

# Perturb and Observe Maximum Power Point Tracking for Photovoltaic Cell

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## Abstract

Maximum power point tracking (MPPT) techniques are used in photovoltaic (PV) systems to maximize the PV array output power by tracking continuously the maximum power point (MPP) which depends on panel's temperature and on irradiance conditions. The issue of MPPT has been addressed in different ways in the literature but, especially for low-cost implementations, the perturb and observe (P&O) maximum power point tracking algorithm is the most commonly used method due to its ease of implementation. A drawback of P&O is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy; moreover, it is well known that the P&O algorithm can be confused during those time intervals characterized by rapidly changing atmospheric conditions. In order to limit the negative effects associated to the above drawbacks, the P&O MPPT parameters must be customized to the dynamic behavior of the specific converter adopted. A theoretical analysis allowing the optimal choice of such parameters is also carried out. In this paper MATLAB-based M file programming scheme suitable for monitoring the I-V and P-V characteristics of a PV array under a nonuniform insolation due to partial shading condition for different configuration (modules in series parallel) of solar PV. It can also be used for developing and evaluating new maximum power point tracking techniques, especially for shaded conditions. Implementation of a novel MPPT technique has been developed using P&O algorithm has been done using MATLAB-based M file programming scheme without applying shading effect to solar array.

**Keywords:** Maximum power point (MPP), maximum power point tracking (MPPT), perturb and observe (P&O), photovoltaic (PV)

## 1. Introduction

As the non-renewable energy sources are reducing fast and the cost of energy is rising, the renewable energy sources become an alternate for energy. Renewable energy resources will be gradually more important part of power generation in the new millennium [1]. With a spurt in the use of non-conventional energy sources, photovoltaic (PV) installation are being more and more employed in several application systems [2]. It exhibits many merits such as cleanness, little maintenance and no noise. Sun is the ultimate sources for photovoltaic energy. Photovoltaic technology is employed for directly converting solar energy to DC electrical energy by the using "solar silicon cell". The DC power is converted to AC power with the help of an inverter. The electricity generated can be utilized for different applications directly or through battery storage system.

A major test in using a PV source is to undertake its nonlinear output characteristics, which vary with solar irradiation and atmospheric temperature [2][4][9][10]. The characteristics get more complex if the whole array does not receive uniform insolation, as in partially shaded (cloudy) conditions, resulting in many peaks. When a typical urban home is equipped with a PV power generation system, the PV modules are normally installed on the roof. Thus, in addition to shadows created by clouds, those created by neighboring homes, trees, utility and/or telephone poles, and power line cables sometimes partially cover these PV modules [6]. The presence of

many peaks reduces the efficiency of the existing maximum power point tracking (MPPT) scheme due to their incapability to distinguish between the local and global peaks [5][11].

It is not merely the size of the PV array but also its pattern (i.e., the number of modules in series and parallel) that considerably affect its power output and the performance of the system. Therefore, a maximum power point tracking (MPPT) control to take out maximum power from the PV arrays at actual time becomes essential in PV generation system. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). Perturbation and observation (P&O) and hill climbing, incremental conductance, ripple correlation, etc. methods are extensively applied in the MPPT controllers due to their simplicity and easy implementation. Numerous MPPT algorithms have been projected from time-to-time [3]. MPPT of a photovoltaic array is usually a necessary part of a PV system. The method vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other respects [8]. It is also a clean source of energy.

The Perturb and Observe (P&O) MPPT algorithm is generally used, because of its easy implementation. It follows the criteria: if the working voltage of the PV array is perturbed in a known direction and if the power drained from the PV array increases, this means operating point has stirred toward the MPP and, therefore, the working voltage must be further perturbed in the similar direction. Otherwise, if the power drained from the PV array decreases, the operating point has stirred away from the MPP and, thus, the direction of the working voltage perturbation have to be overturned [7]. A disadvantage of P&O MPPT method is that, at stable state, the operating point oscillates in the region of the MPP give rise to the waste of several amount of obtainable energy. A number of improvements of the P&O algorithm have been deliberate in order to decrease the number of oscillations in the region of the MPP in stable state, but this slows down the speed of response of the algorithm to altering atmospheric situation and lowers the algorithm effectiveness during dull days.

