Analysis and Investigation of a Two-Diode Solar Cell Using MATLAB/Simulink

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Abstract- Photovoltaic cells are often presented using the single diode and double diode configurations. The model of the double diode representation, which is known to be more accurate, was implemented using MATLAB/Simulink. To track the point of maximum power, the perturb and observe (P&O) algorithm method was implemented. It was shown that the point of maximum power is always located at the expected position, is readily tracked and maintained by minute increases and decreases in voltage. These encouraging results indicate opportunities for the utilization of this algorithm and its hardware implementation.

Keywords- PV Cell, Modelling, Perturb & Observe, MPPT, Algorithm, Insolation.

1. Introduction

Solar technology has been readily available in the international market over several years ago. It allows for the generation of power without the use of fossil fuel. However, power generated by solar cells can face losses due to adverse weather conditions from cloudy or rainy days, decreased irradiance levels, temperature changes etc. Sometimes, it can even be due to the MPPT method used to regulate power [1].

Photovoltaic conversion is simply the process of transforming the photon energy into electrical energy through the absorption of light by the material. In fact, when a photon hits the surface of the material, it rips out and ejects an electron from a lower energy level to a higher level as explained in Figure 1.
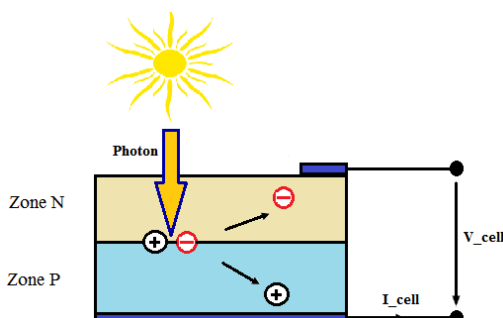

Fig. 1. Photovoltaic conversion working principle.

This process results in the creation of an electron-hole pair at the same level of energy and should return to equilibrium by converting part of the electrical energy into thermal energy. Then, the released electron can pass the forbidden band toward the conduction band if the energy received is sufficient. In case where the width of the band gap is between 0.4 to 0.7 eV (forbidden spectrum of solar energy band), a free flow of electrons is generated and the photovoltaic cell can then be the cause of a continuous-type electric current which should be guided to pass in the external circuit.

Most if not all solar circuitry designs will generate power output. However, all solar designs require fine-tuning to produce maximum power output at all times. Despite weather condition limitations and their effects on solar modules, most solar circuitry designs nowadays use maximum power point tracking for maximum power generation. Many different algorithm methods can be applied for MPPT. The most familiar methods use perturb and observe (P&O) [2-4].

Accordingly, this paper provides a review of the P&O algorithm method and a final conclusion based on a MATLAB simulation. The simulation generates strict conditions such as different irradiance levels and measures the maximum output power for the condition applied. The

MATLAB Simulink tool is widely used to make sound judgments in selecting the best tracking methods.

2. Solar Cell Modelling

The photovoltaic cell modelling was made possible by using equivalent circuits. There are two key parameters that are generally used to characterize a photovoltaic cell. The first parameter is called the short-circuit current (I_{sc}) which is obtained by short-circuiting both terminals of the photovoltaic cell. In this case, the photovoltaic current is expected to reach its maximum value, while the voltage between the two terminals (V_{sc}) is zero. The second parameter is of great importance when it comes to a photovoltaic cell with two terminals that are not connected. In this case, the cell appears as an open circuit and the photovoltaic current is shunted within the cell by the intrinsic diode of the PN junction and the voltage across the cell reaches its maximum value called the open-circuit voltage (V_{oc}), while the current in the external circuit is zero ($I_{oc} = 0A$). The manufacturer of the photovoltaic module usually supplies these two parameters in the module's data sheet.

The simplest model of a photovoltaic cell is that of Figure 2 [5-7], [8], [9]. It is based on an equivalent circuit consisting of an ideal current source connected in parallel with a diode, a shunt resistor (R_{sh}) and a series resistor (R_s).
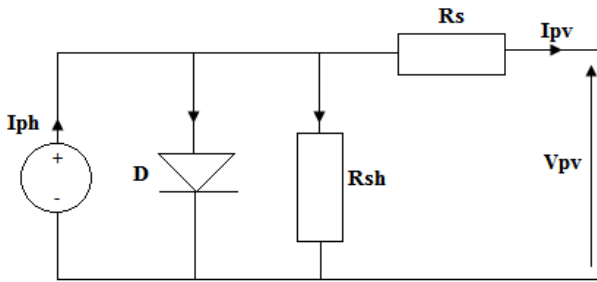

Fig. 2. Single-diode equivalent circuit of a PV cell.

