COLLEGE OF AGRICULTURE & LIFE SCIENCES
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Demystifying The Solar Module

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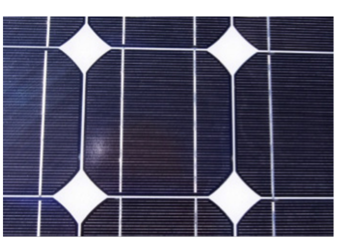
Introduction

The adoption of solar photovoltaic (PV) energy systems to serve as an energy source for residential, commercial and agriculture applications is growing. Early use of solar PV energy as an alternative energy source to fossil fuels became popular in the 1970's during the rise of the environmental movement. The cost of solar power in 1977 was $76.00 per watt. A combination of factors including public awareness, demand for solar, availability of product and service, and improving technology has dropped the cost per solar watt. In 2015, the cost of solar power was $0.613 per watt (Shahan, 2014). Energy rebates offered by local, state, and federal agencies has made the adoption of solar energy more affordable.

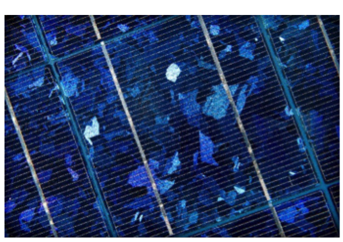
Types Of Modules

Different makes and models of solar PV modules are available for consumers. Most commercially available solar modules are composed of solar cells made of silicon semiconductors or thin-film. Silicon semiconductors are composed of silicon. Silicon is derived from silica (sand), a widely-available element found in our environment (Aldous, Yewdall, & Ley, 2007). The two most common types of commercial silicon modules are monocrystalline, and poly crystalline.

Efficiency ratings of modules range from 15 to 20 percent. The process to produce monocrystalline modules is complex, and a result is a costlier product, whereas the manufacturing

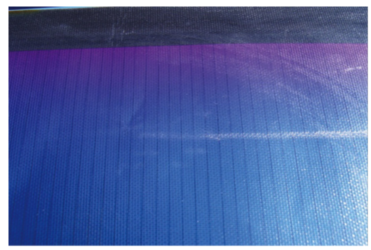


Courtesy of www.nrel.gov



Courtesy of www.nrel.gov

Figure 1. Two types of silicon-based solar modules on the market are monocrystalline (left) and polycrystalline (right). The difference is in the method of the production. Monocrystalline have a higher efficiency, but are more expensive to produce than poly crystalline.



Courtesy of www.homepower.com

Courtesy of www.nrel.gov

Figure 2. Thin-film material is more flexible and less expensive than silicon-type materials. It is used in other solar products such as chargers and calculators.

process of the poly or multicrystalline module is less complex, and results in a more affordable, yet less efficient module (13-16%).

Thin-film solar modules are composed of various semiconductor materials, such as cadmium telluride. The material is less expensive to produce than silicon-type modules, can be made into flexible shapes, and is integrated into products as USB chargers. Limitations to thin-film include lower efficiencies, and less durability or longevity of silicon modules. The thin-film cell is produced from material such as amorphous silicon (a-Si) cadmium telluride (CdTe), or copper indium gallium selenide (CIGS) and deposited on a substrate. It is the least expensive to produce,¬ but the lowest efficiency of the three module types (a range of 7-13%) which means a greater number of modules are needed to equal the efficiency of a monocrystalline module. Thin-film modules make up only 5% of the US residential PV sector.

To determine the efficiency of a module, divide the total watts of the module by the surface area of the module. For example, a PV module rated at 180 watts of total power has dimensions of 1482 mm by 992 mm. The surface area of 1.482m x 9.92m = 14.70m2. Dividing 180 watts by 1,470 (1000watts/m2 * 14.70m2) and multiplying the result by 100% equals 12.24% efficiency

Output

Solar modules produce direct current (DC) electricity when photons from sunlight strike the cell and dislodge electrons. The electrons move from the cell and the PV module to the load where power is provided, and return to the solar cell. The power output of the solar module is measured in watts (w). Commercial modules range in size from five watts to almost 300 watts. On the module spec sheet, watts in power is presented as maximum power (mP). This value varies depending on the size of the module. The number of cells in the module, and the size (square area) of each individual cell determine the output. Module power (or watts) is a function of the volts (V) multiplied by current (I). Mathematically, it is represented as watts = volts x current. Each solar cell is capable of producing approximately 0.50 volt regardless of size. The larger the cell (area), the more current it is able to produce. For example, a module rated to produce 20 watts of power is rated to produce 17.2 volts and 1.16 current (17.2 x 1.16 = 19.95 or 20 watts).