This paper looks at the MPPT for PV system using P&O technique where the immediate value of power are considered each time, and the maximum power point value is reorganized. The main compensation connected with PV arrays is that it consists of no moving parts. Do not produce any noise and maintenance costs are minimal. In this paper, a MATLAB-based simulator cum learning tool, which can be used to improve the understanding and calculate the  $I-V$  and  $P-V$  characteristics curve of large PV arrays. This can be used to learn the result of temperature and insolation variation, varying shading patterns. The reason for using MATLAB is that it is simple, less time consuming and robust. It provides numerous features that can be used to simulate electronic and power electronic circuits and systems, high complex systems, and distributed generation power systems.

## 2. System Structure of a PV Array

A PV system consists of a solar array which is a group of series-/parallel-connected modules, the solar cell rated power varies between 1 and 2 W depending on the material of solar cell and the surface area; thus, to design a solar module, the solar cell power is measured, and then, the modules are connected in series based on the desired output. Fig. 1 shows a PV array system.

The electrical characteristics of the PV system are represented by P-V and by I-V curve. The characteristic curves of the solar cell are nonlinear because of equipped physical phenomena. By using the corresponding circuit of the solar cell shown in Fig. 2, the mathematical model of the generated current in a PV system is represented by

$$I = I_{ph} - I_0(e^{q(V+IR_s)/nkT} - 1) \quad (1)$$

$$I_{ph} = I_{ph(T_1)}(1 + K_0(T - T_1)) \quad (2)$$

$$I_{ph(T_1)} = G * I_{SC(T_1;nom)} / G_{(nom)} \quad (3)$$

$$K_0 = (I_{SC(T_2)} - I_{SC(T_1)}) / (T_2 - T_1) \quad (4)$$

$$I_0 = I_0(T_1) * (T/T_1)^{3/n} * e^{-qV_g/nk*(1/T-1/T_1)} \quad (5)$$

$$I_{0(T_1)} = I_{SC(T_1)} / (e^{qV_{oc(T_1)}/nkT_1} - 1) \quad (6)$$

$$R_s = -dV/dI_{V_{oc}} - 1/X_V \quad (7)$$

$$X_V = I_{0(T_1)} * q/nkT_1 * e^{qV_{oc(T_1)}/nkT_1} \quad (8)$$

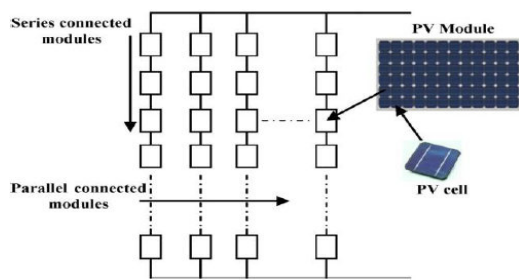


Fig. 1 PV array system

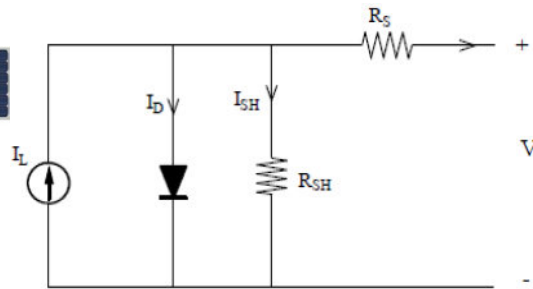


Fig. 2 Equivalent Circuit for solar PV cell

Where  $I_{pv}$  and  $V$  are PV array output current and voltage. Diode saturation current  $I_0$ . Light generated current  $I_{ph}$ . Solar cell series resistance  $R_S$ , which gives a more accurate shape between the maximum power point and the open circuit voltage. This represents the internal losses due to the current flow. Solar cell shunt resistance  $R_{sh}$ , in parallel with the diode, this corresponds to the leakage current to the ground and it is commonly neglected. Either allowing the diode quality factor  $n$  to become a variable parameter (instead of being fixed at either 1 or 2) or introducing two parallel diodes with independently set saturation currents. In an ideal cell  $R_s = R_{sh} = 0$ .  $q$  is the electron charge ( $1.6 \times 10^{-19}$  C),  $k$  is Boltzmann's constant ( $1.38 \times 10^{-23}$  J/K).

