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PHOTOVOLTAIC SYSTEMS MAXIMUM POWER POINT TRACKING ALGORITHMS

BY

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Abstract. The power delivered by a photovoltaic cell generator depends on the operating point at which this works. In order to maximize the energy supplied by the PV system, the generator should be adapted to the load so that the operating point will always correspond to the maximum power point. Usually, when a PV module is connected directly to a load, its operating point is rarely at the maximum power point. The operating principle of the maximum power point tracking is to place a converter between the load and the PV array, to adjust the output voltage and the current of the PV array so that the maximum available power is extracted. In most cases the optimal algorithm is chosen according to several criteria, such as: implementation complexity (autonomy of the systems, connected to the network), the type and number of sensors needed, the ability of the algorithm to detect local maximum points, cost, response time, type of implementation (analog, digital, mixed).

Keywords: Photovoltaic; Maximum Power Point Tracking; algorithm.

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1. Introduction

To achieve maximum power transfer between a PV generator and a load, the Maximum Power Point Tracking (MPPT) systems have been designed in order to follow the maximum power point. By interconnecting a DC-DC converter between PV generator and the load, a continuous adjustment occurs between the load and the PV (Bizon, 2007).The maximum power point techniques lies in the automatic determination of the output voltage or current so as to the generate power and the power supplied to the consumer to be maximum (Reinoso, 2013). There are several techniques used in tracking maximum power point. MPPT techniques can broadly be classified into three groups (Ishaque, 2013):

a) Indirect (off-line) techniques, which use the technical data of photovoltaic panels to estimate MPP: Open circuit voltage method - OCV or Short-circuit current method - SCC (Salas, 2006);

b) Direct techniques (on-line), which use parameters measurement (voltage, current) in real time. These methods do not require measuring the temperature and intensity of solar radiation: the Perturb and Observe - P&O algorithm or the Incremental conductance algorithm - IC;

c) Other methods that include a combination of these methods or based on indirect calculations. The advantage of these methods is their internal robustness (Liu, 2008), high search speed, but the accuracy of tracking is dependent on the model used for the solar cell (Jiang *et al.*, 2012).

In Fig. 1, the power-voltage characteristic of a PV array it is shown. As has been said, the major issue of a MPPT technique is to quickly and automatically find the voltage V_{MPPT} or current I_{MPPT} of PV array so that it operates at maximum output power in different irradiation and temperature conditions.

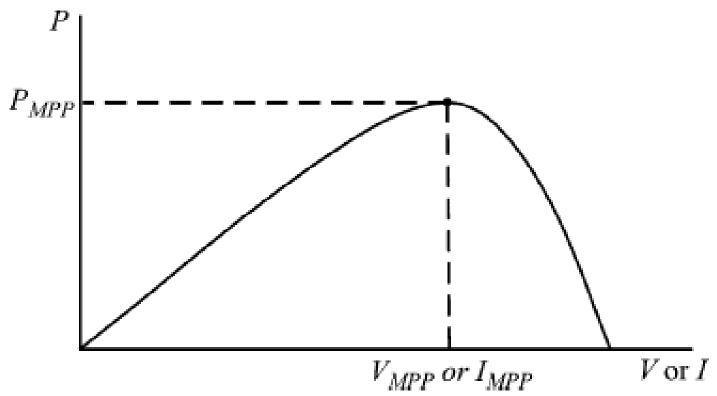


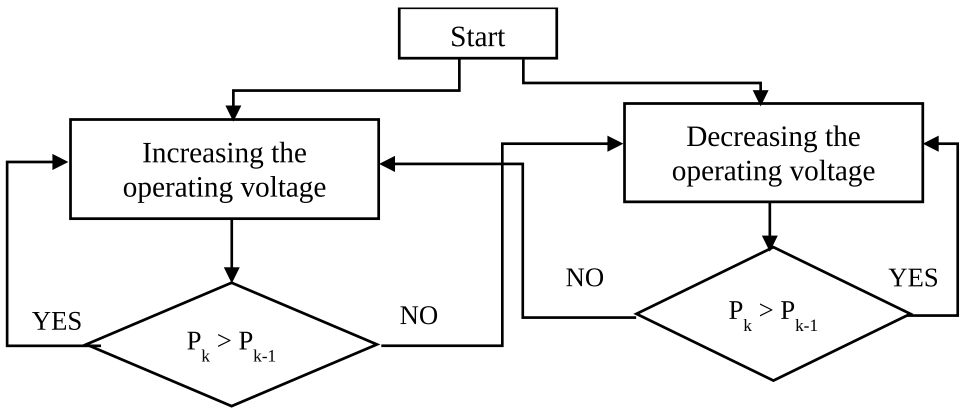
Fig. 1 − Characteristic P-V curve for a photovoltaic panel.

