Non-iterative MPPT Method: A Comparative Study

Md Tofael Ahmed*‡, Masud Rana Rashel*,**, Fahad Faisal*,**, Mouhaydine Tlemçani*

*Department of Physics, Institute of Earth Sciences, School of Science & Technology, University of Evora, Portugal

** Department of Computer Science & Engineering, Daffodil International University, Bangladesh

(ahemd@uevora.pt, mrashel@uevora.pt, d44773@alunos.uevora.pt, tlem@uevora.pt)

‡ Corresponding Author; Md Tofael Ahmed, 7002-554, Tel: +351964956242,

ahmed@uevora.pt

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Abstract- The presented work is a contribution to maximum power point tracking problem with improved performance. The analysed and discussed method is based on mathematical model of a PV panel. The output power of PV panel is dependent on the load as well as the almost unpredictable behaviour of the environment. It has a non-linear implicit behaviour on the load due to the weather parameters dependency. Due to different conditions of PV curve, it may have several local maxima. Existing MPPT techniques are mainly based on iterative method which are more time consuming and complex in nature considering the sense of comparative techniques. The most used approach is based on P&O algorithm with gradient comparison. The proposed technique improves the performance on the basis of time and computational complexity. During a low changing environmental condition this method achieves good result on the way to reach the overall point for maximum power. Taking into account the data sheet values of the panel along with the usage of existing knowledge from the datasheets, this technique is possible to implement and flexible for digital signal processing platform. An experimental setup is also done to verify the accuracy, robustness and simplicity of the introduced algorithm. It is found that the proposed technique is less complex and can be coupled with other method too.

Keywords PV Panel, MPPT, DSP, Instrumentation.

1. Introduction

The main reason for increasing energy consumption in the world is due to the improvement of overall world economy and the human high living standards. The traditional fossil fuels have the highest usage rate among all the other consumed sources. These sources are dangerous and inevitable origin for the environmental pollution and health problems. Due to the harmful effect to the environment these sources are gradually taken over by the renewable energy resources [1].

Due to the reliability, inexhaustibility and being the most abundant way of energy, solar energy is the most predominant source [2]. Besides, it does not produce any greenhouse gases and is so clean source that can efficiently reduce environment pollution, health issues and global warming problems [3]. For the purpose of electricity production solar technology has become one of the most developed and efficient sources of energy [4]. There are several drawbacks in the solar PV technology. Among those the significant are dependency on environmental parameters, the high manufacturing costs and the low efficiency of energy conversion process. The calculated efficiency of energy conversion for solar PV is around 22.5%. Most significant reason for less conversion energy efficiency is related with the power instability of PV array, current and voltage non-linear characteristics of the PV curve at different solar irradiation, temperature instability and loads variation [5].

Usually the property of a solar cell is that- it has only a single maximum power point for a specific temperature and solar irradiance. The main goal of MPPT method is to achieve higher efficiency which results in more power generation. The algorithm related to MPPT technique plays a vital role now-a-days as it has the ability to increase overall energy efficiency. Extensive research work is required to enhance the existing condition of PV cell [6-9].

2. PV System Modeling

PV cells in both parallel and series layouts are connected together in a panel to improve the levels of current and voltage in the photovoltaic system [10-14]. For the designing and analysis of a PV power system modeling of I-V characteristics is significant [15]. The characteristics of the current-voltage (I-V) of a certain model under specific ambient conditions is required for the PV system modeling. Various other factors like PV cell aggregation, series resistance, shunt resistance (finite or infinite), ideality factor of diode for modeling is also significant [16].

Physical models of PV cells consist of the PV electrical equivalent circuit [10]. There are several types of model studied in the literature including the ideal model, four parameter (single diode simple model), five parameter (single diode model), seven parameter (double diode model) [17-22].

The five parameter model is also known as five parameter single diode or single-exponential parameter model [23]. It is composed of a parallel resistance for the accuracy improvement.

A PV cell equivalent circuit for the obtained model is represented in the Fig. 1 below:

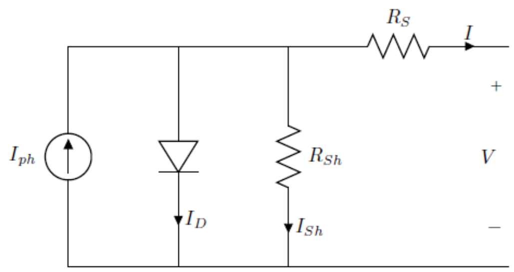

Fig. 1. PV cell equivalent circuit for five parameter model.

