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# Maximum Power Point Tracking theorem by using Solar Photovoltaic Panel

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## Abstract

The Maximum Power Point Tracking (MPPT) is a technique used in power electronic circuits to extract maximum energy from the Photovoltaic (PV) Systems. In the recent decades, photovoltaic power generation has become more important due its many benefits such as needs a few maintenance and environmental advantages and fuel free. However, there are two major barriers for the use of PV systems, low energy conversion efficiency and high initial cost. To improve the energy efficiency, it is important to work PV system always at its maximum power point. So far, many researches are conducted and many papers were published and suggested different methods for extracting maximum power point.

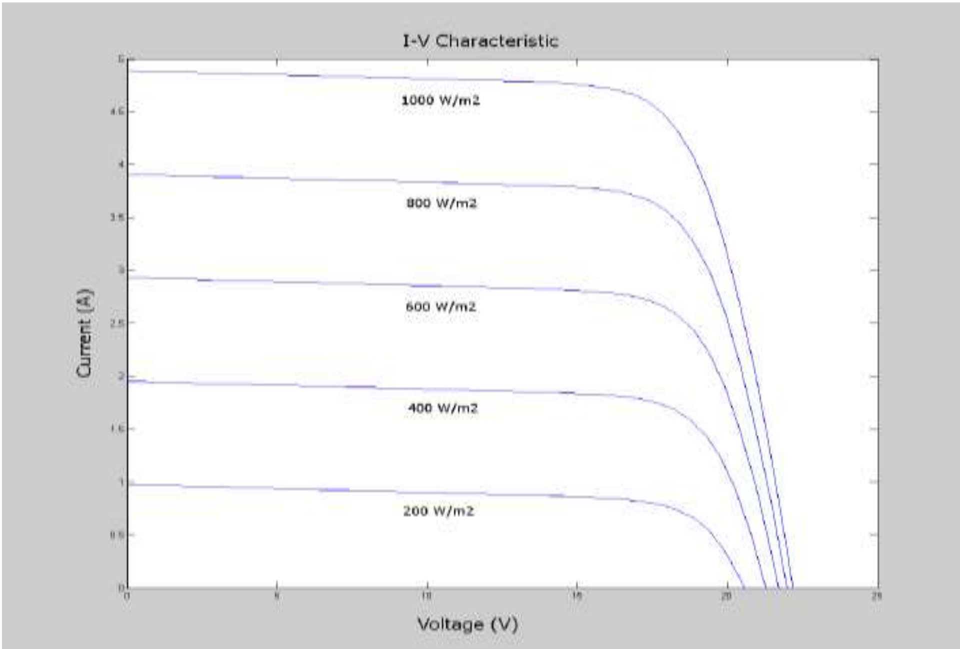
## Keywords
Maximum power point tracking, Perturb and Observe, solar panel MPPT, solar panel characteristics, incremental conductance, fractional short circuit current and fractional open circuit voltage.

## INTRODUCTION

Using a solar panel or an array of panels without a controller that can perform Maximum Power Point Tracking (MPPT) will often result in wasted power, which ultimately results in the need to install more panels for the same power requirement. For smaller/cheaper devices that have the battery connected directly to the panel, this will also result in premature battery failure or capacity loss, due to the lack of a proper end-of-charge procedure and higher voltage. In the short term, not using an MPPT controller will result in a higher installation cost and, in time, the costs will escalate due to eventual equipment failure. Even with a proper charge controller, the prospect of having to pay 30-50% more up front for additional solar panels makes the MPPT controller very attractive. This application note describes how to implement MPPT using the most popular switching power supply topologies. There are many published works on this topic, but only a tiny portion of them show how to actually implement the algorithms in hardware, as well as state common problems and pitfalls. Even when using the simplest MPPT algorithm with a well-designed synchronous switching power supply, it can be expected that at least 90% of the panel's available power will end up in the battery, so the benefits are obvious. The topology presented in this application note is an inverse SEPIC, but the techniques used here can be applied to buck, boost and SEPIC converters. The buck converter is a special case, since it has a linear voltage transfer function when operating in Continuous Conduction Mode (CCM). This simplifies things a lot, and the MPPT controller can be implemented by operating directly on the converter duty cycle. The other topologies have a nonlinear voltage transfer function, and operating directly on the duty cycle will yield unpredictable results, especially at high duty cycles. In this case, the algorithm modifies the solar panel operating voltage by using a proportional integral (PI) control loop, which steers the voltage to the desired value.