Courtesy of www.nrel.gov

Figure 4. PV modules are available in various sizes based on total power (watts). The size of the individual solar cells affect the amount of current. The number of cells will determine the total voltage of the module.

Solar Cell

The silicon solar cell is composed of two very thin wafers. Monocrystalline cells are sliced from round-shaped silicon ingots. The cells are thickness of a single hair. The top and sides of the cell are trimmed to fit more cells into module frame. To increase the movement of electrons, modern silicon solar cells are “doped” with boron and phosphorous. One side of the cell is mixed with boron, and other side is mixed with phosphorous. This results with one side with a negative-layer, and the other side with a positive-layer. In between the layers is the “p-n junction”. This creates the 0.50 volt per cell. A grid of silver connectors is placed into the cell. When exposed to the sun, photons striking the cell, dislodge electrons. Loose electrons are swept up by the conductors. Electrons flowing on the conductor form electrical direct current (DC). The more electrons flowing, the higher the current (measured in amperage). Cells are wired together in series. The positive conductor of each cell is wired to the negative conductor the next cell. The total voltage of the module is the summation of all the cells in the module. For example, a module with 60 cells, will have a total voltage rating of 30 volts. The amount of current produced is affected by the area size of the cell and sunlight intensity. The larger the cell’s area, the more current it is capable of producing (Solar Energy International, 2004).

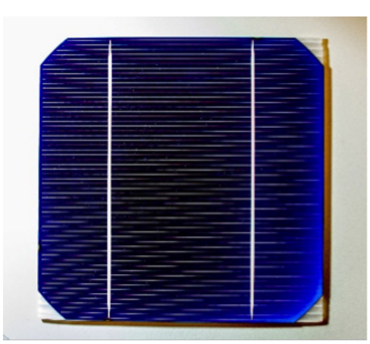
Module Size

Modules are sold on cost per watt basis and vary in size and shape. The dimensions of an example ten-watt module is 302mm (11.89 inches) by 357 mm (14.06 inches), while the dimensions of a sample larger 1-5-watt module is approximately 1,500 mm (59.06 inches) by 675 mm (26.5 inches). A 10-watt module produces 17.0 volts and 0.58 amps (10W = 17.0V x 0.58A) and a 150-watt module produces 18.5 volts and 8.11 amps (150W = 18.5V x 8.11A).

Junction Box

On the back of the module is a plastic enclosure where the silver connectors of the solar cells are landed on terminals. Bare ends of solar PV cable are connected to the terminal strips in the junction box.

On larger commercial modules, the junction boxes include diodes. The diodes serve as an electrical valve. When shade is cast on a portion of the module, the diode reacts to the resistance building in the module and opens. The current flows through the diode and bypasses the blocked row of cells in module.



Courtesy of www.nrel.gov

Figure 3. Individual solar cells are wafer-thin and come with silver connector grids. Monocrystalline cells are sliced from a round ingot and trimmed to shape to fit onto the frame of the PV module to maximize the space.

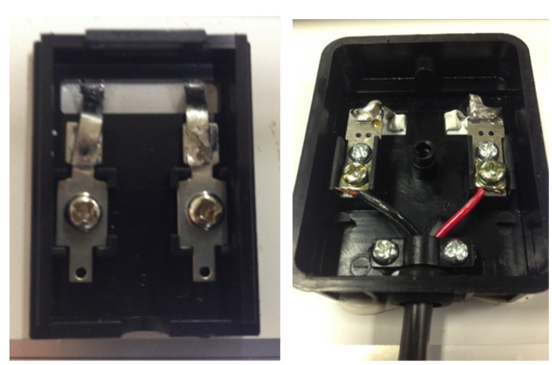


Figure 5. With the protective cover removed, the mounting terminals where the bare wire ends of the PV cable are connected to the junction box is visible. Some modules include cables and connectors, and some modules need to have cables connected prior to use.

