Maximizing the power of a photovoltaic system based on Perturb and Observe control applied to MPPT

A. Attou, A. Massoum, M. Chadli

ICEPS Laboratory (Intelligent Control & Electrical Power Systems), Djillali Liabes University of Sidi Bel-Abbes, Sidi Bel-Abbes, Algeria.
MIS Laboratory (Modelisation, Systems and information), Picardie-Jules Verne University, Amiens, France.

ABSTRACT

The need for renewable energy sources is on the rise because of the acute energy crisis in the world today. Standalone photovoltaic systems are widely used in remote areas after development of photovoltaic cell industry in recent years. The output characteristics of photovoltaic arrays are nonlinear and change with the cell's temperature and solar radiation. Since they cannot ensure that the operating point will match the maximum power point for all radiation and temperature conditions. Maximum Power Point Trackers (MPPT) systems are essential devices employed to maximize the power flow from a photovoltaic module (or array) to a load. In most of applications, the MPPT is composed by a DC-DC converter interposed between the referred photovoltaic module and load. The DC-DC Boost converter is proposed in this paper. A photovoltaic system has been modeled and analyzed using Matlab/Simulink software. The simulation was compared with and without MPPT. The results validate that MPPT significantly increased the efficiency and performance of the photovoltaic system compared to the system without MPPT.

INTRODUCTION

Utilization of renewable energy resources is the demand of today and the necessity of tomorrow. Due to the electric power crisis globally, it is to be thought about the optimized utilization of these resources. The electrical system powered by PV arrays requires special design considerations due to varying nature of the solar irradiation level as well as the operating temperature. So, the PV arrays must be operated at its highest energy conversion output by continuously utilizing the maximum available power of the array (Sharma, D.K., G. Purohit, 2012; Hamidon, F.Z., et al., 2012).

The present paper deals with the last aspect of this challenge, and will describe a way to extract the maximum amount of power from a given solar array by forcing it to operate at its maximum power point, with a particular power conditioning topology, called Maximum Power Point Tracking (MPPT). The problem considered by MPPT techniques are to automatically find the voltage \( V_{MPP} \) and current \( I_{MPP} \) at which a PV array should operate to obtain the maximum power output \( P_{MPP} \) under a given temperature and irradiance.

PV is a nonlinear source that depends on irradiation and temperature in its operation. In the market, perturb and observe (P&O) algorithm method is popular because it is the simplest algorithm and easy to implement as compared to other methods (Zainuri, M.A.A., et al., 2012; Hamidon, F.Z., et al., 2012). The modeling of PV array and P&O MPPT algorithm implementation on MATLAB simulink.

A. Nomenclature

- MPP : Maximum Power Point;
- MPPT : Maximum Power Point Tracking;
- P&O : Perturb and Observe;
- PV array : Photovoltaic array;
- STC : Standard Test Conditions;
- \( G \) : Solar irradiance (W/m²);
- \( I_{ph} \) : photon current;
- \( I_{pmax} \) : Current at the MPP;
- \( I_{sc} \) : Short circuit current;
- \( I_{PV} \) : PV array current;
- \( V_{PV} \) : PV array voltage;

Corresponding Author: A. Attou, ICEPS Laboratory (Intelligent Control & Electrical Power Systems), Djillali Liabes University of Sidi Bel-Abbes, Sidi Bel-Abbes, Algeria.
A. Attou et al, 2013

- $V_{oc}$: Open circuit voltage;
- $\eta$: efficiency in PV array;
- $D$: Duty cycle.

B. System Description

C. TABLE I

D. SPECIFICATIONS OF SOLAR PANELS

<table>
<thead>
<tr>
<th>$P_{max}$</th>
<th>$V_{max}$</th>
<th>$I_{max}$</th>
<th>$V_{oc}$</th>
<th>$I_{sc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.18 W</td>
<td>17.80 V</td>
<td>2.70 A</td>
<td>21.2 V</td>
<td>3.02 A</td>
</tr>
</tbody>
</table>

$P_v$ Cell Model In Simulink:

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell, it can be modeled by utilizing a current source, a diode which is basically a p-n semiconductor junction and two resistors. One diode connected in parallel, one resistor connected in series.