The equivalent electrical circuit consists of photo current (I_{ph}), diode current (I_D), diode ideality factor (N) and the resistances are series $(R_s)$and shunt resistance(R_{sh}). Obtained five parameter mathematical model is stated as [17, 18, 24,25]:

$$I = I_{ph} - I_s\left(\exp\left(\frac{qV + qR_sI}{NKT}\right) - 1\right) - \frac{V + R_sI}{R_{sh}} \tag{1}$$

where, the load current is I, diode saturation current is I_s, q is the absolute value of the charge of an electron (-1.602 × 10^{-19} C), K is Boltzmann's constant (1.381× 10^{-23} J/K), T is the cell temperature (K). And the expression for the voltage (V) is [17]:

$$V = I_{ph}R_{sh} - I\,R_{sh} + I_s\left(\exp\left(\frac{qV + qR_sI}{NKT}\right) - 1\right) - IR_s \tag{2}$$

The equation (1) can be written as:

$$I = I_{ph} - I_s\left(\exp\left(\frac{qV + qR_sI}{NKT}\right) - 1\right) - \frac{V}{R_{sh}} - \frac{R_sI}{R_{sh}} \tag{3}$$

$$I + \frac{R_sI}{R_{sh}} + I_s\left(\exp\left(\frac{qV + qR_sI}{NKT}\right)\right) = I_s - \frac{V}{R_{sh}} + I_{ph} \tag{4}$$

Dividing by I_s in both side of the equation (4) we get as:

$$\left(\frac{R_s + R_{sh}}{R_{sh}I_s}\right)I + \left(\exp\left(\frac{qV + qR_sI}{NKT}\right)\right) = 1 - \frac{V}{R_sI_s} + \frac{I_{ph}}{I_s} \tag{5}$$

$$\left(\frac{R_s + R_{sh}}{R_{sh}I_s}\right)I + \left(\exp\left(\frac{qV}{NKT}\right) \times \exp\left(\frac{R_sI}{NKT}\right)\right) = 1 - \frac{V}{R_{sh}I_s} + \frac{I_{ph}}{I_s} \tag{6}$$

From the above explained equations we can find that the analytical solution for the obtained load current equation is almost impossible [17]. The two terms of the equation $\left(\frac{R_s + R_{sh}}{R_{sh}I_s}\right)$ and $\left(e^{\left(\frac{qV}{NKT}\right)} \times e^{\left(\frac{qR_sI}{NKT}\right)}\right)$ have the load current (I). So, the load current is difficult to obtain by solving analytically. An alternative solution is also possible by ignoring the parameter R_s (series resistance). If we consider $R_s = 0$ then the part $\frac{R_sI}{NKT} = 0$ behaves like this. So, we find the equation as:

$$\left(\frac{R_{sh} + 0}{R_{sh}I_s}\right)I + \left(\exp\left(\frac{qV}{NKT}\right) \times \exp(0)\right) = 1 - \frac{V}{R_{sh}I_s} + \frac{I_{ph}}{I_s} \tag{7}$$

$$\left(\frac{R_{sh}}{R_{sh}I_s}\right)I + \left(\exp\left(\frac{qV}{NKT}\right) \times 1\right) = 1 - \frac{V}{R_{sh}I_s} + \frac{I_{ph}}{I_s} \tag{8}$$

$$\left(\frac{R_{sh}}{R_{sh}I_s}\right)I = 1 - \frac{V}{R_{sh}I_s} - \left(\exp\left(\frac{qV}{NKT}\right)\right) + \frac{I_{ph}}{I_s} \tag{9}$$

$$I = \frac{1}{\left(\frac{R_{sh}}{R_{sh}I_s}\right)} - \left(1 - \frac{V}{R_{sh}I_s}\right) - \left(\exp\left(\frac{qV}{NKT}\right)\right) + \frac{I_{ph}}{I_s} \tag{10}$$

The above equation (10) can be considered as the analytical solution for this case if the series resistance is set to zero.

