Implementation of Enhanced Perturb and Observe Maximum Power Point Tracking Algorithm To Overcome Partial Shading Losses

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Abstract— **Maximum power point tracking is a method to trap maximum available power from a solar panel. Many algorithms have been developed based on the characteristics of solar panel in order to utilize maximum available power. But these algorithms do not consider local maxima and minima in the solar panel characteristics caused due to shading. In this paper an enhanced version of Perturb and Observe maximum power point tracking algorithm is explained which also considers local maxima and minima caused by shading and makes the solar panel to work at its peak maxima. This helps in improving the overall efficiency of the system. Algorithm is implemented on 50W solar panel using ATMega 8 microcontroller and a boost converter.**

Keywords— DC-DC Power Conversion, Maximum Power Point Tracking (MPPT), Microcontroller, Partial Shading, Timer

I. Introduction

The natural resources which are utilized to produce electric power are depleting at an exponential rate. This makes mankind to dependent on renewable resources for producing electricity. Wind, Solar, Biomass, Geothermal Solar are some of the available renewable resources. Pollution is yet another factor to be considered while producing power. A clean pollution free power has also become a necessity. In a world where global warming and natural calamities are causing havoc, energy production with pollution will give an additional thrust to their boom. Considering these factors, solar power is the key player among the mentioned sources.

Solar power can be considered as a cleaner, cheap and sustainable source of energy. Solar panels are the devices which convert incident solar energy to electric power. But efficiency is also an important factor while considering a source for power. Solar panels produce electric power when photons emitted from sun hits their surface. Photon gives its energy to electron and triggering it to flow. So irradiance or amount of power carried by photon is a factor which produces electric power from solar panel. This means energy generated varies with intensity of light and its electromagnetic spectrum. Even if the insolation and temperature is constant, the power delivered from the solar panel depends on the load current (or voltage which are interdependent). If load current is fixed, then the system cannot utilize solar panels to its maximum. And, because of the same reason, additional number of panels may be needed to deliver power at the rated load current. Maximum power point tracking algorithms are used to trigger a DC-DC converter to track most efficient load current, which is altogether known as maximum power point tracking. [2] gives an evaluation study on various maximum power point tracking techniques and proposed tracking factor and as an evaluation entity to quantify the quality of tracking performed by the MPPT algorithm. Detailed global peak power point tracking is not considered in the paper. [3] proposed two new MPPT algorithms to track global maxima of PV strings under shaded conditions. Performance analysis of the aforementioned global power tracking methods is also carried out. [10] gives a comparative evaluation of various global peak power tracking algorithms. It also gives a view on how P&O MPPT tracking technique can be used for reaching global maximum power operating point. [11] Proposed a novel global maximum power point tracking algorithm to track global maximum power point of shaded solar panels based on observation studies made in solar panel array. [4] presented Newton-Raphson method is used to calculate the operating point where maximum power point is present in PV arrays. Accuracy and search time to reach maximum power operating point is obtained to be better than the conventional techniques. But operational performance requirement during partial shading conditions is not given in the work. [12] details a single sensor based modified version of P&O algorithm where step size adapted dynamically to increase the accuracy of tracking.

In this paper, section II discusses about the effect of partial shading in solar panels. In section III simple P & O maximum power point tracking algorithm is briefed and in section IV, enhanced version of the P & O algorithm is detailed. Section V discusses about the dc-dc converter used and implementing issues and results are discussed in section VI. Paper is concluded in section VII. Experimental results and its future expansion possibilities are also discussed in this section.

II. Effect of Shading in Solar Panel

[1]Gives detailed explanation of forming solar panel models based on which electrical characteristics of solar panel which are subjected to various conditions can be obtained. Equivalent circuit of a solar cell is represented using figure 1.

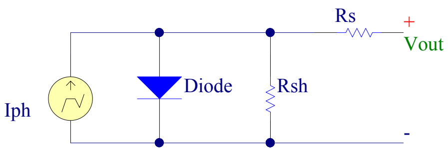


Fig. 1 Solar Cell Equivalent Circuit

IV characteristics of solar cell are determined by equations 1,2 and 3 which is formed by deducing figure 1.

$$I_D = I\,[\exp(q(V + I\,R_S)/KT)) - 1] \quad (1)$$

$$I = I_{ph} - I_D - I_{sh} \quad (2)$$

$$I = I_{ph} - I\,[\exp(q(V + I\,R_S)/KT)) - 1] - (V + I \times R_S)/R_{sh} \quad (3)$$

