Pump Up the POWER

GETTING MORE FROM YOUR GRID-TIED PV SYSTEM

by Jeremy Taylor

With grid-tied PV systems becoming more and more popular, it is important for RE professionals and system owners alike to have realistic expectations of their systems' performance. Solar-electric power production can be affected by several factors. In this article, we discuss many of those factors and offer helpful tips for maximizing system performance.

Courtesy iStockphoto/Olaf Loose

PV modules installed in rows and tilted up require careful placement to avoid one row shading the next.

Smart Siting

One of the most important considerations is locating the PV array to maximize solar exposure. Industry experts recommend siting your array in an unobstructed solar window from 9 a.m. to 3 p.m. You can use a solar site analysis tool (Solar Pathfinder, Solmetric Suneye, or Acme Solar Site Evaluation Tool) or a trusty compass and a sun-path chart for your latitude, to determine true south and the solar window at your site.

Shading. Many people—installers and homeowners alike—fail to consider the impact of even negligible shade caused by overhangs, second stories, trees, exhaust vents, and chimneys. Each PV module consists of dozens of cells that, when even partially shaded, will result in decreased performance, which is like throwing KWH and money down the drain. Lower performance means more electricity purchased from the utility, and less financial return on your solar investment. For those systems that qualify for performance-based incentives, even more revenue is lost with poor performance.

Most PV modules today incorporate bypass diodes that can route power around a shaded portion of the module, thus minimizing power losses from localized shading. Because of the resistance caused by an inactive portion of a series circuit, the impact of shading across a series of cells can be severe. Shading is the number-one system performance problem and should be avoided.

Arrays installed in rows and tilted up from the roof plane require special attention to avoid one row shading the next.


Courtesy Jeremy Taylor

Overhangs, second stories, trees, vents, chimneys, etc. can affect the output of a PV system. Some potential shadings are hard to detect in advance without careful siting efforts.

Calculating the distance needed between the rows can be complex, but at least for flat roofs, there is a simple design rule—the space between a row of modules should be at least three times the height of the row in front of it. For example, if a south-facing array is mounted on a flat roof and stands 2 feet tall, each row would start 6 feet behind the row in front of it. This will provide a clear solar window from at least 9 a.m to 3 p.m., even as far north as 45 degrees latitude. In the southern half of the U.S., closer spacing may be possible, but minimum spacing should not be less than two times the height of the adjacent row. Those are minimums—wider spacing may be used to squeeze out a bit more energy production in the early morning and late afternoon.

Another method is to set up a first row, and then move behind it at roof level with a Solar Pathfinder until the no-shade spot is reached—that is where the next row would begin.

In snowy regions, drifts or accumulated snow can further complicate row spacing and array placement. Be sure to provide ample clearance under and around the array to help keep it clear.

Proper Array Orientation & Tilt. An array's orientation and tilt can make a difference in an array's energy production. For best year-round performance in most locations, fixed arrays should be oriented to *true* south—as opposed to magnetic south—which means taking into consideration the site's magnetic declination.

Array tilt also plays an important role in energy production. For optimal production, arrays generally should be tilted at an angle equal to your latitude. However, most PV arrays are mounted parallel to the roof plane, and have the same tilt as the roof, which is typically pitched at an angle less than the latitude. An array mounted parallel to the roof surface at a tilt less than latitude will produce more energy in summer, when some utilities have higher per-KWH rates.

If your site does not allow for true south orientation or tilt equal to latitude, you can simply factor the production losses into your system design and compensate by using a slightly larger array. See the table for design factors that can be used for less than optimal orientations and tilts. To determine the KWH impact of various tilts and other factors for any PV system at any site, use the National Renewable Energy Laboratory's PVWatts online calculator (see Access).

Energy *Can* Grow on Trees

When it comes to shade, trees pose one of the greatest problems. Removing the culprit obstructing the solar window is the obvious and often hasty solution. But before you reach for the chain saw, consider how the offending object affects the solar window over the full year—rather than one moment, day, or season. Chopping down a tree on the west side of your house that shades your PV array on summer afternoons might mean increased power production during that season, but it also might mean that the loss of shade for your house results in having to run the air conditioner more often.

