Introduction

These course notes are to be read in association with the PI University video course, *Testing Compliance to Energy Efficiency Standards*. In this course, you will learn how to measure the active-mode efficiency and no-load power consumption of an external power supply, according to energy efficiency standards. The approach shown in this course follows the test method referred to by ENERGY STAR, the European Commission Code of Conduct, and the California Energy Commission, and is similar to many other energy efficiency test methods. Energy efficiency standards require testing to be carried out to a stringent level of accuracy. The procedures described in these course notes are designed to ensure that the required level of accuracy is achieved.

An external power supply, also referred to as an EPS, is a power supply that is outside of the product to which it supplies power and is connected via a removable or hard-wired cable or connector. An example of this would be a laptop charger, which is considered an external power supply, as compared with a flat-screen TV power supply, which is internal to the product. Even if your product is not classified as an external power supply, this course may still be of interest as the measurement techniques demonstrated are similar to those used in testing other product types.

Equipment Required

The following equipment is needed for completion of this course:

1. A wattmeter
2. A programmable AC source
3. An electronic load
4. Two digital multimeters (one being a high-resolution current meter)

The energy efficiency compliance measurement of a power supply is a system-level test that includes power losses in the input and output cables. For this reason, the cables used should be the same as the ones that will be provided with the final product. Note that these tests require long temperature stabilization periods between output load and input line voltage changes, so expect to spend one to two hours to complete the testing. Additionally, every time you make a change to your design, this testing will need to be repeated.

Ensuring Testing Accuracy

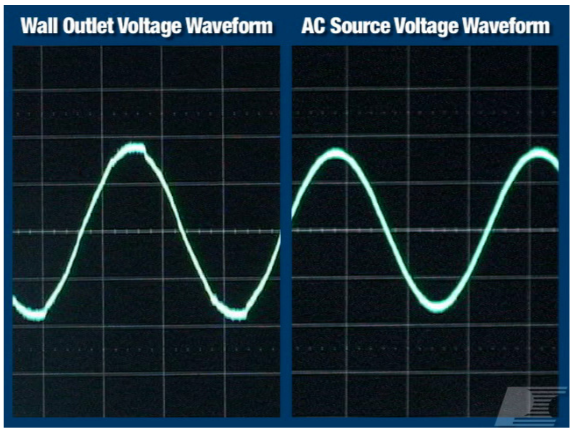
To test compliance with this specification, we will need to measure both the no-load input power and the active-mode efficiency of our external power supply.

To calculate efficiency, you will need to measure both input and output power.

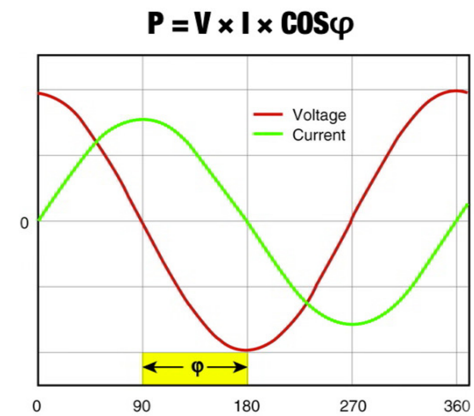
$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

When measuring input power, using a programmable AC source instead of a wall outlet and Variac ensures that testing is performed at a precise input voltage and that the incoming waveform is truly a sine wave and at either 50 or 60 Hz.

The raw AC power from a wall outlet and Variac, seen on the left, is distorted and introduces inaccuracy and uncertainty into the measurement. By comparison, the output from a programmable AC source, seen on the right, is a pure sine wave.



Comparison of raw mains AC quality versus a programmable AC power source



Power factor = cosine of phase angle φ between voltage and current waveforms

A wattmeter is used to measure the input power because it measures and includes the effect of the power factor, cosine of angle phi, between the voltage and current waveforms.

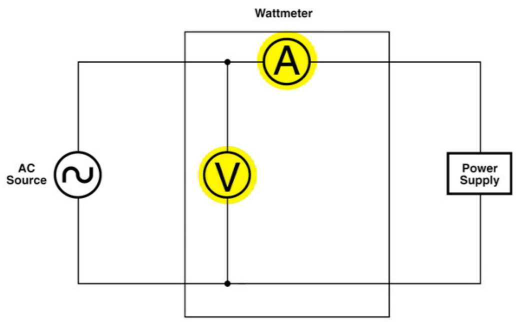
The energy efficiency standard requires an input power measurement uncertainty of less than 2% for power measurements of 0.5 W or greater and 10 mW for power measurements less than 0.5 W.