Where:

I	: Solar cell current (A)
I_{ph}	: Light generated current (photon current) (A) [Short circuit value assuming no series/ shunt resistance]
I_D	: Diode saturation current (A)
q	: Electron charge (1.6×10-19 C)
K	: Boltzmann constant (1.38×10-23 J/K)
T	: Cell temperature in Kelvin (K)
V	: solar cell output voltage (V)
R_s	: Solar cell series resistance (Ω)
R_{sh}	: Solar cell shunt resistance (Ω)

Based on the equation 1, 2, and 3, IV characteristics of solar cell is plotted. In the figure 2, V_{oc} is the open circuit voltage of solar panel. I_{sc} is the maximum current which solar panel can deliver, known as the short circuit current. A 250W solar panel is tested under different insolation and its characteristics are plotted. Figure 2 gives an idea on I-V characteristics when irradiance is 1000 W/m^2. Panel Characteristics vary with temperature and irradiance. Figure 3 shows variation of I-V characteristics under different insolation (irradiance).

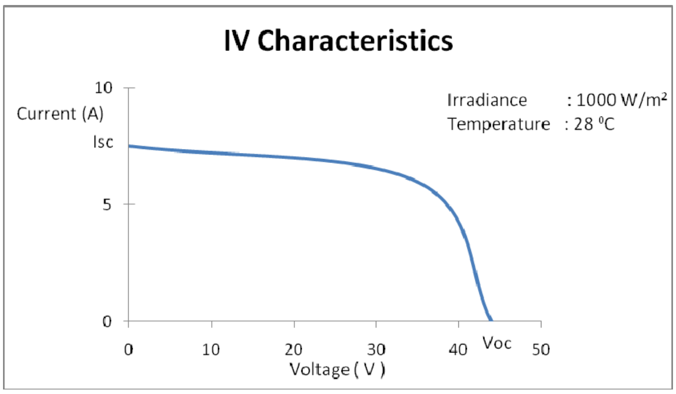


Fig. 2 I-V characteristics of the solar panel used for the experiment, when temperature and irradiance are constant.

P-V (Power Vs Voltage) characteristics of solar panel is a non-linear as shown in figure 4. When a load is connected to the solar panel, operating point of the system (according to the Power-Voltage curve) linearly increases with increase in current. It reaches to a maximum, where the system is said to have attained maximum power. This operating point is known as maximum power point. Aim of all maximum power point tracking algorithms is to fix the operating point of the system at aforementioned maximum power point. Operating point where maximum power can be extracted (Maximum power point) varies with insolation. MPPT trackers have to dynamically adjust to this and maintain its operating point at maxima of the Power-Current curve.

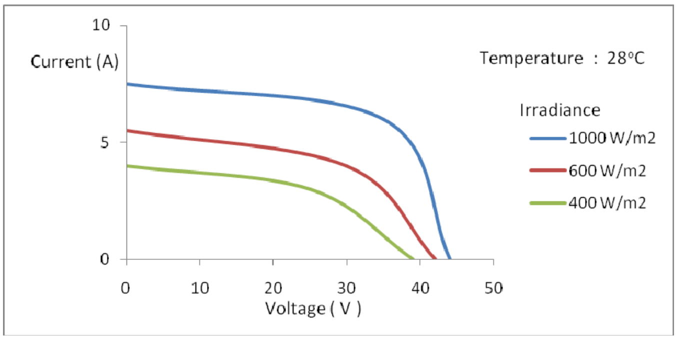


Fig. 3 I-V characteristics of solar panel used for the experiment, with constant temperature and different irradiance.

When the distribution of light on the solar panel is non-uniform, it affects the power generated by the solar panels. Solar panels are made by combining a number of solar cells in series and parallel combination. Each solar cell will have its own individual characteristics.

