Traditional PWM vs. Morningstar's TrakStar™ MPPT Technology

Introduction:

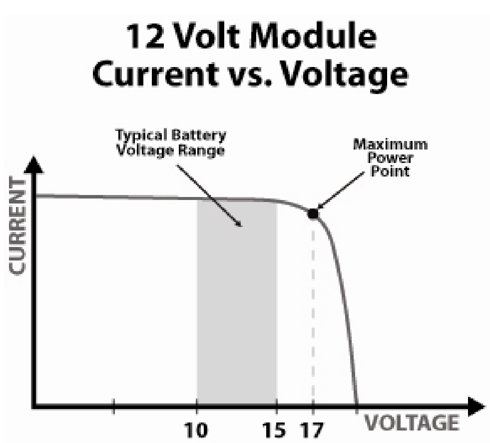
Morningstar MPPT (Maximum Power Point Tracking) controllers utilize Morningstar's own advanced TrakStar™ Maximum Power Point Tracking technology to harvest the maximum amount of power from your solar array. It is generally accepted that even the most basic MPPT controllers will provide an additional 10-15% of charging capability compared to a standard PWM regulator. In addition to efficiency, there are several important differences between PWM and MPPT technology and unique advantages to each. These basic differences are outlined below and an explanation is given on how to properly size solar arrays for each type of controller.

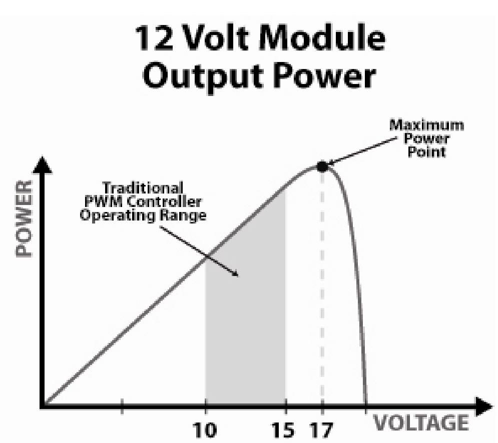
PWM Charging:

Traditional solar regulators featuring PWM (pulse width modulation) charging operate by connecting the solar array directly to the battery bank. When the array is connected directly to the battery bank, the array output voltage is 'pulled down' to the battery voltage. This occurs because the batteries are a very large load for the limited current sourcing capability of a solar array.

The V_{mp} (maximum power voltage) rating is the voltage where the product of the output current and output voltage (amps * volts) is greatest and output power (watts = amps * volts) is maximized. Module wattage ratings (i.e. 100W, 205W) are normally specified at the V_{mp}.

Using a nominal 12V system as an example, the battery voltage will normally be somewhere between 10 – 15 Vdc. However, 12V nominal solar modules commonly have a V_{mp} of about 17V. When the array (having V_{mp} of 17V) is connected to the batteries for charging, the batteries pull down the output voltage of the array. Thus, the array is not operating at its most efficient voltage of 17V, but rather at somewhere between 10 and 15V. The following graphs illustrate this phenomenon:





Because these traditional controllers rarely operate at the V_{mp} of the solar array, energy is wasted that could otherwise be used to charge the battery and power system loads. The greater the difference between battery voltage and the V_{mp} of the array, the more energy is wasted.

TrakStar™ Maximum Power Point Tracking:

Morningstar MPPT controllers feature TrakStar™ technology, designed to quickly and accurately determine the V_{mp} (maximum power voltage) of the solar array. TrakStar™ MPPT controllers 'sweep' the solar input to determine the voltage at which the array is producing the maximum amount of power. The controller harvests power from the array at this V_{mp} voltage and converts it down to battery voltage, boosting charging current in the process.

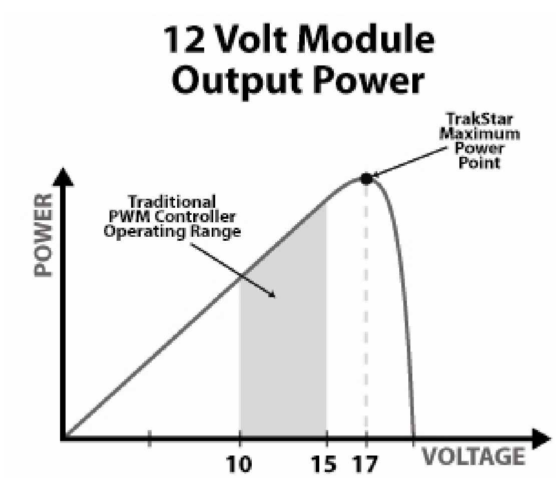
Because power into the controller is equal to the power out of the controller (assuming 100% efficiency, neglecting wiring and conversion losses), it follows that a down-conversion of voltage corresponds to a proportional increase in current. Power (watts) is equal to the product of voltage and current, therefore, if voltage is reduced current must be increased to keep the input/output power equal.

