SPECIFICATIONS

Rated Power at STC (Watts)

Definition: Module power rating at STC—1,000 watts per square meter of solar irradiance at 25°C (77°F) cell temperature.

Importance: Because module power output depends on environmental conditions, such as irradiance and temperature, each module is tested at STC so that modules can be compared and rated on a level playing field. When less sunshine hits the module, less power is produced. Likewise, the hotter it gets, the less power your modules will produce.

STC references *cell* temperature—not ambient air temperature. As dark PV cells absorb radiant energy, their temperature increases and will be significantly higher than the ambient air temperature. For example, at an ambient air temperature of about 23°F, a PV cell's temperature will measure about 77°F—the temperature at which its power is rated. If the ambient air temperature is 77°F (and irradiance is about 1,000 W/m^2), module cell temperature will be about 131°F and power output will be reduced by about 15%. Other factors, like rated power tolerance (discussed below), can impact module power production as well.

Rated Power Tolerance (%)

Definition: The specified range within which a module will either overperform or underperform its rated power at STC.

Importance: Power tolerance is a much-debated module specification. Depending on the module, this specification can vary greatly—from as much as +10% to -9%. A 100 W module with a -9% power tolerance rating may only produce 91 W straight out of the box. With potential losses from high temperatures, it will likely produce even less than that.

Because modules are often rated in small increments, it is not uncommon for modules that fall under the lower power tolerance of the next model to be rated as a higher wattage module. Case in point: A module with a +/-5% power tolerance rating that produces 181 W during the factory testing process could be classified as a 190 W module, as opposed to a 180 W module. For maximum production, look for modules with a small negative (or positive only) power tolerance.

Rated Power Per Square Foot (Watts)

Definition: Power output at STC, per square foot of module (not cell) area. This is calculated by dividing module rated power by the module's area in square feet. Also known as "power density."

Importance: The higher the power density, the less space that is needed to produce a certain amount of energy. With some of the newer-generation modules, power density values are higher due to increased module efficiency. The greatest variation in this specification is in comparing crystalline PV modules to thin-film modules. If space is tight for array placement, consider choosing modules with higher power densities, though more efficient modules can be more expensive. Choose modules with lower power densities, and you'll need more modules for the same amount of energy. That means more infrastructure (module mounts, hardware, etc.) and more installation time. (See "Solar-Electric Options—Crystalline vs. Thin-Film" in *HP127* for more information.)

Module Efficiency (%)

Definition: The ratio of output power to input power, or how efficiently a PV module uses the photons in sunlight to generate DC electricity.

Importance: If 1,000 W of sunlight hit 1 square meter of solar module and that solar module produces 100 W of power from that square meter, then it has an efficiency of 10%. Similar to power density, the higher the efficiency value, the more electricity generated in a given space.

Series Fuse Rating (Amps)

Definition: Current rating of a series fuse used to protect a module from overcurrent, under fault conditions.

Importance: Each module is rated to withstand a certain number of amps. Too many amps flowing through the module—perhaps backfed amps from paralleled modules or paralleled strings of modules—could damage the module if it's not protected by an overcurrent device rated at this specification. Backfeeding from other strings is most likely to exist if one series string of modules stops producing power due to shading or a damaged circuit. Because PV modules are current-limited, there are some cases where series fusing may not be needed. When there is only one module or string, there is nothing that can backfeed, and no series string fuse is needed. In the case of two series strings, if one string stops producing power and the other string backfeeds through it, still no fuse is needed because each module is designed to handle the current from one string. Some PV systems even allow for three strings or more with no series fuses. This is due to 690.9 Exception B of the *NEC* and is possible when the series fuse specification is substantially higher than the module's short-circuit current (Isc). When required, series fuses are located in either a combiner box or in some batteryless inverters.

Connector Type

Definition: Module output terminal or cable/connector configuration.

Importance: Most modules come with "plug and play" weather-tight connectors to reduce installation time in the field. These are connectors such as Solarlok (manufactured by Tyco Electronics), and MC and MC4 (manufactured by Multi-Contact USA). Solarlok and MC4 are lockable connectors that require a tool for opening. Because so many PV systems installed today operate at high DC voltages, lockable connectors are being used on modules in accessible locations to prevent untrained persons from "unplugging" the modules, per *2008 NEC* Article 690.33(C). Due to this new code requirement, most PV manufacturers are updating their connectors to the locking type. Depending on how fast this change is reflected in the supply chain, connectors on a particular module may be an older style or lockable—so be sure to check.

