

AC-DC Power Supply Efficiency Testing for Regulatory Standards

A Guide for Pre- or Full-compliance Efficiency Testing

APPLICATION NOTE



Contents

Introduction	3
Efficiency Standards.....	3
Test Method.....	4
Test Equipment Requirements	5
Power Analyzer.....	5
Electronic Load.....	5
AC Source.....	5
Tektronix Solution	6
PA3000 Power Analyzer	6
2380 Series Electronic Load	7
PWRVIEW Software	7
How to Test Efficiency (Level VI)	8
Instrument Setup Steps.....	8
PWRVIEW Software Setup Steps	9
Running the Efficiency Test.....	9
Further Settings if Required	10
2380 Series Electronic Load Programming.	11
How to Test Standby Power (IEC 62301)	12
Test Setup.....	12
PWRVIEW Setup	13
Further Settings if Required	13
Conclusion.....	14

Introduction

AC to DC power supplies are fully integrated into our daily lives. They are the heart of all our electronics, providing energy for the everyday devices that we rely on. A cell phone charger is a power supply, but so are the power electronic circuits embedded inside almost any electronics or appliance connected to the AC line. This near universal use of power supplies means that although the power that each individual supply draws is small, the cumulative effects are very significant. For this reason it is desirable, and often required by regulation, to control power supply characteristics such as efficiency, standby power and input power quality.

AC–DC power supplies convert electrical energy from their AC line input to provide DC outputs that are:

- Isolated from the dangerous high-voltage, high-capacity AC line.
- Smoothed and low-noise DC voltage.
- Regulated to be largely independent of input voltage changes.
- Current controlled to avoid damage to the load (especially batteries) and to the power supply itself.

Typically, an AC to DC power supply converts the AC line (115/220V and 60/50Hz) into low voltage (12V, 5V, 3V) DC.

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

This application note is intended to assist engineers who design and test power supplies make efficiency and standby power measurements accurately, quickly and safely.

This note is also intended for design engineers who understand the importance of pre-compliance testing for regulatory compliance tests in early design cycles that can help reduce re-runs at third party compliance labs resulting into expensive design changes and board revisions close to release.

Despite the focus of the content of this application note on the Level VI efficiency standard, the principle and underlying methods can be used for any AC-DC power supply or similar converters.

Efficiency Standards

Efficiency and energy consumption standards governed by various institutions over the world have proven very effective in improving energy consumption trends and saving consumer's energy and money. The international efficiency marking protocol is one such successful program that regulates the efficiency and no-load power of external power supplies. Since 2004, the efficiency limits have evolved aggressively adding pressure on design engineers to squeeze out as much efficiency as possible from a power supply design. The latest iteration of requirements by the United States Department of Energy (DOE) furthers these limits for LEVEL VI and mandates the testing on all external power supplies sold in the United States. It's likely that other regions like Europe, greater Americas, Australia and Asia will follow suite.

It is important for all external power supply (EPS) suppliers to stay on top of the regulatory changes and make sure their product complies within their target market to avoid costly delays and fines.

Table 1 shows a summary of performance thresholds required for each level as defined by the international efficiency marking protocol. These levels are represented as roman numerals (I, II, III, IV, V, VI...) on the power supply labels.

Table 1. Efficiency Performance Requirements. (Source: US Department of Energy).

Mark	Performance Requirements				Power Factor
	Nameplate Output Power (P_{no}) ²	No-Load Mode Power ³	Nameplate Output Power (P_{no})	Average Efficiency in Active Mode ⁴	
I	Used if none of the other criteria are met.				
II	0 to ≤ 10 W	≤ 0.75	0 to < 1 W	≥ 0.39 * P_{no}	Not Applicable
	> 10 to 250 W	≤ 1.0	1 to < 49 W > 49 W	≥ 0.107 * $\ln(P_{no}) + 0.39$ ≥ 0.82	
III	0 to < 10 W	≤ 0.5	0 to 1 W	≥ 0.49 * P_{no}	Not Applicable
	10 to 250 W	≤ 0.75	> 1 to 49 W > 49 to 250 W	≥ 0.09 * $\ln(P_{no}) + 0.49$ ≥ 0.84	
IV	0 to 250 W	≤ 0.5	0 to < 1 W	≥ 0.5 + P_{no}	Not Applicable
			1 to 51 W	≥ 0.09 * $\ln(P_{no}) + 0.5$	
			> 51 to 250 W	≥ 0.85	
V	0 to < 50 W	AC-DC: ≤ 0.3 AC-AC: ≤ 0.5	0 to ≤ 1 W	Basic Voltage: ≥ 0.480 * $P_{no} + 1.40$ Low Voltage ⁵ : ≥ 0.497 * $P_{no} + 0.067$	EPSs with ≥ 100 W input power must have a true power factor ≥ 0.9 at 100% of rated load when tested at 115 V/60 Hz.
			1 to ≤ 49 W	Basic Voltage: ≥ 0.0626 * $\ln(P_{no}) + 0.622$ Low Voltage: ≥ 0.0750 * $\ln(P_{no}) + 0.067$	
	≥ 50 to ≤ 250 W	≤ 0.5	> 49 to 250 W	Basic Voltage: ≥ 0.870 Low Voltage: ≥ 0.860	
VI	Single-Voltage				Not Applicable
	0 to ≤ 49 W	AC-DC: ≤ 0.100 AC-AC: ≤ 0.210	0 to ≤ 1 W	Basic Voltage: ≥ 0.5 * $P_{no} + 0.16$ Low Voltage: ≥ 0.517 * $P_{no} + 0.087$	
			> 1 to ≤ 49 W	Basic Voltage: ≥ 0.071 * $\ln(P_{no}) - 0.0014 * P_{no} + 0.67$ Low Voltage: ≥ 0.0834 * $\ln(P_{no}) - 0.0014 * P_{no} + 0.609$	
	≥ 49 to ≤ 250 W	≤ 0.210	> 49 to ≤ 250 W	Basic Voltage: ≥ 0.880 Low Voltage: ≥ 0.870	
	≥ 250 W	≤ 0.500	>250 W	≥ 0.875	
	Multiple-Voltage				
	Any	≤ 0.300	0 to ≤ 1 W	≥ 0.497 * $P_{no} + 0.067$	
> 1 to ≤ 49 W			≥ 0.075 * $\ln(P_{no}) + 0.561$		
> 49 W			≥ 0.860		
VII	Reserved for future use.				

