Get MAXIMUM POWER From Your Solar Panels with MPPT

boB Gudgel

Interested in increasing the output of your solar-electric array, without adding additional panels? A maximum power point tracking (MPPT) controller will allow you to harvest more energy from the sun under most conditions, and often substantially compared to non-MPPT designs. So if optimum system performance is your goal, take a closer look at the technology behind MPPT.

Commercially available maximum power point tracking controllers have been around since at least the 1980s. Now they're becoming standard equipment in all but the most modest solar-electric (photovoltaic; PV) systems. New controller designs with improved, lower cost electronic components, transistors, and microprocessors have made affordable and robust MPPT charge controllers a reality.

Simple PV Charging

When a PV panel is connected to a discharged battery and exposed to sunlight, the voltage (potential energy) of the PV will be higher than the battery voltage, and the PV will begin to charge the battery. Just as water flows downhill from a higher level to a lower level, energy flows from the higher voltage PV source to the lower voltage battery.

As soon as you connect the PV to the battery, the two voltages will be equal. The PV will still typically have a higher voltage potential, but the PV's operating voltage is clamped at the battery voltage. If the battery's state of charge is low, the charging voltage will initially be low too. As the battery is charged, the voltage will rise, and the charge rate (amperage) will decrease.

Typical flooded lead-acid batteries need to be held at a relatively high voltage (at least 14.4 VDC at 77°F for a 12 VDC nominal system with flooded batteries) for an hour or two to receive a full charge. This is called the "absorb" or "finish" charge stage. A few times a year, you'll want to equalize the battery bank. Equalization requires the battery to be charged and held at an even higher voltage (up to 16 VDC for a 12 VDC nominal system) for several hours. These are just two reasons why the actual operating voltage of a PV is higher than what is referred to as its nominal voltage. A 12 VDC nominal PV would actually spend much of its charging cycle at closer to 17 VDC, if the battery (or the charge controller) would let it.

The PWM Revolution

Simply connecting a PV to a flooded lead-acid battery can lead to overcharging and a radically decreased operational life if the charging process is not controlled. Overcharging sealed batteries will destroy them and possibly lead to explosions. So you can see why voltage control is necessary to both protect the battery and charge it properly.

A simple, on-off (or "slam-bang," as some call it) relay controller can provide basic protection. When the battery reaches a preset voltage, the controller turns the array off. When voltage drops below a predetermined lower set point, the controller turns the array back on. Controllers such as the old Trace C30 and mercury displacement relay (MDR) controllers operate in this manner.

A pulse width modulated (PWM) charge controller is the next step up in sophistication. It automatically disconnects and reconnects the PV array at a very fast rate, usually hundreds of times a second. This design approach allows the controller to hold the battery at a steady voltage during regulation, which results in higher quality battery charging, and longer battery life.

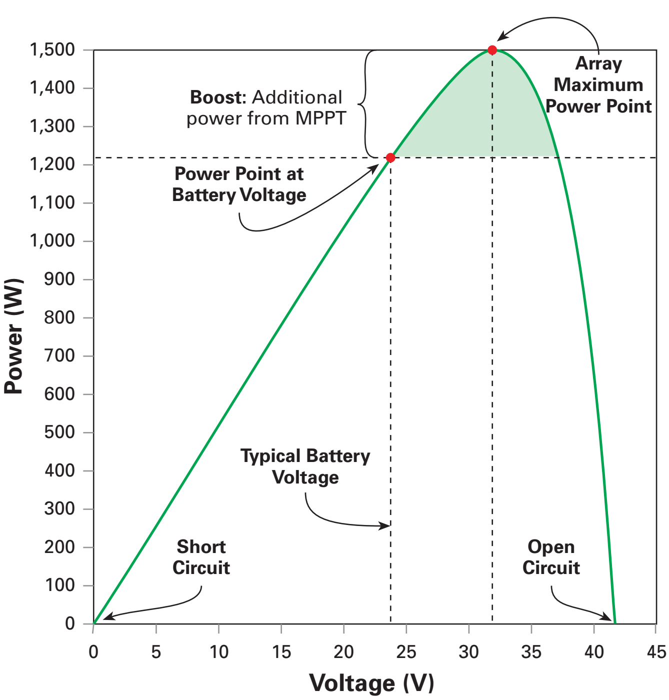
MPPT Is Better

If we look at a typical PV array's wattage versus voltage graphically (see the graph below), we can see how its output might be improved using maximum power point tracking. Power (watts) from a PV array can easily be calculated by multiplying array voltage by array current (amps).

Watts = Volts x Amps

If you look at the right side of the graph, where the wires are disconnected, there's open circuit voltage (Voc), but no amperage (current). Zero amps times any voltage is zero watts. At the left side of the graph, the PV wires are connected directly together, and although we have lots of amps (short circuit current), we have zero volts across this short circuit. Any current times zero volts still equals zero

Power Output of a Typical PV Array



Array Rated Wattage: 1,800 W
Array Nominal Voltage: 24 V
Battery Nominal Voltage: 24 V

How It Works

In a typical MPPT charge controller, the PV array is connected to the controller input terminals and the battery is connected to the output terminals. The controller monitors the PV voltage and amperage, battery voltage, and possibly other things such as battery temperature and load current. An internal microprocessor will make the decisions related to battery charging modes (bulk, float, equalize, track, sleep, wake up), take commands, and display information—everything needed to regulate the battery charging process and interact with the system users.