Components

PV Performance Parameters. PV module power ratings (nameplate ratings) are determined at "standard test conditions" (STC)—1,000 watts per square meter of solar irradiance at a PV cell temperature of 25°C (77°F). A system's

PV Array Output Multipliers for Various Orientations & Tilt Angles

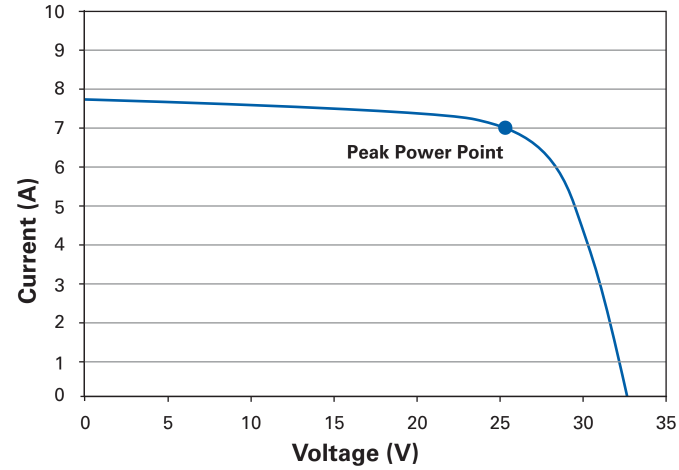
Array Orientation	Array Tilt (From Horizontal): Horizontal	15°	30°	45°	60°	Vertical
Florida						
South	0.93	0.99	1.00	0.96	0.86	0.57
Southeast or southwest	0.93	0.96	0.96	0.90	0.82	0.57
East or west	0.93	0.91	0.85	0.77	0.68	0.49
California						
South	0.89	0.97	1.00	0.97	0.89	0.58
Southeast or southwest	0.89	0.95	0.96	0.93	0.85	0.60
East or west	0.89	0.88	0.84	0.78	0.70	0.52
Arizona						
South	0.89	0.97	1.00	0.97	0.89	0.60
Southeast or southwest	0.89	0.94	0.95	0.90	0.83	0.59
East or west	0.89	0.87	0.82	0.75	0.66	0.48
New York						
South	0.87	0.96	1.00	0.98	0.92	0.66
Southeast or southwest	0.87	0.93	0.94	0.91	0.85	0.62
East or west	0.87	0.85	0.81	0.74	0.67	0.49

Source: NABCEP/Clean Power Estimator. Multipliers are averages for several locations in each state.

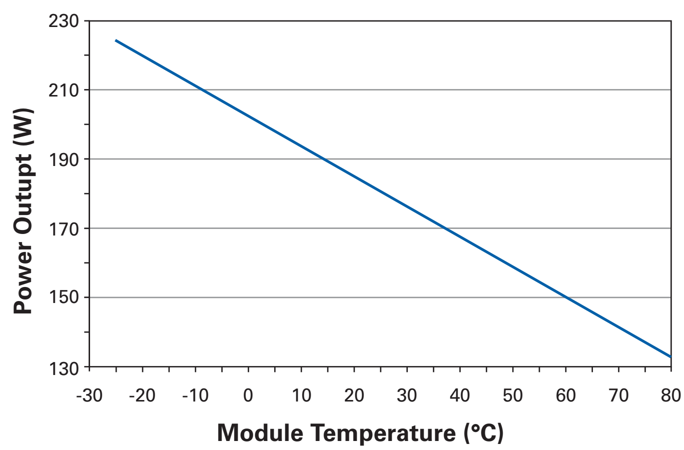
Courtesy Shawn Schreiner (2)

Every new PV module has a label listing its critical specifications.

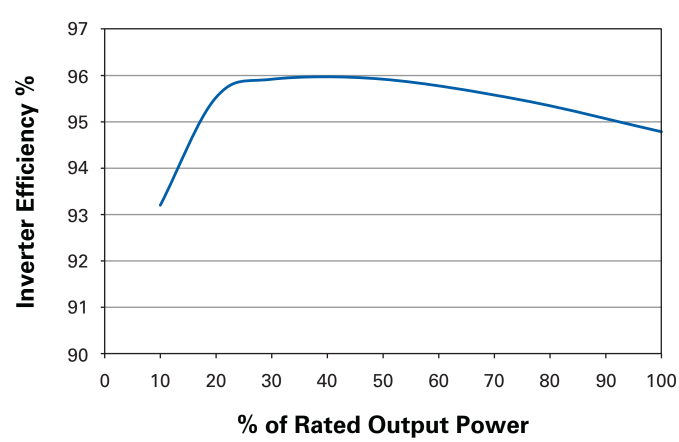
ES-180 STC Current vs. Voltage



ES-180 Power vs. Module Temp.