## SOLAR PANEL MPPT

The main problem solved by the MPPT algorithms is to automatically find the panel operating voltage that allows maximum power output. In a larger system, connecting a single MPPT controller to multiple panels will yield good results, but, in the case of partial shading, the combined power output graph will have multiple peaks and valleys (local maxima). This will confuse most MPPT algorithms and make them track incorrectly. Some techniques to solve problems related to partial shading have been proposed, but they either need to use additional equipment (like extra monitoring cells, extra switches and current sensors for sweeping panel current), or complicated models based on the panel characteristics (panel array dependent). These techniques only make sense in large solar panel installations, and are not within the scope of this application note. Ideally, each panel or small cluster of panels should have their own MPPT controller. This way the risk of partial shading is minimized, each panel is allowed to function at peak efficiency, and the design problems related to converters handling more than 20-30A are eliminated. A typical solar panel power graph (Figure 1) shows the open circuit voltage to the right of the maximum power point. The open circuit voltage (VOC) is obviously the maximum voltage that the panel outputs, but no power is drawn. The short-circuit current of the panel (ISC) is another important parameter, because it is the absolute maximum current you can get from the panel.



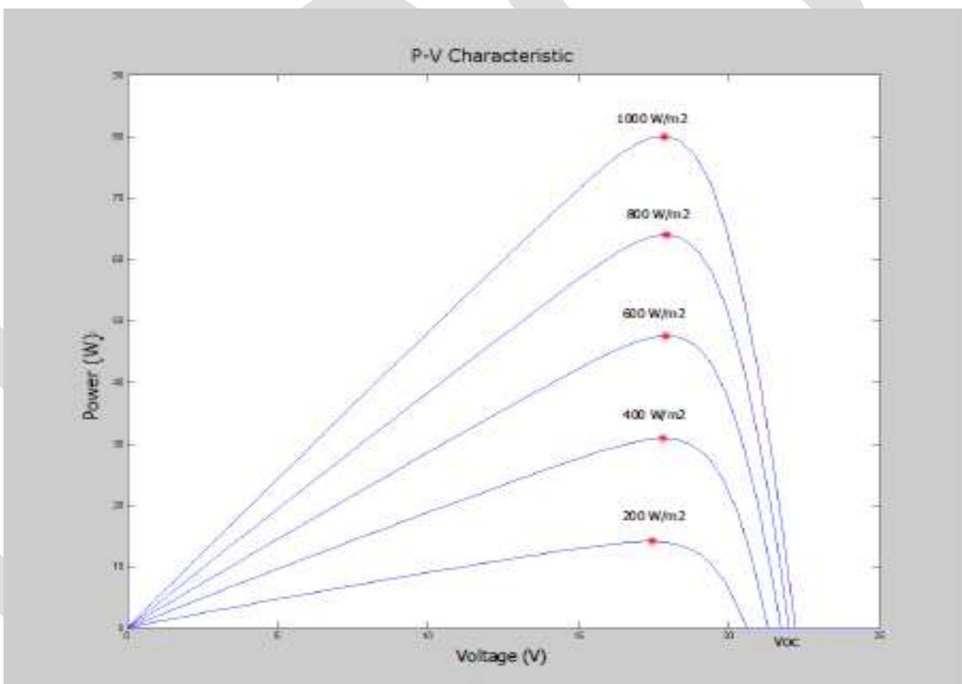




*Figure 1: solar panel characteristics*

The literature on this subject generally agrees that the maximum amount of power that can be extracted from a panel depends on three important factors: irradiance, temperature and load. Matching panel and load impedances with a DC-DC converter makes sense, because for example, if you have a 5V/2A load, and a 20W panel that has the MPP at 17.5V/1.15A, connecting the load directly will not work. Considering a simple resistive load, and the short-circuit current of 1.25A, the panel will only be able to provide about 3V/1.2A, or less than 4W out of 20W. Temperature mainly changes the panel voltage operating point, while irradiance mainly changes the panel operating current. Figure 1 shows the effect of different irradiance levels on the panel voltage, current and power. There are a few MPPT algorithms that can be easily implemented using an 8-bit microcontroller.

## FRACTIONAL OPEN CIRCUIT VOLTAGE

The maximum power point voltage has a linear dependency on the open circuit voltage VOC under different irradiance and temperature conditions. Computing the MPP (Maximum Power Point) comes down to:

**EQUATION 1:**

$V_{MPP} = k_V V_{OC}$ ;

The constant k depends on the type and configuration of the photovoltaic panel. The open circuit voltage must be measured and the MPP determined in some way for different ambient conditions. Usually, the system disconnects the load periodically to measure VOC and calculate the operating voltage. This method has some clear disadvantages, temporary loss of power being an obvious one. An alternate method would be to use one or more monitoring cells, but they also need to be chosen and placed very carefully to reflect the true open circuit voltage of the system. Although this method is quite simple and robust and does not require a microcontroller, the constant only allows a crude approximation of the MPP. Other algorithms will significantly increase the top power drawn from the same PV installation.