3. Maximum Power Point Tracking (MPPT)

Low electric power generation (9% - 17%) because of the efficiency of energy conversion under low irradiation level is one of the major problems of PV generation systems. Solar cell has dependency on the irradiation and temperature besides it has nonlinear I-V characteristics. In the power-voltage (P-V) curve of a PV array there is a particular point where it has the highest value. The peak point in the PV array is the maximum power point (MPP). If the operating point of an array can be maintained continuously at the maximum level only the maximum power can be obtained [26]. That is why tracking of the MPP is the uttermost necessity for increasing the electric power generation in the solar PV systems.

A fundamental way to boost PV systems efficiency is by using the MPP tracking method. Maximum power extraction from PV system in the various conditions is assigned to algorithms of MPPT [26]. In a PV system, an MPPT is one of the most significant techniques in the case of energy efficiency. The techniques of MPPT is one of well-known and most studied topics in the solar energy system [28]. An MPP curve with I-V and P-V curve of a PV cell is illustrated in the Fig. 2 below:

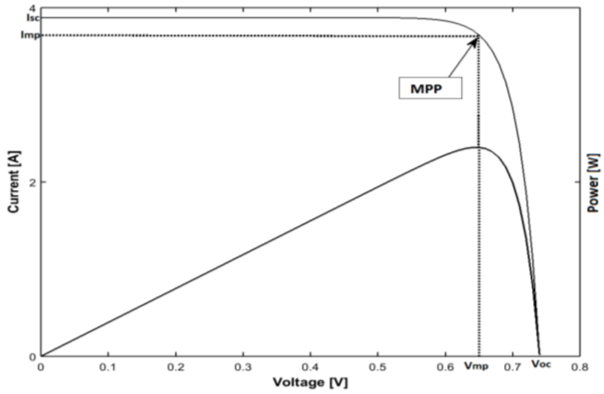

Fig. 2. PV cell maximum power point curve.

It is almost impossible to provide the best performance for an MPPT technique in overall operating conditions. It depends on the specific PV installation system to specify the MPPT algorithm in order to obtain better output from that system.

The ideal MPPT method for photovoltaic system has particular behaviours. For example, it has the ability to track accurately the overall MPP point according to different obstacles. It is totally independent on the PV arrays configurations. In the rapid climatic changing conditions, it is able to respond without any difficulties. Finally, it is very flexible to implement with the low cost instrumentation with high efficiency [28].

3.1. Types of MPPT

MPPT is one of the most used techniques in the solar energy system to improve the total output power. Practically, the implementation of the most appropriate MPPT is a challenging task due to the environmental condition dependency, instrument flexibility and the inherent non-linearity. Besides, it is also crucial to design a robust and reliable MPPT algorithm very effectively during the rapid changing weather condition [27].

The classification of MPPT algorithm is obtained from different aspects in different literatures. In the paper [27], MPPT is primarily classified as model-based and model-free. The examples of model-free approaches are Perturb and Observe (P&O) [26-36], Incremental Conductance (IC) [26-36], and extremum seeking control [38-40]. The MPP determination in these methods occur only by using the PV voltage and current measurements without any previous information. The drawbacks of the model-free approaches are slow tracking speed with poor performance, continuous oscillation around MPP, and voltage perturbation necessity. To determine MPP, a set of data information and different PV system model is used by the model-based MPPT techniques. The drawbacks of the model-free approaches can be overwhelmed by using these techniques [27].

There are two different types of model-based approaches considering analytical and non-analytical methods. Some examples of non-analytical methods are fuzzy logic control [27, 28, 31-33, 35-37, 41], the sliding mode control [27, 28, 33, 38, 42], and adaptive network-based fuzzy inference system [27, 28, 31, 43]. A learning procedure or by using a non-direct PV model the MPP is calculated.

In the paper [30], the MPPT techniques are classified as either off-line or on-line. The PV array associated with irradiance and temperature exact positioning is required in the off-line techniques. For the on-line techniques it is not required to have this type of measurements. The fixed duty cycle, P&O method and constant voltage (CV) [26, 28-30, 36] and IC method is also discussed there. The paper [28] shows the MPPT classification as MPPT under non-uniform irradiance and classic MPPT techniques. The two main problems like partial shading and rapidly changing irradiance are raised here.

The maximum power point for the partial shading problem can be obtained by using the P&O, and INC. For the case of rapidly changing irradiance these conventional MPPT techniques cannot be so useful. In the uniform irradiance conditions the classic methods could be useful but for the non-uniform conditions it cannot reach the global MPP. To overcome the problem and find out a better solution global optimization technique like computational intelligence (CI) can be used. The discussed CI-based MPPTs are artificial neural network (ANN) [28, 31, 35], fuzzy logic control, particle swarm optimization (PSO) [28, 31-32, 35], genetic algorithm [31-33, 41], differential evolution (DE), ant colony optimization (ACO), artificial bee colony (ABC), cuckoo search (CS), firefly algorithm (FA).