Assuming that the battery needs charging when the sun comes up, the MPPT controller will "wake up" and find the PV input voltage that will give the highest charge rate. This maximum power point voltage (MPPV) can be found, or "tracked," in several different ways. One way is to simply "sweep" the PV array input voltage from open circuit voltage (disconnected) downward towards the battery voltage.

The MPPT controller sweeps by adding an increasing load to the PV terminals. The load in this case is the battery. Connect the PV and the battery directly together (full load) and the PV voltage equals the battery voltage. A DC-to-DC converter in the controller can completely disconnect the PV from the battery (open circuit), connect them directly together, or anywhere in between. Somewhere in between the two extremes (open circuit and full load) lies the maximum power point voltage.

For example, on a typical 72-volt nominal array, the sweeping controller will move the PV array voltage from about 130 VDC to 65 VDC, looking for the voltage where the array will put out the highest power. As the voltage is being changed, the controller remembers what the maximum power PV voltage was, and keeps (regulates) its input voltage at that point.

Over the course of the day, the maximum power point voltage will change as conditions do (array temperature, sunlight intensity, etc.), and the controller will "track" this MPPV by periodically looking closely around the previously found MPPV. This nearsightedness ensures that it doesn't waste energy, which might happen if the controller had to restart from scratch every time.

When the battery is fully (or nearly) charged, when maximum power is not needed anymore, the controller will operate the PV input at whatever voltage is necessary to keep the battery voltage at the preset regulation voltage. At night, the MPPT controller will go to sleep, and the next day, it will wake up and start all over again.

B.Z. Products offers MPPT controllers in two amperage ratings.

watts. Somewhere in between the open and short circuit, we have a maximum power point (MPP), which is shown by the high peak. This is where the module will give us the highest output.

A maximum power point tracking charge controller operates the PV array at this maximum power point voltage, and efficiently translates that down to the lower battery voltage. It's like an automobile transmission, translating a high engine rpm down to a lower rpm at the wheels. This voltage-reducing circuit is technically called a "buck" converter. The idea is for this buck converter to operate efficiently and waste very little energy in heat, so we get as much energy out as possible. All controllers will get somewhat warm when processing any significant amount of energy, but high efficiency (less heat) is a good thing.

The Solar Boost 3024i is one of several MPPT controllers made by Blue Sky Energy Inc.

A good MPP tracking algorithm is also desirable. If the controller operates too far to the left or right of the peak, energy will be wasted. Although the maximum power point voltage will usually change slowly, it should at least be checked from time to time. Controllers can do this in many different ways. Normally, some energy will be lost in finding the maximum power point, but it's usually very small.

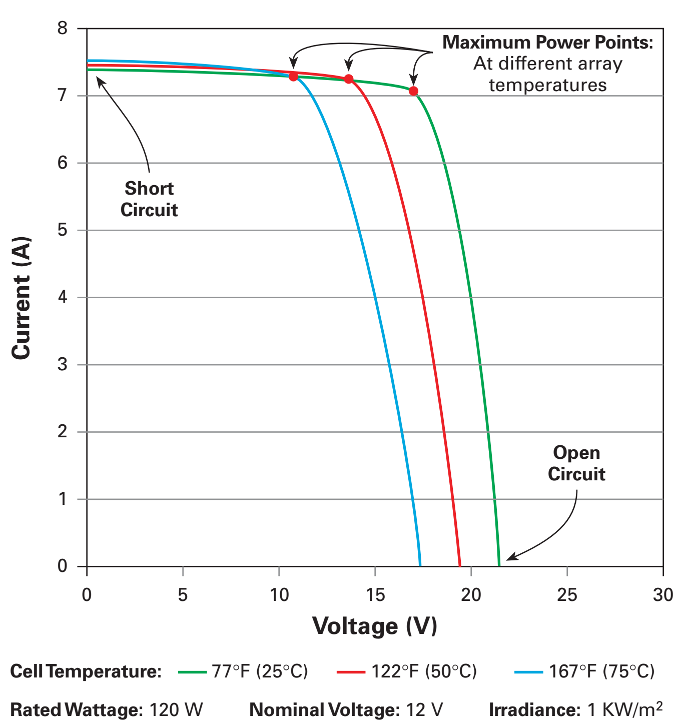
An MPPT controller will allow a solar array to generate more energy than a non-MPPT controller, at a lower cost compared to adding more modules to make up the difference. PV space limitations and wire loss may also be deciding factors in using an MPPT controller.

The increase in output above and beyond the direct PV connection is called "boost." The amount of boost achieved is not always easy to predict. Boost amount can depend on several factors, mainly temperature and battery state of charge. For example, high amounts of boost can happen on a cold sunny day in winter, after a storm, when your batteries are deeply discharged and you need the energy the most.