## FRACTIONAL SHORT CIRCUIT CURRENT

The MPP can also be determined from the short-circuit current of the panel (ISC), because IMPP is linearly related to it under varying atmospheric conditions.

**EQUATION 2:**

$I_{MPP} = k_I I_{SC}$ ;

Similar to fractional open circuit voltage, the constant must be determined for each type of system. Determining ISC is more challenging, because doing so from time to time not only increases power loss and heat dissipation, but also requires an additional switch and current sensor. Obviously, this increases component count and cost. The simplest implementations do not require microcontrollers, but for better accuracy and to solve problems related to partial shading, more processing power is necessary to sweep the panel current from 0 to ISC, and memorize the output voltage profile.

## I. PERTURB AND OBSERVE (P&O)

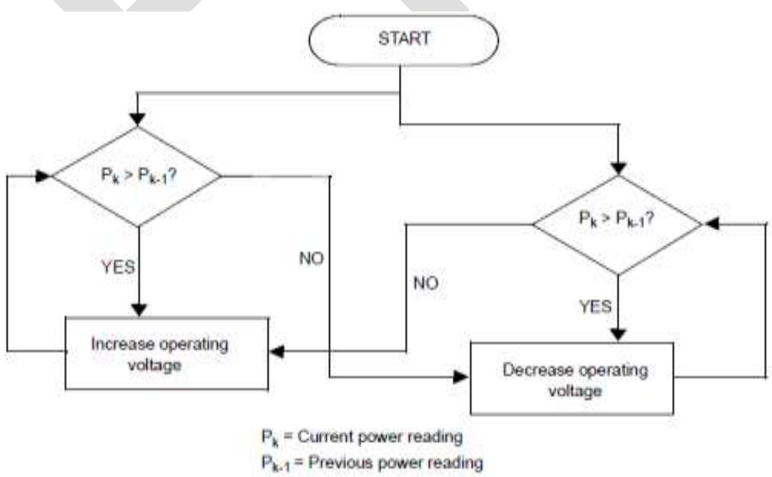



*Figure 2: P&O algorithm*

P&O is one of the most discussed and used algorithms for MPPT. The algorithm involves introducing a perturbation in the panel operating voltage. Modifying the panel voltage is done by modifying the converter duty cycle. The way this is done becomes important for some converter topologies.

Looking at Figure 2 makes it easy to understand that decreasing voltage on the right side of the MPP increases power. Also, increasing voltage on the left side of the MPP increases power. This is the main idea behind P&O.

Let's say that, after performing an increase in the panel operating voltage, the algorithm compares the current power reading with the previous one. If the power has increased, it keeps the same direction (increase voltage), otherwise it changes direction (decrease voltage). This process is repeated at each MPP tracking step until the MPP is reached. After reaching the MPP, the algorithm naturally oscillates around the correct value.

The basic algorithm uses a fixed step to increase or decrease voltage. The size of the step determines the size of the deviation while oscillating about the MPP. Having a smaller step will help reduce the oscillation, but will slow down tracking, while having a bigger step will help reach MPP faster, but will increase power loss when it oscillates. To be able to implement P&O MPPT, the application needs to measure the panel voltage and current. While implementations that use only one sensor exist, they take advantage of certain hardware specifics, so a general purpose implementation will still need two sensors.