4. Non-Iterative MPPT Algorithm

Several MPPT algorithms are discussed in different literature studies by considering different aspects including cost, convergence speed, required sensors, effective range and so on. The existing MPPT techniques for solar photovoltaic system are mostly based on the following methods- iterative, continuous increment and optimized method. According to the iterative method- MPP voltage can be determined iteratively which provides very efficient performance due to its fast convergence speed. This method is suitable for any kind of climatic conditions [44].

To overcome the complexity of conventional iteration method, a non-iterative MPPT algorithm [17, 45, 46] has been proposed in this paper. Via this proposed method, the MPP can be traced easily by performing some simple analytical calculation with reduced computational complexity. In addition to that, this proposed algorithm has several advantages while implementing it in the digital platform.

The description by using a flowchart of the proposed method is illustrate below in the Fig. 3. It is the representation of the used MPPT non-iterative algorithm. After choosing the current and related voltage the power is calculated which is the starting of the method. After that, the next procedures as explained below to obtain the MPP.

Four samples of the voltage V_1, V_2, V_3, V_4 and their corresponding current I_1, I_2, I_3, I_4 are obtained at the first step of the algorithm. Later on, the related powers P_1, P_2, P_3, P_4 are calculated from I-V curve.

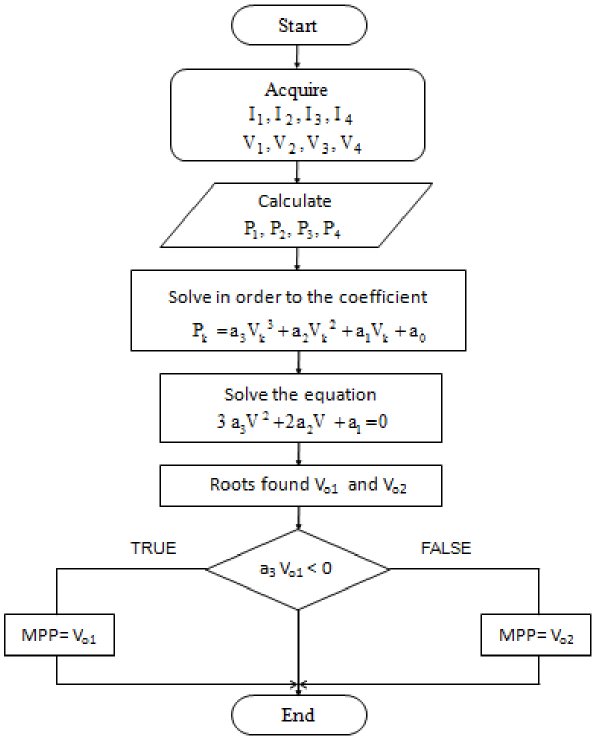

Fig. 3. MPPT non-iterative algorithm flowchart.

The following equations are described to establish the coefficient values:

$$P_k = a_3 V_k^3 + a_2 V_k^2 + a_1 V_k + a_0 \tag{11}$$

To determine the roots- following equation has been used:

$$3a_3 V^2 + 2a_2 V + a_1 = 0 \tag{12}$$

Finally, we determined the roots V_{01} and V_{02} from equation (12). From there we find the solution by picking up the condition. And, the desired MPP is obtained by this way without any iteration.

5. Result Analysis

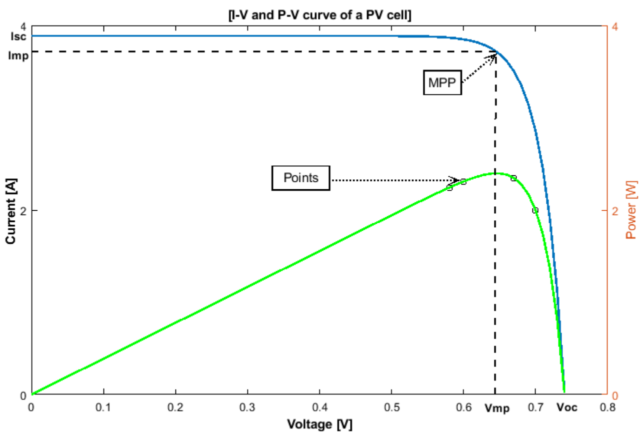

Fig. 4. Determination of MPP via simulation considering points from both sides.

