Evaluation of Micro Controller Based Maximum Power Point Tracking Methods Using dSPACE Platform

Yen-Jung Mark Tung
Dept. of Electrical and Computer Engineering
University of Auckland
38 Princess Street
Auckland
NEW ZEALAND
Email:
marktungatwork@gmail.com

Dr. Aiguo Patrick Hu
Dept. of Electrical and Computer Engineering
University of Auckland
38 Princess Street
Auckland
NEW ZEALAND
Email:
a.hu@auckland.ac.nz

Dr. Nirmal-Kumar Nair
Dept. of Electrical and Computer Engineering
University of Auckland
38 Princess Street
Auckland
NEW ZEALAND
Email:
n.nair@auckland.ac.nz

ABSTRACT

Maximum power point tracking (MPPT) is a widely used control technique to extract maximum power available from the solar cells in a photovoltaic system. In the recent past several MPPT techniques have been developed. The aim of this research is to develop a platform using a dSPACE controller. On such a platform, various control algorithms can be simulated via MATLAB/Simulink, and then downloaded onto a dSPACE card for practical experimentation.

In this paper, three most fundamental methods, the Perturbation and Observe method, Incremental Conductance and Constant Voltage methods were simulated using MATLAB/Simulink/PLECS software packages for future hardware verification. Each method was evaluated and their strengths/weaknesses were identified.

1. INTRODUCTION

The word photovoltaic (PV) literally means conversion of sunlight directly to electricity. It is clean, easy-maintenance and long lifespan (>25 years) characteristics gained a lot of attention in the recent decade. The annual growth of solar energy installation nowadays is around 30% and this number is still climbing [1].

A typical photovoltaic system consists of two major parts: the solar panels that generate DC power from sunlight, and the power electronics that convert DC into standard AC voltages. Most solar cells on the market can achieve 13 ~ 15% of energy conversion, and over 20% in lab environments [2]. While research goes on to improve the PV cell efficiency, it is fundamentally the power electronics that provide controllability over this renewable energy source. In particular, good control to track the maximum power that the PV cells can provide is critically important because the photovoltaic energy is subject to weather changes, and the amount of electricity produced by solar panels is highly unpredictable throughout the day.

There are many issues concerning the development of a practical PV system, e.g., energy conversion, grid connection, etc. In this paper we will only focus on one particular power control technique, that is, maximum power point tracking (MPPT).

Due to the mismatch between load line and operating characteristic of the solar cells, the power available from the solar cells is not always fully extracted [3]. This can be demonstrated by Fig.1.1 below. Maximum power point tracking (MPPT) is a control technique to adjust the terminal voltage of PV panels so that maximum power can be extracted.

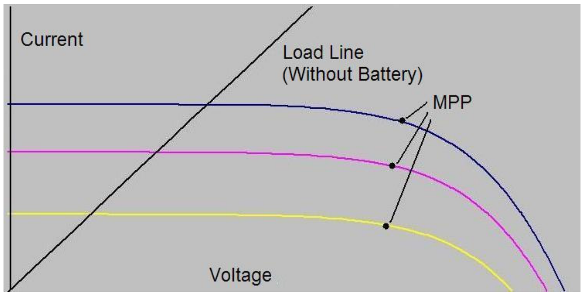

Fig.1.1 Load Line and Solar Cell Characteristic

The location of the maximum power point, or MPP, is subject to the sun's irradiance and therefore must be tracked continuously during operation. Several micro controller based MPPT algorithms have been developed in the recent past, three most commonly used ones are:

- Perturb and Observe method (P&O)
- Incremental Conductance method (IncCond)
- Constant Voltage method (CV)

Each method has its own advantages and disadvantages. The detail of each method will be explained in section 2.

The aim of this research is to develop a testing platform in order to aid the development and evaluation of MPPT methods. This platform features a dSPACE controller with MATLAB/Simulink software package. The algorithm can be constructed in a graphical format and simulated under MATLAB environment. The algorithm can then be downloaded onto the dSPACE control card for practical experimentation. With the help of this testing platform, different MPPT methods can be constructed and tested easily with hardware in simulation loop approach.

2. MPPT ALGORITHMS

The weather and load changes cause the operation of a PV system to vary almost all the times. A dynamic tracking method is necessary to ensure maximum power is extracted from the PV arrays. The following algorithms are the most fundamental MPPT algorithms, and they can be developed using micro controllers.

