Understanding Solar Inverters

In order to use electricity from a photovoltaic array in your home, it must first be converted from direct to alternating current. That's because most electric loads (i.e. lights, appliances, tools, etc.) operate on AC. An ***inverter*** performs this function in a solar power system. A circuit of on/off switches manipulate the current polarity so that it changes back in forth, just like the current that comes from the utility grid.

Technically, the equipment is known as a ***power conditioning unit***, or ***PCU***, since it does other jobs besides changing DC to AC. But that name sounds a little creepy, so most people just call it an inverter. And just in case you're wondering, a rectifier converts AC to DC, while an inverter does the opposite, or inverse. Hence its name.

The Germany company Fronius, in the solar energy business since 1992, makes lightweight, high-tech inverters that sell well in the United States.

Together, the inverter and PV array comprise the big-ticket items of every solar power system. After passing through the inverter, electricity becomes available to power all AC loads. In a utility interactive (*aka* grid-tied) system, any surplus energy not needed at that moment flows into the grid itself, something electricians refer to as backfeeding. As a result, your electric meter may spin or count backwards.

Two principle measurements go into choosing a grid-tied inverter. The first is how much wattage your PV modules are rated for. The second is the total

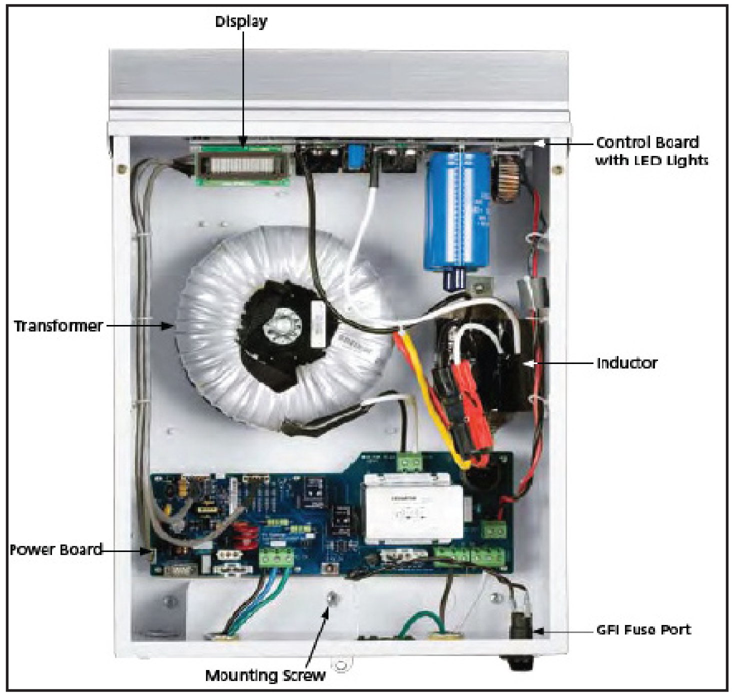


Diagram of a typical grid-tied inverter. Not all inverters use transformers.

voltage configured in an array. For example, if you have two strings of ten 235-watt, 30-volt modules, that would give you an array of 4,700 watts and 300 volts. (Doing the math requires a basic understanding of parallel and series circuits, which is discussed in the solar power tutorial online.) Once you determine these parameters, you can start shopping for an inverter that covers your range. Many manufacturers provide a configuration tool on their websites to help you find the right-sized model.

Calculating Watts and Loads

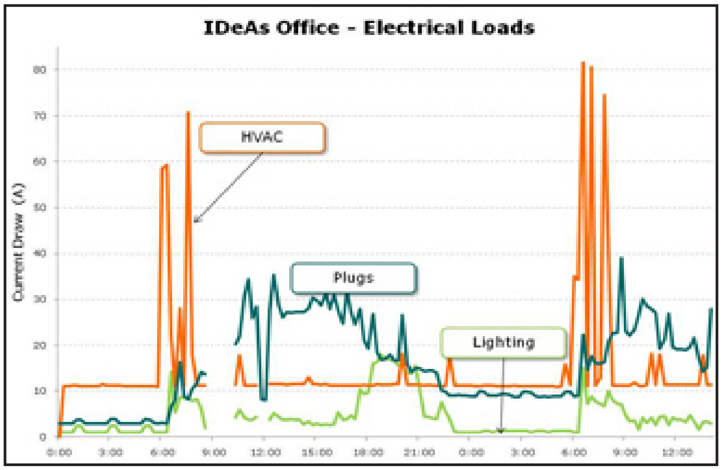
Before selecting an inverter, most homeowners are also encouraged to perform an ***energy audit.*** This determines the total kilowatts needed annually to power your electric consumption -- that is, after instituting conservation measures, such as replacing energy-hog appliances. Once the required power output is known, and the space available for placing an array is measured, the right-sized grid-tied inverter (in watts) can be chosen.