In the Fig. 4, we determined the values of power via simulation by considering 4 different points (both sides of the MPP) where the value of the simulated result was 2.3965 W whereas the value provided by the manufacturer was 2.3969 W.

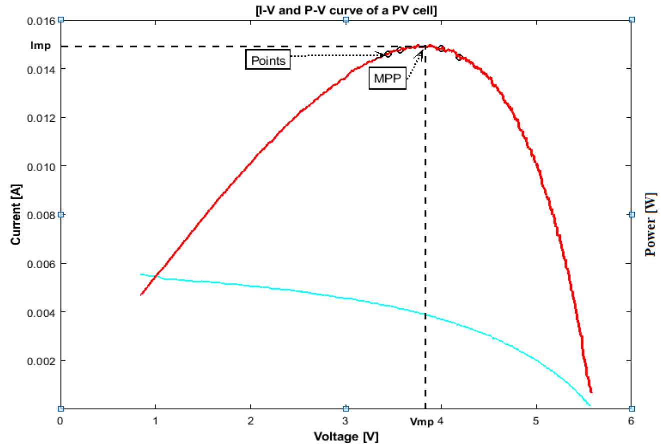

Fig. 5. Determination of MPP experimentally considering points from both sides.

In the Fig. 5 above we determined the values of power experimentally by considering four different points (MPP from both sides) where the result of the measured power was 0.0148 W whereas the value provided by the manufacturer was 0.0150 W.

In the next part we considered of taking values form the left side of the maximum power point. The purpose is the track the MPP by choosing the values from these specific points.

In the Fig. 6, we determined the values of power via simulation by considering only the left side points ($\frac{dp}{dv} > 0$) of MPP where the value of the simulated result was 2.39695 W whereas the value provided by the manufacturer was 2.39690 W.

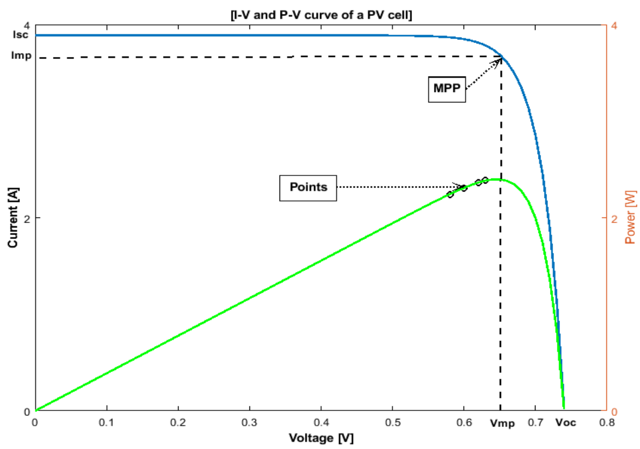

Fig. 6. Determination of MPP via simulation considering the left side points ($\frac{dp}{dv} > 0$).

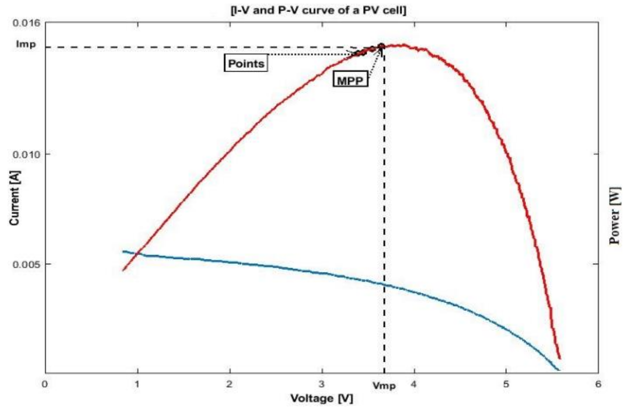

Fig.7. Determination of MPP experimentally considering the left side points $\frac{dp}{dv} > 0$.

In the Fig. 7 above we determined the values of power experimentally by considering only the left side points ($\frac{dp}{dv} > 0$) of MPP where the value of the measured power was 0.0148 W whereas the value provided by the manufacturer was 0.0150 W.