However, a second model, where the equivalent circuit diagram is shown in Figure 3, is also adopted [10]. In this case, the electrical model is known as a double-diode model.

The current source, or insolation, in both equivalent circuit diagrams is represented by the photovoltaic current I_{ph}. The PV cell current I_{pv}, for both models, is given by equations 2 and 3, respectively [5, 8, 9, 10].

$$I_{pv} = I_{ph} - I_0 (e^{\frac{q(V_{pv}+R_s I_{pv})}{AKT}} - 1) - (\frac{V_{pv}+R_s I_{pv}}{R_{sh}}) \qquad (2)$$

$$I_{pv} = I_{ph} - I_{s1}(e^{\frac{q(V_{pv}+R_s I_{pv})}{AKT}} - 1) - I_{s2}(e^{\frac{q(V_{pv}+R_s I_{pv})}{AKT}} - 1) - (\frac{V_{pv}+R_s I_{pv}}{R_{sh}}) \qquad (3)$$

For the situation corresponding to the maximum power point (MPP), the current and voltage are respectively I_{mpp} and V_{mpp}. Accordingly, and based on equation (2), the following equation can be deduced:

$$I_{mpp} = I_{ph} - I_0(e^{\left(\frac{q(V_{mpp}+R_s I_{mpp})}{AKT}\right)} - 1) - \left(\frac{V_{mpp}+R_s I_{mpp}}{R_{sh}}\right) \qquad (4)$$
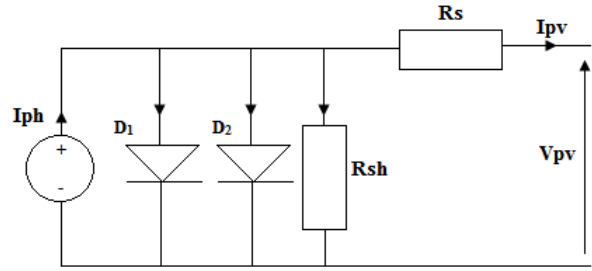

Fig. 3. Double-diode equivalent circuit of a PV cell.

The power delivered to the load and the quality factor of the diode that will make part of the modeling process are given respectively by [10]:

$$P_{PV} = I_{PV} V_{PV} \qquad (5)$$

$$A = \frac{V_{mpp} + I_{mpp}R_s - V_{co}}{V_T \left\{ Ln\left(I_{cc} - \frac{V_{mpp}}{R_{sh}} - I_{mpp}\right) - Ln\left(I_{cc} - \frac{V_{co}}{R}\right) + \frac{I_{mpp}}{I_{cc} - \frac{V_{co}}{R_s}} \right\}} \qquad (6)$$

It is noted that the short-circuit current given in a PV module datasheet is for standard test conditions of irradiance and air mass at a temperature of 25°C ($G_0 = 1000W/m^2$, 25°C, AM1.5). Accordingly, for any given irradiance G, the PV cell current is adjusted using the following equation [8]:

$$I_{sc/G} = \left(\frac{G}{G_0}\right)I_{sc/G_0} \qquad (7)$$

The model described by equation (3) was constructed using MATLAB/Simulink (Figure 4). It includes the parameters that affect the behaviour of the PV cell in terms of output current and voltage. Those parameters are: the radiation G, the temperature T (in Kelvin), the series resistance R_s and the shunt resistance R_{sh}. Figure 5 shows the effects of insolation variation.
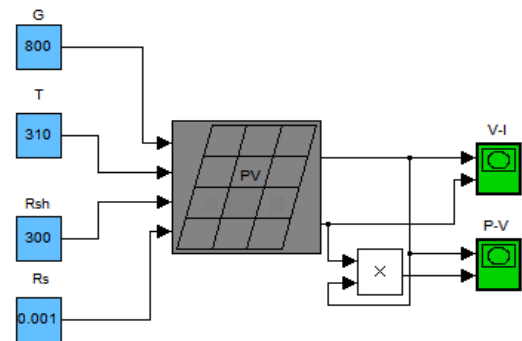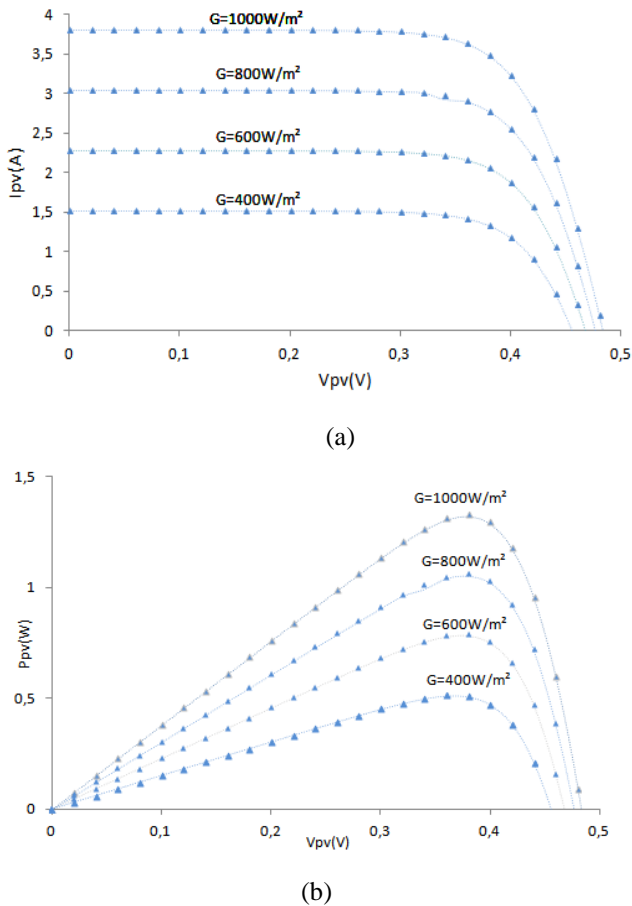

Fig. 4. Double-diode MATLAB/Simulink Model.

(a)

(b)

Fig. 5. Effect of insolation on cell output, (a): *I(V)*, (b):*P(V)*

3. P&O MPPT Algorithm analysis and implementation

As shown in figure 6, the P&O algorithm works on the idea of introducing perturbation to the system's operating point to generate maximum output power. The PV array is perturbed by adding small increments until the maximum power point is reached. Initially P1 (power output) is calculated by measuring the values of V1 and I1 of the solar module. Then a small perturbation is added in the form of ΔV. Then P2 is calculated by measuring the new values of V2 and I2. If the P2 reads positive, the system will keep perturbing in the same direction. Once P2 reads negative, the algorithm will bring the output power value back towards the maximum power point by adding a negative increment. When the maximum power point is reached, the system operating point will start to oscillate constantly around that maximum power point. The controller will track this operating point and try to bring the V of the solar module to perform on this maximum power point [5]. The controller, in this case would be in a DC-DC converter located along the DC module output.

The perturbation method is very simple to apply. However, it has some power losses due to the constant oscillation at the maximum power operating point. The literature also describes another disadvantage to the P&O method, which is that it doesn't give a stable response when there are rapid condition changes in irradiance levels [5]. The circuit models for the PV cell have been designed using

realistic parameters taken from manufacturer's data sheets and using the developed analytical approach. It is worth noting that the analytical model presented above is very useful for simulation and modelling of PV based systems.

