Revue des Energies Renouvelables Vol. 16 N°4 (2013) 773 – 782
DOI: https://doi.org/10.54966/jreen.v16i4.418

Comparative study between two maximum power point tracking (MPPT) techniques for photovoltaic system

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(reçu le 10 Mars 2013 – accepté le 29 Décembre 2013)

Abstract - *Solar panels have a nonlinear voltage-current characteristic, with a distinct maximum power point (MPP), which depends on the environmental factors, such as temperature and irradiation. In order to continuously harvest maximum power from the solar panels, they have to operate at their MPP despite the inevitable changes in the environment. This is why the controllers of all solar power electronic converters employ some method for maximum power point tracking (MPPT). This paper presents a comparative study between two most popular algorithms techniques which are incremental conductance (INC) and perturb and observe (P&O) in order to optimize the efficiency of the solar generator. The MPPT techniques will be compared, by using Matlab tool Simulink.*

Résumé – *Les panneaux solaires ont une caractéristique tension-courant non linéaire, avec un point de puissance maximale (MPP), qui dépend des facteurs environnementaux, comme la température et de l'irradiation. Pour optimiser la production électrique des panneaux solaires, ils doivent fonctionner à leur puissance maximale quelque soit les conditions atmosphériques. C'est pourquoi les contrôleurs de tous les convertisseurs d'électronique de puissance solaires emploient une méthode pour le suivi du point de puissance (MPPT). Cet article présente une étude comparative entre deux algorithmes les plus populaires qui sont la perturbation et observation (P&O) et l'incrémental conductance (INC) afin d'optimiser l'efficacité du générateur solaire. Les techniques MPPT seront comparées, en utilisant l'outil Matlab Simulink.*

Keywords: Solar panels - Maximum power point tracking (MPPT) - Perturbation and observation (P&O) - Incremental conductance (INC).

1. INTRODUCTION

The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy is one of the most important renewable energy sources. As opposed to conventional unrenewable resources such as gasoline, coal. The main applications of photovoltaic (PV) systems are in either stand-alone (water pumping, domestic and street lighting, electric vehicles, military and space applications) [1] or grid-connected configurations (hybrid systems,

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power plants) [2]. Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9 ÷ 17 %), especially under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions.

Moreover, the photovoltaic voltage-current ($V-I$) characteristic is nonlinear and changes with irradiation and temperature. In general, there is a point on the $V-I$ or voltage-power ($V-P$) curves, called the Maximum power point (MPP), at which PV operates with maximum efficiency and produces its maximum output power. The state of the art techniques to track the maximum available output power of PV systems are called the maximum-power point tracking (MPPT). Controlling MPPT for the solar array is essential in a PV system. There are many techniques have been developed to implement MPPT, these techniques are different in their efficiency, speed, hardware implementation, cost, popularity [1].

2. PV MODULE MODELING

Many models of PV cell with different configurations depending on the needs of use are available in the literature. In this work, the model based on the equation defining the static behavior of a conventional PN junction diode. The equivalent circuit of a PV cell is shown in Fig. 1. This model comprises a direct current generator I_{ph} that models the conversion of electrical energy into luminous flux parallel with the PN junction diode modeling, one diode and two resistors R_p and R_s respectively characterizing currents and the junction leakage of various resistors connection contacts [3].

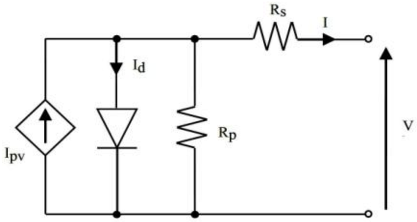

Fig. 1: Equivalent model of PV cell

The $V-I$ characteristic of the equivalent solar cell circuit can be determined by following equations [4]. The current through diode is given by:

$$I_d = I_0 \times \left(\exp\left(\frac{q(V + R \times I)}{A \times k \times T} \right) - 1 \right) \tag{1}$$

While, the solar cell output current:

$$I = I_{ph} - I_0 \times \left(\exp\left(\frac{q(V + R \times I)}{A \times k \times T} \right) - 1 \right) - \frac{V + R_s \times I}{R_p} \tag{2}$$

With: I_0, Diode saturation current (A); q, Electron charge (1.6×10^{-19} C); A, Ideality factor of diode; k, Boltzman constant (1.38×10^{-23}J/K); T : Cell temperature (K).

