for regulations such as EN610003-2

Power supply types cover a vast range of applications from microwatts (plug top chargers) to megawatts large inverter systems.

This application notes describes the measurements that are required on power supplies and how to makes them.

Using a power analyzer capable of analyzing complex waveforms and having high bandwidth accuracy is essential to designers, production and QA. If a complex waveform is not correctly represented in measurements, misleading results may result.

Critical Power Supply Measurements



Table 1a.

Critical Power Supply Measurements				
Parameter	Critical for:	Power Meter Essentials		
PF (Power Factor)	Required for compliance, optimizes use of available voltage and current	$Power \ Factor = \frac{Real \ Power}{Apparent \ Power}$		
CF (Crest Factor)	Analyzing current waveforms with high peak value	Instruments with high crest factor measurement capability are able to analyze these typical switch mode waveforms. Voltage Voltage Current Current Time		
THD (Total Harmonic Distortion)	Required to analyze the effect of non lineanity's	equired to analyze the fect of non lineanity's Power DSP analysis capability for accurate measurement of THD.		
Standby Power	Required of Energy Star and IEC62301	A year 2000 study in the US claimed that standby power accounted for around 10% of household power- consumption (\$6 billion). Shown here an IEC62301 test report.		



Figure 1. Vrms and Arms waveform.

2. The Key to Measuring Volts, Amps and Watts

Power Supplies connected to the AC line generally draw distorted, non-linear currents. Many AC voltage and current meters respond to the average value of a waveform, although calibrated in RMS, they are only accurate for pure sine waves.

Tektronix power analyzers obtain RMS values by taking a large number of instantaneous voltage and current samples over many cycles of the voltage and current waveform. The true RMS value is obtained even for highly distorted waveforms. Tektronix power analyzers are AC and DC coupled to be able to make accurate power measurements over all frequencies and wave shapes.

Phase and amplitude samples of current and voltage are the fundamental building block for algorithms to derive the many parameters needed to characterize power supplies. Measuring the input and output power provides an efficiency specification for the power supply. High efficiency measurements demand high accuracy of input and output power measurements. Power supplies are generally characterized for normal operating power and standby power (equipment with power continually applied but turned off by electronics). The current drawn will be non-linear, making it essential to measure true RMS current and voltage. The current and voltage waveform from a typical switched mode power supply shown in Figure 1.

A power analyzer with high frequency sampling is essential to accurately measure all essential design parameters including RMS power, power factor, harmonics etc. as shown in Figure 1.

Tektronix power analyzers are peak ranging instruments. That means they automatically measure waveforms with a crest factor of up to 10, without user intervention or additional erros.



Figure 2. Root Mean Square waveform.

2.1. RMS (Root Mean Squared Value)

The RMS value is the most commonly used and useful means of specifying the value of both AC voltage and current. The RMS value of an AC waveform indicates the level of power that is available from that waveform and is equivalent DC at the same voltage. This is one of the most important attributes of any AC source. The calculation of an RMS value can best be described by considering an AC current waveform and its associated heating effect such as that shown in Figure 2.

The current (Amp) is considered to be flowing through a resistance; the heating effect at any instant is given by the equation:

$$W = I_2 R$$

By dividing the current cycle into equally spaced coordinates (samples), the variation of the heating effect with time can be determined as shown in Figure 2 above. The average heating effect (power) is given by:

$$W = \frac{I_1^2 R + I_2^2 R + I_3^2 R \dots I_n^2 R}{n}$$

To determine the equivalent value of current that would produce the average heating effect value shown above, then the following applies:

$$I^{2}R = \frac{I_{1}^{2}R + I_{2}^{2}R + I_{3}^{2}R...I_{n}^{2}R}{n}$$

Therefore:

$$I = \sqrt{\frac{I_1^2 + I_2^2 + I_3^2 \dots + I_n^2}{n}}$$

The RMS value of the current = the square root of the mean of the squares of the current. This value is often termed the effective value of the AC waveform, as it is equivalent to the direct current that produces the same heating effect (power) in the resistive load. It is worth noting that for a sinusoidal waveform:

$$RMS \ value = \frac{peak \ value}{\sqrt{2}}$$

$$RMS = 0.707 \ x \ peak \ value$$



Figure 3. Average calculated methodology.

2.2 Average Value

The average value of a waveform such as that shown in Figure 3 is given by:

It is clear the average value can only have real meaning over one half cycle of the Waveform, for a symmetrical waveform, the mean or average value over a complete cycle is zero. Most simple multi-meters determine AC values by full-wave rectification of the AC waveform, followed by a calculation of the mean value. Such meters; however, will be calibrated in RMS and will make use of the known relationship between RMS and average for a sinusoidal waveform, i.e.