When the rays are not uniformly spread, local and global maxima are introduced in the characteristic curves. In order to recognize such phenomena, a PV array system with nine modules connected in series and parallel is measured. There are dissimilar possibilities for the radiation sharing among the PV modules; the five cases are considered.

- One module in each column is completely shaded (viz., modules 2, 5, and 8).
- One module in each column is partially shaded with equal radiation levels (viz., modules 3, 6, and 9).
- One module in each column is partially shaded with unequal radiation levels (viz., modules 1, 4, and 7).
- Two modules in the first column and one module in each other column are partially shaded with equal radiation levels (viz., modules 2, 3, 5, and 8).
- All modules are partially shaded with different radiation levels.

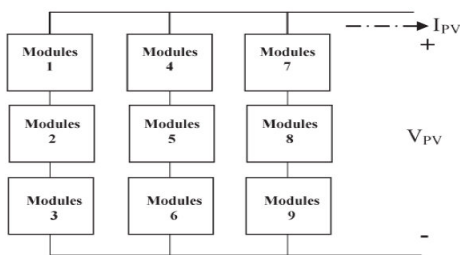


Fig. 3 PV array system with nine modules connected in series and parallel.

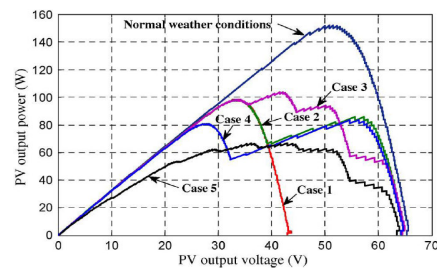


Fig. 4 PV output power characteristics under the five cases

Model consequences for the five cases point to that a totally shaded module causes a decrease of the PV output power without creating local maxima. However, partially shaded modules result in a decrease of the PV output power, creating local maxima, where the number of local maxima increases as the distinction of the production levels on each module increases. The PV output P-V characteristics for the five different cases are shown in Fig. 4.

### 3. Modeling under Partial Shading Condition

A mathematical model is requisite to stand for the PV system under partial shadowing conditions. A wide study has been undertaken for different PV module relations to get a general PV mathematical model under shadowing conditions. Fig. 6 shows the  $I-V$  characteristic of three series-connected PV modules with different shadowing levels.

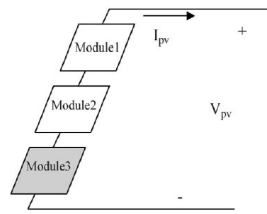


Fig. 5 Block diagram of the three-series-connected-PV-module system.

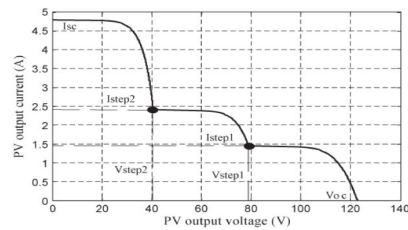


Fig. 6 Characteristic curve of the PV output I-V

The PV system shown in Fig. 5 is tested under different partial shading conditions. Two PV modules are partially shaded and receive two different radiation levels, which are 500 and 300 W/m<sup>2</sup>, and the third module receives rated radiation, which is 1000 W/m<sup>2</sup>. Two more observations are added to the previous observations as follows.

- $I_{step2}$  is the short-circuit current of the shaded PV modules with the highest radiation level.
- $V_{step1}$  is the open-circuit voltage of the unshaded modules plus the summation of the shaded module open circuit voltages without the open-circuit voltage of the lowest radiation module.

#### 4. Matlab Model of PV Module

Due is well-suited to predictable applications of photovoltaics; the Solarex MSX60 PV module was selected for modeling. The MSX 60 module has 36 series linked polycrystalline silicon cells and provides 60 watt of nominal maximum power. Electrical parameters of Solarex MSX60 60W PV array are shown in Table 1. The model of the PV module was implemented using a Matlab program. The model parameters are evaluated for the duration of implementation using the equations planned on the earlier section. The program, compute the current  $I$ , using electrical parameter of the module ( $I_{sc}$ ,  $V_{oc}$ ), and the variables Voltage, Irradiation ( $G$ ), and Temperature ( $T$ ).