Example Inverter Efficiency vs. Output Power



size is nominally stated by multiplying the STC rating by the number of modules—but you shouldn't count on this being an accurate reflection of the system's actual output.

STC testing is performed in a laboratory setting where modules are flashed with a light source and power output is measured. This measurement doesn't account for temperature or wind variations, which can drastically affect performance. Like any material exposed to sunlight, PV modules heat up as they absorb solar infrared radiation, becoming less efficient at converting light to electrical energy. For cell temperature to be 77°F, the same as STC, the ambient air temperature has to be much lower (about 23°F to 32°F)—unusually low temperatures in most circumstances.

Another standard, PTC (PVUSA test conditions) was developed to better simulate real-world installations. PTC is conducted at the same irradiance, but at a somewhat more realistic ambient temperature of 68°F (with cell temperature about 113°F), and at a wind speed of 1 meter per second (2.24 mph). Because temperature-related power loss averages -1/2% per °C rise for crystalline PV modules, their PTC ratings typically range from 85% to 90% of the STC rating.

The underlying lesson is to provide for sufficient airflow around mounted PV modules to minimize production losses due to heat. In general, allow a 3- to 5-inch unrestricted air gap between the roof and flat-mounted modules. Modules tilted up from the roof plane fare even better—but to some, tilting can be aesthetically undesirable.

Warranted PV Minimum Power Ratings. To most accurately project long-term performance, also consider the module manufacturer's warranted minimum power rating. After modules are placed into service, their power output will decrease over time. Besides initial photon degradation due to the physical process that generally occurs within the first few hours of a PV module's operation, the long-term effects of weather and photon degradation influence module performance over its lifetime. One report estimates that initial degradation will be 0% to 3.9% of a crystalline PV module's performance, while continuous degradation can reduce performance from 0.1% to 1.0% per annum (see Access). Reported degradation values will vary.

Most modules are warranted for minimum peak power output within two different time frames—90% of minimum peak power for 10 years, and 80% for 20 to 25 years. While you can't do much to prevent module degradation, you can select wisely. Before you buy, compare the rated power tolerance for various modules. Most modules have a tolerance of ±5% (or better) of STC-rated power. For example, if a 100 W module has a specified power tolerance of ±5%, then the minimum peak power value for this module will be 95 W, and the module warranty will be based on this value rather than the STC rated power of 100 W. The tighter the tolerance, the more you can be assured that you're getting the wattage that you paid for.

Lastly, because module degradation can result in lower voltage output, be careful when matching a PV array to a particular inverter's input voltage range. Say a grid-tied inverter input window will accept eight to twelve modules in series. After many years in the field, the voltage of the PV array could degrade to the point that on a hot, sunny day, eight modules in series no longer stay within the inverter's input voltage window. To avoid this problem, aim for the higher end of an inverter's input voltage window when you're determining the number of modules in series strings.


Courtesy www.directpower.com

The modules in this array are about six inches off the roof, allowing adequate ventilation to keep them as cool as possible.

Calculating Array Output

A system's power output can be calculated fairly accurately given the array size (rating at STC), module temperature, solar irradiance, inverter efficiency estimation, and a basic system derate value. For this example, assume the system has been installed within the past year and that there is no shading on the modules.

Array size = 4 KW (STC)

Irradiance at array tilt & orientation = 80% of full sun (800 W/m^2)

Module temperature efficiency = 84% (-0.5% per degree over 25°C—57°C assumed for this example)

Inverter "CEC weighted" efficiency = 94%

System losses derate value = 85%

Estimated array output = 4,000 W x 0.80 x 0.84 x 0.94 x 0.85 = 2,148 W

This figure can then be compared with system metering or output measurements to make sure the system is operating as expected.