Some manufacturers still offer modules with junction boxes (J-boxes). J-boxes allow the use of conduit in between modules, as raceways are required for PV source and output circuits (with a maximum system voltage greater than 30 volts) installed in readily accessible locations per *2008 NEC* Article 690.31(A). This approach is used to prevent an unqualified person from accessing array wiring.

Materials Warranty (Years)

Definition: A limited warranty on module materials and quality under normal application, installation, use, and service conditions.

Importance: For the modules listed in this guide, material warranties vary from 1 to 10 years. Most manufacturers offer full replacement or free servicing of a defective module.

Power Warranty (Years)

Definition: A limited warranty for module power output based on the minimum peak power rating (STC rating minus power tolerance percentage) of a given module.

Importance: The manufacturer guarantees that the module will provide a certain level of power for a period of time—at least 20 years. Most warranties are structured as a percentage of minimum peak power output within two different time frames—90% over the first 10 years and 80% for the next 10 years. For example, a 100 W module with a power tolerance of +/-5%, will carry a manufacturer guarantee that the module should produce at least 85.5 W (100 W x 0.95 power tolerance x 0.9) under STC for the first 10 years. For the next 10 years, the module should produce at least 76 W (100 W x 0.95 power tolerance x 0.8). Module replacement value provided by most power warranties is generally prorated according to how long the module has been in the field.

Cell Type

Definition: The type of silicon that comprises a specific cell, based on the cell manufacturing process.

Importance: For the modules listed, there are four basic types—monocrystalline, multicrystalline, ribbon, and amorphous silicon (a-Si). Each cell type has pros and cons. Monocrystalline PV cells are the most expensive and energy-intensive to produce but usually yield the highest efficiencies. Though multicrystalline and ribbon silicon cells are slightly less energy intensive and less expensive to produce, these *cells* are slightly less efficient than monocrystalline cells. However, because both multi- and ribbon silicon modules leave fewer gaps on the module surface (due to square or rectangular cell shapes), these *modules* can often offer about the same power density as monocrystalline modules. Thin-film modules, such as those made from amorphous silicon cells, are the least expensive to produce and require the least amount of energy and raw materials, but are the least efficient of the cell types. They require about twice as much space to produce the same power as mono-, multi-, or ribbon-silicon modules. Thin-film modules do have better shade tolerance and high-temperature performance but are often more expensive to install because of their lower power density.

Some manufacturers now offer a cell with a combination of cell types—Sanyo's "bifacial" HIT modules are composed of a monocrystalline cell and a thin layer of amorphous silicon material. In addition to generating power from the direct rays of the sun on the module face, this hybrid module can produce power from reflected light on its underside, increasing overall module efficiency.

Cells in Series

Definition: Number of individual PV cells wired in series, which determines the module design voltage.

Importance: Crystalline PV cells each operate at about 0.5 V. When cells are wired in series, the voltage of each cell is additive. For example, a module that has 36 cells in series has a maximum power voltage (Vmp) of about 18 V. Why 36? Historically, these modules—known as 12 V modules—were designed to push power into 12 V batteries. But to deliver the 12 V, they needed to have enough excess voltage (electrical pressure) to compensate for the voltage loss due to high-temperature conditions. Modules with 36 ("12 V") or 72 ("24 V") cells are designed for battery-charging applications.

Modules with other numbers of cells in series are intended for use in batteryless grid-tied systems. Grid-tied modules now combine a certain number of cells for the goal of maximizing power with grid-tied inverters and their maximum power point tracking (MPPT) capabilities. Due to the increased availability of step-down/MPPT battery charge controllers, grid-tied PV modules can also be used for battery charging, as long as they stay within the voltage limitations of the charge controller.

Maximum Power Voltage (Vmp)

Definition: The voltage generated by a PV module or array when exposed to sunlight and connected to a load—typically a batteryless inverter or a charge controller and battery.