2.1. Perturb and Observe Method

The Perturb and Observe method (P&O) is the most commonly used MPPT method because of its simplicity [4]. Fig 2.1 below shows the Power-Voltage curve of a typical PV array. During the operation, the terminal voltage is continuously perturbed and power is measured. If the power increases due to a perturbation of voltage to a given direction, it indicates the operating point is moving towards MPP. Therefore the voltage should be changed in the same direction in the next cycle. If the power decreases, it indicates the operating point has passed the MPP and must be changed in the opposite direction.

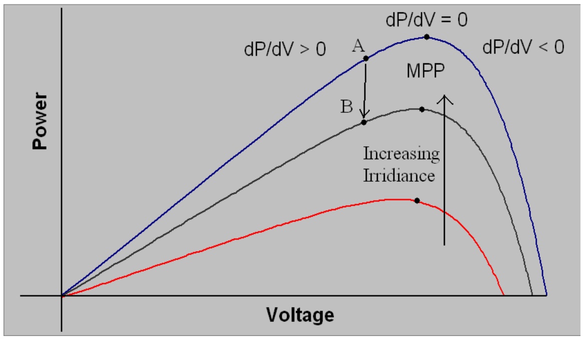

Fig 2.1 Power-Voltage Curve of PV array

One problem with the P&O method is that the true MPP can hardly ever be achieved due to the continuous perturbation. The operation point will swing around the MPP but will hardly stay there. Moreover, the P&O can lose track of MPP under fast changing weather condition. For example, if there was a sudden drop in irradiance, say from point A to point B. This drop in power, although not caused by the change of the terminal voltage, the algorithm will simply fail to interpret the operation, and will therefore further reduce the voltage in the wrong direction, resulting in more power losses.

2.2. Incremental Conductance Method

The incremental conductance method (IncCond) has the advantage over P&O method in that it calculates the direction of the perturbation without constantly varying the voltage. The operating principle of incremental conductance method is based on the following characteristic of the P-V curve that can be shown by Fig 2.1. [5]

- $I/V > dI/dV$ for $dP/dV > 0$
- $I/V < dI/dV$ for $dP/dV < 0$
- $I/V = -dI/dV$ for $dP/dV = 0$

The relationship between I/V and dI/dV determines the direction of the perturbation. The incremental conductance is capable of identifying whether the MPP is reached or not. Once the MPP is reached the perturbation action stops, and it starts again only when I/V and dI/dV are not equal.

The incremental conductance method can track the MPP with higher precision, and it has higher accuracy under fast changing weather conditions compared to the P&O method. However it requires more calculation process and thus slows down sampling speed. This method also requires extra sensors in order to measure the current and voltage.

2.3. Constant Voltage Method

The Constant Voltage method (CV), also in some literature called Open voltage Ratio method, uses the fact that the MPP voltage at different irradiance is approximately equal, as shown in Fig 2.2 below.

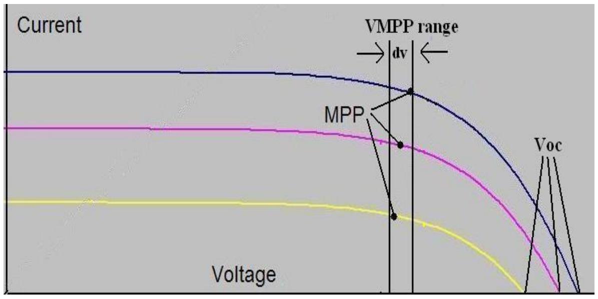

Fig 2.2 Constant Voltage Method

V_{OC} is the open circuit voltage of the PV panel. V_{OC} depends on the property of the solar cells. A commonly used V_{OC}/V_{MPP} value is 76% [6]. This relationship can be described by equation 2.1 below:

$$V_{MPP} = k * V_{OC} \quad [2.1]$$

Where $k \approx 0.76$ in this case.

The solar panels are constantly disconnected from the converter for a short period of time for V_{OC} measurement. The operating voltage of the MPP is then set to 76% of the measured V_{OC}. The major advantage of this method is that the MPP may be located very quickly. However at the same time this method suffers from low accuracy, because the V_{OC} is also affected by the temperature of the solar cells which may change the V_{OC}/V_{MPP} ratio significantly. Any small deviation of the V_{OC} after the sampling can cause large difference in tracking the MPP during that sampling period. Moreover, power is lost during the short sampling time, further reducing the efficiency of constant voltage method.