² P_{no} is the Nameplate Output Power of the unit under test.

³ In Australia and New Zealand, AC-AC external power supplies are not required to meet the no-load mode power requirements.

⁴ "ln" refers to the natural logarithm.

⁵ A low-voltage model is an EPS with nameplate output voltage of less than 6 volts and nameplate output current greater than or equal to 550 milliamperes. A basic-voltage model is an EPS that is not a low-voltage model.

Test Method

The official test methods for testing single and multiple voltage external power supplies for LEVEL VI protocol as per DOE are published under Title 10 of the U.S. Code of Federal Regulations, Appendix Z to Subpart B of Part 430. The information is available from the U.S. Government Printing Office at www.ecfr.gov.

Though a detailed description of the test method is beyond the scope of this document, here is a summary of the general requirements:

- The external power supply has to be tested under load and no-load conditions.
- The unit under test has to be tested at 115 V at 60 Hz in the United States. This requirement might differ based upon region.
- The input voltage and frequency must be within $\pm 1\%$ of the specified values.
- The THD of the input voltage shall be $\leq 2\%$, up to and including the 13th harmonic. The crest factor of the input voltage shall be between 1.34 and 1.49.
- The unit under test must be operated at 100% load current for 30 minutes immediately before conducting efficiency measurements.
- After the 30 minute warm-up period, AC input power must be monitored for 5 minutes to check for device stability. The power level drift should be within 1% from the maximum value observed.
- The 5 minute stability check must be performed at each loading condition as noted below. The warm-up period of 30 minutes is only required once at the start of the testing procedure.
- The unit under test must be tested at 100%, 75%, 50%, 25% and 0% of de-rated load ($\pm 2\%$) in that specific order.
- Standard also states loading conditions for multiple-output power supplies but those details are beyond the scope of this document. Refer to the original publication for test method.

- Efficiency must be calculated real-time as a ratio, expressed as percentage, of the output active power to AC input active power at each loading condition and recorded separately.

$$\text{Efficiency} + \frac{P_{OUT}}{P_{IN}} \times 100\%$$

- Power consumption must be calculated as the difference between the active output power and the active AC input power at each loading condition and reported separately.
- The power consumption testing at no-load (Standby Power) shall conform to the requirements specified in “Test Method for Calculating the Energy Efficiency of Single-Voltage External AC-DC and AC-AC Power Supplies” published by California Energy Commission. The requirements for this document are essentially derived from IEC 62301 standby power testing standard.

Test Equipment Requirements

It is important to select the right equipment for power supply efficiency testing, especially when testing per standards. Following are the equipment parameters and features required for accurate efficiency and power measurement.

Power Analyzer

Power analyzers are required to measure input and output power accurately on AC-DC power supplies while making efficiency measurements.

Power analyzers used for efficiency testing, based on regulatory standards, are required to have the following specifications:

- Uncertainty of ≤ 2 percent at 95 percent confidence level while measuring ≥ 0.5 W power.
- Uncertainty of ≤ 0.01 W at 95 percent confidence level while measuring < 0.5 W power.
- The power measurement instrument shall have a resolution of:
 - 0.01 W or better for measurements up to 10 W;
 - 0.1 W or better for measurements of 10 to 100 W; or
 - 1 W or better for measurements over 100 W.
- Measurements of energy (Wh) shall be made with an uncertainty of ≤ 2 percent at the 95 percent confidence level.

- Measurements of voltage and current shall be made with an uncertainty of ≤ 1 percent at the 95 percent confidence level.
- Requirements for standby power testing are defined by the IEC 62301 test standard.
- All equipment used to conduct the tests must be selected and calibrated to ensure that measurements will meet the above uncertainty requirements.

Electronic Load

- Active or passive load is required to set output current of the DUT while testing efficiency.
- Electronic loads, though relatively expensive, can provide significant benefits over passive loads due to their versatility and programmability.
- Electronic loads can also help automate efficiency testing, reducing testing time and user errors.
- Electronic loads, if used, are required to be set in constant current mode while testing efficiency by regulatory standard.
- Both passive and electronic loads also need to maintain the load current at all required output voltages with an accuracy of $\pm 0.5\%$.

AC Source

- AC sources are required in most cases for efficiency testing to regulatory standards.

- The input voltage from the AC wall socket can be very unreliable and can have significant variations based on various factors like time of day, wiring impedance and load variations.
- Voltage signals from wall sockets are notorious for high harmonic content (THC). This can be especially bad in lab testing environments due to presence of various other electronic instruments and constantly varying loads.
- Voltage signals from wall sockets will also create significant issues with repeatability of measurements, as it is very difficult to get a consistent voltage value.
- Electronic AC sources solve these problems by providing a traceable and reliable voltage output that has a calibrated tolerance within the required standards.
- Most electronic AC sources also allow programming, which makes it easy to automate efficiency testing and reduce time and user errors.
- AC source used for efficiency testing per standards are required to have the input voltage and frequency within ± 1 percent of the specified values.
- The sources are also required to have the total harmonic content (THC) of the input voltage within ≤ 2 percent, up to and including the 13th harmonic.
- The crest factor of the input voltage source has to be between 1.34 and 1.49.
- It's important to choose an AC source that complies with these specifications for efficiency testing.