A photovoltaic module is the basic element of each photovoltaic system. It consists of many jointly connected PV cells. The equivalent module circuit equation for an N_s PV cells in series, leads to equation (3) [5, 6].

$$I = I_{ph} - I_0 \times \left(\exp\left(\frac{q(V + R_{se} \times I)}{N_s \times A \times k \times T} \right) - 1 \right) - \frac{V + R_{se} \times I}{R_{pe}} \tag{3}$$

Where, R_{se}, equivalent series resistances ($R_{se} = N_s \times R_s$); R_{pe}, equivalent parallel resistances ($R_{pe} = N_s \times R_p$).

The $I-V$ and $P-V$ characteristics at Standard Temperature Condition (STC) are given in Fig. 2 and 3.

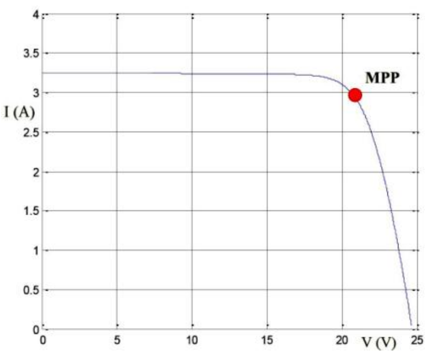

Fig. 2: $I-V$ characteristic of a module

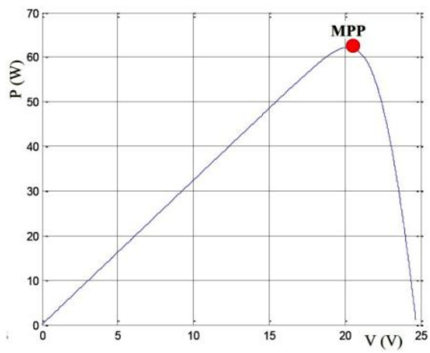

Fig. 3: $P-V$ characteristic of a module

The characteristic $P-V$ has only one maximum power point called MPP.

3. EFFECT OF CHANGES IN PARAMETERS ON THE CHARACTERISTICS OF PV MODULE

Fig. 4 and 5 present the characteristics $I-V$ and $P-V$ for various irradiation with fixed temperature at 25°C. As one can see in these figures, the module current is proportional to the radiation, while the open-circuit voltage changes slightly with irradiation [7].

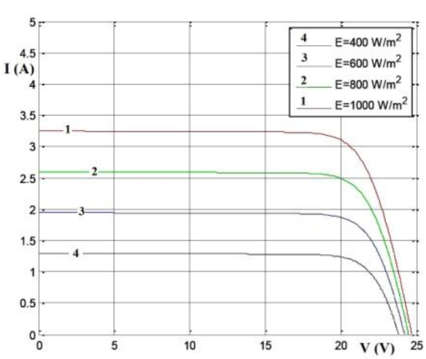

Fig. 4: The effect of the irradiation on $I-V$ characteristic

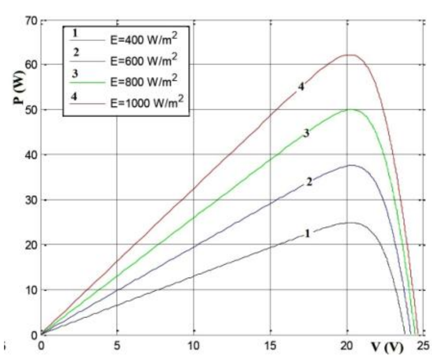

Fig. 5: The effect of the irradiation on $P-V$ characteristic

Table 1 illustrates the values of different MPP during variation of irradiation, the MPP increases from 24.85 for an irradiation of 400 W/m^2 to 62.2 for an irradiation of 1000 W/m^2. So, the increase of irradiation allows the increase of MPP.

