Comparative study of three MPPT algorithms for a photovoltaic system control

Lashab, Abderezak; Bouzid, Aissa; Snani, Hamza

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Comparative study of three MPPT algorithms For a photovoltaic system control

Lashab Abderezak  
Laboratoire d’Electrotechnique de Constantine  
Université des frères Mentouri Constantine, Algeria  
abderezak.lashab@lec-umc.org

Bouzid Aissa  
Laboratoire d’Electrotechnique de Constantine  
Université des frères Mentouri Constantine, Algeria  
you.bouzid@yahoo.fr

Snani Hamza  
Laboratoire d’Electrotechnique de Constantine  
Université des frères Mentouri Constantine, Algeria  
snani.hamza@yahoo.fr

Abstract— In this paper, we compare between three types of algorithm which track the maximum power point (MPPT) of a photovoltaic (PV) system under variable temperature and solar irradiation conditions, the PV system is constituted by photovoltaic arrays, a resistive load, and a MPPT to control a DC-DC boost converter. The simulation results present a clear performance enhancement of MPPT technique for energy production from PV panel based on fuzzy control in comparison with perturb and observe (P&O), and Incremental Conductance (INC) algorithm.

Keywords— MPPT; maximum power point tracking, P&O; perturbation and observation, INC; incremental conductance, FLC; fuzzy logic control.

I. INTRODUCTION

In the last years, the accumulation of the demand in energy as well as the pollution coming from the needs to use of fossil energies force the general public to use renewable energies[1]. In this framework, the PV energy is one of the important renewable energy sources which presents an outcome to our problems of energy production. Moreover, this energy seems non polluting, most promising and inexhaustible, the production of this energy is non linear and it varies according to the temperature and solar irradiation. Consequently, the operation point of the PV panel does not coincide with the MPP. So we need a controller which has the ability to extract the maximum power at the output of PV generator regardless of atmospheric conditions, via an intermediate DC-DC converter. Therefore, several studies have focused on the PV systems, they tried to improve algorithms to extract the maximum energy converted by the panel then allowing optimal operation of the PV system [2]. Research work Found in the literature use different algorithms which based on the following methods: the Perturbation & Observation (P&O) (which is the most known) and Incremental Conductance (INC) [3], [4]. There are also called smart controls that are based on fuzzy logic (FLC) [5], [6], [7]. In this paper, a model of a PV has been developed using Matlab/Simulink as well as the model of a DC-DC boost converter, first with a P&O controller which oscillate around the MPP searching for it, second with a INC controller, Therefore an intelligent control technique using fuzzy logic associated with a MPPT controller are used to improve energy conversion performance of the PV system [8].

II. PHOTOVOLTAIC POWER GENERATION

The essential component of the PV array is the photovoltaic cell, this latter may be regarded as an ideal current source which provides the current Iph, and this is proportional to the incident light power, in parallel to the current source there is a diode D and a high resistance Rsh which is represented by the junction PN. All these elements are in series with a small resistor Rs, Therefore, the PV cell can be modeled by Fig. 1[9] The corresponding equations are as follows:

\[ I = I_{ph} - I_{sat} \left( e^{\frac{q(v_{ph}+R_{s}xI)}{nKT}} - 1 \right) - \frac{v_{ph}+R_{s}xI}{R_{sh}} \]  

(1)

By considering the parallel resistance Rsh is infinite \((Rsh = \infty)\), the equation (1) becomes:

\[ I = I_{ph} - I_{sat} \left[ e^{\frac{q(v_{ph}+R_{s}xI)}{nKT}} - 1 \right] \]

(2)

Such as:

\[ I_{ph} = I_{Sat_{ref}} \frac{E}{E_{0}} \left[ 1 + a(T - T_{ref}) \right] \]

(3)

\[ a = \frac{l_{Sat_{ref}} - I_{Sat_{ref}}}{l_{Sat_{ref}}} \frac{1}{T - T_{ref}} \]

(4)

\[ l_{Sat} = I_{so} \left( \frac{T}{T_{ref}} \right)^{\frac{3}{2}} \left( \frac{E_{0}}{E_{0}} \right) \left( \frac{1}{T - T_{ref}} \right) \]

(5)

And the series resistor Rs,

\[ R_{s} = - \frac{dv}{dl_{Vco}} - \frac{1}{K_{i}} \]

(6)

\[ K_{i} = I_{so} \frac{q}{nKT_{ref}} \exp \left( \frac{qV_{oc_{ref}}}{nKT_{ref}} \right) \]