Tektronix Solution

The Tektronix PA3000 Power Analyzer and Keithley 2380 Series Electronic Loads along with PWRVIEW software are optimized for providing an easy and accurate solution for testing efficiency on AC-DC power supplies per regulatory standards.

PA3000 Power Analyzer

The PA3000 Power Analyzer is a multi-channel power analyzer that offers numerous features and specifications that are tailored for efficiency and standby power testing:

- 0.04% basic accuracy on voltage and current signals easily exceeds the accuracy requirements of the efficiency standards testing.
- Multiple channels enable measuring input and output simultaneously.

GROUP A Ch1	GROUP B Ch2	GROUP C Ch3	GROUP D Ch4	Result 1332
Vrms 109.85 V	Vrms 12.077 V	Vrms 109.88 V	Vrms 11.965 V	▲
Arms 330.82 mA	Arms 1.3762 A	Arms 136.85 mA	Arms 527.76 mA	▲
Watt 20.628 W	Watt 16.620 W	Watt 7.3105 W	Watt 6.3129 W	▲
VA 36.339 VA	Vdc 12.077 V	VA 15.037 VA	Vdc 11.965 V	▼
Freq 60.000 Hz	Adc 1.3762 A	Freq 60.000 Hz	Adc 527.63 mA	▼
PF 0.5677		PF 0.4862	VII -----	▼
Apk+ 1.0227 A		Apk+ 494.55 mA		▼
Apk- -1.0184 A		Apk- -485.91 mA		▼
Vdc 10.299 mV		Vdc 37.148 mV		▼
EFFICIENCY1 80.569 %		EFFICIENCY2 86.329 %		▼
-----		-----		▼
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Figure 1: Efficiency testing on multiple power supplies.

- 1 amp internal shunt with capability of measuring 90 μ A can measure standby power as low as 10 mW at 150 V.
- Continuous high speed (1 Ms/s) sampling rate ensures no-gap data for highly accurate RMS measurements.

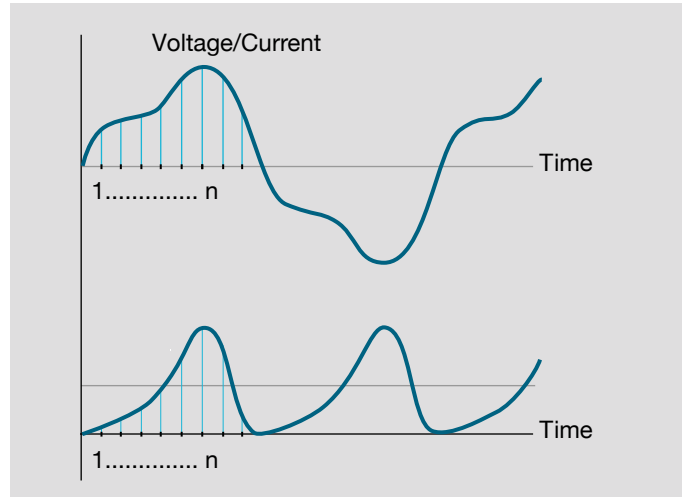


Figure 2: Continuous 1 Ms/s sampling for true RMS.

- Peak ranging to ensure there is no clipping on high crest factor waveforms common to AC-DC power supplies.

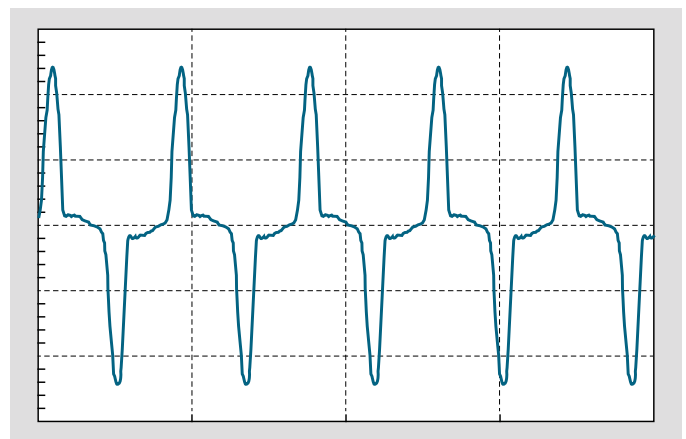


Figure 3: Peak ranging for high crest factor waveforms.

- Free PWRVIEW Software allows logging and archiving data for all efficiency testing.
- IEC 62301 full compliance mode helps test for standby power with live uncertainty calculation as required by the standard.
- Harmonic analysis capability to measure input voltage THC as required by the standard.
- Long averaging feature as required for standby power testing.
- Auto-up ranging feature for measurement on highly dynamic standby current.

2380 Series Electronic Load

The Keithley 2380 Series Electronic Loads feature 0.05% reading accuracy and 0.1mV/0.01mA voltage and current resolution to provide a perfect solution for AC-DC efficiency testing applications.

- High accuracy guarantees accurate loading at all required voltage outputs on the AC-DC power supply.
- 200W, 250W and 750 watt models enable testing of a wide range of AC-DC power supplies at different power levels.
- Along with constant current (CC) mode that is required by the efficiency standards, 2380 Series Electronic Loads also support constant voltage (CV), constant resistance (CR) and constant power (CP) modes to test various load configurations on the DUT.