This model is known as a single diode model of solar cell. Fig. 1 depicts the block diagram of the PV system, built in MATLAB/Simulink. The PV array panel has the following specifications at the standard test conditions (STD, solar irradiance of 1000 W/m² and temperature of 25 °C). The V-I characteristic of a solar array is given by (1).

$$ I = I_{sc} - I_0 \left\{ \exp \left[ \frac{q(V + R_s I)}{nkT} \right] - 1 \right\} - \frac{V + R_s I}{R_{sh}} $$

(1)

Where:
- $V$ and $I$ represent the output voltage and current of the PV, respectively.
- $R_s$ and $R_{sh}$ are the series and shunt resistance of the cell.
- $q$ is the electronic charge.
- $I_{sc}$ is the light-generated current.
- $I_0$ is the reverse saturation current.
- $n$ is a dimensionless factor.
- $k$ is the Boltzmann constant, and $T_k$ is the temperature in °K.

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current ($I_{sc}$). Thus, $I_{ph} = I_{sc}$, when there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage ($V_{oc}$) [9][10]. A moderate model of pv cell is shown in Fig. 1.

Fig. 1: Equivalent circuit of PV array

Characteristics of a PV Panel:

The PV array characteristics significantly influence the design of the inverter and the controller for the whole PV system. Therefore, it is essential to review the model of the PV array as the preliminary design to obtain the respective I-V and P-V characteristic curves.

A. Effect of Irradiance (Insolation):

Fig. 2 shows the P-V curve and I-V curves for a PV panel at irradiance levels of 400, 600, 800 and 1000 W/m².
The current of the PV array increases from 1.19A to 3.02A while the open-circuit voltage increases marginally as the irradiance levels change from 400 m² to 1000 m², as depicted in Fig. 2. The maximum power point of the panel increases with a steep positive slope, proportional to the irradiance. Higher irradiance levels result in associated higher power maxima and in higher voltages at the power maxima, if the cell temperature is constant (SUGANYA, J., M. CAROLIN MABEL, 2012; Abu Tariq, Mohammed Asim and Mohd.Tariq, 2011; Roberto, F., et al., 2012).

A. Effect of Cell Temperature Variations:

The effect of cell temperature on the P-V and I-V characteristics are plotted in Fig.3. Note the reduction of maximum available PV power and the lower voltage of this peak power point, as a function of higher cell temperatures.

The open-circuit voltage of the PV array decreases from 15V to 21.2V while the current increases marginally from 3.02A to 3.21A as the temperature changes from 25 °C to 75 °C, as depicted in Fig. 3.

The current and power at MPP are slightly decreased as the temperature increases.

From the above figures, it is clear that there is a maximum point at each irradiance value with the temperature value.

Running the system without MPPT:

Direct connection of the solar panel to a battery is cheapest. The major drawback of this operation is directly dependent on the power supplied by the generator PV. The power transmitted directly to a battery is not always carried out at the maximum power (P_max).
Boost Converter:

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation. In this mode of operation; the switch is closed and the inductor is charged by the source through the switch (SUGANYA, J., M. CAROLIN MABEL, 2012; Saurav Satpathy, 2012).

The charging current is exponential in nature but for simplicity is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor. In this mode of operation; the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation (Sharma, D.K., G. Purohit, 2012; Ansel Barchowsky, et al., 2012).

The boost converter provides the higher output than input as per the following formula: \[ V_{out} = \frac{V_{in}}{1 - D} \] where \( D \) is the duty cycle of the boost converter. The power switch is responsible for modulating the energy transfer from the input source to the load by varying the duty cycle \( D \) (Sharma, D.K., G. Purohit, 2012; Abu Tariq, Mohammed Asim and Mohd.Tariq, 2011).
Fig. 6: Typical forms wave of boost converter

The MPP tracker operates by periodically incrementing or decrementing the solar array current. If a given perturbation leads to an increase (decrease) the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction.