3. dSPACE PLATFORM SETUP

3.1 *The dSPACE Control Card and PLECS*

The dSPACE controller card supports graphical simulation tools like MATLAB/Simulink. The model-based design environment allows the researcher to construct different control methods with already built-in function blocks. PLECS is a tool box under the MATLAB/Simulink environment that is specially designed for electrical and power electronics circuit simulation. The circuit block can interact directly with function blocks from other tool boxes under Simulink environment. The overall algorithm is then simulated to check the performance. The control algorithm can then be translated to hardware code via the on-board code generator and downloaded onto the microcontroller for practical experimentation

3.2 Solar Panel Model

The P-V characteristic of the solar panels is modeled by the following equation: [5]

$$V_{pv} = N\lambda \ln\left(\frac{I_{sc} - I_{pv} + MI_0}{MI_0}\right) - \frac{N}{M} R_s I_{pv} \qquad [3.1]$$

Where:

I_{PV} and V_{PV} - the current and voltage of the solar panel, respectively.
N - Number of series cells per string
λ - Material coefficient of PV cell
I_{SC} - Short circuit current
I_0 - PV saturation current
M - Number of parallel string
R_S - Series resistance of PV cell

Equation 3.1 can model a real PV panel with higher accuracy; however it may require longer processing time due to the complicated calculation. In order to reduce the processing time required, a simpler model was used in the simulation study:

$$V_{PV} = \begin{cases} -0.625 * I_{PV}^2 + 45 & \text{for } I_{PV} \leq 4 \\ -140*(I_{PV} - 4)^2 + 35 & \text{for } 4 \leq I_{PV} \leq 4.5 \\ 0 & \text{for } I_{PV} \geq 4.5 \end{cases} \qquad [3.2]$$

The curve produced by both equations are plotted in MATLAB and shown as Fig 3.1 below. The outer and inner curves correspond to Equation 3.1 and 3.2, respectively. As it can be seen that the two curves match quite closely before the MPP, and differs slightly after MPP. The MPP of each model is 139.3W and 140W respectively.

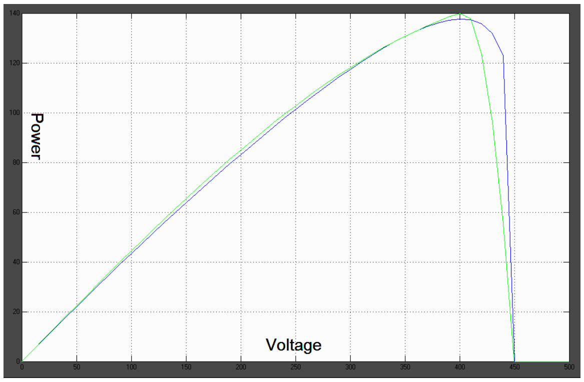

Fig 3.1 PV Model

3.3 Circuit Model

A boost configuration was used for power conversion and control. The simulation model of the boost converter with MPPT control can be demonstrated by Fig 3.2 below. The PV panel voltage and current are measured periodically. The MPPT algorithm is embedded in the logic block and produces a reference voltage. The reference voltage is fed into a comparator and compared with a saw tooth waveform. Finally a PWM switching signal is generated to drive the switch S. The frequency of the saw tooth wave is chosen to be 20 kHz. The resistor represents a load to the converter.

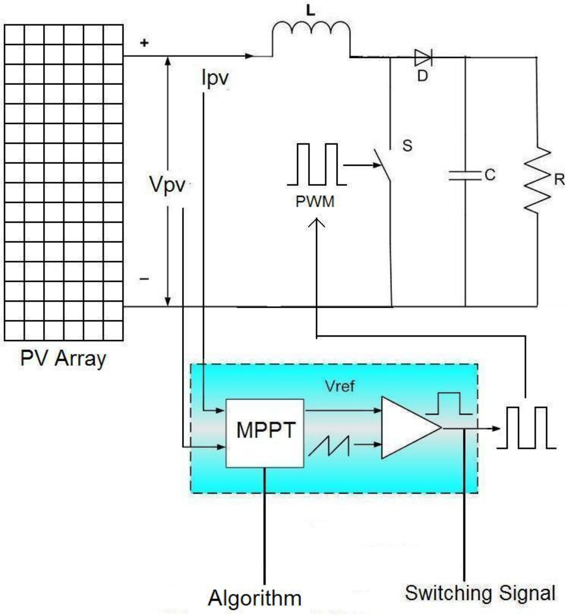

Fig.3.2 Boost Converter with MPPT control

4. SIMULATION STUDY

4.1 Simulation Results

All three methods were simulated with the same boost converter block under the same loading and weather conditions. Full sunlight and partial cloudy conditions were used to test the algorithms. The results are shown in the following figures. The voltage and current are sampled at a sampling frequency of 100Hz for all three methods.