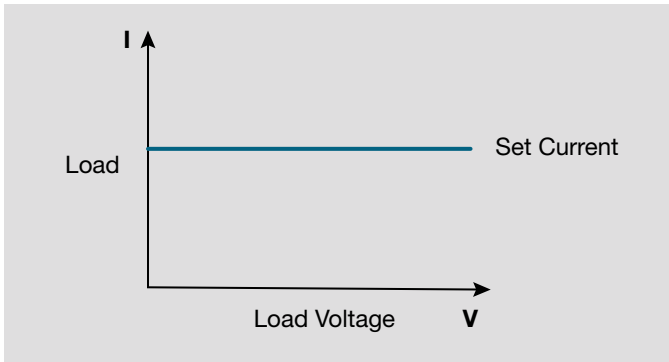


Figure 4: Constant Current (CC) load control I-V Plot.

- Constant power (CP) mode enables the DUT to be loaded by fixed power levels. This can be useful if the DUT operates under a hyperbolic voltage-current power profile rather than a rectangular voltage-current profile. Then the DUT can be tested at full load and percentages of full load based on the maximum power specification.

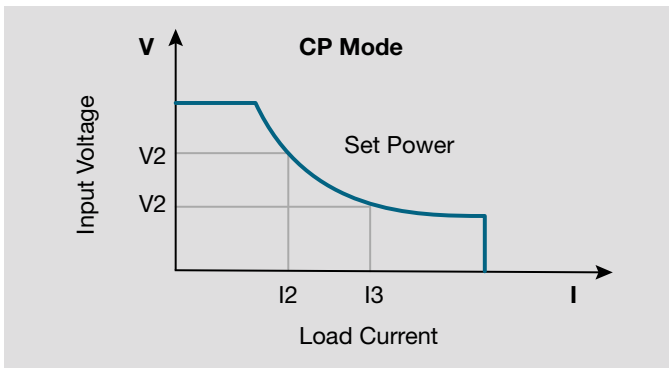


Figure 5: Constant Power (CP) load control I-V Plot.

- 2380 Series Electronic Loads make automating efficiency testing easy by using 'List' Mode. List mode allows users to program the load with various load currents for specific turn on and turn off times.
- List mode can be used to set up a test routine such that the 2380 Series Electronic Loads start in full load condition for about a 30 minutes warm-up time and then switch through 75%, 50%, 25% and 0% each, providing an easy way to automate efficiency tests based on regulatory standards.

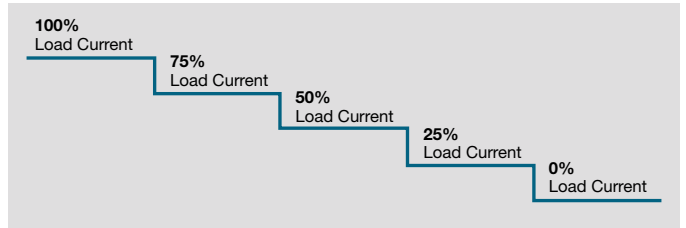


Figure 6: List Mode for automating efficiency testing.

PWRVIEW Software

PWRVIEW is a software application that compliments and extends the functionality of Tektronix power analyzers. It is available as a free download on the Tektronix website at www.tek.com.

PWRVIEW offers easy, wizard-driven test solutions for power supply efficiency testing, standby power and many other target applications. It also comes standard with compliance tests like IEC 62301 to make regulatory standards testing easy.

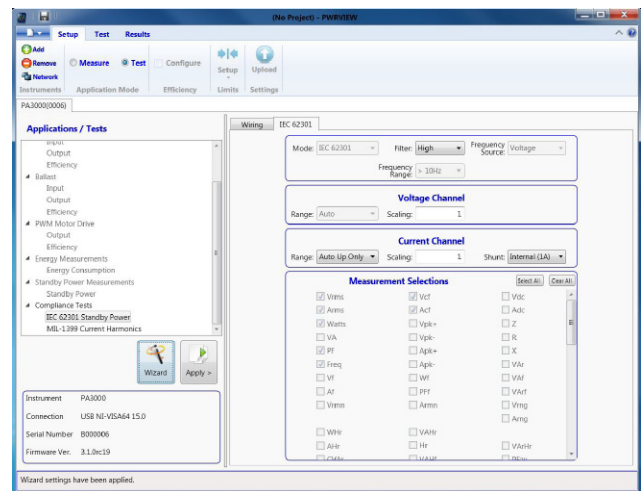


Figure 7: PWRVIEW software setup page.