It's a little more difficult to prepare a ***load analysis.*** This calculation measures the actual on/off usage of all the home's AC loads and is necessary if you're incorporating a battery bank into your system. If, for instance, you were to use a ***bimodal*** inverter with batteries to provide electricity during a power outage, you would need to calculate the critical loads that require power until the grid comes back online. A load analysis will inform you how big the battery bank needs to be to cover those loads (such as a refrigerator, security alarm and a few lights). The analysis

continued

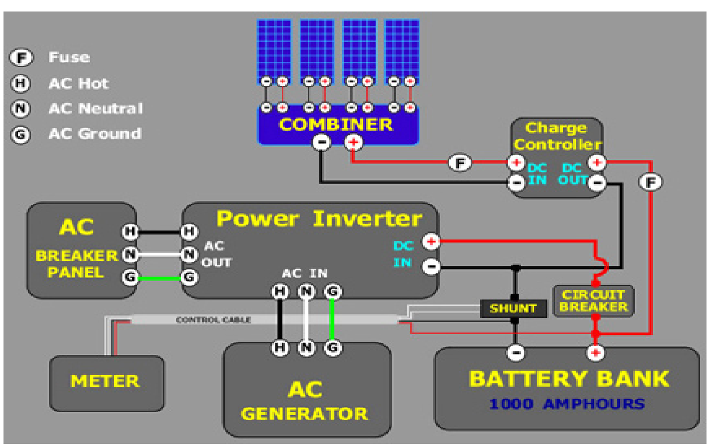
cont. from previous page

also determines how many watts the inverter must be capable of delivering at one time. Normal grid-tie systems, however, don't include battery backup. Only an energy audit is necessary to qualifiy for a tax credit or rebate.



A load analysis shows the average on/off usage of appliances, lights and other loads. With multiple loads on at the same time, you can determine the total current that a standalone or bimodal inverter must deliver.

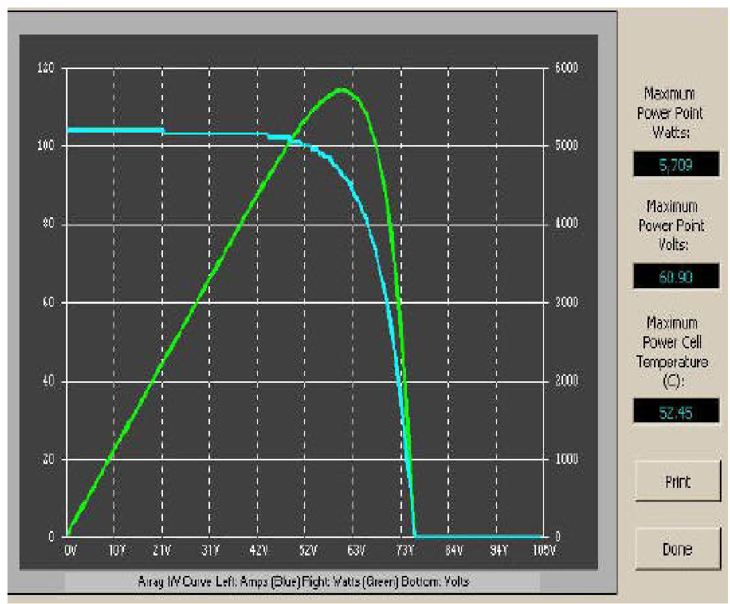
If you were to live off-grid and rely solely on a ***standalone*** inverter supplying electricity from a PV array, the calculations become more complicated still. In this scenario, you'll have to power all your loads day and night from electricity generated by the solar modules while the sun is shining. In the winter, a solar array may not be sufficient to do the job, so a wind turbine, AC generator or other power source may be configured into the circuit.



Here's a diagram of a stand-alone, hybrid system that might be used in a remote area with no access to a utility grid. A grid-tied system with a bimodal inverter would look a lot like this, except without the AC generator. Because batteries are used, a charge controller is needed to regulate the flow of electricity into and out of them. In a normal grid-tied system, the array is wired directly to the inverter, although a few smaller devices, like a combiner (which "combines" the wiring from the array), may come in between.

One other difference between a simple grid-tied system and one with batteries is that in the latter case, the inverter receives its DC electricity from the battery bank. An additional piece of equipment called a ***charge controller*** is connected to the array, as illustrated in the diagram below left. The extra equipment can nearly double the price of a solar power system.