(7)
The output characteristics of the PV array, $I_{ph}$ is the generated light current (A) at certain insulation, $I_{sat}$ indicates a diode reverse saturation current (A), $q$ is the electronic charge $q=1.6\times 10^{-19}$C, $k$ is Boltzmanns constant $K=1.3807\times 10^{-23}K$, $n$ denotes the dimensionless deviation factor from the ideal PN junction diode, $E_g$ is the Band gap for silicon, $E$ is the PV cell insulation and $T$ is the Cell temperature (Kelvin), The data sheet details of a photovoltaic generator (TOTAL ENERGY TE 600) at 25°C, 1000W/m$^2$ used in this paper are given in the table 1

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power, PM</td>
<td>63W</td>
</tr>
<tr>
<td>voltage at max power, VM</td>
<td>17.75V</td>
</tr>
<tr>
<td>Open circuit voltage, Voc</td>
<td>22.5V</td>
</tr>
<tr>
<td>Short circuit current, Isc</td>
<td>3.5A</td>
</tr>
<tr>
<td>Total cells in series, Ns</td>
<td>36</td>
</tr>
<tr>
<td>Total cells in parallel, Np</td>
<td>1</td>
</tr>
</tbody>
</table>

The output characteristics of the PV array are non-linear as it is dependent on the cell temperature and the solar irradiance as shown in Fig. 2 and Fig. 3 [10], [11], these figures show the I-V and P-V characteristics of a typical PV module for different degrees of insulation intensity and temperature, we can notice that the output voltage of the PV array has a great influence by the temperature. The increase of the PV module temperature decreases the output power, An increase of temperature by 1K, leads to approximately a 0.4 to 0.5% decrease in the electrical efficiency of the crystalline silicon and nearly 0.25% in the amorphous silicon cells [12], while PV output current has approximate linear relationship with the insulation intensities. In fact, there is only one point on the I-V or P-V curve, called the Maximum Power Point (MPP), Hence it is necessary to continuously track the MPP under the environmental changes in order to maximize the output power from the PV array, there is a need to determine its exact location, this can be operates at its MPP. In general, a MPPT system controls a MPPT system. An MPPT system is an electronic control device, its role is to guarantee always operates at its MPP. In general, a MPPT system controls a DC-DC converter, installed between the PV module and the load [12], The DC-DC converter is controlled by an algorithm, which calculates the value of the duty cycle.

### III. DC-DC BOOST CONVERTER

The chopper or DC-DC converter is a power electronics device that is implements one or more controlled switches and which changes the value of the voltage of a DC voltage source, the choppers have excellent yields because of the low power consumption of the of the composite elements such as capacitors, the inductors and mainly switches. For $t \in [0, aT]$, the transistor is on. Thereafter, the converter can be modeled by the following equations:

\[
L \frac{dI_1}{dt} = V_1 
\]

\[
\frac{dV_2}{dt} = - \frac{V_2}{R_{Load} \times C} 
\]

For $t \in [aT, T]$, the transistor is off. Thereafter, the converter can be modeled by the following equations:

\[
L \frac{dI_k}{dt} = V_1 - V_2 
\]

\[
\frac{dV_2}{dt} = - \frac{I_k}{C} \frac{V_2}{R_{Load} \times C} 
\]

Where $T$ is the period of the boost converter and $a$ is the ratio cycle. The data sheet details of the boost DC-DC converter are given in table 2.
The perturbation method and observation (P&O) is an essential control for optimum operation of the PV system. The principle of this control is based on the automatic variation of the cyclic ratio \( a \) by bringing it to the optimal value to maximize the power output of the PV panel. For this reason, we will present and discuss later the most popular control algorithms. The more popular PV MPPT algorithms are Constant Voltage, P&O, INC, Short Circuit Current and Open Circuit Voltage [13], these algorithms use PV output voltage data, output current data, or both, to track the MPP, and it is based on mathematical relationship obtained from empirical data.

### IV. MPPT ALGORITHM

**A. Perturb and Observe (P&O) Method**

The perturbation method and observation P&O is an approach widely prevalent in the research MPPT because it is simple and requires only voltage measurements and current of the photovoltaic panel \( V_{PV} \) and \( I_{PV} \), respectively, it can detect the MPP even during variations in illumination and temperature. As its name denotes, the P&O method works with voltage perturbation \( V_{PV} \) and observing the effect of this change on the output power of the photovoltaic’s panel.

With the algorithm of the P&O method, at each cycle, \( P_{PV}(k) \) is calculated through the measurement of \( V_{PV} \) and \( I_{PV} \), this instantaneous value \( P_{PV}(k) \) is compared with the previous value \( P_{PV}(k-1) \) which is calculated in the previous cycle.