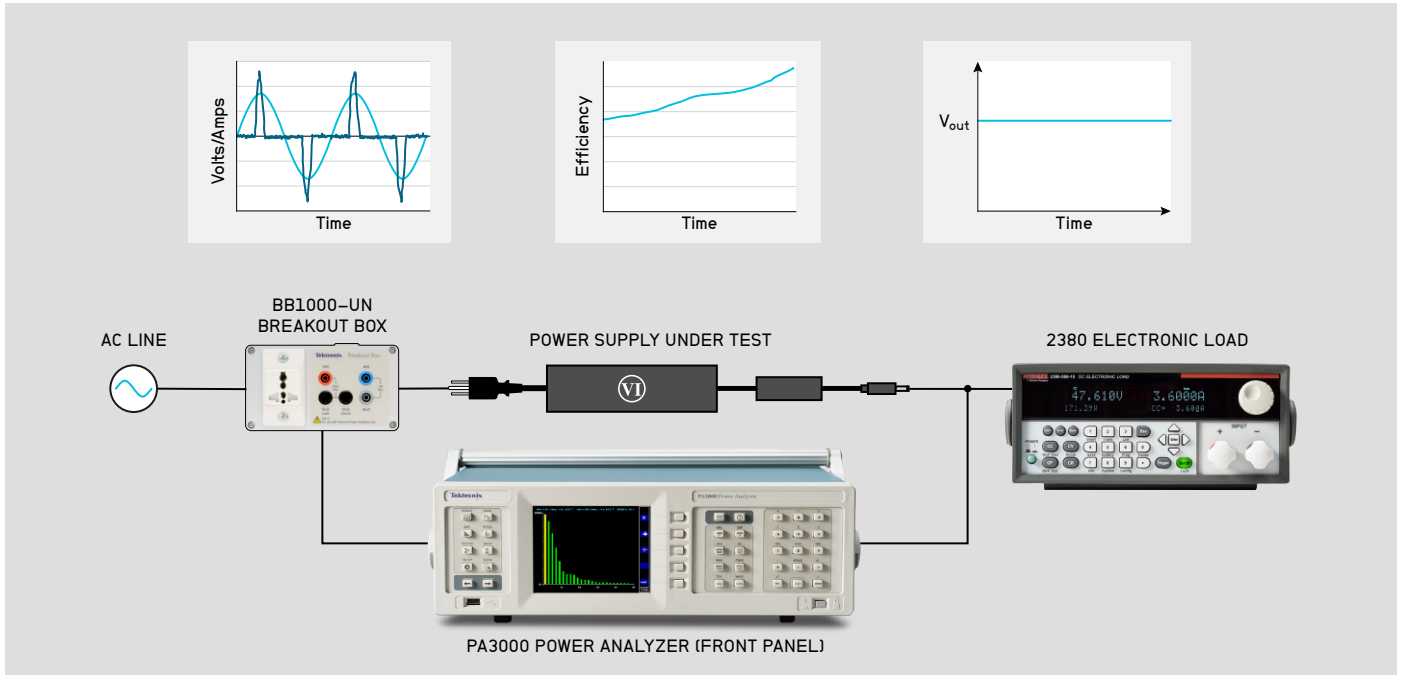


Figure 8: Efficiency testing setup for AC-DC Power Supply.

Following are some useful features of PWRVIEW software that are important for power supply testing:

- User-friendly measure grid makes it easy to acquire, monitor and analyze real-time data.
- Record function enables logging and exporting of all required test measurements.
- Remote operation of the PA3000 over any of the instrument's comms port (USB, LAN and GPIB) makes it easy to automate efficiency testing.
- Dedicated Efficiency mode makes efficiency testing setup effortless.
- User-defined hi/lo limits can help with quick pass-fail tests.
- Waveforms, harmonic bar charts and trend charts help with visually analyzing the incoming data, making it easier to monitor tests.
- Grid setup enables writing formulas for custom calculation of power conversion efficiency and other parameters.

Running the Efficiency Test

- The AC source and electronic load are set to the required source and load conditions respectively.
- Before making any measurements, the power supply under test has to go through a 30-minute 'warm-up' period by setting the load value to a 100% rated current. The warm-up period is required only once in the beginning of the test.
- The 2380 Series Electronic Load is set up in constant current (CC) mode and set to draw the rated full load current.
- After the 30 minute warm-up period, the input AC power is monitored for five minutes for stability, where, input power has to stay within 1% of the maximum value observed.
- PWRVIEW is used for logging and monitoring input power during the five-minute stability period using the record function.
- Specific logging rate and logging time can be set up to match the stability period.
- The trend chart can also be activated on PWRVIEW software to monitor input power stability.
- Once the stability is established, efficiency measurement is made for 100% load condition.
- This procedure is repeated for 75%, 50%, 25% and 0% load conditions following the 5-minute stability period between each load change.
- The 0% load condition is also called standby power and requires a special method of testing based on IEC 62301. This test method is described in the next section.
- The 2380 Series Electronic Load can also be set up in List Mode to automatically switch load values every five minutes to automate the whole testing process.
- Likewise, PWRVIEW can be set up to continuously log during the whole test period, thus making the test seamless and hands-free.

Further Settings if Required

Waveform, Harmonics, and Trend Chart. In the measurement grid, you can view Waveform, Harmonics, and Trend charts while testing efficiency by clicking the respective icons on the menu bar.

Waveforms in the PWRVIEW software are constructed using the harmonic data collected from the power analyzer. The accuracy of the waveform depends on the amount of harmonic information available. For optimum results, select the maximum number of harmonics to display in the setup area. Selecting 100 harmonics for the PA3000 gives the best results. If no harmonics are selected, the waveform feature will display a blank screen.

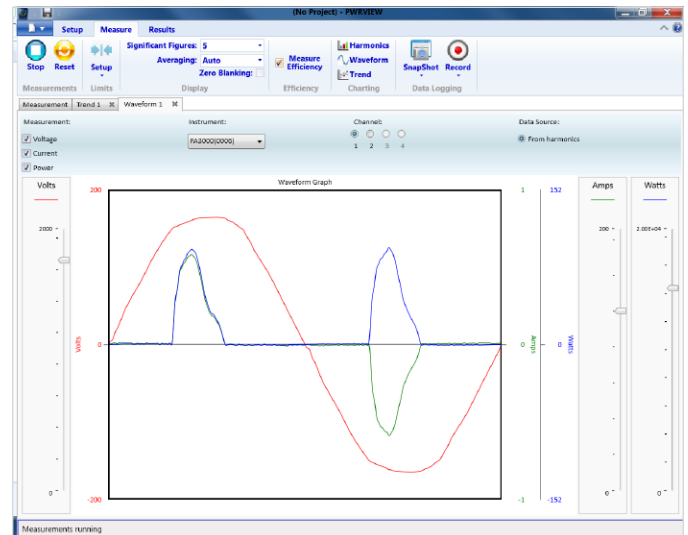


Figure 11: Waveform display.