Table 1: Values of different MPP during variation of the irradiation

Irradiation (W/m^2)	400	600	800	1000
Power(W)	24.85	37.53	50	62.2

Temperature is also an important parameter in the behavior of PV module. Fig. 6 and 7 show that the increase in temperature leads to a net decrease in the open circuit voltage. [8].

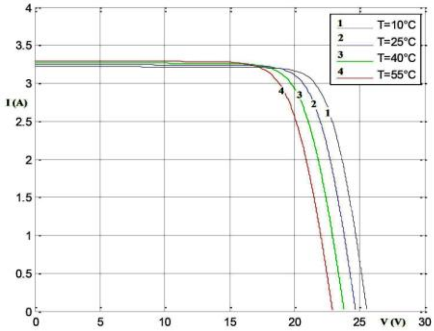

Fig. 6: The effect of the temperature on I – V characteristic

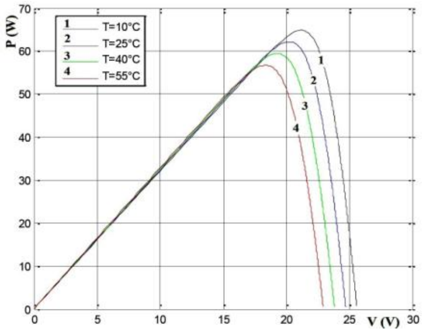

Fig. 7: The effect of the temperature on P – V characteristic

Table 2: Values of different MPP during variation of the temperature

Temperature (°C)	10	25	40	55
Power(W)	64.89	62.2	59.47	56.72

Table 2 shows the values of different MPP during variation of temperature, the MPP decreases from 64.89 for a temperature of 10°C to 56.72 for a temperature of 55°C. So, the augmentation of temperature allows the decrease of the MPP.

Furthermore, as we can see from Fig. 8, the operation of a solar panel depends strongly on the characteristics of the load to which it is associated, in fact, only a charge, which passes through its characteristic MPP, allows extract the maximum power, called optimal resistance.

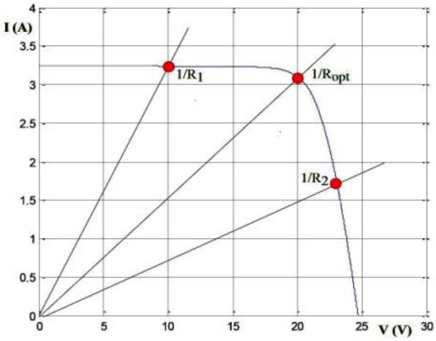

Fig. 8: Direct connection between a solar module and a resistive load

The value of the optimal resistance is given by the following relationship:

$$R_{opt} = V_{opt} / I_{opt} \tag{4}$$

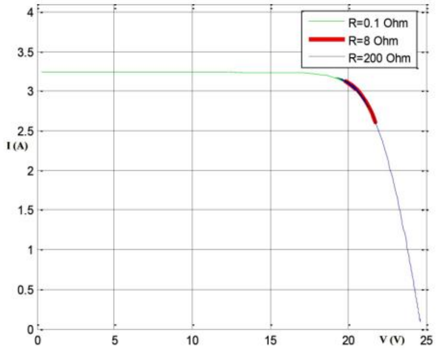

Fig. 9: Characteristic of Current-Voltage for different resistance

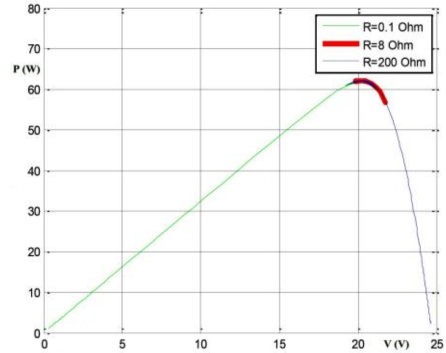

Fig. 10: Characteristic of Power-Voltage for different resistance

Under these conditions, the MPP of the PV array changes continuously; consequently the PV system's operating point must change to maximize the energy produced. An MPPT technique is therefore used to maintain the PV module's operating point at its MPP.