Assuming 100% efficiency:

Input Power = Output Power

Volts In * Amps In = Volts Out * Amps Out

For example: a 100W panel (V_{mp} of 17V) is used to charge a battery at 12V with a TrakStar™ MPPT controller. In ideal conditions, 5.88A of solar current flow into the MPPT (100W / 17V = 5.88A). But the output voltage (battery voltage) is 12V, meaning current flow to the battery is 8.33A (100W / 12V = 8.33A). You can see that the greater the voltage difference between the V_{mp} and the battery, the more "boost" current the battery will receive. The following graph illustrates the advantage of operating at the TrakStar™ Maximum Power Point:



A consequence of this is: the less charged the batteries are (lower battery voltage), the more "boost" current they will receive. This is precisely the time when batteries will benefit from an increased amount of charging current.

Environmental Considerations:

Environmental conditions can cause the V_{mp} of a solar array to fluctuate. Partial array shading and module temperature will have the most impact on the V_{mp} of the solar array. MPPT technology allows the system to track the changing V_{mp} and maximize energy harvest in any environmental conditions.

The most noticeable increase in charging efficiency will be seen in colder temperatures. As solar modules drop in temperature, their V_{mp} increases (see Appendix). Using a standard PWM regulator, a decrease in temperature would correspond to reduced charging efficiency (because there is an increased difference between the V_{mp} and battery voltage). However, an MPPT controller tracks the increasing V_{mp} and converts the excess voltage being produced into additional charging current. In general, any rise in V_{mp} will increase an MPPT controller's harvest relative to a PWM controller. (Conversely, any drop in V_{mp} will decrease an MPPT controller's harvest relative to a PWM regulator.)

As seasons change, the angle of the sun striking a solar module will change as well (assuming stationary modules). The greater the angle of incidence, the less power a module will ultimately produce. During times of the year where the angle of incidence is greatest (and relative power output is decreased), MPPT technology is very useful for harvesting the maximum amount of energy.

Array Sizing for PWM Regulators:

The first consideration in sizing the array for a PWM regulator is open circuit voltage (V_{oc}). Every regulator has a maximum input voltage rating. The array must have a temperature compensated (see Appendix) V_{oc} less than the controller's maximum input voltage rating. During PWM switching cycles, the controller input is exposed to the array open circuit voltage. Using an array with a temperature compensated V_{oc} greater than the controller input rating will damage the regulator.

Next, consider the maximum power voltage (V_{mp}). The V_{mp} of the array needs to be higher than the battery's maximum charging voltage. Recommended values for V_{mp} are below:

12V systems:	$V_{mp} > 15V$
24V systems:	$V_{mp} > 30V$
36V systems:	$V_{mp} > 45V$
48V systems:	$V_{mp} > 60V$

For most solar modules, power output decreases significantly at voltages higher than V_{mp}. Therefore, V_{mp} must be higher than full battery voltage to ensure efficient charging over the entire battery voltage range. ***NOTE:*** *The V_{mp} of the array should be higher than, but as close to, the maximum battery voltage as possible. V_{mp} significantly higher than max battery voltage reduces efficiency and puts more stress on the switching components of the regulator.* ***Only off-grid modules should be used with PWM controllers.***

Finally, the current output of the array is considered. Unlike MPPT controllers, standard PWM regulators are not able to "boost" the amount of charging current by converting excess input voltage into amperage. This means that the input current from the solar array will be equal to the output current delivered to the battery. The solar array must be sized so that the short circuit current (I_{sc}) does not exceed the nameplate current rating of the controller being used. An array with I_{sc} greater than the current rating of the regulator will consistently trip overcurrent protections or damage the unit. ***IMPORTANT:*** *For the system to be NEC (National Electric Code) compliant the current rating of the controller must be equal to or greater than 125% of the array short circuit current output (I_{sc}). Therefore, the maximum allowable solar array input to a 30A controller would be 24A (24A * 1.25 = 30A).*

NOTE: *Morningstar offers a String Sizer tool to assist in the proper sizing/configuration of your solar array with Morningstar controllers. Users may choose between a selection of pre-populated module data or input their own module specifications. This tool also allows adjustment of design parameters such as range of expected battery voltages and min/max temperatures expected at the installation site. A link to the String Calculator can be found on the Morningstar homepage: www.morningstarcorp.com.*

Array Sizing for MPPT Regulators:

As with PWM regulators, the most basic concern when sizing an MPPT solar array is open circuit voltage (V_{oc}). The temperature compensated (see Appendix) V_{oc} of the array must be less than the maximum input voltage rating of the MPPT controller. Higher V_{oc} has the potential to damage the unit.

For a given MPPT current rating and nominal system voltage, there is an effective maximum solar array wattage that can be used. Morningstar MPPT controllers have current ratings which specify the maximum battery charge current the unit can support. ***NOTE:*** *The battery charge current is different from the solar input current due to the MPPT's ability to "boost" charging amperage.* The MPPT current rating multiplied by the battery voltage will give the maximum solar panel wattage which can be used:

> *Example #1:* A 15A MPPT controller is being used in a 12V nominal system (actual battery voltage between 10V and 15V). Multiplying current rating and battery voltage gives about 200W (15A * 13.3V = 200W). The maximum array wattage that can be used in this system is therefore 200W.
>
> *Example #2:* A 15A MPPT controller is now being used in a 24V nominal system (actual battery voltage between 20V and 30V). The maximum array wattage will therefore be 400W (15A * 26.6V = 400W).