- The harmonic bar chart can be enabled for all voltage, current, and watts measurements. Up to 100 harmonics can be selected through the setup screen. Hovering over any harmonic bar will display the absolute value and percentage of fundamental for that harmonic.

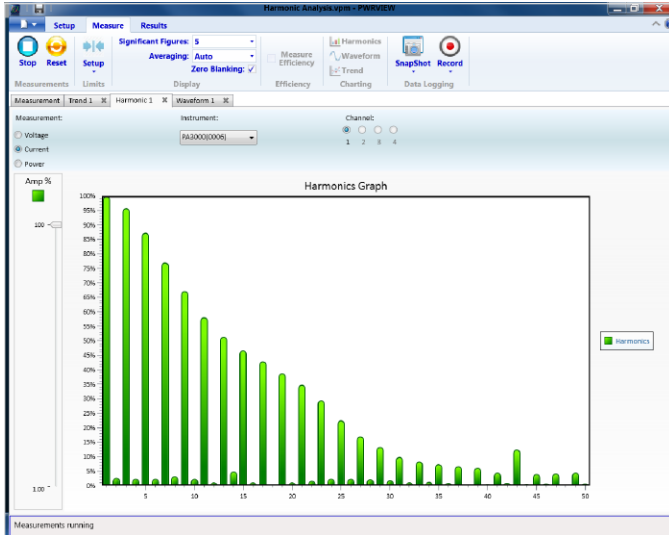


Figure 12: Harmonic bar chart.

- The trend chart can be activated for any measurement parameter by either right clicking on the desired parameter or by clicking the trend icon on menu bar. The trend chart can be reset by using the Reset button on the menu bar. Trend charts are very useful for stability measurement and efficiency measurement trend over period of time.

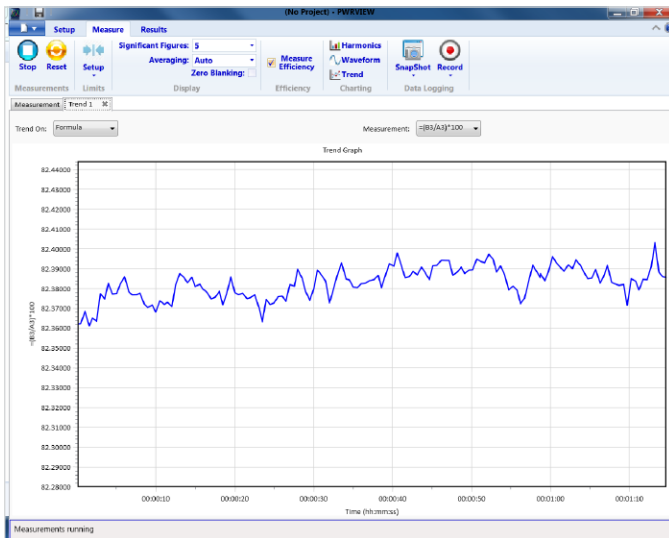


Figure 13. Efficiency trend chart.

Data logging. Recording data is important for most efficiency measurements where load and source sweep are required.

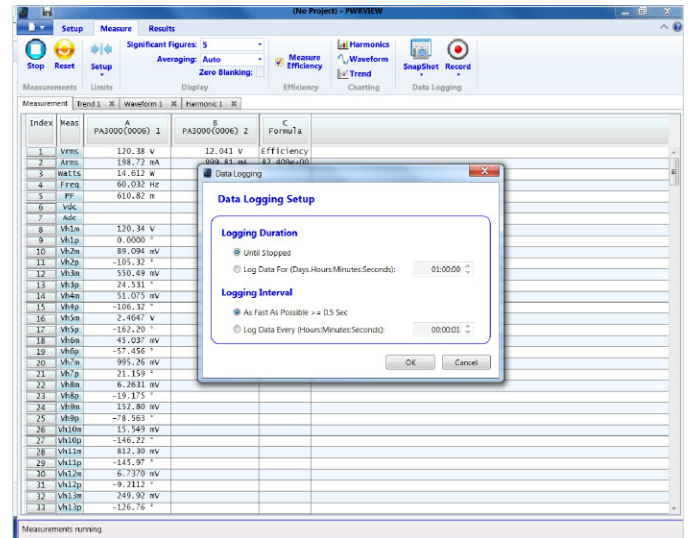


Figure 14: Logging setup.

- Data can be recorded on PWRVIEW software by clicking the Record button on the menu bar. The software will start recording all the selected data including formulas and limits.
- The data logging rate or the total logging time can be set from the drop down menu on the Record icon.
- All the recorded data is stored in a database on the local computer. The archived data can be accessed from the Results tab.
- Data can be exported as an .xls or .csv file.

Custom limits. Custom limits can also be set with any of the measurement parameters. Custom limits help set limits based on various standards or test specifications.

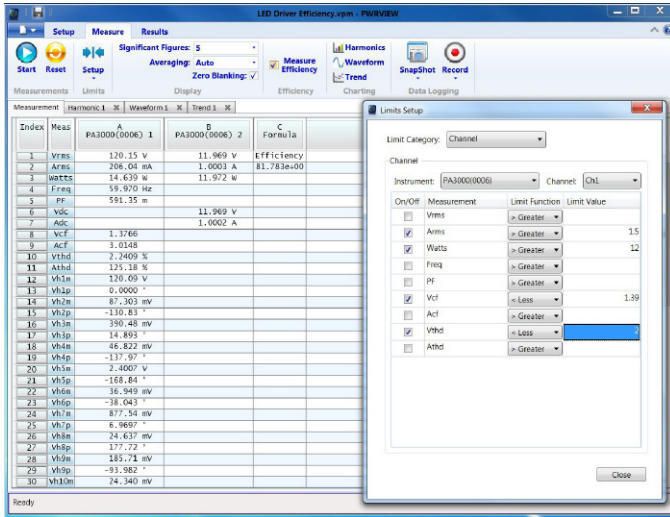


Figure 15: Custom limits setup.