RMS = 1.11 x mean

However, for waveforms other than a pure sine wave, the readings from such meters will be invalid. RMS values will need to be calculated using techniques shown in Figure 3.

2.3 Real and Apparent Power (W & VA)

A sinusoidal voltage source of, say, 100V RMS is connected to a resistive load of, say, 100Ω , then the voltage and current can be depicted as in Figure 4 and are said to be "in phase". The power that flows from the supply to the load at any instant is given by the value of the product of the voltage and the current at that instant, as illustrated in Figure 4.

From this, it can be seen that the power flowing into the load fluctuates (at twice the supply frequency) between 0 and 200W and that the average power delivered to the load equals 100W-which is what one might expect from 100V RMS and a resistance of 100Ω . However, if the load is reactive (i.e. contains inductance or capacitance as well as resistance) with an impedance of 100Ω , then the current that flows will still be 1A RMS but will no longer be in-phase with the voltage. This is shown in Figure 5 for an inductive load with the current lagging by 60 degrees. Although the power flow continues to fluctuate at twice the supply frequency, it now flows from the supply to the load during only a part of each half cycle-during the remaining part, it actually flows from the load to the supply. The average net flow into the load, therefore, is much smaller than in the case of a resistive load as shown in Figure 4- with only 50W of useful powering delivered into the inductive load.

In both of the above cases the RMS voltage was equal to 100V RMS and the current was 1A RMS. The product of these two values is the apparent power delivered into the load and is measured in VA as follows:

Apparent Power =
$$V_{RMS} \times A_{RMS}$$

The real power delivered has been shown to depend on the nature of the load. It is not possible to determine the value of real power from the knowledge of RMS voltage and the use of a true AC power meter, capable of computing the product of the instantaneous voltage and current values and displaying the mean of the result is required. VA is often measured to ensure that the ac supply has sufficient capacity.



Figure 4. Voltage and current phase waveform.



Figure 5. The power that flows from the supply to the load.



Figure 6. Power factor waveform.

2.4 Power Factor

It is clear that, in comparison with DC systems, the transferred AC power is not simply the product of the voltage and current values. A further element, known as the power factor must also be taken into consideration. In the previous example (real and apparent power) with an inductive load, the power factor is 0.5 because the useful power is exactly one half of the apparent power. We can therefore define power factor as:

$$Power \ Factor = \frac{Real \ Power}{Apparent \ Power}$$

In the case of sinusoidal voltage and current waveforms, the power factor is actually equal to the cosine of the phase angle (θ) between the voltage and current waveforms. For example, with the inductive load described earlier, the current lags the voltage by 60 degrees.

Therefore:

Power Factor = $cos\theta = cos60^\circ = 0.5$

It is for this reason that power factor is often referred to as $\cos\theta$. However, it is important to remember that this is only the case when both voltage and current are sinusoidal [Figure 6 (I1 and I2)] and that power factor is not equal to $\cos\theta$ in any other case [Figure 6 (I3)]. This must be remembered when using a power factor meter that reads $\cos\theta$, as the reading will not be valid except for pure sinusoidal voltage and current waveforms. A true power factor meter will compute the ratio of real to apparent power as described in section discussing real and apparent power.

Tektronix power analyzer retains high accuracy even at very low power factor, which is very important for product characterization and development.

2.5 Crest Factor

Tektronix power analyzers can measure a high Crest Factor (~10). This is critical for characterization of switched mode power supplies, which usually have high peak current draw. It has already been shown that for a sinusoidal waveform:

Peak Value = RMS
$$x \sqrt{2}$$

The relationship between peak and RMS is known as the crest factor and is defined as:

 $Crest Factor = \frac{Peak Value}{RMS Value}$

Thus, for a sinusoid:

Crest Factor =
$$\sqrt{2}$$
 = 1.41

Many items of modern equipment connected to the AC supply take non-sinusoidal current waveforms. These include power supplies, lamp dimmers, and even fluorescent lamps. Power supplies can often exhibit a current crest factor of around 4 and up to 10.

2.6 Harmonic Distortion

If a load introduces distortion of the current waveform, it is useful, in addition to knowing the crest factor, to quantify the level of distortion of the wave shape. Observation on an oscilloscope will indicate distortion but not the level of distortion. It can be shown by Fourier analysis that a nonsinusoidal current waveform consists of a fundamental component at the supply frequency plus a series of harmonics (i.e.) components at frequencies that are integral multiples of the supply frequency). For example, a SMPS, a lamp dimmer or even a speed-controlled washing machine motor can contain harmonics of even greater significance as shown in Figure 7.

