

Technical Brief: Using Excel to Calculate AC-DC Converter Efficiency

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Ever wonder how efficient your AC to DC converter really is? Do you need a simple way to determine its efficiency? This Technical Brief describes an accurate method to do just this. All that is required is a two-channel digitizing oscilloscope, a current probe, a voltage probe, a load for your DC output, and any spreadsheet software (such as Excel).

Efficiency is defined by dividing the real output load power by the real input power consumed. Take for example a DC-DC buck converter. Suppose you have designed a 12V_{in} and a 5V_{out} buck controller circuit. Now you load the output with 1A which gives you a 5W output sink. Then you measure the 12V input current to be 500mA which equates to 6W coming from the 12V source ($12V \times 0.5A = 6W$). The buck controller has an efficiency of $5W/6W = 83\%$.

Now take an AC-DC Converter with, for example, a 120VAC line input and a constant output current. The difficulty with the majority of AC-DC converters is that the input current is not a constant nor is it sinusoidal. (If both the voltage and the current were sinusoidal, then one could conventionally find the input power by multiplying the RMS-voltage times the RMS-current times the power factor where the power factor is the cosine of the angle between the voltage and the current.) *Figure 1* shows a 120VAC input line voltage and a representative asymmetrical, 3ms wide, 2.0A peak input current.

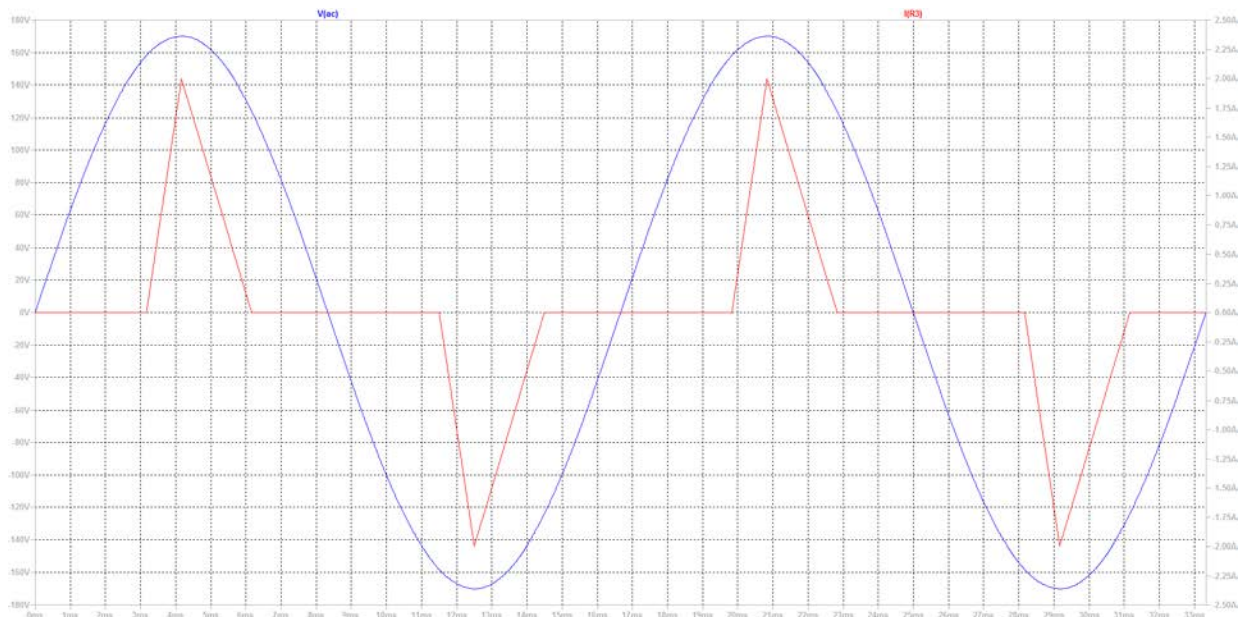


Figure 1: Input Voltage (Sinusoidal) and Current (Triangular) for an AC-DC Converter

Luckily a simple means exists whereby the efficiency of the converter may be easily calculated! All that is required is capturing the input voltage and the input current (whatever its shape) then importing the digitized representations into a spreadsheet. We will then calculate the instantaneous power and the average input power.