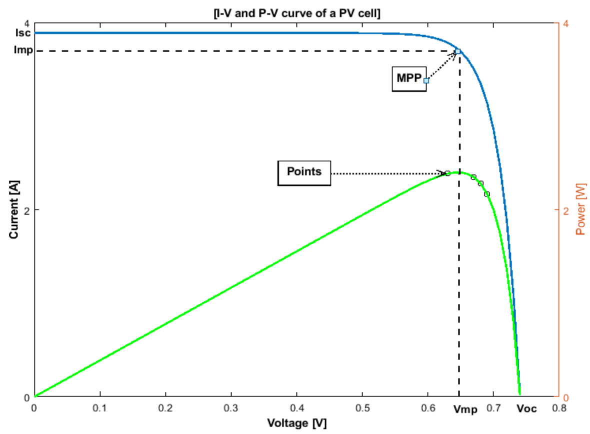

Fig. 8. Determination of MPP via simulation considering the right side points ($\frac{dp}{dv} < 0$).

In the Fig. 8 above we determined the values of power via simulation by considering only the right side points ($\frac{dp}{dv} < 0$) of MPP where the value of the simulated result was 2.3967 W whereas the value provided by the manufacturer was 2.3969 W.

Next, in the Fig. 9, we determined the values of power experimentally by considering only the right side points ($\frac{dp}{dv} < 0$) of MPP where the value of the measured power was 0.0150 W whereas the value provided by the manufacturer was 0.0150 W.

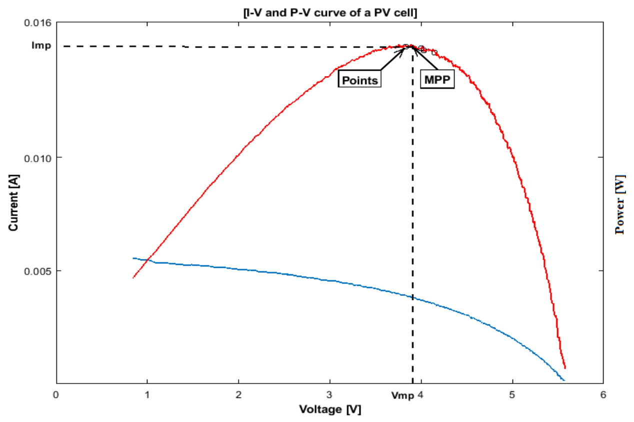

Fig. 9. Determination of MPP experimentally considering the right side points ($\frac{dp}{dv} < 0$).

In the Fig. 10 below we determined the simulated values of power by applying the conventional method (Perturb and Observe) which is represented by MPP3 along with our proposed non-iterative method which is represented by MPP2. The rated power is represented by MPP1.

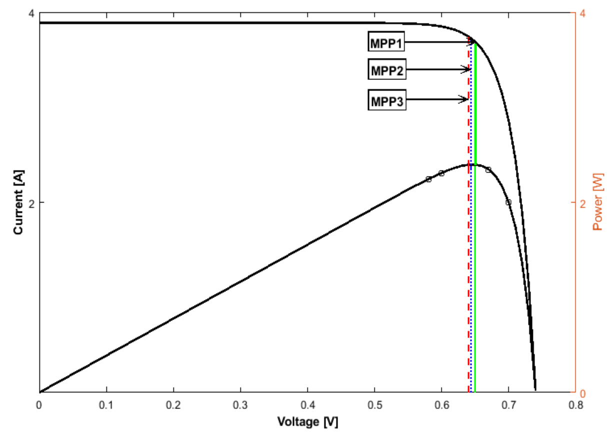

Fig. 10. MPPT comparison for simulated values considering both side of MPP.

Later on we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1= 2.3969 W, MPP2 = 2.3965 W, MPP3 = 2.3960 W

It is clearly evident that from the simulation that the non-iterative method is providing better result while tracking the MPP in comparison to the typical perturb & observe method.

The above result clearly demonstrates that, non-iterative method performs better than the conventional method if we consider the points from both sides.

In the Fig. 11, we determined the experimented values of power by applying the conventional method (Perturb and Observe) which is represented by MPP3 along with our proposed non-iterative method which is represented by MPP2.