Figure 7 shows the MATLAB/Simulink model of the MPPT connected to the DC-DC converter. It simplifies the mathematical computations and design of solar modules without altering physical parameters that are very well known for solar cells. Hence, the parameters derived even though purely mathematical, give an accurate description of the expected physical behaviour of a PV module and array. For different solar insulations, the point of the maximum power is tracked as shown in red in figure 8.
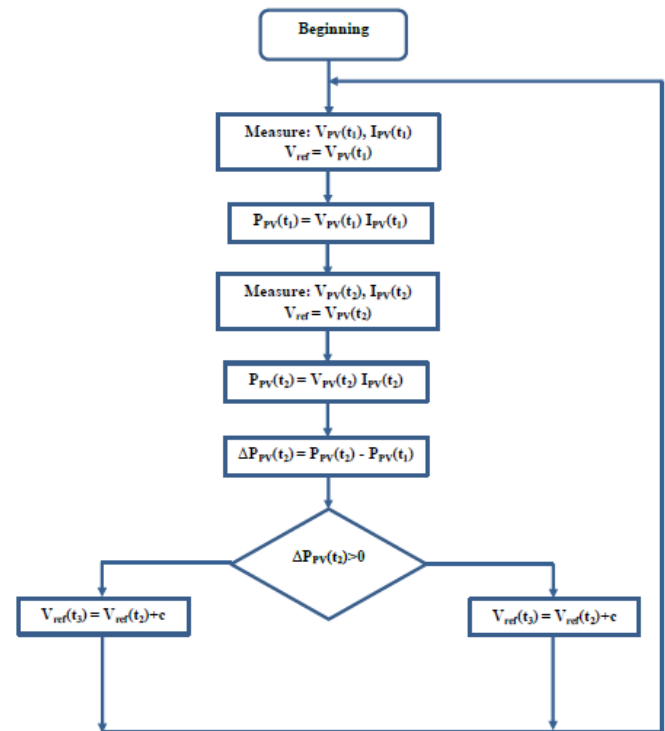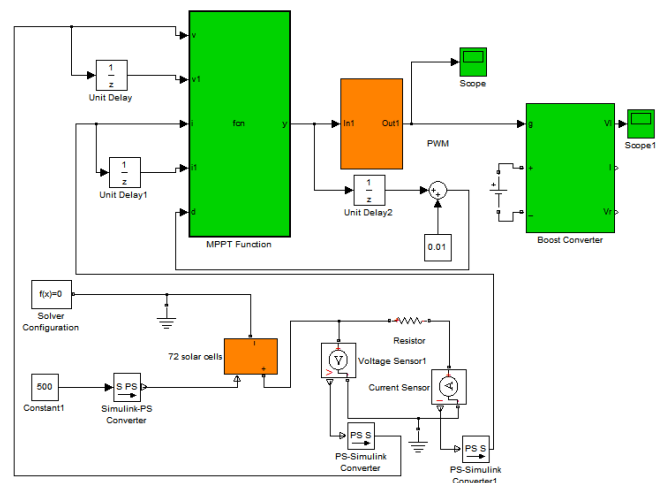

Fig. 6. P&O Algorithm flowchart.

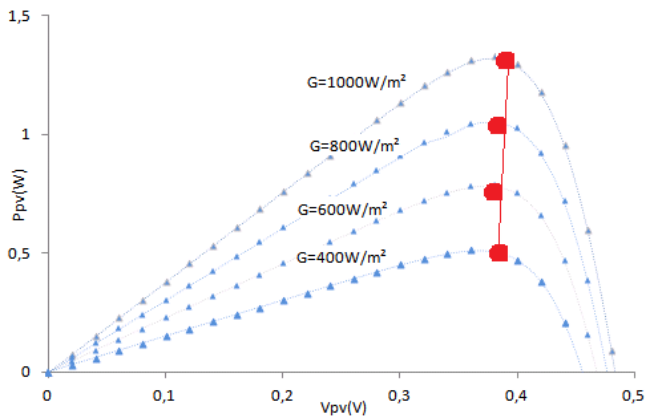**Fig. 7**. P&O MPPT MATLAB/Simulink Algorithm.

Fig. 8. MPP variation using the P&O algorithm and MATLAB/Simulink.

4. Conclusion

This paper deals with modeling a double-diode solar cell based on mathematical equations using MATLAB/Simulink. The focus of this research was specifically on the effects of varying insolation values. As expected, it was shown that the higher the radiation the more the extracted power. The second section of the paper was dedicated to implementing a unique perturb and observe algorithm to track and maintain the maximum power point or MPP. The results indicated that the MPP can be tracked and very nearly maintained. The results suggest that using this method, power output can be efficiently maximized and implementation in low-cost DC DC microcontrollers appears to be warranted. This implementation will be the focus of near future research works.

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