Introduction to Photovoltaic Systems Maximum Power Point Tracking

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ABSTRACT

Photovoltaic (PV) systems have been used for many decades. Today, with the focus on greener sources of power, PV has become an important source of power for a wide range of applications. Improvements in converting light energy into electrical energy as well as the cost reductions have helped create this growth. Even with higher efficiency and lower cost, the goal remains to maximize the power from the PV system under various lighting conditions.

1 Introduction

The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature, and the current drawn from the cells. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. Such applications as putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT. In these applications, the load can demand more power than the PV system can deliver. In this case, a power conversion system is used to maximize the power from the PV system.

There are many different approaches to maximizing the power from a PV system, these range from using simple voltage relationships to more complex multiple sample based analysis. Depending on the end application and the dynamics of the irradiance, the power conversion engineer needs to evaluate the various options.

2 Photovoltaic Operation

Figure 1 shows a simple model of a PV cell. R_S is the series resistance associated with connecting to the active portion of a cell or module consisting of a series of equivalent cells. Using Equation 1 and I-V measurements, the value of R_S can be calculated. Figure 2 shows that R_S varies with the reciprocal of irradiance.

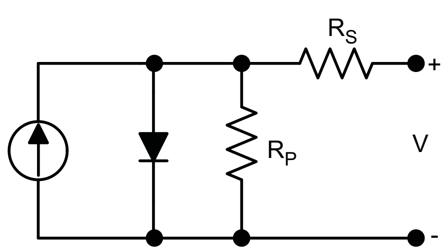

Figure 1. Simple PV Model

Simple PV output current:

$$I = I_{ph} - I_O \times (e^{\frac{q \times (V + I \times R_S)}{n \times k \times T}} - 1) - \frac{V + I \times R_S}{R_P} \quad (1)$$

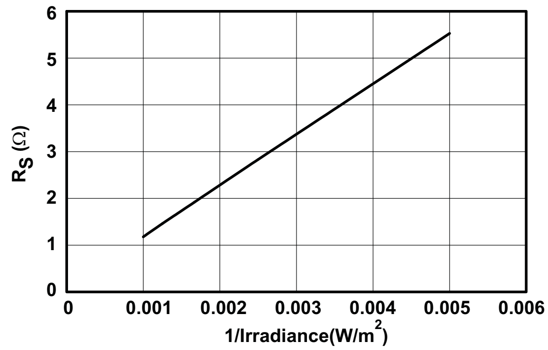

Figure 2. R_S vs Reciprocal of Irradiance for Sanyo HIT 215W

R_P is parallel leakage resistance and is typically large, > 100kΩ in most modern PV cells. This component can be neglected in many applications except for low light conditions.

Current through the diode is represented by Equation 2:

$$I_O \times (e^{\frac{q \times (V + I \times R_S)}{n \times k \times T}} - 1): \tag{2}$$

Where:

- I_O = Diode saturation current
- q = Electron charge ($1.6x10^{-19}$ C)
- k = Boltzmann constant ($1.38x10^{-23}$J/K)
- n = Ideality factor (from 1 to 2)
- T = Temperature (ºK)

The value $\frac{q}{n \times k \times T}$ is weak function of ln(irradiance). This most likely is a change in the ideality factor as the irradiance changes.

The parameters usually given in PV data sheets are:

- V_{OC} = Open circuit output voltage
- I_{SC} = Short circuit output current
- V_{MP} = Maximum power output voltage
- I_{MP} = Maximum power output current

These values are typically given for 25°C and 1000W/m². Figure 3 shows a comparison of the I-V and power characteristics at different values of irradiance.

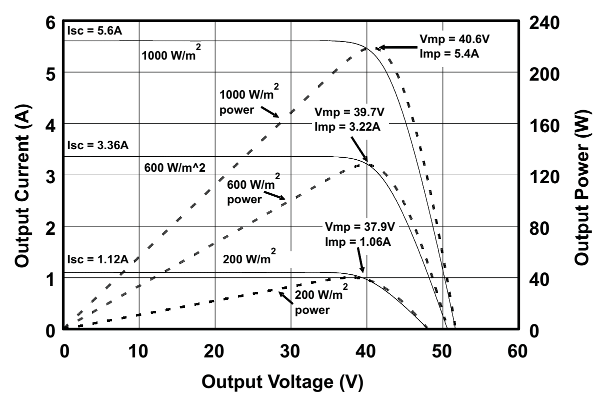

Figure 3. Sanyo HIT 215W

The I_{SC} values are proportional to the irradiance. As well, the I_{MP} changes in proportion to the irradiance as shown in Figure 9.