In addition to conditioning and moving electricity where it needs to go, an inverter/PCU monitors and adjusts the current in the solar array. The circuit that performs this function is called a ***Maximum Power Point Tracker***. The MPPT monitors the changing voltage and current in the PV array to insure optimum power output. While this may seem like a minor technical spec not worth fretting over, power tracking is essential to the bottom line of solar power systems. Producing as many kilowatt hours of energy as possible insures the quickest payback on your investment..



An MPPT tracking screen.

As mentioned earlier, an array's production of energy fluctuates, depending on the amount and intensity of sunlight. Thus, the MPPT acts like a traffic cop in adjusting voltage and resistance. Research shows that solar panels produce more energy when the circuit is maintained near the peak of its ***I-V curve*** (referring to current intensity and voltage). To do this requires variable loading, which the MPPT provides in the face of changing conditions.

Inverter Specs and Features

Here are the main specs to watch for:

Wattage rating - Inverter models are designated by

continued

cont. from previous page

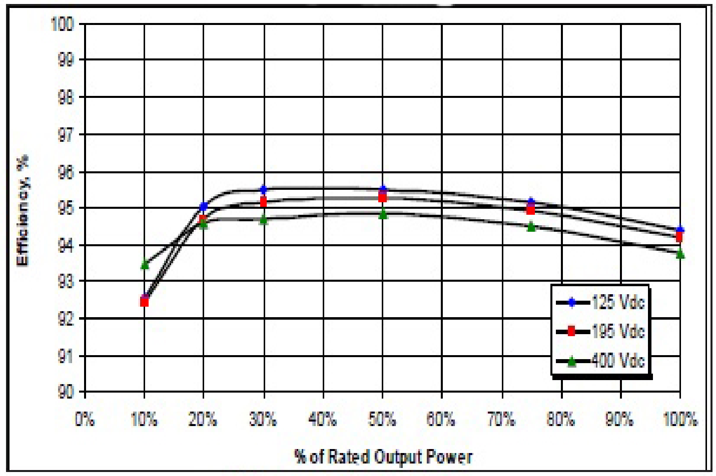
wattage, just like PV modules. As explained earlier, the size you pick depends on the size of the array (in watts) if you're buying a grid tied inverter, or the size of your maximum AC load, if you're buying a stand-alone inverter. If you think you might want to add more modules in the future, you may decide to buy a slightly bigger inverter so it can handle the extra juice. Just don't buy one that's too big; if you do, the MPPT circuit may not work effectively.

Input Voltage - Inverters offer a range (or window) of voltages to accomodate different designs and sizes of PV arrays. A solar company or system designer must make sure the maximum voltage coming out of the array is less than what's listed on the inverter's spec sheet. At the same time, the ***starting voltage*** of the inverter shouldn't be so high that the equipment won't kick on during periods of lower irradiance. Ideally, your array's maximum open-circuit voltage should be two-thirds to three-quarters of the high end on the inverter's operating range. For instance, an inverter range of 150-450 volts would be right for an array configured between 300-400 volts.

AC Output - This is the maximum load your home appliances and other electric devices can expect from the inverter at one time. For normal grid-tied systems, this spec is not a big deal, since the grid is there to supplement any power generated by a PV array.

Surge Power - Like the previous spec, this one is primarily important for standalone and bimodal inverters. Many appliances and tools require an extra burst of energy to start their motors. The voltage spike that accompanies these moments may last one-tenth of one second, or a few seconds, which means an inverter must be capable of sending the extra juice for just that period of time.

Efficiency Rating - Like solar panels, an inverter is rated for its efficiency in processing energy. The rating takes into account current losses due to: circuits heating up, low voltage levels, changes in the way the current flows or gets stored, and the unit's internal energy consumption. Beware, however, of a single efficiency rating listed on a product spec sheet. The actual efficiency of an inverter varies with the different loads it encounters (or no loads), so an inverter with 90 percent "peak" efficiency may not be better than one with 85 percent peak efficiency. A better spec (if you can find it) is the "weighted efficiency". You can also sometimes find a graph on the spec sheet, known as the ***efficiency curve***.



Efficiency curve 1502x / 208 V

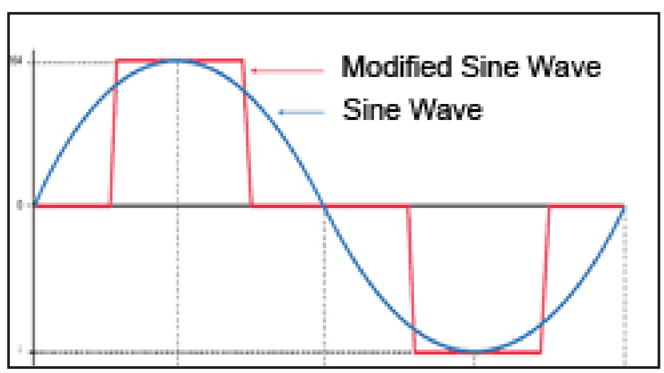
This is an efficiency curve for the Kaco Blue Planet 1500-watt inverter. Notice that efficiency dips significantly when less than 20% of output power is used. Even so, it remains well above 90%, as indicated on the Y axis.