In the following diagrams only the tracking performance under full sunlight are shown. Please refer to appendix I for the equation used to simulate the partial cloudy weather condition.

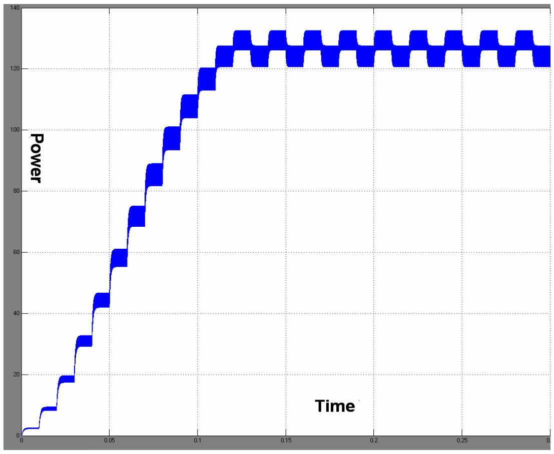

Fig 4.1(a) Power produced by P&O method

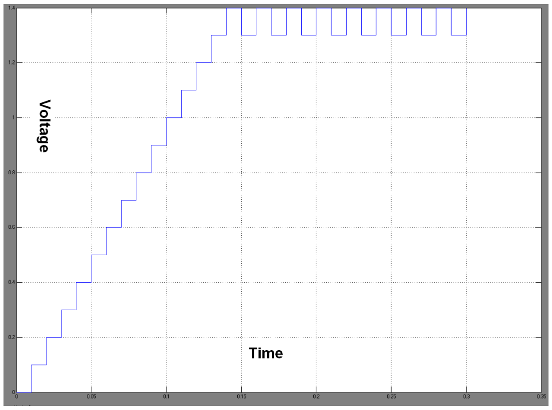

Fig 4.1(b) V_{REF} of P&O Method

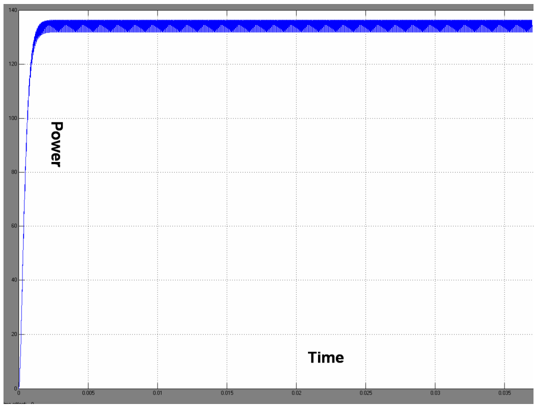

Fig 4.2(a) Power produced by CV Method

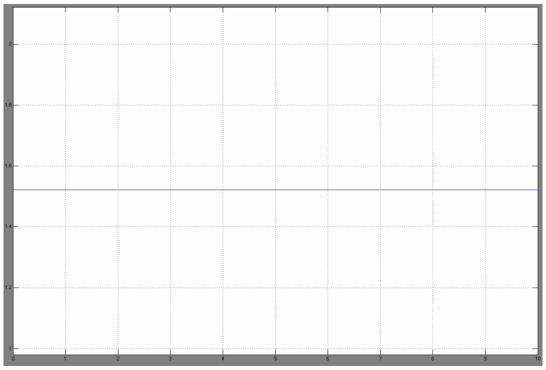

Fig 4.2 (b) V_{REF} of CV Method

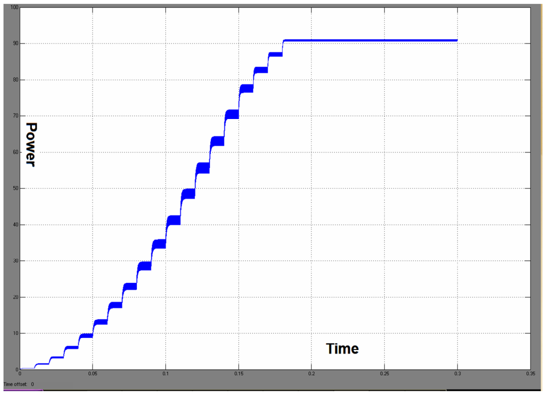

Fig 4.3(a) Power produced by IncCond Method

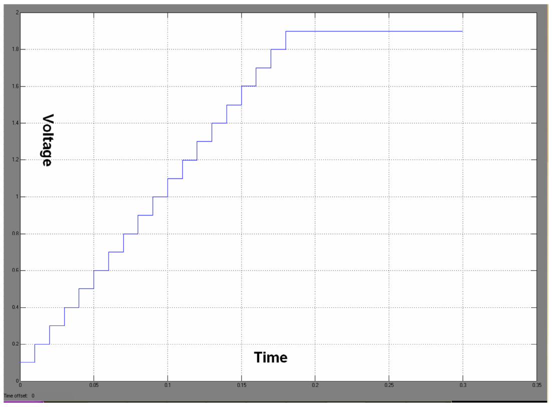

Fig 4.3(b) V_{REF} of IncCond Method

The features of each method are clearly shown by the shape of the output power curve and V_{REF}.

4.2 Evaluation

For the P&O method, it can be seen that some oscillation occurs around the MPP. The magnitude of oscillation depends on Δd, the duty step size. To reduce the power loss caused by the oscillation, the duty step size need to be adjusted dynamically according to different weather conditions. Longer sampling period can be used if weather condition is constant.

Constant voltage method has dramatic fast tracking capability as demonstrated by fig 4.2. However its performance under different weather conditions is poor due to the nonflexible constant k, or in other words, the V_{REF} remains constant for all weather conditions. Choosing the right constant k value requires careful calibration of the solar panel.

Incremental conductance method demonstrates more stable performance under different weather conditions. It also eliminates the oscillation problem associated with P&O method. However it was found that a tolerance range needs to be defined for IncCond method so it stops perturbing V_{REF} once the power falls within that range.

The efficiency is defined by equation 4.1 below:

$$\text{MPPT Efficiency \%} = \frac{P_{out}}{P_{available}} \qquad [4.1]$$

The efficiency of the three methods under two different weather conditions can be summarised in table 4.1 below.

Weather	P&O	IncCond	CV
Full Sun	91.4%	94.6%	95.7%
Partial Cloudy	95.6%	94.9%	75.0%

Table 4.1 Comparison of Efficiency

4.3 Proposed Testing Platform