If the output power of the PV array has increased, \( V_{PV} \) is adjusted in the same direction as in the previous cycle, if the output power of the PV array decreased, \( V_{PV} \) is adjusted in the opposite direction than in the previous cycle. When the MPP is reached, \( V_{PV} \) oscillates around the optimum value \( V_{opt} \), this oscillation increases with the step of the incrementing of the perturbation, consequently causes a loss of power, if this step is big, the MPPT algorithm can responds quickly to sudden changes in atmospheric conditions. In addition, if the step increment is small, the losses, during stable or slow changes in operating conditions will be lower but the system cannot respond quickly to sudden changes in temperature or light. The ideal step increment is experimentally determined according to the needs.

### B. Algorithm of Incremental conductance

In this algorithm the derivative of the output power of the panel is calculated otherwise, it is calculated as a function of the voltage \( V \) and the difference \( dV \) and the current \( I \) and its difference \( dI \), this derivative is zero at the MPP, positive on the left of point MPP and negative on the right. The solar panel power is given by:

\[
P = V \times I \quad (13)
\]

The partial derivative \( \frac{dP}{dV} \) is given by:

\[
P \frac{dP}{dV} = I + \frac{dI}{dV} \quad (14)
\]

\[
P \frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV} \quad (15)
\]

We define the conductance of the source \( G = \frac{I}{V} \) and incremental conductance \( \Delta G = \frac{dI}{dV} \). Since the voltage \( V \) of the panel is always positive, the equation (16) explains that the point of maximum power MPP is achieved if the conductance of the source \( G \) equals the incremental conductance \( \Delta G \) of the source with a minus sign, and is left of this point when the conductance \( G \) is greater than the incremental conductance \( \Delta G \) and vice versa, as follows:

\[
\begin{align*}
\frac{dP}{dV} > 0 & \quad \text{if} \quad \frac{I}{V} > -\frac{dI}{dV} \\
\frac{dP}{dV} = 0 & \quad \text{if} \quad \frac{I}{V} = -\frac{dI}{dV} \\
\frac{dP}{dV} < 0 & \quad \text{if} \quad \frac{I}{V} < -\frac{dI}{dV}
\end{align*}
\quad (16)
\]

The Voltage and the current of the panel are monitors, so that the controller can calculate the conductance and incremental conductance and decide their behavior. This algorithm involves a large number of derivations.

### C. fuzzy logic algorithm

Recently, the control based on fuzzy logic has been used in the track of MPPT systems this control offers the advantage of being a robust control and which does not require the knowledge exact mathematical model of the system. In particular, this command is better suited to nonlinear systems. The operation of this algorithm is in three blocks: fuzzification, inference and defuzzification figure Fuzzification allows the conversion of the input physical variable in the fuzzy sets. In our case, we have two entries error \( E \) and change in error \( \Delta E \) which expresses the moving direction of the MPP [14]. These entries are defined as follows:

\[
E = \frac{P_{PV}(k) - P_{PV}(k-1)}{I_{PV}(k) - I_{PV}(k-1)} \quad (17)
\]

\[
\Delta E = E(k) - E(k-1) \quad (18)
\]

Where, \( K \) is the sampling time, \( P_{PV}(k) \) is the instantaneous power of the PVG, and \( I_{PV}(k) \) is the corresponding instantaneous current.

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**TABLE II. COMPONENT VALUES OF DC-DC BOOST CONVERTER.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance, ( R_{rel} )</td>
<td>100Ω</td>
</tr>
<tr>
<td>Inductor, ( L )</td>
<td>0.0001H</td>
</tr>
<tr>
<td>Capacitor, ( C )</td>
<td>400μF</td>
</tr>
</tbody>
</table>

---

Fig. 5. diagram of fuzzy logic algorithm.
1) Fuzzification: Attributed to change in error $\Delta E$ and error $E$ the linguistic variables: big negative (BN), small negative (SN), Zero (ZE), small positive (SP) and big positive (BP). The shape of membership function and the partition of fuzzy subsets, which can adapt shape up to suitable system, are shown in Fig. 6, Fig. 7 and Fig. 8.

2) Inference method: In the inference step, making decisions. Indeed, it embeds logical relationships between inputs and output while defining membership implications. The MIN-MAX fuzzy implication method is used to identify the output fuzzy set. Here we are using MIN-MAX fuzzy implication method [15], subsequently, it paints a table’s inference rules (table 3).