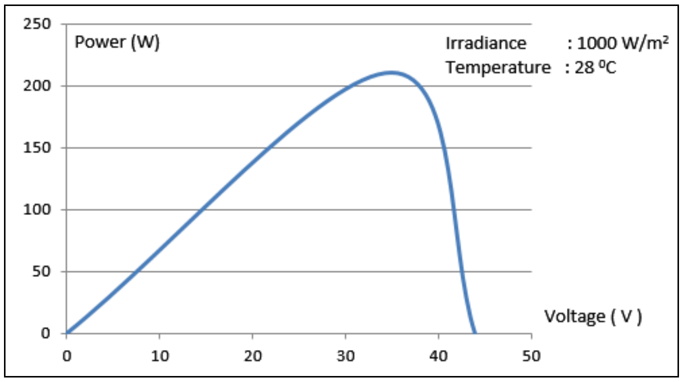


Fig. 4 P-I Characteristics of the solar panel

[6]Depending on the orientation of solar panel with respect to the sun, the irradiance seen by individual solar cells in the panel varies. This happens when solar panels are kept in an uneven order. Solar panels may not be kept at an optimum inclination level. Clouds are another cause for shading. When solar panel strings are formed by combining more than one panel, chances of shading due to clouds are more. Partial shading can also occur when the panels are kept near building walls or it can also occur when shades of nearby panels fall on adjacent solar panels. [7]When insolation on different solar cells is uneven, it gives rise to multiple maxima and minima in the Power Vs Current or Power Vs Voltage characteristics of the solar panel. This affects MPPT trackers. Instead of getting the panel to operate in its peak maxima, system gets trapped at

the local maxima. Thus, the overall efficiency of the system reduces drastically. In order to see the effect of shading in panel characteristics, one cell of 250W solar panel under test is deliberately shaded with twigs and leaves. Panel was tested and characteristics were plotted. Solar panel under test was made of polycrystalline solar cells. It consisted of 72 cells arranged in six columns and twelve rows.

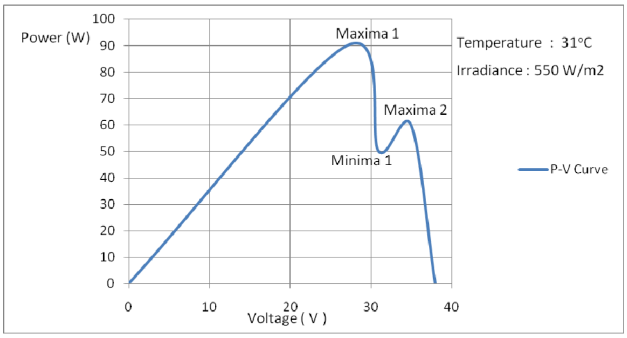
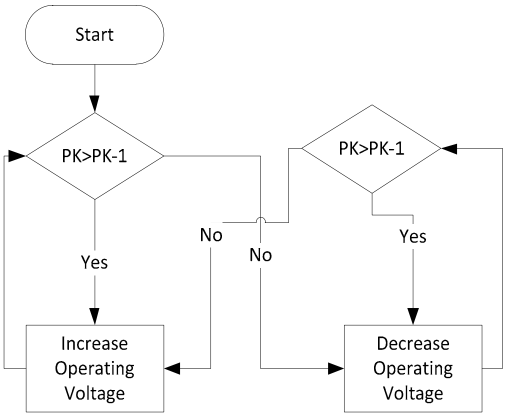


Fig. 5 P-V Characteristics of the solar panel with partial shading

Panel was placed under 550W/m^2 insolation. Two maxima and minima were obtained. One maximum is at co-ordinate (27V, 90W) and other at (35V, 60W). Figure 5 shows the characteristics only when one cell was shaded. But in real time, shading effect can become worse, which can add multiple maxima and minima to the operating characteristics.

III. Perturb and Observe MPPT Algorithm

Perturb and observe MPPT tracking algorithm is a commonly used algorithm. [2]This algorithm is simple yet powerful algorithm. It is a type hill climbing algorithm because of its nature of operation. System starts with open circuit voltage and enters into the loop. It gives a trigger, by adjusting the voltage and new power is fed back.



(PK- Current power, PK-1 – Previous Power)

Fig. 6 Block diagram of Perturb and observe algorithm

[5]When the modified power is greater than the previous power, it continues to operate in the same direction (either increasing voltage or decreasing panel voltage by adjusting duty ratio). Once it hits a flip, direction of operation is also reversed and continues to operate in the other loop (given in figure 6). [2] By applying this technique, system reaches at maximum power point and continues to jump between the loops. This creates an oscillation in the system which is an inherent problem of this algorithm which can't be removed. But the rate of oscillation and amount of oscillation can be adjusted by adjusting step size and data sampling interval of the system. When there is shading in the solar panel, system can get stuck in the local maxima. By analyzing figure 5, system starts its operating point initially from its open circuit voltage at 38V. It shifts its operating point in the left direction with respect to open circuit voltage point (refer figure 5). Then it sees maxima 2 at co-ordinate (35V, 60W).