Importance: Batteryless grid-tied inverters and MPPT charge controllers are built to track maximum power throughout the day, and the Vmp of each module and array, as well as array operating temperatures, must be considered when sizing an array to a particular inverter or controller. Increasing temperatures cause voltage to decrease; decreasing temperatures cause voltage to increase. Fortunately, series string-sizing programs for grid-tied inverters allow you to input both the high and low temperatures at your installation site, and calculate the correct number of modules in series to maximize system performance.

Maximum Power Current (Imp)

Definition: The maximum amperage produced by a module or array (under STC) when exposed to sunlight and connected to a load.

Importance: This specification is most commonly used in performing calculations for PV array disconnect labeling required by *NEC* Article 690.53(1), as the rated maximum power-point current for the array must be listed. Maximum power current is also used in array and charge controller sizing calculations for battery-based PV systems.

Open-Circuit Voltage (Voc)

Definition: The maximum voltage generated by a PV module or array when exposed to sunlight with no load connected.

Importance: All major PV system components (modules, wiring, inverters, charge controllers, etc.) are rated to handle a maximum voltage. Maximum system voltage must be calculated in the design process to ensure all components are designed to handle the highest voltage that may be present. Under certain low-light conditions (dawn/dusk), it's possible for a PV array to operate close to open-circuit voltage. PV voltage will increase with decreasing air temperature, so Voc is used in conjunction with historic low temperature data to calculate the absolute highest maximum system voltage. Maximum system voltage must be shown on the PV array disconnect label.

Short-Circuit Current (Isc)

Definition: The amperage generated by a PV module or array when exposed to sunlight and with the output terminals shorted.

Importance: The PV circuit's wire size and overcurrent protection (fuses and circuit breakers) calculations per *NEC* Article 690.8 are based on module/array short-circuit current. The PV system disconnect(s) must list array short-circuit current (per *NEC* 690.53).

Maximum Power Temperature Coefficient (% per degree C)

Definition: The change in module output power in percent of change per degree Celsius for temperatures other than 25°C (STC temperature rating).

Importance: This specification allows us to calculate how much module power will be lost or gained due to temperature shifts. In hot climates, cell temperatures can reach an excess of 70°C (158°F). Consider a module maximum power rating of 200 W at STC, with a temperature coefficient of -0.5% per degree C. At 70°C, the actual output of this module would be approximately 155 W. Modules with lower power temperature coefficients will fare better in higher-temperature conditions. Notice the relatively low values listed for thin-film modules. This specification reflects their usually-better high-temperature performance.

Open-Circuit Voltage Temperature Coefficient (mV per degree C)

Definition: The change in module open-circuit voltage in millivolts per degree Celsius at temperatures other than 25°C (STC temperature rating). Expressed as millivolts per degree Celsius in this table, but can be shown as percentage per degree Celsius, volts per degree Celsius, or volts per degree Kelvin.

Importance: If given, this specification is most commonly used in conjunction with open-circuit voltage to calculate maximum system voltage (per *NEC* Article 690.7) for system design and labeling purposes. For example, consider a series string of ten 43.6 V (Voc) modules installed at a site with a record low of -10°C. Given a Voc temperature coefficient of -160mV per degree Celsius, the rise in voltage per module will be 5,600 mV [-160 mV per degree Celsius x (-10°C – 25°C)], making for an overall maximum system voltage of 492 V [10 x (5.6 V + 43.6 V)]—under the 600 VDC limit for PV system equipment.

Nominal Operating Cell Temperature

Definition: NOCT is the temperature of each module, given an irradiance of 800 W/m^2 and an ambient air temperature of 20°C.

Importance: This specification can be used with the maximum power temperature coefficient to get a better real-world estimate of power loss due to temperature. The difference in cell temperature and ambient temperature is dependent on sunlight's intensity (W/m^2). Less-than-ideal sky conditions are common in many areas, so a standard of 800 W/m^2 is the basis for this specification, rather than 1,000 W/m^2, which is considered full sun. The construction and coloring of each module is slightly different, so the actual cell temperature under these conditions will vary per module.

For example, if a particular module has an NOCT of 40°C and a maximum power temperature coefficient of -0.5% per degree Celsius, power losses due to temperature can be estimated at about 7.5% [0.5% x (40°C – 25°C)].