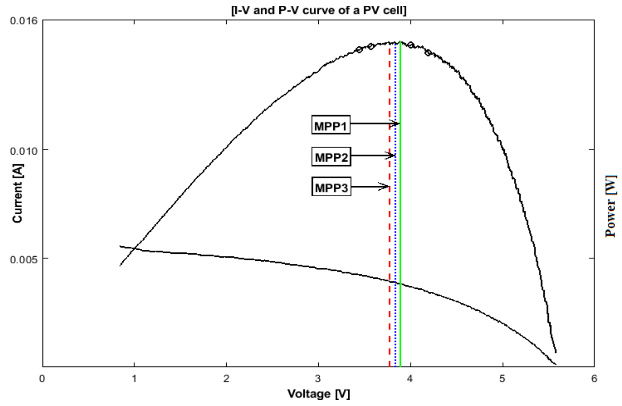

Fig. 11. MPPT comparison for experimental values for both sides.

The rated power is represented by MPP1. Later on we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1= 0.0150 W, MPP2 = 0.0149 W, MPP3 = 0.0148 W

Likewise, the simulated result, the measured value from experiment using non-iterative method is also providing more accurate result than P&O method while tracking the MPP.

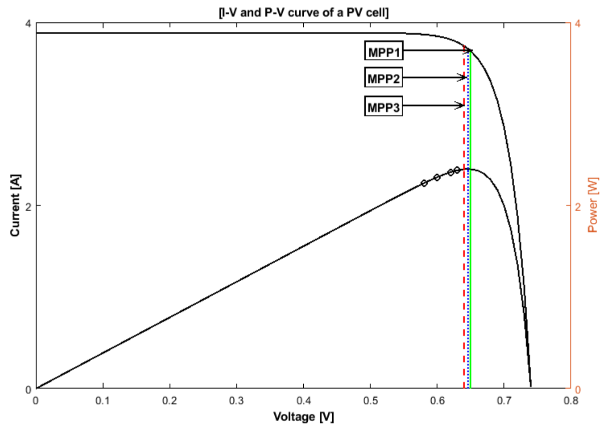

Fig. 12. MPPT comparison for simulated values of left side

$(\frac{dp}{dv} > 0)$.

In the Fig. 12 above we determined the simulated values $(\frac{dp}{dv} > 0)$ of power by applying the conventional method (Perturb and Observe) which is represented by MPP3 along with our proposed non-iterative method which is represented by MPP2. The rated power is represented by MPP1. Later on, we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1 = 2.3969 W, MPP2 = 2.3959 W, MPP3 = 2.3949 W

Again, we found that, the non-iterative method is providing better result while tracking the MPP in comparison with the typical P&O method.

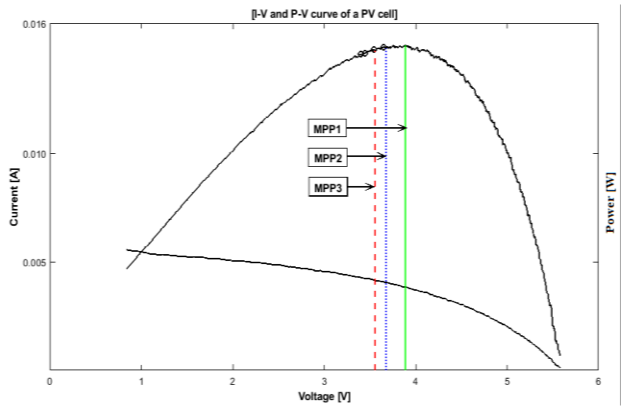

Fig. 13. MPPT comparison of experimental values for left side $(\frac{dp}{dv} > 0)$.

In the Fig. 13 above we determined the experimented values of power by applying the conventional method (Perturb and Observe) which is represented by MPP3 along with our proposed non-iterative method which is represented by MPP2. The rated power is represented by MPP1. Later on we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1= 0.0150 W, MPP2 = 0.0148 W, MPP3 = 0.0147 W

Likewise the simulated result, the measured value from experiment using non-iterative method is also providing more accurate result than P&O method while tracking the MPP for left side points $(\frac{dp}{dv} > 0)$

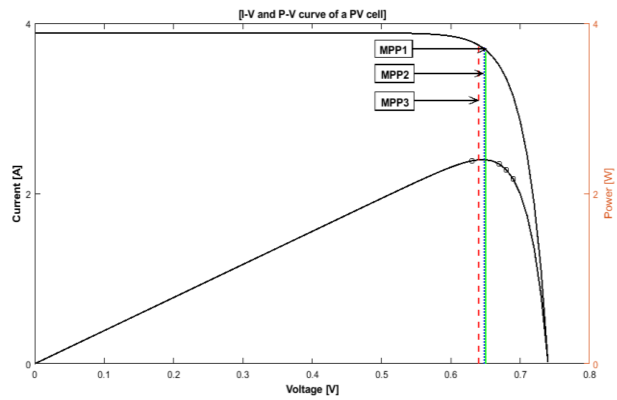

Fig. 14. MPPT comparison for simulated values of right side $(\frac{dp}{dv} < 0)$.