Module Mismatch. Manufacturing tolerances mean that modules of the same make and model will have slightly different current-voltage characteristics resulting in a decreased efficiency when the modules are connected together—you can figure in a loss of up to 2% because of mismatch. "Module mismatch," as discussed here, is *not* referring to modules of differing make or models being wired together. This is a separate issue—and if mixing modules is done incorrectly it can result in much more significant power loss. If modules are wired in series, then all within the series string should be of the same model and with the same tilt and orientation.

Inverter Inefficiencies. The next consideration in the system loss lineup is inverters, which convert the PV array's DC into AC for household use. Unlike modules, inverters should be installed out of direct sun. Too much heat is a deadly enemy of all electronics, and inverters are no exception. Installing in a high temperature environment can cause a unit to operate less efficiently and may lead to premature component failure. Even inverters that have weather protection and are rated to be installed outdoors must be kept shaded, even if it means installing an awning over them. Likewise, be sure that inverters installed in closets or small rooms have sufficient air circulation to help remove heat buildup.

Most modern inverters are rated at efficiencies of 90% or greater, but actual operating efficiency can vary. One factor that can affect power production is an inverter's maximum power point tracking (MPPT) performance. PV module voltages fluctuate as light and temperature conditions change, and the inverter must be able to work efficiently within a range of voltages. If an inverter's effective MPPT voltage range is too narrow, then production can drop accordingly.

Always consider the efficiency of inverters before buying. A 1% improvement in efficiency can mean thousands of KWH gained over the lifetime of your system, and more money in your pocket. Each inverter lists maximum efficiency in its specifications, but a more realistic value is the "weighted efficiency"—a useful comparison tool for designers and consumers. A weighted efficiency is estimated by assigning a percentage of time the inverter resides in a particular range of operation to approximate its efficiency over the full day. Because available sunlight and array operating conditions are constantly fluctuating, actual array power will vary throughout the day, so weighted efficiency can be a better predictor of system performance.

Miscellany

Line Losses. The amount of energy lost in conductors and electrical connections is known as line loss. The wasted energy from resistive losses—voltage drop in the electrical circuit—from source to load should be designed to be less than 5%. Since voltage drop is additive for each individual wire run within a circuit, keeping the overall voltage drop from source to load under 5% means voltage drops of the individual wire runs will have to be much lower (2% or less). Maximize performance by evaluating and sizing each wiring run individually. Of particular importance is the output circuit from a grid-tied inverter to the main service panel. This wire run usually needs to have a 1% or lower voltage drop to ensure that the inverter has enough excess voltage to be able to push its energy onto the utility grid and to make sure the voltage from the grid stays within the inverter's AC operating window. Using higher voltages and larger conductors means less resistance losses. Additionally, reliable, low-resistance connections between conductors and equipment will help minimize losses.

Soiling. Dirt, dust, bird excrement, and snow can filter out some sunlight from the PV cells. According to the National Renewable Energy Laboratory, modules in areas that experience high levels of particulate pollution and infrequent rain can experience soiling losses of up to 25%, especially on flat-mounted arrays. Isolated soiling that remains for an extended time can cause "hot spots" that prematurely degrade or damage PV cells. It's nothing a squeegee, some water, and a little elbow grease can't conquer—keep your modules clean. In many areas, a periodic rainfall can do the job. But if it's been a long time since the last rain and you notice a fine layer of dirt or dust building up, you will boost your system's energy production with a little cleaning.

Mixed Orientations

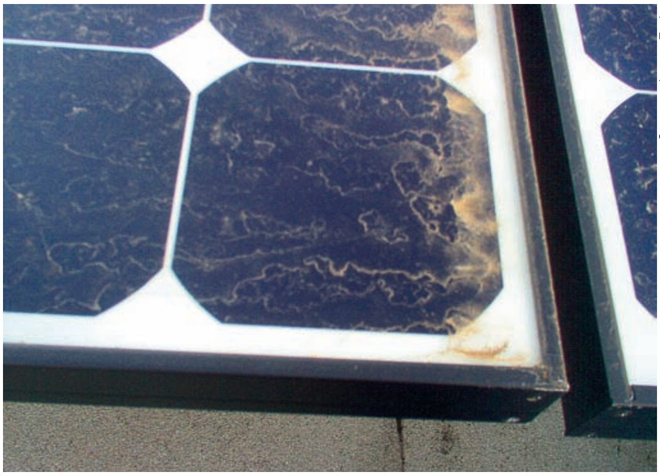
Modules from different manufacturers often have very different operating characteristics and dissimilar modules should not be used in the same series string. Likewise, mixed orientations of the same module will have dissimilar operating characteristics. But what if a site's circumstance requires two different orientations? If half of an array faces east and the other half west, isolate the modules from each plane into separate series strings. Then use multiple inverters or an inverter that can track multiple maximum power points (MPPTs), like Magnetek's Aurora inverter. Some grid-tie inverters with only one MPPT may work fine with non-optimal module configurations, but the exact impact is inverter-specific. For example, Fronius says its inverter can handle multiple PV orientations with a loss of 1% or less. But SMA America recommends keeping modules in the same plane for their inverters—no variations, period. So if working with mixed module orientations, and a single MPPT inverter is desired, make sure the inverter you are considering will handle the orientations you want.