## II. INCREMENTAL CONDUCTANCE

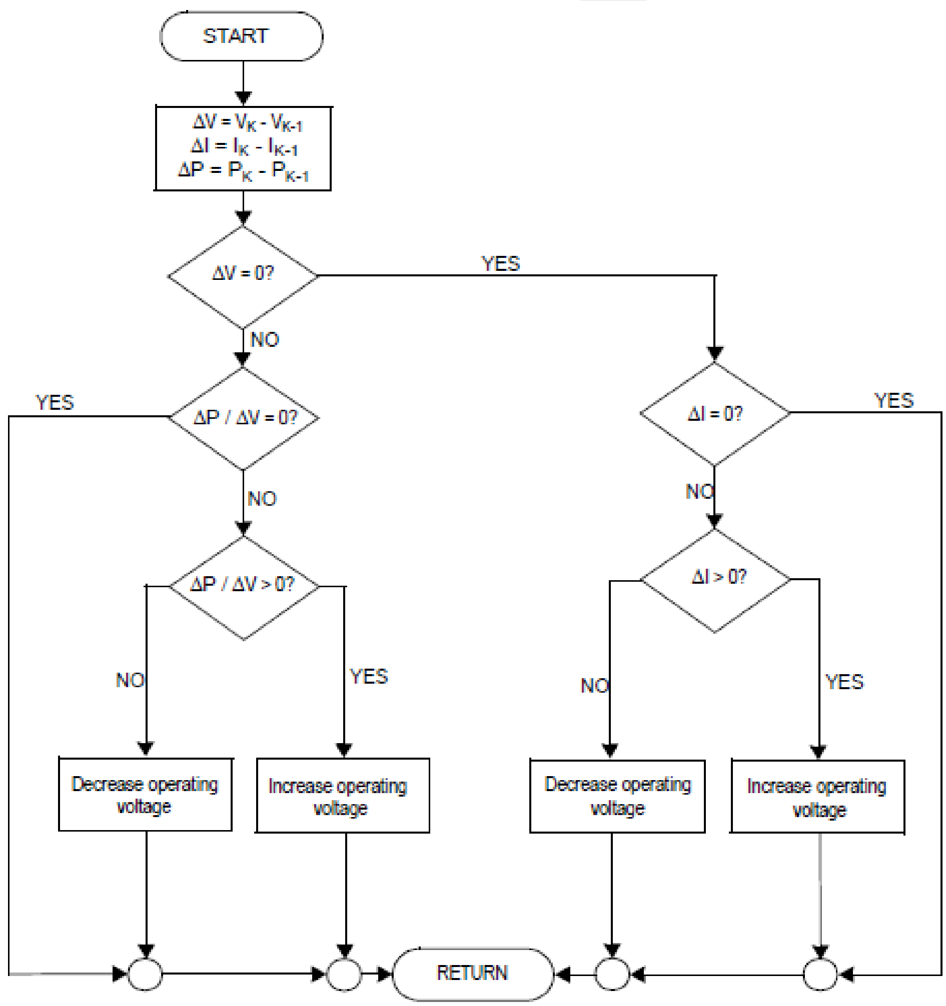



*Figure 3: INCCOND algorithm*

The incremental conductance algorithm uses the fact that the panel power curve derivative (or slope) versus voltage is 0 at MPP, positive on the left side and negative on the right side of the MPP.

**EQUATION 3:**

$$(1)\begin{cases} \frac{dP}{dV} = 0, at\ MPP \\ \frac{dP}{dV} > 0, left\ of\ MPP \\ \frac{dP}{dV} < 0, right\ of\ MPP \end{cases}$$

The power derivative can be also written as:

**EQUATION 4:**

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = \frac{IdV}{dV} + \frac{VdI}{dV} = I + V\frac{dI}{dV}$$
$$I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V}$$

So the first bundle of equations (1) can be rewritten as:

$$(2)\begin{cases} \frac{\Delta I}{\Delta V} = -\frac{I}{V}, at\ MPP \\ \frac{\Delta I}{\Delta V} > -\frac{I}{V}, left\ of\ MPP \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V}, right\ of\ MPP \end{cases}$$

The main idea is to compare the incremental conductance ($\frac{\Delta I}{\Delta V}$) to the instantaneous conductance ($\frac{I}{V}$). Depending on the result, the panel operating voltage is either increased, or decreased until the MPP is reached. Unlike the P&O algorithm, which naturally oscillates around the MPP, incremental conductance stops modifying the operating voltage when the correct value is reached. A change in the panel current will restart the MPP tracking. Depending on the ambient conditions, the same functionality may be achieved by using the initial equation ($\frac{\Delta P}{\Delta V}$).

The basic incremental conductance algorithm uses a fixed step size for the panel operating voltage updates. Using a bigger step size will speed up tracking, but may also cause the algorithm to oscillate around the MPP instead of locking on. Implementing the incremental conductance algorithm requires the voltage and the current output values from the panel (two sensors). Because it needs to keep track of previous voltage and current values, this algorithm is usually implemented using a PIC device or a DSP.

## CONCLUSIONS

Using MPPT with solar panel installations has clear advantages. The initial investment is smaller because smaller panel wattage is required (very little potential power is wasted), and adding correct battery-charging algorithms will also decrease operating costs (batteries are protected and last longer).

By utilizing the techniques presented in this application note, it is possible to optimize the cost and extend the life of any solar powered application ranging from a few watts to two hundred watts by adding MPPT.

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