In partial shading environment conditions, multiple local maximum points can occur, even if only one maximum point exists. Algorithms have a fast response to environment changes, especially depending on the variation of temperature and irradiance values.

2. MPPT Techniques

A. Perturb and Observe algorithm (P&O)

The algorithm is widely used especially for its simplicity in implementation and the satisfactory results obtained. The method consists in modifications of the PV panel voltage in the periodic iterations, as well as a permanently analysis of generated power. When the power obtained increases with the change of the voltage in a certain direction, this direction is maintained in the next iteration. If the power obtained is lower than the previous values, the search direction is changed. Once the maximum power point is achieved, due to the small differences in power generated, more points around the maximum power point can be obtained. The oscillations around the maximum power point can be removed by introducing a variable step forward (Mohssine, 2015). Another error occurs when there are quickly changes in the weather conditions, which cause the system to deviate from the maximum point. This inconvenience is also mitigated by introducing auxiliary points around the maximum point that helps to stabilize (Hanen, 2015). The flow chart of P&O algorithm is depicted in Fig. 2.



P_k = the current value of the power;
P_{k-1} = the power value at the previous step;

Fig. 2 − Perturb & Observe algorithm flow chart.

Compared to the incremental conductance algorithm, which is introduced to solve some of the shortcomings of the presented method, the Perturb & Observe algorithm has a faster convergence, for different weather conditions (Manish, 2015).

B. Incremental conductance algorithm (IC)

The incremental conductance algorithm is based on the fact that the gradient of the power at the maximum point is equal to 0, less on the left side and greater on the right side. Unlike the method presented above, it offers better results and it does not oscillate around the maximum point. Furthermore, the IC algorithm provides an exact result, with the difference that the convergence rate is lower for variable weather conditions relative to the Perturb & Observe algorithm.

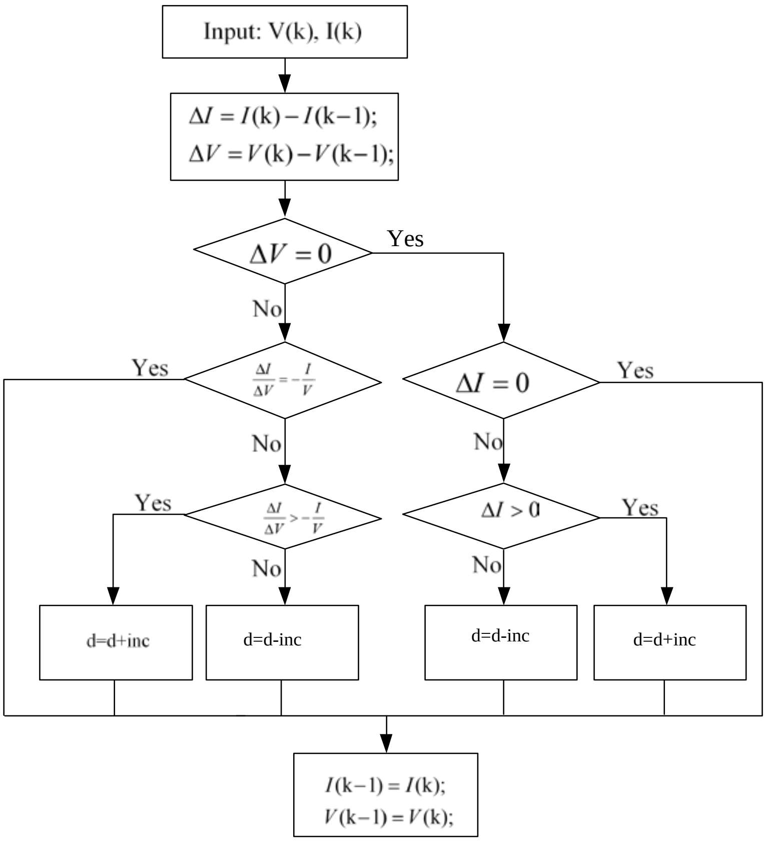


Fig. 3 − Incremental conductance algorithm.