Another aspect that sometimes is overlooked is that the output current is also a function of the angle of incidence. Although the total irradiance may be constant, if the angle of incidence is not zero compared to the source, the effective irradiance is reduced which results in a reduction in current as shown in Figure 4. This factor may be more evident when a PV system has modules that cannot be uniformly mounted or the system is mobile. In the case where the system is mobile, the angle may be continuously changing and the maximum power point tracking system may require greater tracking speed.

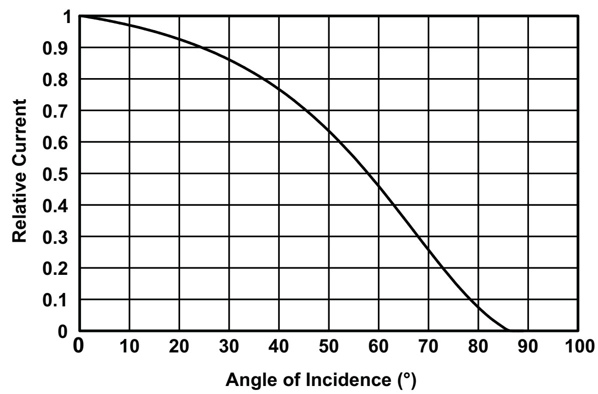

Figure 4. Angle of Incidence vs Relative Output Current

3 MPPT Methods

One of the more complete analyses of MPPT methods is given in Reference 1. This paper compares 7 different methods along derivatives of two of the methods.

These methods include:

1. Constant Voltage
2. Open Circuit Voltage
3. Short Circuit Current
4. Perturb and Observe
5. Incremental Conductance
6. Temperature
7. Temperature Parametric

MPPT methods 1 through 5 are covered in this document.

3.1 Constant Voltage

The constant voltage method is the simplest method. This method simply uses single voltage to represent the V_{MP}. In some cases this value is programmed by an external resistor connected to a current source pin of the control IC. In this case, this resistor can be part of a network that includes a NTC thermistor so the value can be temperature compensated. Reference 1 gives this method an overall rating of about 80%. This means that for the various different irradiance variations, the method will collect about 80% of the available maximum power. The actual performance will be determined by the average level of irradiance. In the cases of low levels of irradiance the results can be better.

3.2 Open Circuit Voltage

An improvement on this method uses V_{OC} to calculate $V_{MP.}$ Once the system obtains the V_{OC} value, V_{MP} is calculated by Equation 3:

$$V_{MP} = k \times V_{OC} \tag{3}$$

The k value is typically between 0.70 to 0.80. It is necessary to update V_{OC} occasionally to compensate for any temperature change. Figure 5 show that V_{OC} also changes with ln(irradiance).

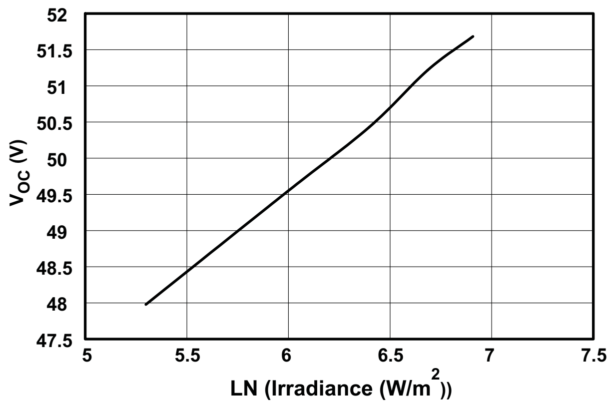

Figure 5. V_{OC} vs ln(irradiance) for Sanyo HIT 215W

Sampling the V_{OC} value can also help correct for temperature changes and to some degree changes in irradiance. Monitoring the input current can indicate when the V_{OC} should be re-measured. The k value is a function of the logarithmic function of the irradiance, increasing in value as the irradiance increases. An improvement to the V_{OC} method is to also take this into account. Figure 6 gives an example of how input current can also be used to adjust the k value for indoor lighting PV systems. As the V_{MP} value is adjusted, I_{PV} becomes closer to the I_{MP}.