Performance Check

System owners should periodically inspect their PV system and check performance to make sure all is functioning correctly. Physically inspect for broken modules and potential shading issues (for example, a growing tree). For checking performance, most grid-connected inverters have a meter that displays the amount of power (W) being produced and how much energy (KWH) has been produced that day and over the lifetime of the inverter.

Some systems may incorporate data-monitoring to remotely check the power and energy production. (See *HP121*, "The Whole Picture: Computer-Based Solutions for PV System Monitoring.") Metering is helpful for a quick check on power production—but if it seems that the system is not performing as well as it should, more information will be needed. Irradiance and temperature, which are not typically a function of standard inverter metering, are constantly fluctuating and can significantly affect system performance; they need to be measured for accurate system assessment.

Other system losses (such as line loss, module mismatch, inverter efficiency, etc.) can also be estimated. PV professionals have basic tools to get a fairly accurate assessment of system performance, such as a hand-held solar irradiance meter and



Courtesy Jeremy Taylor

Keeping modules clean can remarkably increase the output of your system. If you live in a particularly dusty location, you may need to clean your modules monthly.

Microclimates, Peak Power & You

Adjustments to the design of a PV system will need to be made according to the site's microclimate and other local circumstances. For instance, in Colorado, where afternoon clouds are frequent, a more southeasterly array orientation may be favorable, so that the array can receive more direct sunlight when it is available. Similarly, in coastal Central and Northern California, where mornings are often foggy, a more westerly orientation can be beneficial.

Also consider your utility rate structure. Some utilities offer "time of use" (TOU) metering programs—charging more per KWH during peak consumption times, generally mid-afternoon. In states like California, where the grid experiences huge summertime afternoon air-conditioning loads, these rate structures are helpful in keeping grid usage within bounds. TOU programs penalize peak users and reward peak producers in an effort to meet afternoon loads without having to build more generation capacity. That's good news for PV system owners who can get greater net billing KWH credit by making sure their systems perform optimally during those peak times. To capitalize on peak selling rates, systems should be oriented and tilted toward the sun during those hours. And by reducing energy consumption during peak rate times, you can further increase your financial benefit from TOU rates.

an infrared temperature reader. With irradiance and module temperature known, installers can calculate how much power the system should be producing (see Calculating Array Output sidebar) and compare that value to the inverter's meter or a reading on a clamp-on multimeter on the output circuit. If the two values vary significantly, there may be a problem to troubleshoot—perhaps a faulty module, a blown fuse, or poor inverter MPPT performance.

With the significant cost of PV systems and the need to maximize output for production-based incentives, wringing as many KWH as possible out of your system makes economic and environmental sense. Paying attention to installation details and monitoring a system's output over its lifetime will give you the most value from your investment.

Access

Jeremy Taylor (sun1ness@yahoo.com) is a NABCEP-certified industry veteran, residing in southern California. He began his solar career in 2002, learning from the roof down from PV projects on-grid and off, ranging from 5 W to 1 MW. His focus is primarily on system design and performance monitoring.

PVWatts • http://rredc.nrel.gov/solar/codes_algs/PVWATTS/

Go Solar California • www.gosolarcalifornia.org • List of inverters & their weighted efficiencies

Dunlop, Ewan D. "Lifetime Performance of Crystalline Silicon PV Modules." Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, Volume 3, May 12–16, 2003: 2,927–2,930.