Energy Efficiency Standard Power Measurement Uncertainty Requirements

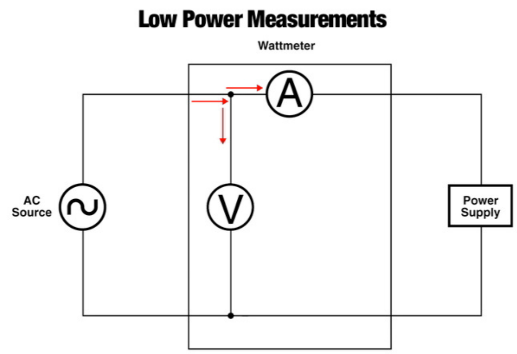
Uncertainty	$< 2\%$ for powers ≥ 0.5 W
Uncertainty	< 10 mW for powers < 0.5 W

The Yokogawa WT210, along with several other makes and models, meets these requirements when properly configured.

A wattmeter contains both a current and a voltage sensing element. The voltage sensing element can be configured either before or after the input current sense element. Information on how to set up and change this configuration on your wattmeter can be found in the associated user manual. For low- or no-load power measurements, better accuracy is obtained when the voltage sense is connected before the current sense element.



Wattmeter senses current and voltage

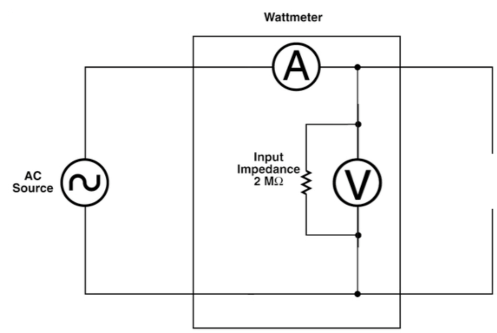


Connect voltage sense before current sense for low or no-load measurements

This prevents the current through the voltage sense element from being measured by the current sense element. When measuring no-load input power, this is critical to meet the uncertainty requirement, as the power consumed by the voltage sense element is typically greater than the allowable 10 mW at 230 VAC.

To measure the power consumed by the voltage element in the wattmeter, place the voltage element after the current element, remove all loads from the output of the wattmeter, and apply 230 VAC with the programmable AC source.

In this example, the input power measured on the wattmeter is 26.7 mW. This is the power consumed by the voltage sense element at 230 VAC and is consistent with the 2 MOhm input impedance specified for the voltage sense in the WT210.

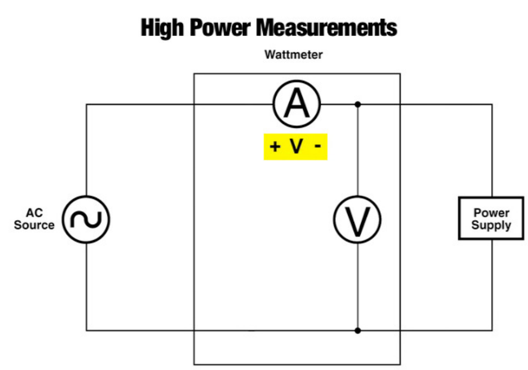


Measuring the power consumed by the voltage sense element of the wattmeter

High-Power Designs

In high-power designs, this power loss in the voltage sense is negligible and the voltage sense should be connected after the current sense, closest to the power supply input. This prevents the voltage drop across the current sense element and the internal wiring of the wattmeter from being incorrectly included in the power measurement and leading to lower efficiency calculations.

To produce more stable results, set the meter to average over 32 samples.