- Custom limits can be set either by right-clicking the desired measurement parameter or clicking the Limits Setup icon on the menu bar.
- Custom limits will display red fonts if the limits are failing. Hovering over the results will display the limit function, limit value, and relative value.

2380 Series Electronic Load Programming.

- In addition to the List mode described earlier, the load can also be triggered via hardware, external trigger or a command from a controller, if a software is used to automate the setup.

How to Test Standby Power (IEC 62301)

All power supplies are required to be tested for no load condition (standby power) and are required to be within the stated no load power limits as published in the efficiency standard.

The PWRVIEW software along with PA3000 can test the standby power using full compliance techniques of IEC 62301 Ed. 2.0 / EN50564.

The PWRVIEW software makes the setup easy and accurate and calculates real time power stability, uncertainty and executes power averaging as required by the standard.

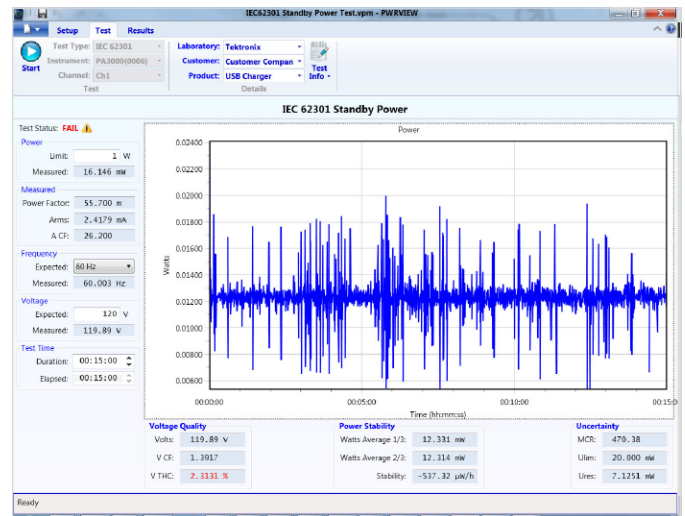


Figure 16: Full compliance IEC 62301 standby power test.

Test Setup

The DUT is connected using a Tektronix BB1000 Breakout Box as shown in the wiring diagram. (See **Figure 17.**)

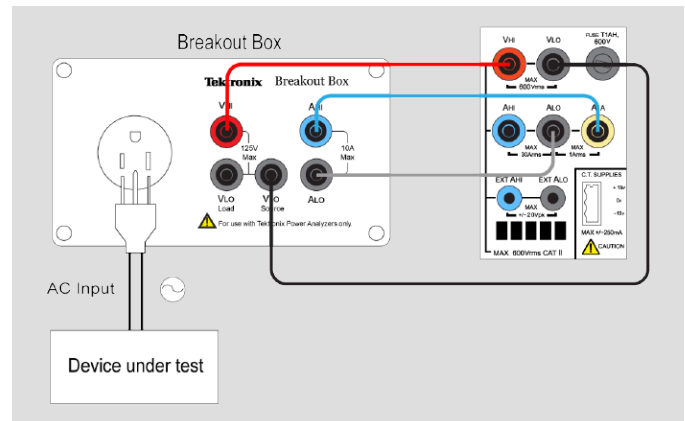


Figure 17: Standby power measurements wiring diagram.

- 1A shunt is used in cases where the maximum load current is lower than 1 A. This helps with higher resolution and better accuracy on low current measurements.
- While measuring standby power, the power analyzer's current shunt should be connected on the load side of the voltage low terminal as shown in **Figure 18**.

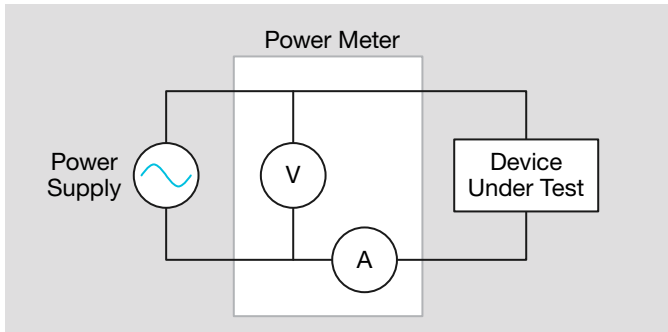


Figure 18: Correct wiring methods for low power measurements.

Connecting current shunt on the source side of the voltage low terminal can cause significant errors due to inclusion of drop across the voltmeter impedance in the low power measurement as shown in **Figure 19**.

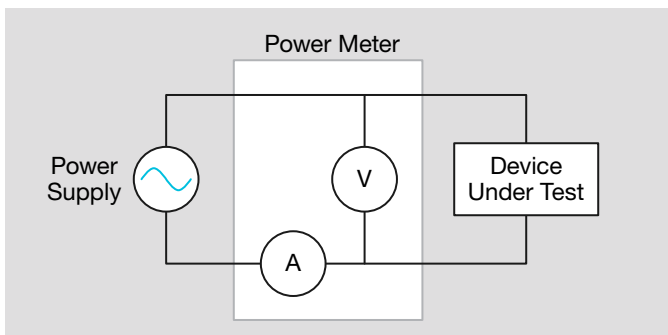


Figure 19: Incorrect wiring method for low power measurements. (Ok for high power measurements.)