4. TRACKING THE POINT OF MAXIMUM POWER (MPPT)

In order to overcome the above mentioned undesired effects on the PV output power, a maximum power point tracker (MPPT) is used for extracting the maximum available power from the solar PV panel and transferring it to the load. MPPT consists of a DC-DC converter and control circuit where there will be a MPP seeking algorithm.

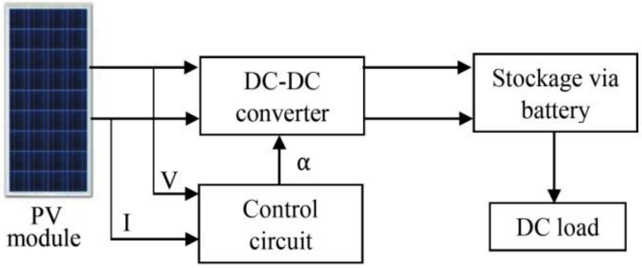

Fig. 11: System configuration of PV system with MPPT

4.1 DC-DC Converter

In power electronic converters choppers are static energy, which pass electrical power from a DC source to another steady source [9]. They are defined by their duty cycle D D. There are choppers lifting or boosters (boost) or step-down chopper step down (Buck) and Buck-boost chopper (Fig. 12).

Buck-boost converter or serial-parallel converter converts a DC voltage into another DC voltage lower or higher value but of opposite polarity [9].

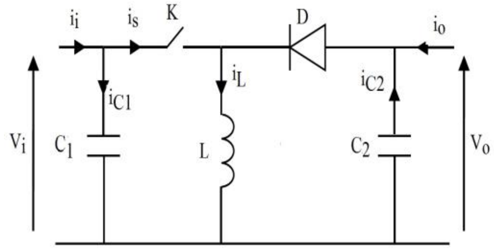

Fig. 12: Buck Boost converter

The conversion ratio is given by the following by:

$$M(\alpha) = V_s / V = -\alpha / (1-\alpha) \quad (5)$$

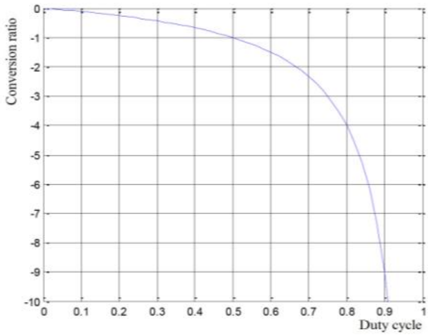

Fig. 13: Conversion ratio versus duty cycle

4.2 MPPT Control algorithm

There are many MPPT methods available in the literature; the most widely-used techniques are described in the following sections.

4.2.1 Perturbation and Observation (P&O)

Perturb and Observe (P&O) technique has been selected to implement a MPPT control algorithm due to its simplicity and the possibility to introduce improvements. [10, 11].

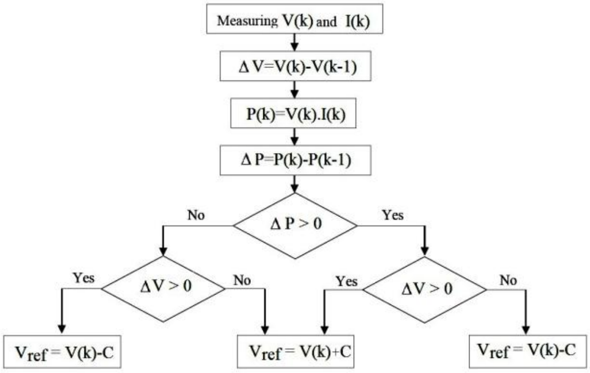

Fig. 14: Flowchart of P&O method

In this algorithm, PV-output voltage (V_k) and PV output current (I_k) are sensed. Then power is calculated (P_k) and compared with the power vale calculated in the previous sample (P_{k-1}) in order to get ΔP_k .