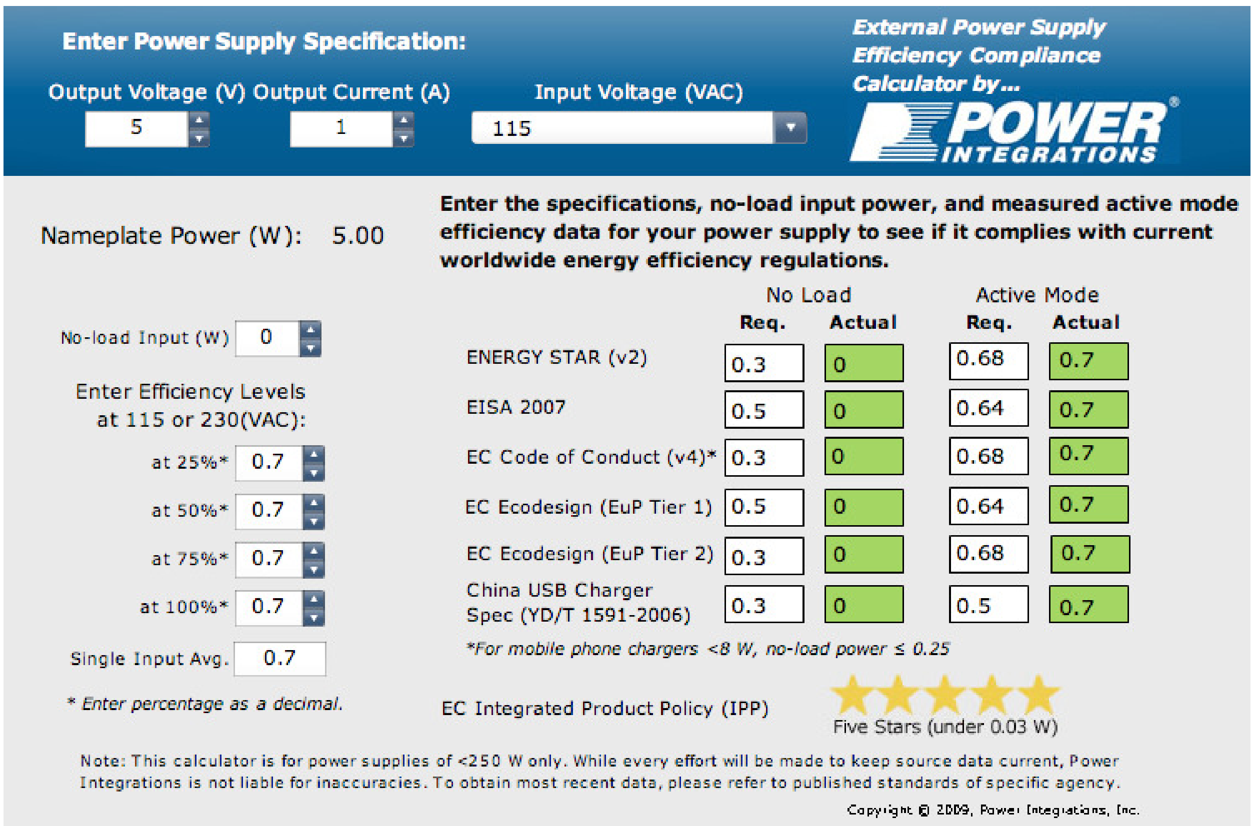
Connect the voltage sense after the current sense for high-power measurements

To measure the output power, you will need two multimeters -- one set to measure output voltage and the other current -- connected at the end of the output cable. Use the highest resolution meter available for the current measurement. Because output power is purely DC, it is calculated simply as output voltage times output current.

DC power	=	Volts x Amps
Output power	=	Output Voltage x Output Current

Using PI's Efficiency Compliance Calculator

The targets for no-load and active-mode efficiency are derived from the nameplate rating of the power supply. Using Power Integrations' *Efficiency Compliance Calculator*, enter the nameplate power rating to get the target values for a specific application.

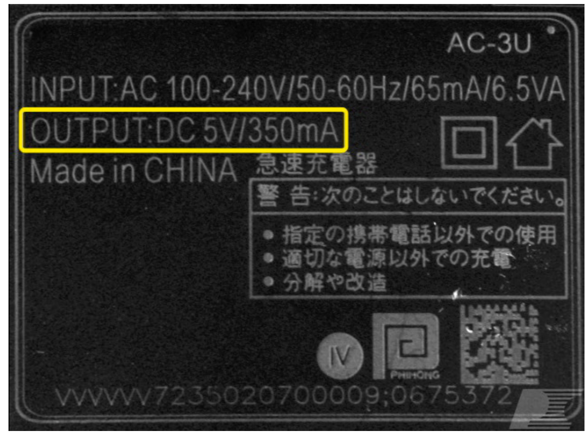


Power Integrations' External Power Supply Efficiency Compliance Calculator

After you have made your measurements, enter the results into the calculator to see if your EPS complies with current worldwide energy efficiency regulations. The nominal nameplate rating is simply the rated output marked on the power supply case. This value is the minimum rated output power of the supply at room temperature and nominal line.

For example, a constant voltage, constant current charger with a nameplate rating of 5 V, 350 mA will deliver 5 V, 350 mA minimum.

Enter the nameplate output power rating for your design into the Efficiency Compliance Calculator and note the target values for compliance to the energy standards applicable to your design. For designs that accept universal input voltages, the measurements are made at both 115 VAC, 60 Hz, and 230 VAC, 50 Hz. For single input voltage designs, measurement should be made at the nominal line voltage of either 115 or 230 VAC.