**Running the System with MPPT:**

The Maximum Power Point Tracking (MPPT) is a technique used to obtain the maximum possible power for more wide range from a varying source. The aim of any MPPT algorithm is to extract the maximum power from the PV array panels. There are many methods used for MPPT. In this paper, the P&O method is being used to accurately track the MPP.

**Perturb & Observe Algorithm:**

The Perturb and Observe algorithm is considered to be the most commonly used MPPT algorithm of all the techniques because of its simple structure and ease of implementation. It is based on the concept that on the power-voltage curve $dP/dV$ goes to zero at the top of the curve as illustrated in Fig. 2 or Fig. 3. The P&O operates by periodically perturbing (incrementing or decrementing) the PV array terminal voltage or current and comparing the corresponding output power of PV array $P(n+1)$ with that at the previous perturbation $P(n)$. If the perturbation in terminal voltage leads to an increase in power ($dP/dV > 0$), the perturbation should be kept in the same direction otherwise the perturbation is moved to the opposite direction. The perturbation cycle is repeated until the maximum power is reached at the ($dP/dV=0$) point. The flowchart of P&O algorithm is shown in Fig. 7 (Aashoor, F.A.O., F.V.P. Robinson, 2012; Zainuri, M.A.A., et al., 2012).
The duty cycle of the boost converter is controlled in accordance with the varying solar insolation by using a controller algorithm. In Fig. 7, set Duty out denotes the perturbation of the solar array voltage; Duty+ and Duty− represent the subsequent perturbation in the same or opposite direction, respectively (Sharma, D.K., G. Purohit, 2012).

Using an adaptation stage (boost converter) optimizes energy production for any operating condition; we will see the next test results obtained with this approach.

**Fig. 7:** Flowchart of the P&O algorithm.

**Fig. 8:** System simulation model

Fig. 9 show the simulation results of Voltage, current, and power output of PV Panel using MPPT control.
Comparing the simulation results of the converter (shown in Fig. 9) with measurements made in Fig 4:

- With the measured values of the characteristics of the panel for $G = 1000\text{W/m}^2$, we have:
  
  - $I_{\text{pmax}} = 2.705\text{ A}$, $V_{\text{pv}} = 17.81\text{ V}$, $P_{\text{max}} = 48.18\text{ w}$
  
- Direct connection, we have in simulation:
  
  - $I_{\text{pv}} = 2.93\text{ A}$, $V_{\text{pv}} = 12\text{ V}$, $P_{\text{pv}} = 35.26\text{ w}$.
  
  The efficiency in the maximum power point: $\eta_{\text{MPP}} = 73\%$.

- With the converter, we have in simulation:
  
  - $I_{\text{pv}} = 2.84\text{ A}$, $V_{\text{pv}} = 16.56\text{ V}$, $P_{\text{pv}} = 47.02\text{ w}$, $\eta_{\text{MPPT}} = 97.6\%$.

The PV system would operate at around 73% matching without the use of a MPPT converter. By using MPPT, the matching for this case could be improved to at least 97.5%.

So, we can say that the use of the MPPT algorithm has better efficiency.

**Conclusion Algorithm:**

The operating conditions of the optimum PV power gained from the PV array is affected by solar irradiation, cell temperature and loading conditions and the output current-voltage characteristics of solar arrays are nonlinear. Therefore, a maximum power point tracking control is needed to continually match the PV internal resistance with the loading effect. In this paper, a proposed P&O algorithm for MPPT control in boost DC-DC converter is presented. MPPT control by P&O algorithm with the PV generator can operate on the power optimal curve electrical problems throughout the entire range of variation of light and temperature. Therefore, it was seen that using the P&O MPPT technique increased the efficiency of the photovoltaic system from an earlier output power. So, it can be concluded that the proposed P&O algorithm based MPPT will be able to achieve the better efficiency in comparison to the direct connection. Therefore, the results show that it gives better correlation with the datasheet values.

**REFERENCES**