If the results of ΔP_k is zero the system is working in MPP. Otherwise and according to the sign of ΔP_k and to the sign of ΔV_k the command voltage to control the duty cycle α of the converter (let's say the perturbation), will be decreased or increased in order to force the working point of the PV module towards the MPP.

The algorithm is illustrated in the flowchart shown in Fig. 14.

4.2.2 Incremental Conductance (INC)

The incremental conductance (INC) algorithm is derived by differentiating the PV module power equation with respect to voltage and setting the result equal to zero [12-14]. This is shown in Equations (6) to (10).

$$P = V \times I \tag{6}$$

Differentiating equation (6) with respect to dV :

$$dP / dV = I + V \times dI / dV \tag{7}$$

From equation (7), the basic equations of this method are as follows:

$$dI / dV = -I / V \quad , \quad dP / dV = 0 \qquad \text{at MPP} \tag{8}$$

$$dI / dV > -I / V \quad , \quad dP / dV > 0 \qquad \text{left of MPP} \tag{9}$$

$$dI / dV < -I / V \quad , \quad dP / dV < 0 \qquad \text{right of MPP} \tag{10}$$

Fig. 15 shows the flow chart of the Incremental Conductance (INC) method.

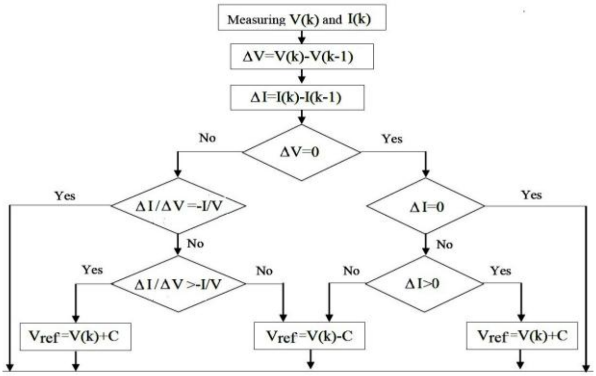

Fig. 15: Flowchart of INC method

5. EFFECT OF VARIATION OF TEMPERATURE

It is very important to test the performance of the command using the two algorithms P&O and INC, with respect possible variations in temperature as shown in Fig. 16. The parameter of illumination is kept constant at 1000 W/m^2.