Type of Sine Wave - This feature may sound kind of geeky, but it's still important. Most efficient (although higher-costing) inverters move electricity around to conform to what's known as a ***pure sine wave***.

Many popular off-grid inverters use a ***modified sine wave***, which is a lot cheaper than those with a pure sine wave. However, you run the risk of ruining some devices (especially computers) with this lower-quality electric current. A modified sine wave can cause an appliance or tool to use more power than it would otherwise, which can burn out a motor or other circuitry. Even less expensive are ***square wave*** inverters, which should probably not be used outside of a barn or warehouse.

Grid-tied inverters should always feature a pure

continued



An oscilloscope is a measuring instrument that tracks electrical current, producing a curving horizontal line across a screen. This is how scientists measure the amplitude and frequency (i.e. how frequently the polarity changes) in an AC current.

cont. from previous page

sine wave. Since you'll be using it over the course of many years, the greater expense for this type of inverter will be offset by the additional energy that comes from its much higher efficiency.

Ambient Temperature Range - If you live where the temperature dips or rises to extremes, then your inverter will be susceptible to excessive heat or voltage spikes due to cold weather. Besides carefully choosing a location for the unit (inside or outside, shaded from the sun, away from the snow, etc.), you'll want the inverter to have its own heat mitigation response, such as a fan *(aka* forced air). In any case, a range of -20°C - 50°C (-4°F - 122°F) should work for all but the most borderline environments.

Functionality and Other Features

Other considerations in choosing an inverter include:

- noise emissions **(hopefully not too loud)**
- system monitoring features
- **(needed to track performance and troubleshoot)**
- overcurrent protection device (OCPD) **(should be included)**
- ground fault interrupter circuit (GFIC) **(should be included)**
- night power consumption **(should be one watt or less)**
- expansion slots **(allows plug-in of external sensors or a remote display)**
- weight and dimensions **(the unit may have to fit a specific location or mounting structure)**
- type of enclosure **(NEMA 3R is typical)**
- warranty **(At least 10 years is required for most rebates)**
- reputation of the manufacturer
- tax credit/rebate compliance **(Some incentive programs publish a list of acceptable models.)**

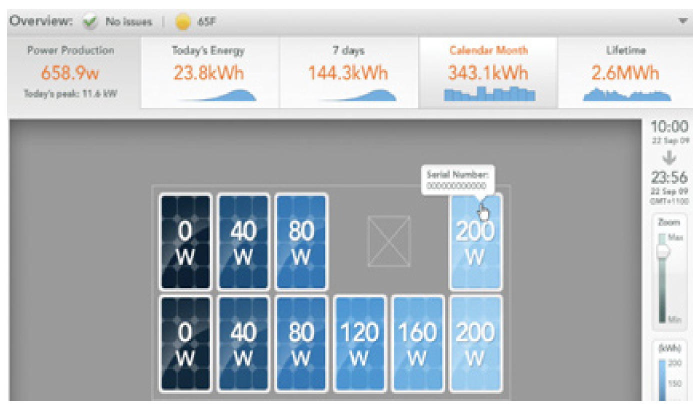
Micro-Inverters

A single, central grid-tied inverter may be the most uncomplicated approach when installing a solar power system. But it's not the only game in town. When part of a solar array is either shaded or obstructed by debris or snow, it can significantly reduce the energy production of the entire array. So one manufacturer, Enphase, came up with the micro-inverter, a small unit installed underneath each module. This approach offers several advantages:

- It maximizes system power by locating an MPPT right at the module.

An Enphase microinverter mounted on racking. The PV module to which it attaches will sit right on top when the array is installed. Photo: Phillipsburg Electrical and Air.

- Shading across one module doesn't affect the output elsewhere in the array.
- Realtime monitoring reports the activity of each module.
- It's easier to expand your array in the future.
- All current flowing downstream is AC.



Screenshot of Enphase's data monitoring app, which reports the wattage produced by each module.

Enphase includes software with its product that allows you to track your array ouput from a mobile phone. For this reason alone, the microinverter has become wildly popular with new homeowners going solar. Not all brands of modules work with the units, so be sure to check the list Enphase has posted on its website.

-- Rosemary Regello