The formulas that give the logical analysis of the slope are presented in (1) - (6) (Srdjan, 2012).

$$\frac{\Delta_P}{\Delta_V} < 0\text{, on the right side of the MPPT} \quad (1)$$

$$\frac{\Delta_P}{\Delta_V} = 0\text{, at MPPT} \quad (2)$$

$$\frac{\Delta_P}{\Delta_V} > 0\text{, on the left side of the MPPT} \quad (3)$$

Because the power relation depends on current and voltage, the above formulas become:

$$\frac{\Delta I_{PV}}{\Delta U_{PV}} < -\frac{I_{PV}}{U_{PV}}\text{, condition for the points on the right side of the MPPT} \quad (4)$$

$$\frac{\Delta I_{PV}}{\Delta U_{PV}} = -\frac{I_{PV}}{U_{PV}}\text{, condition for the maximum point} \quad (5)$$

$$\frac{\Delta I_{PV}}{\Delta U_{PV}} > -\frac{I_{PV}}{U_{PV}}\text{, condition for the points on the left side of the MPPT} \quad (6)$$

The algorithm starts by measuring the panel voltage and current, and calculates the incremental differences from the next step. The measured values are subtracted from the previous ones. In parallel, the incremental sum is also calculated $\frac{\Delta I_k}{\Delta U_k}$ and the instant sum $\frac{I_k}{U_k}$ .The sign of this amount is checked to determine the change of the panel voltage. These steps are done taking into account the fact that the incremental sum is zero at the maximum point. Once the maximum point is reached, the algorithm checks the current difference in the panel. If changes are observed, the algorithm will set a new starting point. The flow chart of the IC algorithm is depicted in Fig. 3.

C. Fractional Open-Circuit Voltage algorithm (FVoc)

This algorithm, also known as Constant Voltage algorithm, is a very simple maximum power point tracking algorithm that has been developed based on experimental measurements of some commercial PV panels. A switch mounted in series with the PV panel it is used for measuring the idle voltage V_{OC} and to impose to the system to function at voltage level equal to 76% of the measured voltage (Femia, 2013).

The Fractional Open-Circuit Voltage algorithm is a MPPT control method that consists in comparing the voltage of the PV panel with a reference voltage corresponding to the optimal voltage, V_{OPT}. The voltage error is then used to adjust the fill factor of the PV system converter. Relation (7) gives the reference voltage (Rekioua, 2012):

$$V_{OPT} = K_1 \times V_{OC} \tag{7}$$

where: K_1 is a proportionality constant which, according to (Rekioua, 2012), is between 0.71 and 0.87.

After the constant K_1 is determined, the optimum voltage, V_{OPT}, can be calculated using (7), by measuring the open circuit voltage V_{OC} at each time interval, directly obtaining the reference voltage (Rekioua, 2012). Although this method is the simplest, it is difficult to choose an optimal value for K_1 (Salas, 2006). Assuming that the ratio between the PV cell voltage corresponding to the maximum power point V_{MPP} and its corresponding V_{OC}, open circuit voltage, is relatively constant throughout the normal operating range, results: (Bollen, 2011):

$$K = \frac{V_{MPP}}{V_{OC}} \tag{8}$$

Depending on the material used for the PV panel, the constant K has an approximate value of 0.76. The open circuit voltage is obtained with a pilot cell, placed near the PV matrix and that is not connected to the consumer. This method is fast, but because the weather conditions may be different for the pilot cell and the PV panel, its accuracy could be questionable (Bollen, 2011). In (Enslin, 1997) it is shown that the MPP point is usually at a voltage close to 76% of the open circuit voltage of the PV array. A more reasonable range of V_{MPP} / V_{oc} ratio in the range of 70% - 82% is indicated in (Xiao, 2007).

Such MPPT methods based on fractional open-circuit voltage and short-circuit current are generally defined as indirect MPPT techniques because they do not measure the power extracted from the PV matrix so the MPP point can only be tracked approximately. Indirect MPPT methods are based on estimating or measuring a voltage or current (Femia, 2013; Masoum, 2002.) states that the I_{MPP} value is 86% of the short-circuit current, so the dual approach can be applied by periodically measuring the short-circuit current instead of the open-circuit voltage (Femia, 2013). The open circuit voltage method is very simple and easy to implement, as it does not necessarily require digital signal processor or microcontroller control. In the case of the short-circuit current method, a simple feedback control loop can be used instead of a digital signal processor (Rekioua, 2012).