It gets stuck there and continues to operate there. But global maximum point is at co-ordinate (27V, 90W). System looses 30W power. This power is lost till the shading is moved from the system. Above mentioned case was when one cell was deliberately shaded. But in real time, shading can occur at any given time of day and can create more than one maximum in the system. Variations in shading in are very random and unpredictable. So there are enough chances that the system may get stuck in the local maxima.

IV. Enhanced Perturb and Observe MPPT Algorithm

Perturb and observe MPPT tracking algorithm either tries to move in increasing slope direction or in decreasing slope direction of P-V characteristics (figure 4). When there is a flip in the direction of slope, it starts oscillating at that point. This flip in the slope can occur at any maxima. Hence it can get stuck at the local maxima.

In this algorithm (figure 7), the system performs a complete sweep of the curve by adjusting the PWM of the converter from zero to its maximum limit. Then it finds the point where maximum power is available. Then it sets the PWM at the operating point where maximum power point was found and it starts perturb and observe algorithm from the operating point obtained. This helps to make a jump from local maxima to the peak maxima. Sweep in the system is made once every fifteen minutes so as to find the maximum power point in the operating curve. This algorithm is implemented in ATmega8 microcontroller.

Initially PWM is set to zero and all other parameters such as voltage, current, old power, new power are set to zero. It then jumps to perturb and observe routine. Timer0 of the microcontroller was utilized to generate a trigger in every 15 minutes. Once it receives a trigger, it jumps to sweep routine (figure 8). In the sweep routine, it again resets the PWM, starts climbing the hill (figure 4, P-V characteristics) from the initial voltage as open circuit voltage of the panel. Minimum step size is utilized to perform the sweep. Operating point is varied in a predefined delay time to obtain proper response from solar panel. Finds the PWM corresponding to maximum power point and restarts perturb and observe algorithm. Sweep routine is completed in 500ms.

[9]ATMega8 microcontroller is equipped with six channel 10bit analog to digital converter. ADC channel 0 and ADC channel 1 are used to get current and voltage sense

information. Reference voltage of ADC peripheral is set to 5V. In order to measure the voltage, a resistor divider network is used. And shunt resistance method is used to measure current. Current sense signal from shunt resistance terminals are then amplified using an instrumentation amplifier before giving it as input to ADC channel of microcontroller.

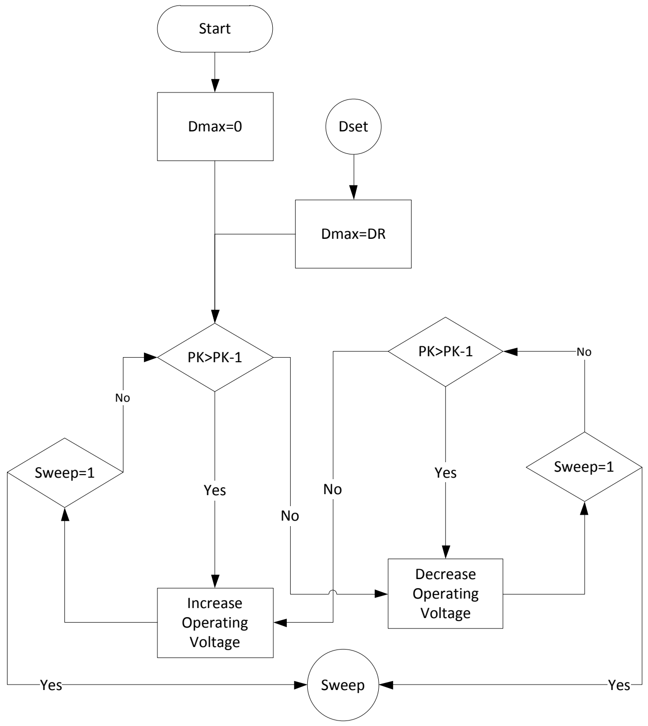


Fig. 7 Block diagram of Enhanced Perturb and observe algorithm

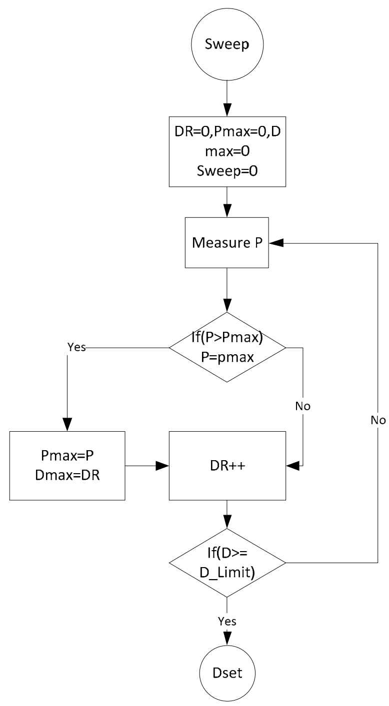


Fig. 8 Block diagram of Sweep routine in Enhanced Perturb and observe algorithm.