Spreadsheet Method: Place a current probe in series between the hot AC Line Voltage and the AC-DC converter. Place a known, constant load on the output of the converter, and then capture the incoming AC line Voltage waveform along with the AC line current waveform with your oscilloscope.

You might consider using a 100:1 voltage probe to protect your scope instead of a conventional 10:1 probe. Use a current probe with sufficient bandwidth both above and below 60 Hz. (We use the Pearson 411 current transformer which is rated from 1Hz to 20MHz and up to 75A RMS.) Be careful not to shock yourself with the AC line voltage; place the current and voltage probes when the power is turned off! The load on the power converter can either be a power resistor or an electronic load. Probably, you'll want to select the load to represent a typical condition. An electronic load is nice because you can easily repeat the measurements here under different conditions.

A minimum of four full 60-Hz cycles is probably sufficient. Download the data of the current and voltage waveforms into a spreadsheet as follows:

Column A contains the AC Line voltage

Column B contains the input AC Line current

Format the data as needed such that the beginning and end points contain integer multiples of a full 120V AC cycle. At 60Hz and four complete cycles, this will require 66.67ms worth of data.

Column C will be the instantaneous power calculation. Assuming cell A2 is the first voltage value and cell B2 is the first current value, multiply these two together for the value of cell C2. Copy cell C2 all the way down to the end of the data (assume the last cell is number C1026). Sum the column C values from C2 to C1026 then divide the sum by the number of total summed cells, which in this example would be 1024. This calculates the average value of the input power. Using the example from Figure 1, the average power calculates to 59W. Assuming a 5V output and a load of 8A, the output power is 40W. Then this AC-DC converter efficiency is 67.8%.

Note that the current peaks do not need to be coincident with the voltage peaks to accurately calculate the input power! They may be anywhere and the power calculation will still be accurate.

Fini!

Notes:

The following equation computes the Average Power for any waveform:

$$P = \frac{1}{T} \int_0^T p(t) dt$$

where P = average power; T = the time period; and p = instantaneous power, v(t) x i(t)

The integral computes an area which is equal to the total energy. Area is a two-dimensional quantity which can be thought of as the x-axis times the y-axis. Multiplying the integral by 1/T, or dividing by the x-axis, results in the average quantity of the y-axis which is the average power.

Terms can be confusing. Various authors use different words for the same thing. Here is a partial list of a variety of phrases one may find when reading about power: active power, real power, average power, mean power, working power, RMS power.... Mostly, these terms refer to average power or Watts. Watts are the units of measure of what does work.

Estimation Method: One can also estimate the input power. Using Figure 1 as an example, the current looks triangular and we know the area of a triangle is 1/2 Base times Height. With a 2A peak, the average current is therefore 1A average. The peak of the current is located at the peak of the 170VAC, so the power here is around 170W (1A x 170V). The time period of 1/2 cycle of the 60Hz is 8.33ms, and the time period of the current pulse is 3.0ms. The ratio of 3.0ms to 8.33ms is 0.360 which means that the current is active for a little over 1/3 of the time. 170W times 0.360 equals 61.2W which is close to the calculated 59W. (If you use an estimated average voltage of the sine wave during the current pulse, 170V +/- 1.5ms, this is around 164V. 164V times 0.360 = 59W!)

FFT Method: Another method for finding the average power is a more complex one which requires harmonic analysis of the current waveform (assuming the voltage is sinusoidal). It consists of computing the harmonic content of the current (often using a fast Fourier transform, or FFT) and calculating a so-called distortion power factor. An explanation of this method may be found here:

<http://www.syscompdesign.com/assets/images/appnotes/power-factor-measurement.pdf>