Charger nameplate rating

As an example, the 5 V, 350 mA cell phone charger unit rated for universal input will be tested. The first series of tests will be to measure the active-mode efficiency of this power supply at 115 VAC, 60 Hz. Active-mode efficiency is defined as the average of efficiencies measured at 25%, 50%, 75%, and 100% of the nameplate rating at a nominal line input voltage and nominal line frequency.

Active Mode Efficiency

$$\eta_{avg} = \frac{eff_{25} + eff_{50} + eff_{75} + eff_{100}}{4}$$

η = efficiency

The nameplate load rating for the charger is 350 mA. So the efficiency must be measured at the following currents:

- Full load: 350 mA
- 75% load: 262 mA
- 50% load: 175 mA
- 25% load: 88 mA

The first measurement should be made at 100% load, after allowing a 30-minute warm-up time. Connect the power supply to an AC source and apply a 60 Hz, 115 VAC input. Increase the load on the supply to full load, and allow at least 30 minutes for the circuit to reach thermal equilibrium and the input power reading to stabilize. Before recording your measurements, make sure no oscilloscope probe or other meters are connected to the circuit.

Here and throughout the testing, it may be necessary to manually set the voltage and/or current range of the wattmeter to prevent it from auto-ranging and giving fluctuating results. Refer to the operator's manual to determine the range that will give you the highest accuracy.

Next, take an initial power reading from the wattmeter. Wait five minutes, and take a second reading. If you find less than 5% difference between these readings, then record the second measurement. If, on the other hand, you find greater than 5% difference, you will need to integrate the input power and divide this result by the time period.

Procedure to Calculate the Integral Input Power

To measure the input power of a design where the input power varies over time (for instance, if the load draws a variable load during normal operation), the input power will need to be integrated by following these steps:

1. Set your wattmeter to integration mode.
2. Set the interval of integration for your wattmeter to capture approximately one full cycle of variable input power. (The longer the duration, the more accurate your results will be. Power Integrations recommends integrating over a period of 1 minute for most applications.)
3. Read the input energy from your wattmeter as W-hr.
4. Divide this number by the interval of integration, making sure to adjust the time units so they cancel. For example:

$$\frac{\text{Ein (W – hr)}}{\text{Interval (1 min)}} * \frac{\text{60 mins}}{\text{1 hr}} = \text{Pin (W)}$$

Note, for designs using a Power Integrations device, varying input power is uncommon and may indicate a problem with the design.

In the example, the output current is recorded as 0.35 A and the output voltage 6.124 V from the multimeters, giving an output power of 2.14 W.

Efficiency is then calculated as:

$$\text{Efficiency at full load} = \frac{\text{Pout}}{\text{Pin}} = \frac{2.14\text{ W}}{3.14\text{ W}} = 68.2\%$$

Next, adjust the load to 75%, or 262 mA. When using the averaging feature on the wattmeter, allow at least one minute for the new reading to stabilize and then record the input power from the wattmeter. Wait five minutes and record it again. If you find the difference is less than 5%, then use the second input power measurement for your calculations. If the difference is greater than 5%, continue sampling the input power at five-minute intervals until it stabilizes.

In the example the output current is recorded as 0.262 A and the output voltage 6.502 V from the multimeters, giving an output power of 1.704 W.

Efficiency is then calculated as:

$$\text{Efficiency at 75\% load} = \frac{1.704\text{ W}}{2.42\text{ W}} = 70.4\%$$

Repeat this procedure for 50% and 25% load levels.

Measure No-Load Input Power

Finally the no-load input power of the design will be measured. Disconnect the output load and all output multimeters from your power supply. If you have not already configured your wattmeter with the voltage sense element before the current sense element, turn off the AC input and do so now.

Take an initial power reading from the wattmeter. Then wait five minutes and take a second reading. If the difference between these two readings is less than 5%, record the second measurement. If the difference is greater than 5%, then you will again need to integrate the input power and divide by the time period of integration. See the procedure described earlier for how to perform this measurement.