After simulating the both side and left side points of MPP, we simulated for right side points of MPP which is shown in the Fig. 14. Here again, the simulated values followed by the conventional method (Perturb and Observe) is represented by MPP3 and our proposed non-iterative method is represented by MPP2. The rated power is represented as usual by MPP1. Later on we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1 =2.3969 W, MPP2 = 2.3959 W, MPP3= 2.3955 W

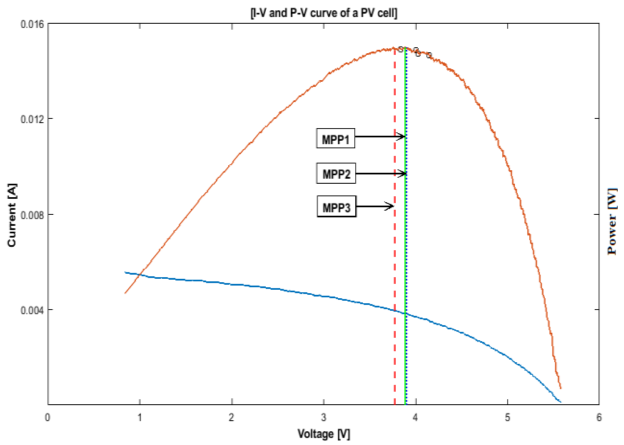

Fig. 15. MPPT comparison of experimental values for right side ($\frac{dp}{dv} < 0$).

In the Fig. 15, we determined the experimented values of power by applying the conventional method (Perturb and Observe) which is represented by MPP3 along with our proposed non-iterative method which is represented by MPP2. The rated power is represented by MPP1. Later on, we compared the obtained values (MPP2, MPP3) with rated power (MPP1). The following values have been obtained:

MPP1= 0.0150 W, MPP2 = 0.0150 W, MPP3 = 0.0148 W

Table 1. Comparative analysis for different MPPT algorithms

MPPT Technique	PV Array Dependency	Analog/ Digital	Convergence Speed	Implementation Complexity	Sensed Parameters
Perturbation and Observation	No	Both	Varies	Low	Voltage, Current
Incremental Conductance	No	Digital	Varies	Medium	Voltage, Current
Non-iterative Method	No	Both	Instantaneous	Low	Voltage, Current
Fuzzy Logic Control	Yes	Digital	Fast	High	Varies
Neural Network	Yes	Digital	Fast	High	Varies
Ripple Correlation Control	No	Analog	Fast	Low	Voltage, Current
FOCV	Yes	Both	Medium	Low	Voltage, Current
Sliding Mode Control	No	Digital	Fast	Medium	Voltage, Current

As we can see from the Table - 1 that, non-iterative method suppresses the other methods while considering different parameters including dependency on the PV array, analog/digital, speed of convergence, complexity for implementation, sensed parameters etc.

6. Conclusion

The existing energy sources are already overexhausted to meet the incerasing demand of the current world thus renewable energy sources are getting more attention now-a-days. PV power generation is one of them that is getting most attention than other sources. Power generation from PV technology is not constant in nature and difficult to predict the output due to rapid changing environmental conditions.

To get maximum power from a PV panel it is important to design a good MPPT. Due to poor performance of MPPT, it is possible to loss a huge amount of power that generated from the panel. Lots of work has been done and still continuing to develop a high performance MPPT. Existing MPPT techniques are mainly iterative and complex in nature. Due to iterative nature they take time to get the MPP. Some of them are very complex for implementing in operational phase. Some of them are time consuming. Due to these limitations, PV panels are failing to produce maximum power. This work is one of them to design a system which is fast enough with less complexity to obtain the maximum power point.

This work shows a new technique based on mathematical calculation to find maximum power in real time scenario. Simulation is performed with Matlab tool and the method has been implemented in laboratory environment as well. The results from the simulation and implementation demonstrates a promising idea to obtain MPP efficiecntly with this system which is fast enough with lower complexity.

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