Up to date control block design has been finished and simulation study has been completed to verify the capability of each methods. Future work will include testing the methods on physical circuits. Modification to each method will also be made in order to improve the efficiency. Helios solar panels (75W) will be used in the practical experiments.

5. CONCLUSIONS

A dSpace platform has been set up to evaluate three most popular maximum power tracking algorithms of photovoltaic cells based on micro controllers, namely the Perturbation and Observe Method (P&O) Incremental Conductance Method (IncCond) and Constant Voltage Method (CV). They were simulated using MATLAB/Simulink/PLECS software packages. The preliminary results have demonstrated that the Constant Voltage method is the fastest in tracking the maximum power, while IncCond method has the most stable performance under different weather conditions.

6. ACKNOWLEDGEMENTS

The author of the paper would like to give thanks to Dr. Patrick Hu and Dr. Nirmal Nair for their guidance and suggestions throughout the research process.

7. REFERENCES

[1] *NZPVA Info sheet #1*. [Online]. Available: http://www.photovoltaics.org.nz/infosheets.html [15th April 2006]

[2] *NZPVA Info sheet #2*. [Online]. Available: http://www.photovoltaics.org.nz/infosheets.html [15th April 2006]

[3] W. Swiegers, Johan H.R. Enslin, *(1998) An Integrated Maximum Power Point Tracker for Photovoltaic Panels.* [Online], Available: IEEE Explore database. [20th July 2006]

[4] K.H Hussein, I. Muta, T. Hoshino, M. Osakada, *Maximum Photovoltaic Power Tracking: an algorithm for rapidly changing atmospheric conditions.* [Online], IEE Proceeding of Generation, Transmission and Distribution, Vol 142, No. 1 Jan 1995. [20th July 2006]

[5] X. Wang (2004), *Control Design for Distributed Photovoltaic Systems.* Masters Thesis, University of Auckland.

[6] D.P Hohm, M.E. Ropp, *Comparative Study of Maximum Power Point Tracking Algorithm Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed.* [Online], Available: IEEE Explore Database [12th July 2006]

APPENDIX I

Equation for Partial Cloudy weather simulation

$$V_{PV} = \begin{cases} -1.11*I_{PV}^2 + 42 & \text{for } I_{PV} \leq 3 \\ -128*(I_{PV} - 3)^2 + 32 & \text{for } 3 \leq I_{PV} \leq 3.5 \\ 0 & \text{for } I_{PV} \geq 3.5 \end{cases}$$

Maximum power point = 3 * 32 = 96W