Table: 1 Electrical parameters of Solarex MSX60 60W PV array

At Temperature	$T$	25	°C
Open Circuit Voltage	$V_{oc}$	21.0	$V$
Short Circuit Current	$I_{sc}$	3.74	$A$
Voltage max power	$V_m$	17.1	$V$
Current max power	$I_m$	3.5	$A$
Maximum Power	$P_m$	59.9	$W$

The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:

Under most of the climatic conditions, the cells in a module work hotter than the ambient temperature. Nominal Operating Cell Temperature is a pointer of this temperature differential, and is the cell temperature under Standard Operating Conditions: ambient temperature of 20°C, solar irradiation of 0.8 kW/m<sup>2</sup>, and wind speed of 1 m/s. Illumination of 1 kW/m<sup>2</sup> (1 sun) at spectral distribution of AM 1.5; Cell temperature of 25°C or as otherwise specified (on curves).

#### 5. Simulation Procedure

In this section the process used for simulation of the  $P-V$  and  $I-V$  characteristics of an incompletely shaded PV array is described. It is necessary to recognize how the shading pattern and the PV array arrangement are defined in MATLAB. This method consists of defining groups, assemblies, etc., for use with the MATLAB model developed corresponding to Fig. 7. This is explained with the help of explanation 1. Consider a simple case with just two unlike shades on the PV array.

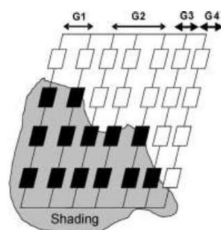


Fig. 7 PV array with groups G1 to G4

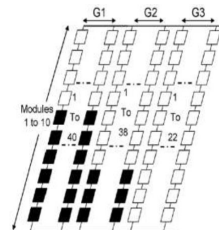


Fig. 8 PV array, corresponding to the shading pattern of Table 2.

### 5.1 Explanation 1

A PV array consisting of 1000 PV modules set into 100 series assemblies, linked in parallel, each one having 10 modules. It is preferred to obtain the  $P-V$  and  $I-V$  curve of a variety of components of this PV array, which consists of three groups with unlike insolation patterns, as given in Table 2. Groups G1 through G3 have 40, 38, and 22 series assemblies, respectively. The complete PV array is shown in Fig. 8. As seen in Fig. 8 only two different insolation levels are considered for simplicity. Shaded modules, receiving an insolation,  $\lambda = 0.1$  kW/m<sup>2</sup>, are indicated in dark color. It explains the method.

Table: 2 Insolation pattern

Group	No. of unshaded Modules in series Assembly( $\lambda=1$ )	No. of shaded Modules in series Assembly( $\lambda=0.1$ )	No. of series assemblies in a group
G1	4	6	40
G2	7	3	38
G3	10	0	22



Fig. 9 (a) Without Shading (array 10x100, T=40,  $\lambda=1$ )



Fig. 9 (b) With Shading as per scheme 1

### 5.2 Explanation 2

Let us take a more complex case, it is desired to obtain the  $P-V$  characteristic of an array consisting of 1000 ( $10 \times 100$ ) modules and receiving insolation at several different levels. The array is arranged into five groups G1, G2, G3, G4 and G5 with 50, 40, 30, 20 and 10 series temperature, 1, 0.75, 0.5, 0.25 and 0.1 insolation of the different modules. A screen shot of the MATLAB command window, shown in Fig. 10, illustrates the manner in which one can feed the information into this generalized program. In this scheme, the array has five different groups and five different shades. But Fig. 11(a) and (b) shows six different peaks (or steps), indicating that the number of peaks, their magnitudes, and the overall nature of the PV curve is dependent on the temperature of the modules, the insolation level, the shading pattern, and the array configuration. A generalized program can provide a better solution to learning and understanding the behavior of a PV array in a complex scenario. Colors taken for plotting graphs at different temperature (T) and insolation level ( $\lambda$ ) (shading patterns) are given below.