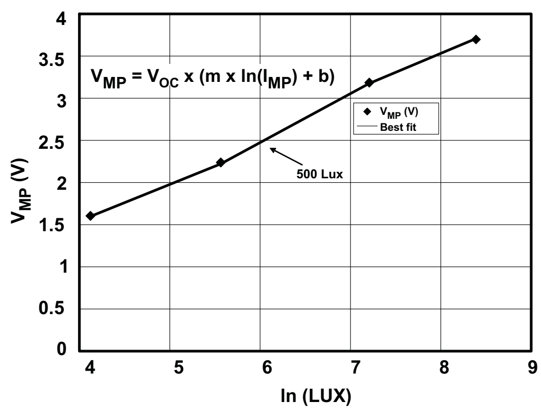

Figure 6. V_{MP} vs Illumination (Lux) for Low Irradiance

3.3 Short Circuit Current

The short circuit current method uses a value of I_{SC} to estimate I_{MP}.

$$I_{MP} = k \times I_{SC} \tag{4}$$

This method uses a short load pulse to generate a short circuit condition. During the short circuit pulse, the input voltage will go to zero, so the power conversion circuit must be powered from some other source. One advantage of this system is the tolerance for input capacitance compared to the V_{OC} method. The k values are typically close to 0.9 to 0.98.

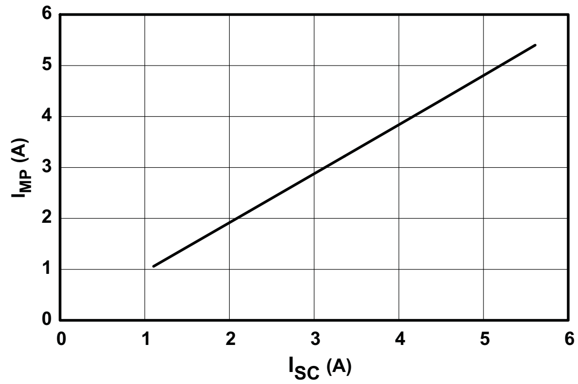

Figure 7. I_{MP} vs I_{SC} From 200 to 1000 W/m^2 for Sanyo HIT 215W

As can be seen from Figure 7, the estimate of I_{MP} is quite good with a R^2 value of 0.99999.

3.4 Perturb and Observe

Perturb and Observe (P and O) searches for the maximum power point by changing the PV voltage or current and detecting the change in PV power output. The direction of the change is reversed when the PV power decreases. P and O can have issues at low irradiance that result in oscillation. There can also be issues when there are fast changes in the irradiance which can result in initially choosing the wrong direction of search.

The designer has a choice of either changing the PV voltage or current. Figure 8 shows that changes in V_{MP} are closely related to ln(irradiance) and Figure 9 shows that I_{MP} is proportional to irradiance. Tracking PV power by changing the PV voltage is less sensitive to changes in irradiance. This becomes more of an issue as the irradiance decreases as shown in Figure 10. So finding I_{MP} will better locate the maximum power point particularly at lower insulation.

Choosing the proper step size for the search is important. Too large will result in oscillation about the maximum power point and too small will result in slow response to changes in irradiance.

To reduce the response to noise, averaging the PV power value is important when making a direction decision. Keep in mind that whenever the system is not at the maximum power point, it is not operating at the optimal point.

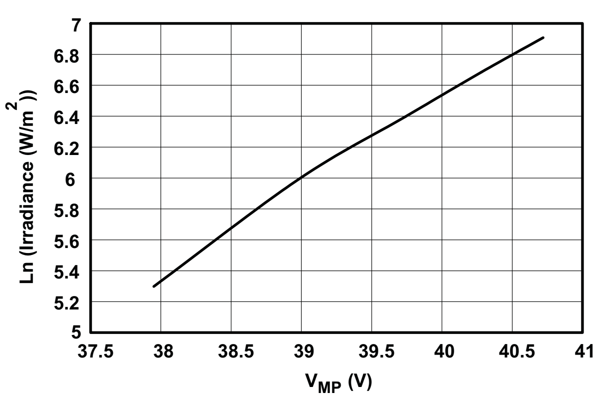

Figure 8. Ln(Irradiance) vs V_{MP} From 200 to 1000 W/m^2 for Sanyo HIT 215W

3.5 Incremental Conductance

Incremental conductance (IC) locates the maximum power point when:

$$\frac{dI_{PV}}{dV_{PV}} + \frac{I_{PV}}{V_{PV}} = 0 \tag{5}$$

This condition simply states that the maximum power point is located when the instantaneous conductance, $\frac{I_{PV}}{V_{PV}}$, is equal to the negative value of incremental conductance, $\frac{dI_{PV}}{dV_{PV}}$, References 1 and 4.