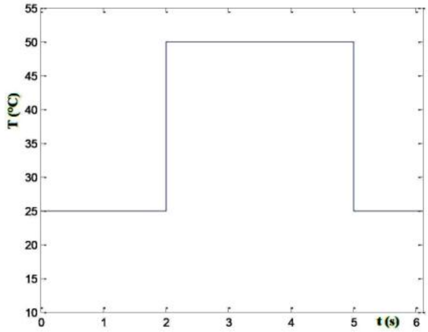

Fig. 16: Temperature's variation

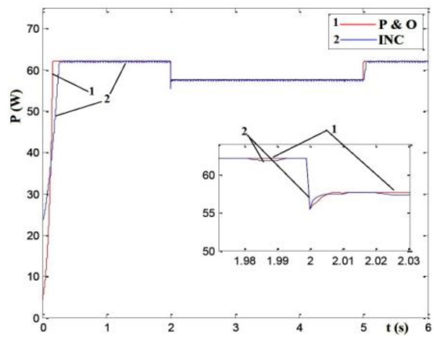

Fig. 17: Output power versus time using P&O and INC

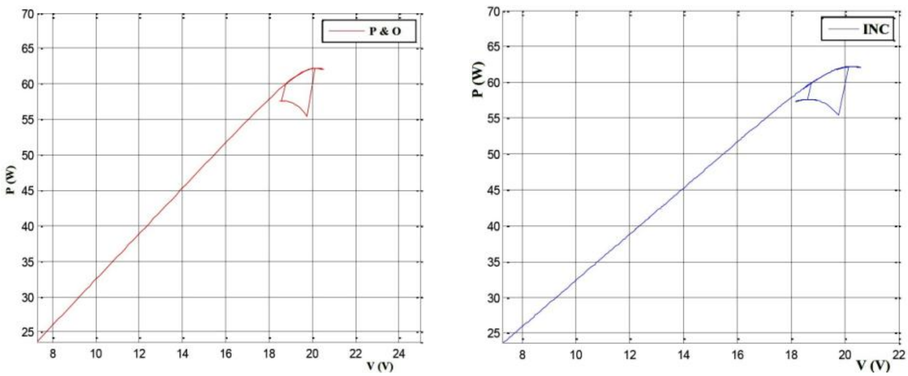

Fig. 18: Output power versus voltage using P&O and INC during variation's temperature

6. EFFECT OF THE IRRADIATION VARIATION

We will test the response of the two controllers, for a change in illumination from 1000 W/m^2 to 800 W/m^2 during 3 second's, the temperature in this case is constant and equal to 25 °C.

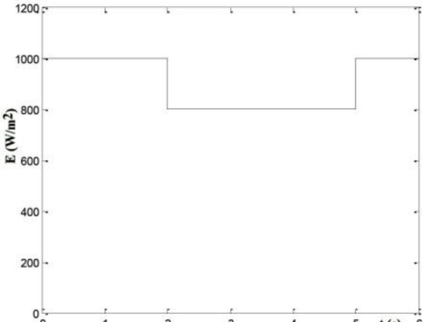

Fig. 19: Irradiation's variation

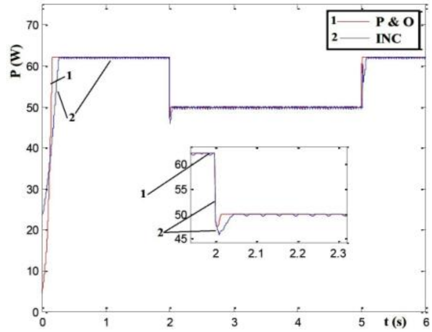

Fig. 20: Output power verses time

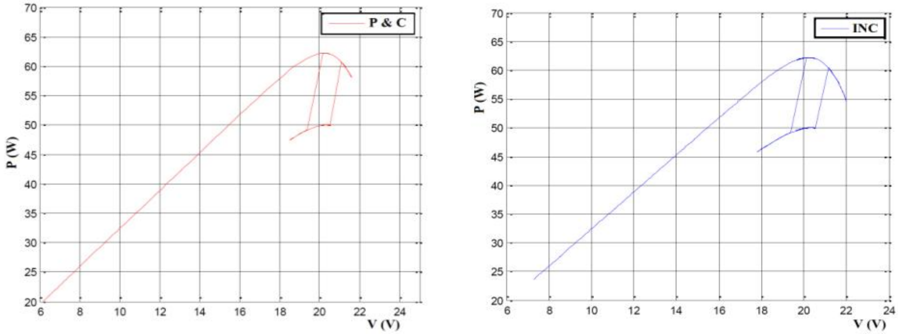

Fig. 21: Output power versus voltage using P&O
and INC during variation's irradiation

6. CONCLUSION

The work presented in this paper consists of a comparison between two MPPT algorithms: Perturb and Observe (P&O) and Incremental Conductance (INC).

The role of the maximum power point tracking, was to match the load power required with maximum of the available power that can be generated from a photovoltaic module. In order to effectuate this work, we started with the model of PV module. Then, the model of DC-DC buck-boost converter and MPPT algorithms are combined with it to complete the PV simulation system. We show that the MPPT control with P&O and INC force the system to work optimally at all times around the MPP.

The study of robustness for both algorithms showed that INC reach the MPP faster than P&O for a decrease of temperature and P&O can reach first the MPP faster than INC for a change of irradiance. These results depend on the coefficient C of perturbation.

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