Maximum Power Point Voltage May Vary

PV module temperature plays a big part in determining how much boost you will get. The hotter the modules, the lower the maximum power point voltage and power will be. Of course, as soon as the sun shines on the modules, they will heat up. This can, at times, put the maximum power point at or even below the battery voltage. In this case, you will get no boost, and a PWM controller would work just as well as an MPPT controller.

Maximum Power Points of a 120-Watt PV Panel



In general, when the modules are cold, the output and maximum power point voltage go up, and a PWM-type charger will not be able to take advantage of the available power. Partial shading of an array will reduce the output and may also reduce the maximum power point voltage.

One way to be sure that the maximum power point voltage stays higher than the battery voltage, if the controller will allow it, is to simply wire more PV modules in series increasing the voltage of the array. Normally, wiring the PV one nominal voltage higher than the battery will do the trick, such as a 36-volt nominal array charging a 24-volt nominal battery. MPPT controller efficiency will generally go down slightly with higher input voltages, but the overall system gain will usually be more than the lower controller efficiency. Higher PV voltage can also improve early morning and evening low-light performance.

Author boB Gudgel at the bench where he designs and tests MPPT charge controllers for OutBack Power Systems.

Reduce Your Losses

But wait! There's more! As long as we're raising the PV voltage a bit, why stop there? As mentioned before, power (watts) equals voltage times amperage. When we are talking about power lost in the PV wires, we use the equation:

$$P = I^2 \times R$$

Where P is power lost, I^2 is current squared (amps x amps), and R is wire resistance.

If we reduce the amperage by two (by doubling the voltage), we reduce the power lost by four. If we reduce the amperage by four, we can reduce the power lost by sixteen, etc. We do this by increasing the voltage by two or four times, respectively. For a very long wire run, this can add up to real savings very quickly!

OutBack Power Systems makes the MX-60, an MPPT controller with a 60-amp capacity.

Let's say we need to place a 24 VDC nominal, 1,400-watt PV array 250 feet (76 m) away from a 24-volt nominal battery bank (500 feet; 152 m of wire, total). This situation comes up much more often than you might think. If we use #4/0 (107 mm^2) cable, we will have 3.3 percent loss (46 watts) in that length cable. From one RE dealer, 500 feet of #4/0 cable costs about US$1,200.

If we wire that same PV array for 48 volts nominal, we can use #2 (33 mm^2) wire for the same wire loss of 3.3 percent. The same dealer sells 500 feet of #2 for US$385. This example just saved US$815 in wire and paid for an MPPT controller with down-conversion capability, with change to spare. Depending on the MPPT controller capabilities, along with the voltage wiring versatility of the PV modules being used, you can save even more wire cost and power by wiring the array for 60 or 72 volts nominal. Utilities send electricity cross-country at a half a million volts or more for this same reason.

Here's the Point

Maximum power point tracking charge controllers come in varying amperage ratings, from just a few amps to 60 or 70 amps. The minimum wattage array to consider purchasing an MPPT controller for is about 250 watts. Of course, you may want to buy one even for a smaller array if you plan to expand your system later. The approximate maximum array size (in rated watts) that you can connect to a controller's input can be calculated by multiplying the battery voltage by the controller's output current rating.

Maximum power point tracking is an immediate way to increase system performance without going to the trouble or expense of adding extra PV modules. Often, you'll be throwing away part of your PV investment if you are not using an MPPT charge controller. Adding an MPPT controller will help you to charge harder, spin your utility meter backwards faster, and save money while the sun shines.

Access

boB Gudgel, OutBack Power Systems, 19009 62nd Ave. NE, Arlington, WA 98223 • 360-435-6030 • Fax: 360-435-6019 • bgudgel@outbackpower.com • www.outbackpower.com

Other MPPT charge controller manufacturers:

Apollo Solar, 23 Francis J. Clarke Circle, Bethel, CT 06801 • 203-790-6400 • johnp@apollo-solar.net • www.apollo-solar.net

Australian Energy Research Laboratories P/L MS 660, 336 Lawsons Broad Rd., Proston, Queensland 4613, Australia • 61-7-4168-9308 • Fax: 61-7-4168-9197 • aerl@hotkey.net.au • www.windsun.com/ChargeControls/maximize.htm

Blue Sky Energy Inc. (formerly RV Power Products), 2598 Fortune Way, Ste. K, Vista, CA 92081 • 760-597-1642 • Fax: 760-597-1731 • sales@blueskyenergyinc.com • www.blueskyenergyinc.com

BRUSA Elektronik AG, Neudorf 14, Postfach 55, CH - 9466 Sennwald, Switzerland • 41-81-758-1900 • Fax: 41-81-758-1999 • info@brusa.biz • www.brusa.biz

B.Z. Products Inc., 7614 Marion Ct., St. Louis, MO 63143 • 314-644-2490 • Fax: 314-644-6121• bzp@brick.net • www.bzproducts.net

Solar Converters Inc., 558 Massey Rd., Unit 1, Guelph, ON, Canada N1K 1B4 • 519-824-5272 • Fax: 519-823-0325 • info@solarconverters.com • www.solarconverters.com