V. DC-DC CONVERTER

Trigger pulse which is calculated based on the algorithm is to be given to a DC-DC converter to realize the global maximum power point tracking. Selection of DC-DC converter depends on following parameters.

1. Power
2. Minimum and maximum voltage input
3. Output voltage
4. Isolated or non isolated

Here input is a 50W solar panel with following specification at 1000 W/m^2 insolation and 27 ^{o}C.

- V_{OC} = 19V
- I_{SC} = 4A
- V_{MP} = 16.5V
- I_{MP} = 3.1A

Output or load of the system is a battery. It consists of two 12V, 7AH batteries in series with maximum charging current of 700mA. So the nominal output voltage of the system is 24V and 27.5 V when battery is fully charged.

Since output voltage is higher than input voltage, a boost DC-DC converter is needed. Isolation of the system is not a concern as the working voltage is less than 50V. Fig. 8 Circuit diagram of Boost converter. Mosfet Q1 in figure 9 acts as switch and output voltage of the converter varies from input voltage according to equation 4.

$$V_o = V_{in}\ X\ \frac{D}{1-D} \qquad (4)$$

$$L = \frac{V_{in}\ X\ (V_o - V_{in})}{\Delta i_L\ X\ F_S\ X\ V_o} \qquad (5)$$

[8]Based on the boost converter design, the circuit shown in figure 9 is formed.

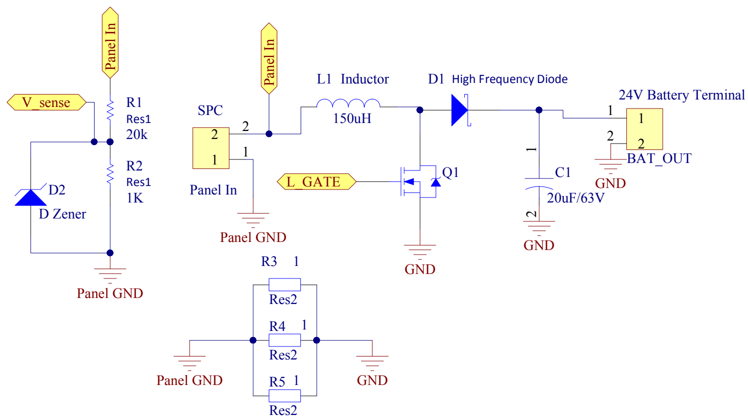


Fig. 9 Detailed circuit diagram of Boost converter

Before implementing this algorithm, boost converter was tested with 18V input voltage and a DC load. Output voltage is forcedly regulated at 24V by manually adjusting duty ratio of 50 KHz pulse which was triggered at MOSFET Q1 using MOSFET driving unit. Converters output load is adjusted to obtain rated output power. Figure 10 shows efficiency curve of boost converter.

VI. IMPLEMENTATION DETAILS OF THE ALGORITHM

In order to test the algorithm, 2 cells of 50W solar panel were shaded. Then V-I characteristics of the panel is plotted. Figure 11 shows PV characteristics 50W panel when subjected to shading. Boost converter is triggered using this algorithm employing an ATMega 8 microcontroller and a totem pole mosfet driving unit. The circuit was tested using the solar panel from 12:00 noon to 1:00 pm. In order to test if the panel was operating in the right operating point (Maxima 1 of figure 11), the circuit was also manually triggered by shifting the driving unit from ATMega 8 controller to manual PWM generation unit and forcing to work at MPP point in every 5 minutes.