The main disadvantage of these techniques is that when the actual operating conditions differ too much from those initially considered for the model adopted, for example, the effect of parametric deviations, the energy losses are significant. These methods are not suitable for cases where MPPT control must be provided with high precision for any environmental conditions of operation of the PV generator. Another disadvantage of these methods is the occasional measurement of the idle voltage of the PV cell/matrix which causes a reduction in energy production. The weak point of such an approach is that it requires a disconnection unit (*e.g.* a switching converter) between the source and the load, so that the desired voltage can be adjusted at the terminals of the PV array. Another considerable limitation is that the value of 76% for the constant K_1 is not valid for any PV panel and for any operating conditions. The higher the radiation level at which the V_{OC} voltage is measured, the higher the energy losses (Rekioua, 2012). The algorithm steps are described in Fig. 4.

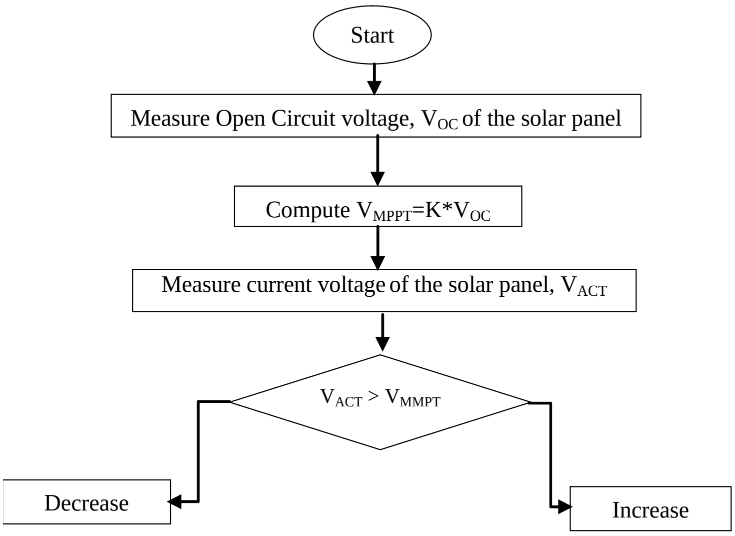


Fig. 4 – Flow chart of conventional Fractional open circuit voltage algorithm.

3. Matlab Simulink Model of Photovoltaic Panel

In this chapter, the Matlab Simulink has been used for modelling a real PV panel, in order to determine the maximum power point using the Perturb and Observe algorithm. A built-in Simulink component for a photovoltaic panel named “PV Array”, has been used for simulating the effect of solar irradiance variation. The panel is built of strings of modules connected in parallel, for that every string is compound of modules connected in series. The PV Array block uses a five parameter model, namely the current source I_L (light-generated current), diode (diode saturation current, diode ideality factor), series resistance R_S and shunt resistance R_{SH} to represent the I-V characteristics of the modules relative to irradiance and temperature levels (Matlab Simulink Help documentation).

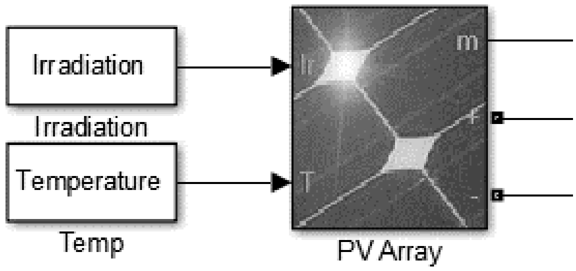


Fig. 5 – PV Array block in Simulink Environment.

For Simulink modeling of photovoltaic systems we started from a simple system consisting of photovoltaic panels and a DC-DC converter. Fig. 6 shows the Matlab Simulink model of a PV system using a DC-DC boost converter. The input voltage to the converter is measured with "Scope2" and the output voltage with "Scope". The output voltage control is adjusted using the PWM signal generator, which controls the MOSFET switching transistor with a switching frequency of 5 kHz.