Figure 6. Single PV cable is covered with rubber insulation. It can be ordered and purchased in vary lengths with connectors crimped to the ends. The cable can be cut and the ends stripped to connect to a PV module.

PV Cables

There are two insulated cables, one positive (+) and one negative (-), connected to the junction box. Cable length and size (gauge) varies depending on the size of the module. Larger modules are fitted with 10 gauge-size cables. The size and length of the cable depends on the size of the module and junction box. Modules designed to serve as chargers for 12-volt batteries may have alligator-type clamps connected to the end of the cables. Smaller PV modules may be equipped with 12 gauge or 14 gauge wire.

Connectors

On the end of the PV cable are multi-contact connectors. They are labeled positive (+) and negative (-). These may be rubber or plastic and have slip (female to male) or interlocking ends. The metal components are crimped on the bare ends of the solar cable.

Courtesy of Bryan Norkunas, P-V Cables.com

Figure 7. Female (left) and male (right) MC-3 connectors. The MC-3 feature a rubber cover shielding the metal pins. These connectors seal tightly and prevent moisture from entering. However, the connectors can be pulled apart easily.

Courtesy of Bryan Norkunas, P-V Cables.com

Figure 8. Female (left) and male (right) MC-4 connectors. The housing is plastic and has interlocking pieces. A special tool is used to unlock the connectors. This prevents accidental separation and possible arcing under load.

Standard Test Conditions

The solar industry uses standard test conditions (STC) as a consistent mean for measuring solar module output under ideal environmental conditions. The three test conditions are solar irradiance (measured in 1,000 watts per square meter) also called one peak sun hour, solar cell temperature of 25oC (77 oF), and 1.5 atmosphere (ATM). An atmosphere of 1.5 is equivalent to where the sun is shining on a tilted angle of 37o (which is a condition of the 48 contiguous states).

A solar module rated to produce 20 watts is doing this under a clear sky with solar irradiance of 1,000 w/m2, and a solar temperature of 25oC. As the irradiance level changes over the course of the day, the expected power output of the module will change. If the irradiance level is at 500 w/m2, it is expected the output to be at 10 watts. Also, as cell temperature increases (from exposure to the sun), the rated module voltage will decline.

Reading The Specification Sheet

Information found on the specification sheet on the backside of the module includes Power (watts max power = Pmp), volts (max volts = Vmp), and current (max current = Imp). Short-circuit current (Isc) and open-circuit voltage (Voc) are maximum values when the module is not producing power under a load.

To measure the open-circuit voltage, the leads of a multimeter are placed on the ends of the connectors. There is no load connected to the module and the reading reflects the maximum electrical pressure when no current is flowing. The short-circuit current is measured when the module is not connected to other components in a solar energy system. Using a clamp-on DC multimeter is a safe method to measure short-circuit current.

MODULE BRAND
Ratings at 1,000 W/m^2
Cell Temp. 25°C 1.5 ATM

Max Power (Pmp):	230W
Voc:	48.7V
Vmp:	41.0V
Isc:	5.99A
Imp:	5.61A

Figure 9. Modules are rated under standard test conditions. This allows for comparison of values.

Figure 10. Measuring short-circuit current (Isc) with a clamp-on DC multimeter to check if the rated short-circuit current (Isc) value matches the specification sheet.

Conclusions

Solar PV modules are available in multiple sizes, power capacities (in watts) and material compositions. Presently, the silicon-based modules (monocrystalline and polycrystalline) make up a major portion of the commercial PV market compared to thin-film modules. Affordability, durability, and cost are factors the user should consider when making the investment. Module manufacturers offer warranties. However, solar PV manufacturers enter and leave the commercial market. The user should research manufacturers, and compare modules not only on power output, but on module size, type, and availability. The total number of PV modules needed for a system will be based on factors such as location of the array (for example, a roof-mount with limited space, or a ground-mount with more space), total energy needs to meet, and cost. When conducting tests to evaluate module performance, the user must follow safe practices. Always read the manufacturer's instructions, and safety instructions. When in doubt, always consult an electrician.

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