3) Defuzzification: For this system, the output of FLC is the duty ratio (cycle), to compute it we used the table method. The first test consists to verify the ability to track the MPP for the three methods under the standard conditions which is: $25^\circ C$ of temperature and $1000 W/m^2$ of solar irradiation, Fig. 9 shows the result of the tracked power by the three controllers. From Fig. 9, it is noticed that P&O, INC and fuzzy logic can track the maximum power operating voltage point.

The next simulation is under fast variation of solar irradiation, at 0.02 sec from $1000 W/m^2$ to $800 W/m^2$ and at 0.03 sec from $800 W/m^2$ to $600 W/m^2$. Another simulation is under a fast variation of temperature, at 0.02 sec from $45^\circ C$ to $30^\circ C$ and at 0.03 sec from $30^\circ C$ to $15^\circ C$. According to the Fig. 9, Fig.10 and Fig. 11, The MPPT which made in FLC method have been shown to be functioning well under varying atmospheric conditions, we can see that the P&O method has a major disadvantage which is bad behavior following an abrupt change of illumination (clouds).

The INC Algorithm seems to have an improvement over the P&O algorithm, indeed, it behaves better during a fast change of the metrological conditions. However, the FLC algorithm it is more complex than the precedent, the algorithm based on fuzzy logic is a robust and effective algorithm. Indeed, this algorithm functions at the optimal point with less oscillation, and it has better response time comparing to P&O and INC method. Moreover, it is characterized by a good behavior in transitory state.

### TABLE III. FUZZY INFERENCE TABLE.

<table>
<thead>
<tr>
<th>E</th>
<th>$\Delta E$</th>
<th>NB</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>ZE</td>
<td>ZE</td>
<td>BP</td>
<td>BP</td>
<td>Bp</td>
<td></td>
</tr>
<tr>
<td>NS</td>
<td>ZE</td>
<td>ZE</td>
<td>SP</td>
<td>SP</td>
<td>SP</td>
<td></td>
</tr>
<tr>
<td>ZE</td>
<td>SP</td>
<td>ZE</td>
<td>ZE</td>
<td>ZE</td>
<td>ZE</td>
<td>ZE</td>
</tr>
<tr>
<td>PS</td>
<td>SN</td>
<td>SN</td>
<td>SN</td>
<td>ZN</td>
<td>ZE</td>
<td>ZE</td>
</tr>
<tr>
<td>PB</td>
<td>BN</td>
<td>BN</td>
<td>BN</td>
<td>ZE</td>
<td>ZE</td>
<td>ZE</td>
</tr>
</tbody>
</table>

![Fig. 6. Membership function plots for input E.](image)

![Fig. 7. Membership function plots for input $\Delta E$.](image)

![Fig. 8. Membership function plots for output D.](image)

V. SIMULATION RESULTS AND DISCUSSION

The PV model with controlled DC-DC boost converter is simulated using MATLAB/Simulink software, to demonstrate the features of the MPPT algorithms based fuzzy logic in comparison with the INC and the Conventional P&O MPPT method. The next simulation is under fast variation of solar irradiation, at 0.02 sec from $1000 W/m^2$ to $800 W/m^2$ and at 0.03 sec from $800 W/m^2$ to $600 W/m^2$. Another simulation is under a fast variation of temperature, at 0.02 sec from $45^\circ C$ to $30^\circ C$ and at 0.03 sec from $30^\circ C$ to $15^\circ C$. According to the Fig. 9, Fig.10 and Fig. 11, The MPPT which made in FLC method have been shown to be functioning well under varying atmospheric conditions, we can see that the P&O method has a major disadvantage which is bad behavior following an abrupt change of illumination (clouds).

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![Fig. 9. PV power curves generated by P&O algorithm, INC algorithm and FLC at $25^\circ C$ of temperature and $1000 W/m^2$ of solar irradiation.](image)
VI. CONCLUSION

In this paper, we described the principal elements of system statement that is a Photovoltaic panel. Then, we presented the P-V and the I-V characteristics of TOTAL ENERGY TE600 solar array, we pointed out the principle of three of the most popular MPPT algorithms. Lastly, we finished by a simulation of the various algorithms. The goal of this work was to control the duty cycle of the boost converter in order to obtain the maximum power possible from a PV generator, whatever the solar insulation and temperature conditions. The results of simulations show that the INC algorithm gives results better than the P&O one. In addition, the P&O and the INC are widely used but the control based on fuzzy logic shows a good behavior and better performances compared to the other methods.

REFERENCES