It is important to note that exceeding the maximum array wattage for a given controller/ nominal voltage combination will not damage the controller. Any wattage in excess of the max array wattage will simply be lost. (i.e. Using a 300W array in a system where the max array W is only 200W will not damage the controller, but the 300W array will effectively act like a 200W array and 100W of power will be lost.)

IMPORTANT: *MPPT controllers can be used with off-grid or on-grid modules. PWM controllers should only be used with off-grid modules.*

Maximizing Efficiency

Morningstar TrakStar™ MPPT controllers will operate at slightly different efficiencies depending upon the nominal battery voltage being used, the V_{mp} of the array, and the total wattage of the array. These efficiency curves are printed in the appropriate manual for every Morningstar MPPT controller. This data can be used to optimally size your solar array for best performance and maximum energy harvest.

NOTE: *Morningstar offers a String Sizer tool to assist in the proper sizing/configuration of your solar array with Morningstar controllers. Users may choose between a selection of pre-populated module data or input their own module specifications. This tool also allows for the adjustment of design parameters such as range of expected battery voltages and min/max temperatures expected at the installation site. A link to the String Calculator can be found on the Morningstar homepage: www.morningstarcorp.com.*

PWM Over MPPT?

The preceding discussion of PWM vs. MPPT may cause some to wonder why a PWM controller would ever be chosen in favor of an MPPT controller. There are indeed instances where a PWM regulator is a better choice than MPPT and factors which will negate advantages the MPPT may provide. The most obvious consideration is cost. MPPT controllers will cost more than their PWM counterparts. When deciding on a controller, the extra cost of MPPT should be analyzed with respect to the following factors.

Low power (specifically low current) charging applications may have equal or better energy harvest with a PWM controller. PWM controllers will operate at a relatively constant harvesting efficiency regardless of the size of the system (all things being equal, efficiency will be the same whether using a 30W array or a 300W array). MPPT regulators commonly have noticeably reduced harvesting efficiencies (relative to their peak efficiency) when used in low power applications. Efficiency curves for every Morningstar MPPT controller are printed in their corresponding manuals and should be reviewed when making a regulator decision. (Manuals are available for download on the Morningstar website www.morningstarcorp.com.)

As explained in the Environmental Considerations section, the greatest benefit of an MPPT regulator will be observed in colder climates (V_{mp} is higher). Conversely, in hotter climates V_{mp} is reduced. A decrease in V_{mp} will reduce MPPT harvest relative to PWM. Average ambient temperature at the installation site may be high enough to negate any charging advantages the MPPT has over the PWM. It would not be economical to use MPPT in such a situation. Average temperature at the site should be a factor considered when making a regulator choice (See Appendix).

Systems in which array power output is significantly larger than the power draw of the system loads would indicate that the batteries will spend most of their time at full or near full charge. Such a system may not benefit from the increased harvesting capability of an MPPT regulator. When the system batteries are full, excess solar energy goes unused. The harvesting advantage of MPPT may be unnecessary in this situation.

Appendix - Temperature Compensation

It is important to take into account temperature compensation and understand how it relates to both the output voltage and output current of a solar module.

Solar modules have performance ratings under standard test conditions (STC); normally a cell temperature of 25°C and 1000W/m^2 irradiance. Actual operating conditions will, of course, vary from STC. Manufacturers publish temperature coefficients which can be used to determine module output current/voltage under expected conditions. The two most important are the V_{oc} and I_{sc} Temperature Coefficients.

The V_{oc} temp coefficient, specified in volts per degree C (or F), is a negative value. This indicates that the open circuit voltage of the module has an inverse relationship with temperature (V_{oc} decreases with increasing temperature and increases with decreasing temperature). When determining if the V_{oc} of an array is appropriate for the controller's maximum input voltage, it is essential to take into account temperature effects. In warm weather, the V_{oc} of a module may be low enough to use with a certain controller. However, as seasons change and temperature drops, the V_{oc} may rise past a voltage safe to use with that controller.

Worst case temperature effects should always be used when sizing an array. For example: the V_{oc} of a module under STC (25°C) is 21V. The V_{oc} temp coefficient is -0.05V/°C. If the record low temperature for the area in which the module will be placed is -10°C, the worst case (highest) V_{oc} will be 22.75V_{oc}:

-10°C - 25°C = -35°C

-35°C * -0.05V/°C = 1.75V

21V(@STC) + 1.75V = **22.75V**(@-10°C)

The I_{sc} temp coefficient, specified in amps per degree C (or F), is a positive value. This indicates that the short circuit current will rise with increasing temperature and fall with decreasing temperature. Normally, the I_{sc} coefficient is small enough to be neglected.