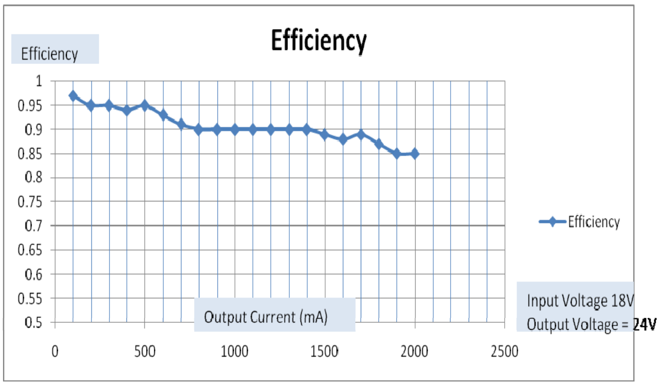


Fig. 10 Efficiency curve of boost converter

Figure 13 shows power injected to the battery in every 5 minutes, both using automatic tracking technique based on the algorithm and by manual triggering.

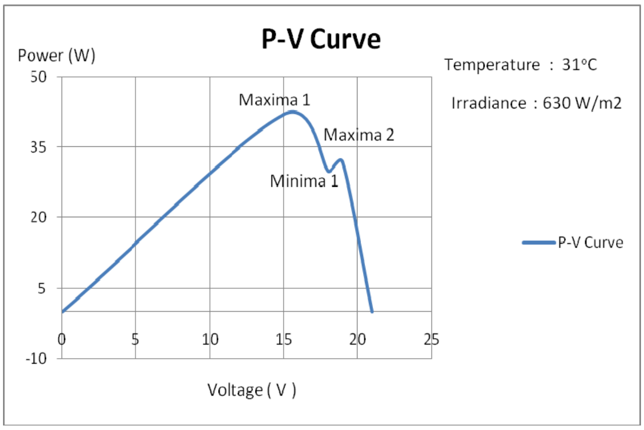


Fig. 11 P-V Characteristics of 50W Solar panel with partial shading

Figure 12 shows hardware unit used to evaluate the perfomance of the global peak power tracking algorithm.

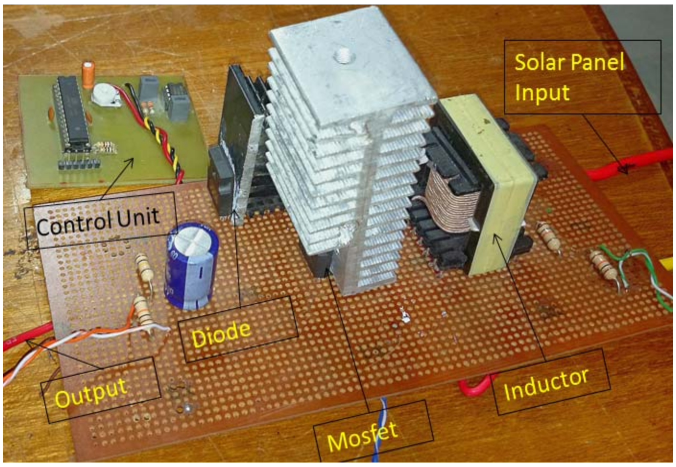


Fig. 12 P-V Test Circuit Setup

VII. CONCLUSION

This paper presents a modified version of Perturb and Observe MPPT algorithm which tracks maximum power point under partial shading condition. Algorithm is tested by implementing it in ATMega 8 microcontroller and test results are validated. Difference between the power point tracked output and actual expected power is due to the granularity of the triggering PWM pulse. Step size can be reduced to make MPP tracked output more near to the expected maximum power point.

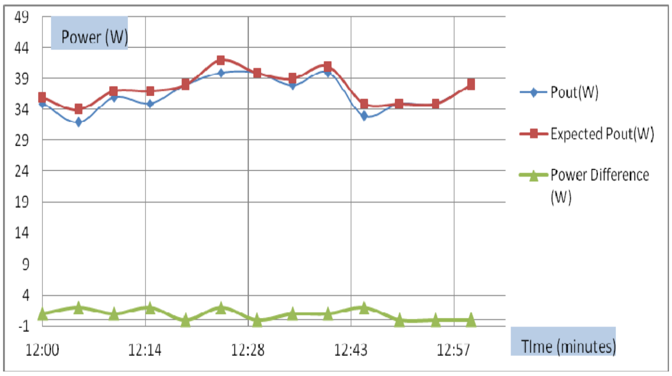


Fig. 13 MPPT converter output power and expected output power characteristics

The sweeping technique in the algorithm can also be used in other tracking techniques like incremental conductance algorithm to overcome local maxima and to keep the system run at global maximum power point.

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