Test at 230 VAC

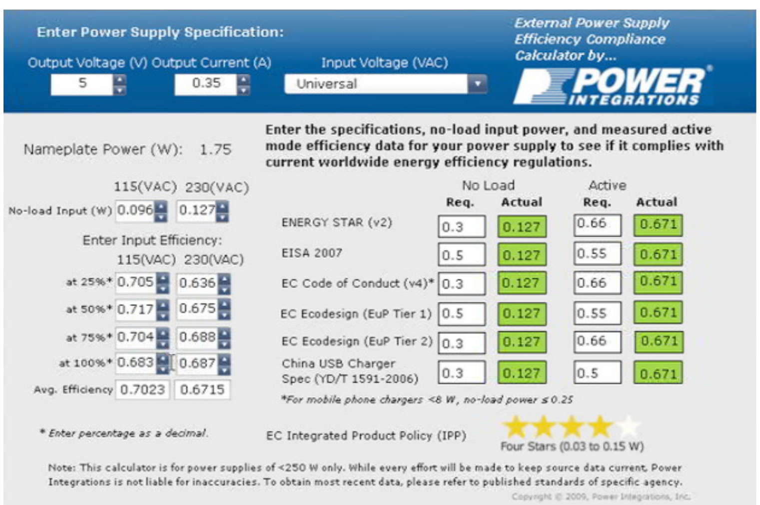
All testing at 115 VAC is now complete. Reattach your load and output multimeters, and increase the input voltage to 230 VAC. Repeat all previous testing at the new line voltage. Remember to set up your wattmeter appropriately for your power range before continuing. A complete set of data for the example is shown at right.

	115 VAC	230 VAC
25%	70.5%	63.6%
50%	71.7%	67.5%
75%	70.4%	68.8%
100%	68.2%	68.7%

Complete table of data

Enter results into PI Efficiency Compliance Calculator

Now that all the data has been collected, you can enter it into the Efficiency Compliance Calculator. After entering the nameplate specifications in the top input fields, enter your test data in the columns along the left side of the window.



Data entered into PI Efficiency Compliance Calculator

The calculator will compute active-mode efficiency as the equally weighted average of efficiency at all load levels. The fields on the right side of the window show various efficiency standards, along with the calculated compliance requirements for active-mode efficiency and no-load input power. The calculator will compare your results against these requirements and highlight the comparison red or green, depending upon whether the requirement is met.

Hand Calculations and Rounding

When calculating these values by hand, note that the standards requirements are rounded to two digits for both no-load requirements and active-mode efficiency.

Below is an example calculation of minimum efficiency using the ENERGY STAR formula for a 12 V, 1.1 A supply

$$\text{Nameplate power} = 12\text{ V} \times 1.1\text{ A} = 13.2\text{ W}$$
$$\eta_{min} \geq [0.0626 \times \text{Ln} \times (13.2)] + 0.622$$
$$\geq 0.784 \text{ or } 78.4\%$$
$$\geq 0.78 \text{ or } 78\% \text{ rounded to two digits}$$

Measured values are also rounded. Below is an example showing the effect of rounding using measured results for a 12 V, 1.1 A supply.

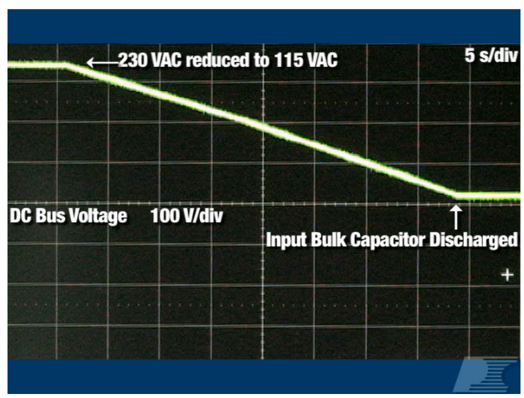
$$\eta_{avg} = \frac{eff_{25} + eff_{50} + eff_{75} + eff_{100}}{4}$$
$$= \frac{79.2 + 78.4 + 75.9 + 80.5}{4}$$
$$= 0.785 \text{ or } 78.5\%$$
$$= 0.79 \text{ or } 79\% \text{ rounded to two digits}$$

So, if the active-mode efficiency is calculated to be 78.5%, this would be rounded up to 79% and compared against the energy efficiency standard requirement. In this case, the supply would fail to meet the requirement.

A Tip to Follow When Changing Input Voltage

When measuring no-load, always apply full load to the output when changing input voltage during testing. If the output is left with no load connected when the input voltage is dropped from high line to low line, the input bulk capacitor will support the DC bus voltage for a long time before drawing power from the AC input.

This causes the power supply to have a no-load input power of 0 W for a significant period of time. For this reason, it is best to start with the power supply fully loaded and then remove all output loads to make the measurement.



Under no-load, the input bulk capacitor takes a significant time to discharge

For More Information

More information on energy efficiency standards and links to the relevant agencies can be found in the Green Room. If you have any questions or comments about the information presented in this course, please email PIUniversity@powerint.com.