- T=50;  $\lambda=1$
- T=40;  $\lambda=0.75$
- T=30;  $\lambda=0.5$
- T=20;  $\lambda=0.25$
- T=10;  $\lambda=0.1$

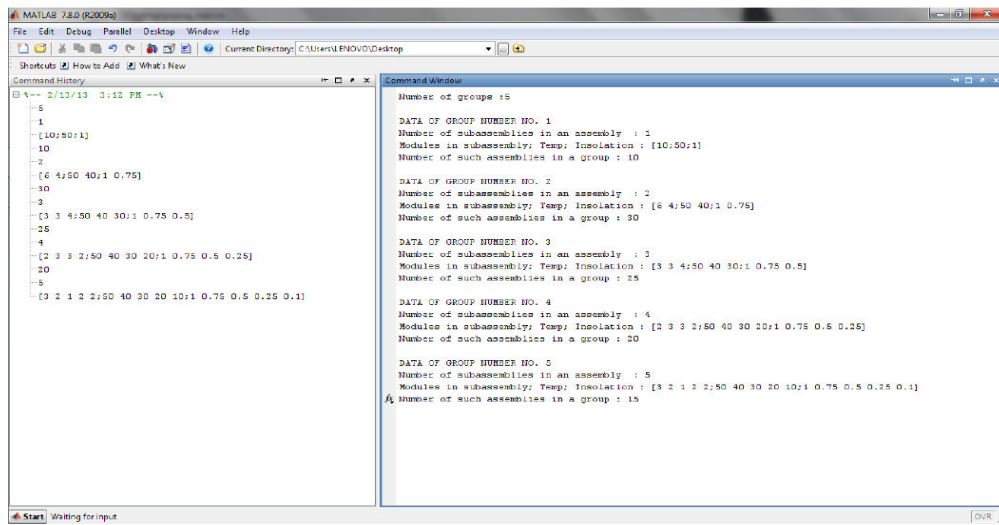
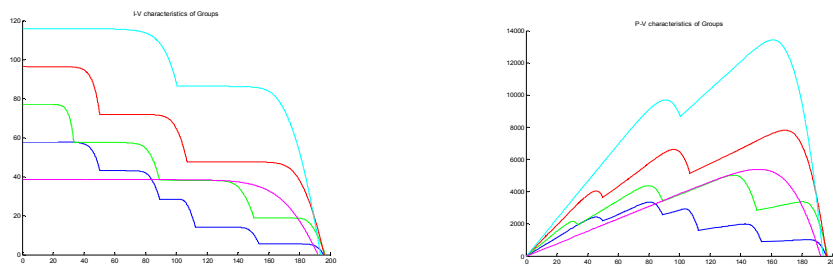


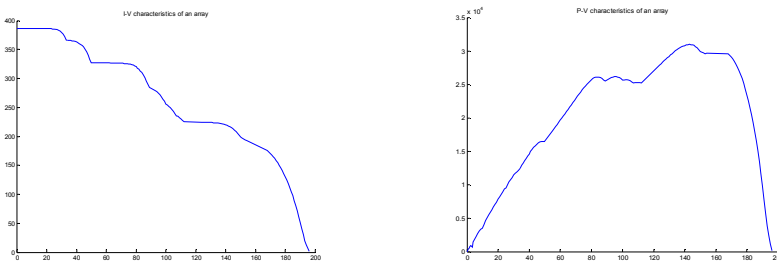
Fig. 10 Screen shot of the MATLAB command window showing how the input parameters are fed into the model to simulate a more complex and generalized array.



(a) I-V

(b) P-V

Fig. 6.11 (a) I-V and (b) P-V Characteristic of groups



(a) I-V

(b) P-V

Fig. 6.12 (a) I-V and (b) P-V Characteristic of an array

Now estimate Fig. 6.9(a), (b) and 6.12 (a), (b) we can see that PV curve in without shading has only one peak but with shading having 5 groups, 5 different shadings and 5 different insolation gives 6 peaks.

## 6. Conclusion

The PV Array has been mathematically modelled. The programmes implemented in the MPPT for PV application using P&O technique achieve the maximum power point. It has been shown that for the particular irradiance levels the maximum power is achieved. The same is carried out if there is a variation in temperature. It is a simple MPPT setup resulting in a highly efficient system. The non-conventional energy sources will dominate the conventional sources of energy in the near future and here one uses the greatest renewable energy of all, the sun's energy.

## Future Scope

There are still some optimizations and experiment needed to be done as the future work. For example, a drawback of P&O MPPT technique is that, at steady state, the operating point oscillates around the MPP giving

rise to the waste of some amount of available energy. Several improvements of the P&O algorithm have been proposed in order to reduce the number of oscillations around the MPP in steady state, but they slow down the speed of response of the algorithm to changing atmospheric conditions and lower the algorithm efficiency during cloudy days. This problem will be studied in the future.

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