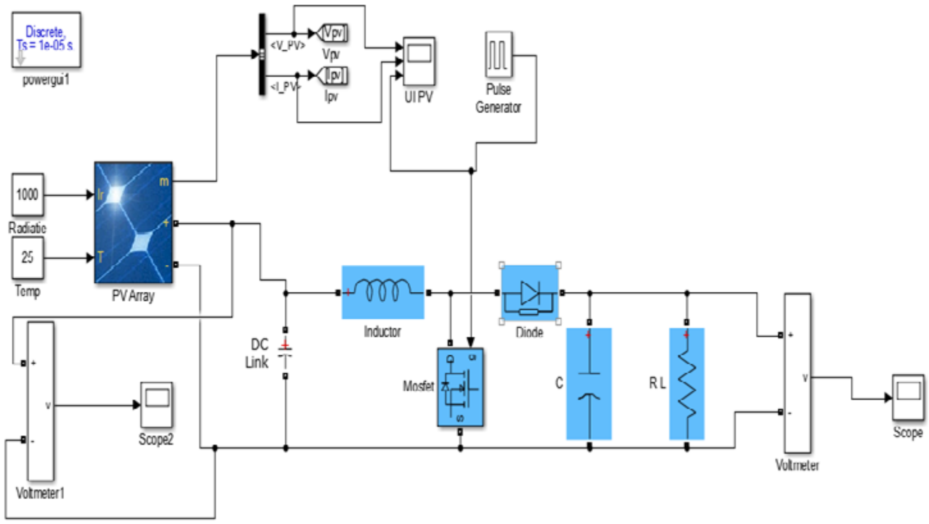


Fig. 6 – Matlab Simulink Model for PV panel.

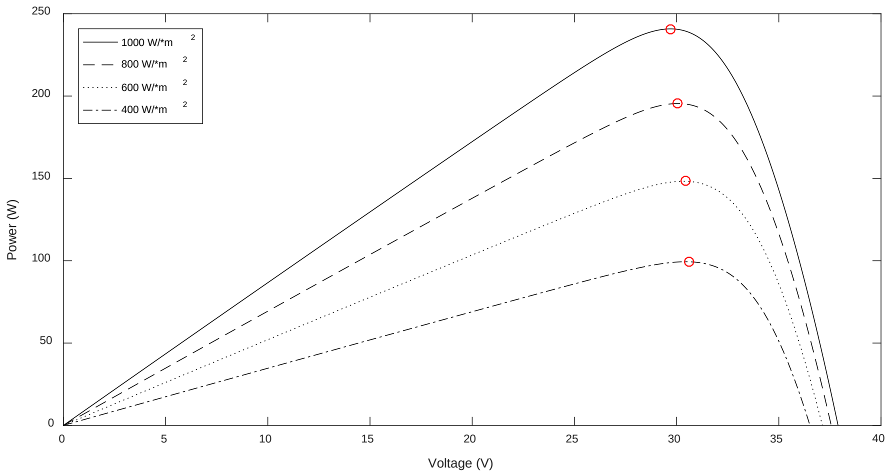


Fig. 7 ─Power – Voltage characteristic of photovoltaic panel for different irradiance.

The simulation was carried out at different values of irradiance: 1000 W/m^2, 800 W/m^2, 600 W/m^2, 400 W/m^2 and constant value of temperature 25°C, using Perturb and Observe algorithm. As can be seen from Fig. 7, the P&O algorithm has found the maximum value of power. For instance, at a 1000W/m^2 solar irradiance, the maximum power point is 240.8 W. At 800 W/m^2 the maximum power point is 195.5 W, and at 600 W/m^2 the maximum power point is 148.2 W, respectively.

4. Conclusions

The MPPT has a very important role in maximization of energy production of PV panels. The MPPT algorithms needs to be analysed in various environmental conditions to ensure a fast and accurate adjustment process of voltage and current, process that has to maximise the output power of PV.

In first part of paper, the main algorithms used for MPPT technique has been presented, whereas in the second part of paper a Matlab simulation has been conducted in order to analyse the response of P&O algorithm for a power-voltage characteristic of a PV panel, analysed under different environmental conditions. The analysis from this paper will be further extended to other algorithms, in order to have a comparison between them, for different environmental condition and also under partial shading conditions.

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ALGORITMI DE URMĂRIRE A PUTERII MAXIME A SISTEMELOR FOTOVOLTAICE

(Rezumat)

Puterea furnizată de un generator format din celule fotovoltaice depinde de punctul la care funcționează. Pentru a extrage o cantitate cât mai mare de energie dintr-un sistem fotovoltaic, generatorul trebuie să se adapteze la sarcină, la condițiile meteo, astfel încât punctul de funcționare să corespundă sau să fie cât mai aproape de punctul maxim de putere. De obicei, atunci când un modul fotovoltaic este conectat direct la o sarcină, punctul său de funcționare este rareori la punctul de putere maximă. Principiul de funcționare pentru urmărirea punctului de putere maximă este plasarea unui convertor între sarcină şi panoul fotovoltaic, pentru a regla tensiunea de ieșire (sau curentul) panoului, astfel încât să fie extrasă puterea maximă disponibilă. Algoritmul optim pentru stabilirea punctului de putere maximă este ales în funcție de mai multe criterii: complexitatea implementării (sisteme autonome, conectate la rețea); tipul și numărul de senzori necesari; capacitatea algoritmului de a detecta punctele maxime locale, costul, timpul de răspuns, tipul de implementare (analogic, digital, mixt).