The IC uses a search technique that changes a reference or a duty cycle so that V_{PV} changes and searches for the condition of Equation 5 and at that condition the maximum power point has been found and searching will stop. The IC will continue to calculate dI_{PV} until the result is no longer zero. At that time, the search is started again. In some cases, a non-zero value is used for comparison so the search will not be triggered by noise.

When the left side of Equation 5 is greater than zero, the search will increment $V_{PV.}$ When the left side of Equation 5 is less than zero, the search will decrement V_{PV}.

Incremental Conductance (IC) is good for conditions of rapidly varying irradiance. However, noise may cause continuous searching so some amount of noise reduction may be needed. Figure 11 shows an example of the IC method. In this case, five points were used for each test of maximum power point. This was accomplished using a least squares method to determine $\frac{dI_{PV}}{dV_{PV}}$ and I_{PV}. However, artifacts due to noise can be seen starting around 45V.

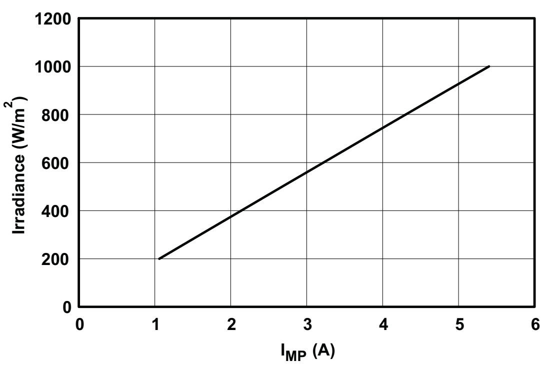

Figure 9. Irradiance vs I_{MP} from 200 to 1000 W/m² for Sanyo HIT 215W

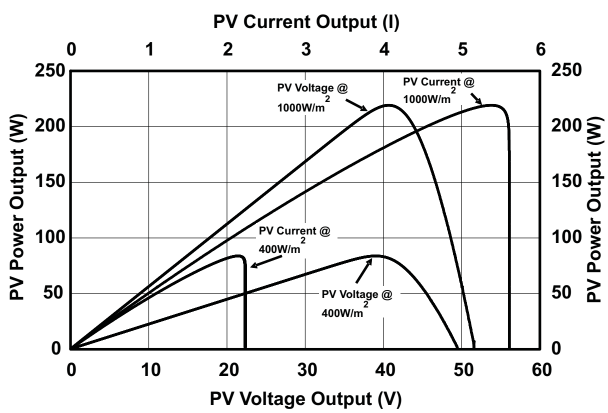

Figure 10. PV Output Power at 1000W/m² and 400W/m² vs PV Voltage and Current Sanyo HIT 215W

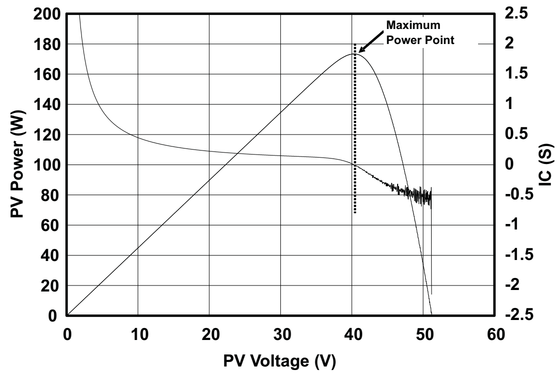

Figure 11. Incremental Conductance Method for Maximum Power Point Power at 800W/m^2 Sanyo HIT 215W

4 Conclusions

There are many approaches to finding and tracking the maximum power point for PV cells and groups of cells. Additional interesting methods are presented in References 2 and 3. These are by no means the only practical maximum power point tracking methods.

Many systems will combine methods, such as using V_{OC} to find the starting point for the iterative methods like P and O or IC. In some cases, changing from one method to another is based on the level of irradiance. At low levels of irradiance, methods like Open Circuit Voltage and Short Circuit Current may be more appropriate as they can be more noise immune.

When the cells are arranged in a series, the iterative methods can be a better solution. When a portion of the string is shade or does not have the same angle of incidence, then searching algorithms are needed.

In general, for whatever method that is chosen, it is better to be accurate than fast. Fast methods tend to bounce around the maximum power point due to noise present in the power conversion system. Of course, an accurate and fast method would be preferred but the cost of implementation needs to be considered.

5 References

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3. **On the control of photovoltaic maximum power point tracker via output parameters,** D. Shmilovitz
4. **An investigation of new control method for MPPT in PV array using DC – DC buck – boost converter,** Dimosthenis Peftitsis, Georgios Adamidis and Anastasios Balouktsis