- For example, the drop across the voltmeter channel impedance of $1\text{ M}\Omega$ will be 53 mW when supplied from 230 V . This may not be a significant value when measuring power over 1 W but can lead to significant errors while measuring power as lower than 100 mW .
- The Tektronix BB1000 Breakout Box makes this connection easy by providing two different terminals to switch between source and load side terminals.

PWRVIEW Setup

PWRVIEW provides a full compliance test solution for IEC 62301 Ed. 2.0 standby power testing.

- The PA3000 is connected to the computer with the PWRVIEW software installed using a USB cable. Ethernet or GPIB can also be used.
- IEC 62301 standby power test is available under default compliance tests on the setup page.
- Selecting the IEC 62301 Standby Power option under the Compliance tests and clicking the Wizard button opens a setup wizard window that can help set up the compliance test.
- The test is available under the Test tab where specific test details such as laboratory, customer, product information, and environmental conditions can be filled in on the top ribbon.
- Important test parameters like the power limit, expected frequency, and input voltage can be set up from the left panel.
- The default time for running the standby power test according to IEC 62301 is 15 minutes; this can be changed based on regional or local requirements.
- The test, once started, will run for the time duration selected and will update all the required measurements in the left panel. The standby power variation over time is displayed graphically.
- Voltage quality, power stability, and uncertainty are also evaluated in real time as required by the IEC 62301 standard.
- The test will display the pass/fail status based on all evaluated parameters.
- The test summary can be reviewed under the Results tab. All of the required parameters will be summarized with a pass/fail status under Test Summary and General Results.
- The Power Readings tab allows scrolling through the time scale and to debug specific issues on a given time stamp.
- The test results can be exported as a full report by clicking the Full Report PDF icon on the top ribbon. Alternately, the raw data can be exported using the Export CSV icon.

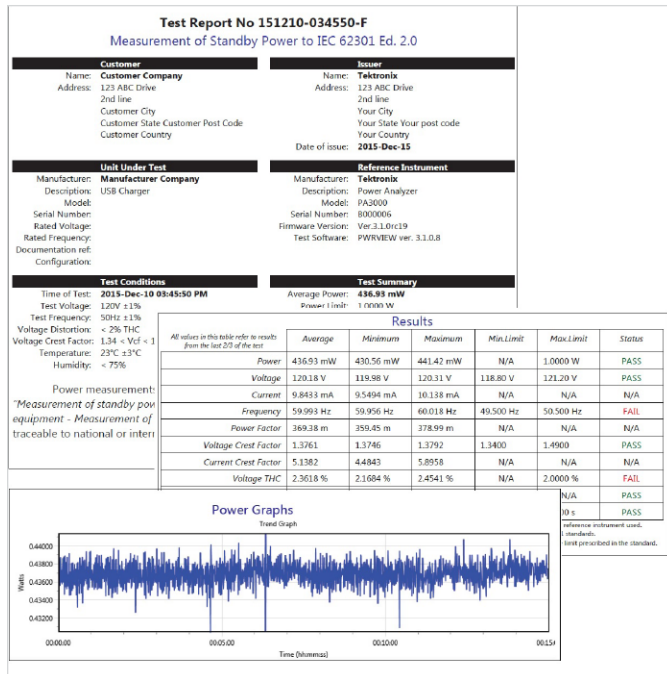


Figure 20: IEC 62301 Ed. 2.0 standby power test report.

Further Settings if Required

Ranging: By default, the PWRVIEW software sets up the PA3000 current range in Auto-Up-Only. The Auto-Up-Only option ranges up the PA3000 until it finds the highest range where the input signal is not clipped. This helps with setting the best range for the test. Otherwise, if the expected peak currents are known, a manual range can be selected for higher accuracy. The manual range can be selected for the selected shunt through the setup page under range options.

Bandwidth: For low power standby signals that have undesired high frequency components, low bandwidth filters can be enabled. A low bandwidth 10 kHz filter is available through the setup screen under the filter drop down option. Applying low pass filters might vary the RMS values of voltage, currents, and power as high frequency components affect the RMS values.

AC source: The IEC 62301 standby power full compliance test requires that the AC source be very stable as discussed earlier. The voltage and frequency are required to be within 1% tolerance. In addition, the input voltage total harmonic content (VTHC) must be within 2% for the first 13 harmonics and the voltage crest factor (VCF) must be within the 1.34 to 1.49 range. The IEC 62301 test on PWRVIEW tests for AC source quality in real time.

Conclusion

Efficiency, standby power and all other critical power related measurements on power supplies require sophisticated and accurate instrumentation to ensure that the power supply performs to its specification.

The Tektronix PA3000 Power Analyzer and Keithley 2380 Series Electronic Load incorporate a wide range of advanced features that makes them an optimum solution for efficiency testing.

The PA3000's high accuracy of 0.04% on voltage and current and ability to measure as low as 10 mW offer unique value for critical power supply measurements.

A range of operating modes and programming features make the 2380 Series High-precision DC Electronic Load the ideal solution for all loading requirements on power supply tests.

With the PA3000 Power Analyzer, 2380 Series Electronic Load and PWRVIEW software, power supply designers faced with the challenges of ever increasing efficiency and lower standby power requirements can always be confident that their designs will meet specifications.

Tip: Watch this video to learn how to make efficiency measurements on an external power supply that has been certified for the latest Level VI efficiency standard using the PA3000 Power Analyzer and 2380 Series Electronic Load with PWRVIEW software.

<http://www.tek.com/how/efficiency-measurement-level-vi-power-supply>



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