The only useful current is the fundamental component of current, as it is only this that can generate useful power. The additional harmonic current not only flows within the power supply itself, but in all of the distribution cables, transformers and switchgear associated with the power supply and will thus cause additional loss. There is an increasing awareness



Figure 7. An example of Harmonics Barchart.

of the need to limit the level of harmonics that equipment can produce. Controls exist in many territories to provide mandatory limits on the level of harmonic current permitted for certain types of load. Such regulatory controls are becoming more widespread with the use of internationally recognized standards such as EN61000-3-2. Thus, there is a need for an increased awareness amongst equipment designers as to whether their products generate harmonics and at what level. It is only the fundamental which generates power, harmonics in general do not.

2.7 Standby Power

Standby power is the power drawn by a power supply when its load is not performing its full function. This may be the power consumed just by the clock on a microwave oven or the power drawn by a laptop charger when the battery is fully charged.

To make the measurement requires not only very low measurement ranges, but special techniques to overcome the problems of power supplies operating in burst mode.

Tektronix power analyzers have both a quick 1-button standby mode for the designer and, together with PWRVIEW pc software will perform full compliance ENERGY STAR and IEC62310 Ed.2 standby power measurements. Please see our detailed application note on this subject.

3. What Types of Power Supply

Designs generally fall into two categories, either linear or switched mode. In general switched mode power supplies are used in high efficiency applications such as computers and wall chargers. They are also compact and inexpensive. Linear power supplies are generally chosen where the output (and possibly input) needs to be very clean (low EMI/EMC) and low noise. However they are inefficient and bulky.

Inverters - There is significant interest in micro- to large-scale inverters for solar power applications, taking DC from a PV (Photo voltaic) cell and converting this to single or multiphase AC for grid connection.

LED Drivers - Power supplies (drivers) for LED (Light Emitting Diode) lamp systems have many topologies with the driving force being low cost and high efficiency. Often the output voltage is AC or rectified DC with PWM (Pulse Width Modulation) control for brightness.

4. Conclusion

Power and power related measurements on power supplies require sophisticated and accurate instrumentation to ensure that the power supply performs to its specification.

The Tektronix PA1000 power analyzed incorporates a wide range of advanced features including peak raging, dual shunts and waveform display that speed and enhance the test and development of modern power supplies.

5. Reference

- Making Ballast Measurement with PA1000, www.tek.com
- Making Standby Low Power Measurement with PA1000, www.tek.com
- PA1000 User Manual, www.tek.com
- Power Analyzer Accessory Brochure, www.tek.com

Contact Tektronix:

ASEAN / Australia (65) 6356 3900 Austria* 00800 2255 4835 Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777 Belgium* 00800 2255 4835 Brazil +55 (11) 3759 7627 Canada 1 (800) 833-9200 Central East Europe and the Baltics +41 52 675 3777 Central Europe & Greece +41 52 675 3777 Denmark +45 80 88 1401 Finland +41 52 675 3777 France* 00800 2255 4835 Germany* 00800 2255 4835 Hong Kong 400-820-5835 Ireland* 00800 2255 4835 India +91-80-30792600 Italy* 00800 2255 4835 Japan 0120-441-046 Luxembourg +41 52 675 3777 Macau 400-820-5835 Mongolia 400-820-5835 Mexico, Central/South America & Caribbean 52 (55) 56 04 50 90 Middle East, Asia and North Africa +41 52 675 3777 The Netherlands* 00800 2255 4835 Norway 800 16098 People's Republic of China 400-820-5835 Poland +41 52 675 3777 Portugal 80 08 12370 Puerto Rico 1 (800) 833-9200 Republic of Korea +822-6917-5000 Russia +7 495 664 75 64 Singapore +65 6356-3900 South Africa +27 11 206 8360 Spain* 00800 2255 4835 Sweden* 00800 2255 4835 Switzerland* 00800 2255 4835 Taiwan 886-2-2656-6688 United Kingdom* 00800 2255 4835 USA 1 (800) 833-9200 * If the European phone number above is not accessible, please call +41 52 675 3777 Contact List Updated June 2013

For Further Information

B Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit www.tektronix.com

Copyright © 2013, Tektronix. All rights reserved. Tektronix products are covered by U.S. and foreign patents, issued and pending. Information in this publication supersedes that in all previously published material. Specification and price change privileges reserved. TEKTRONIX and TEK are registered trademarks of Tektronix, Inc. All other trade names referenced are the service marks, trademarks or registered trademarks of their respective companies.

11/13 DM/WWW

55W-29828-0

