Modeling and Simulation of a Single-Diode Photovoltaic Cell Using MATLAB: Impact of Physical Parameters on Performance

Karim SALIM [1-2], Mohamed el fatah NEHAL[1-2]

[1] Tissemsilt University- AHMED BEN YAHIA ELWANCHARISSI, Algeria
[2] Materials Development and Characterization Laboratory, Department of Electronics, DJILLAILI LIABES University, BP89, Sidi Bel Abbés 22000, Algeria

*Corresponding author; Email: k.salim@univ-tissemsilt.dz

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ABSTRACT

This article presents the modeling and simulation of a single-diode photovoltaic (PV) cell using MATLAB. The electrical model allows for performance analysis of the PV cell by considering various physical and environmental parameters. A parametric study was conducted to evaluate the influence of temperature, irradiance, as well as series and shunt resistances on the current-voltage (I-V) characteristics of the cell. The results show that an increase in temperature leads to a rise in the short-circuit current (Isc) but a significant decrease in the open-circuit voltage (Voc), causing a shift of the maximum power point (Pmax) to lower values. Similarly, a decrease in irradiance proportionally reduces the generated current, negatively affecting the output power. The study also highlights the effects of parasitic resistances on the shape of the (I-V) curves and the overall efficiency of the cell. Finally, the impact of the diode quality factor is discussed, emphasizing its role in the energy performance of the system. These simulations help in understanding the real behavior of solar cells and optimizing their operation under varying conditions.

I. Introduction

The global energy transition and the pursuit of more sustainable renewable energy sources have generated increasing interest in photovoltaic (PV) systems [1]. To optimize both their design and operation, accurate modeling of solar cells has become a key area of focus. In this context, the MATLAB environment stands out as a powerful tool for the development, simulation, and analysis of photovoltaic models. With its robust numerical computation and graphical visualization capabilities, MATLAB enables precise representation of the performance of individual solar cells as well as the overall PV system under study.

This work is based on the single-diode electrical model, which is widely used to describe the behavior of photovoltaic cells. The model is implemented in MATLAB to analyze the influence of various physical and environmental parameters such as temperature, irradiance, series resistance, shunt resistance, and the diode

quality factor on the current-voltage (I-V) characteristics and the overall performance of the system.

The results obtained from the simulations are processed using well-defined comparison criteria and performance indicators. This analysis helps identify the operating conditions under which the photovoltaic system achieves optimal and cost-effective performance. Therefore, the main objective of this study is to evaluate the impact of these parameters on the efficiency of a modeled solar cell, with the aim of gaining deeper insight into its real-world behavior and improving its operational performance.

II. Solar Cell Modeling

For this study, a moderately complex model was employed, incorporating the temperature dependence of both the diode current and the reverse saturation current. The series resistance was included in the model, while the shunt resistance was not considered. A simple shunt diode, as shown in Fig.1, was used to achieve a better fit to the shape of the current–voltage (I-V) curve.

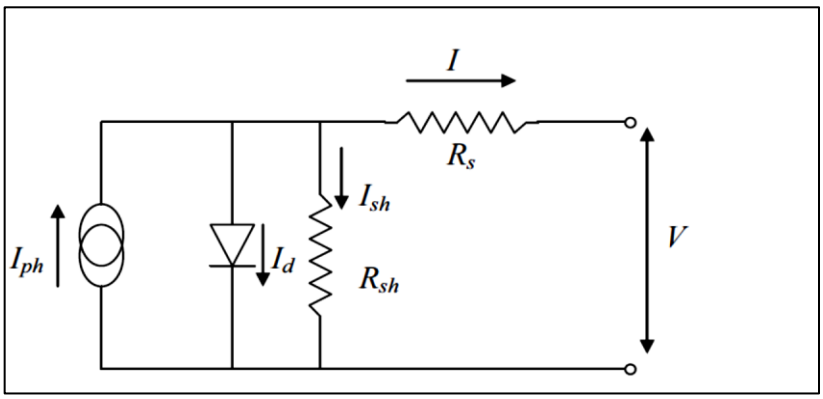


Figure 1. Equivalent circuit of a PV cell Single-diode model [2].

This model assumes that the dark current of a solar cell can be described by a single exponential dependence and a diode quality factor (see Equation 2). The parameter values in the equation must be determined in order to accurately reproduce the (I-V) curve. This requires a system of five-variable equations with five unknowns, which must be solved simultaneously to obtain the model parameters.

There are three key points on the (I-V) curve of a photovoltaic cell :

1. **Short-circuit current** : The current when the output terminals are shorted (V = 0), representing the maximum current the cell can deliver.
2. **Open-circuit voltage** : The voltage across the cell when the output current is zero (I = 0), representing the maximum voltage under illumination.
3. **Maximum power point** : The point on the curve where the product V×IV \times IV×I is maximized, corresponding to the optimal operating condition of the cell.

These points are critical for accurately modeling the behavior of the cell and for extracting the electrical parameters needed for simulation and performance evaluation.

The short-circuit point, the maximum power point, and the open-circuit point are the three key operating points on the I–V characteristic curve of a photovoltaic cell [3]:

$$I = I_{ph} - I_s\left[\exp\left\{\frac{q(V + IR_s)}{AKT}\right\} - 1\right] - \frac{V + R_s I}{R_{sh}} \quad (1)$$

Based on the equivalent circuit shown in Figure 1, the following equation can be written [4]:

$$I_{ph} = I_d + I + IR_{sh} \tag{2}$$

The current flowing through the shunt resistance Rsh, Rsh is given by [5]:

$$I_{Rsh} = \frac{V + IR_S}{R_{sh}} \tag{3}$$

The current through the diode is given by [6]:

$$I_d = I_s \times \left[e^{\frac{q \times (V + R_S I)}{AKT}} - 1 \right] \tag{4}$$

Where Is is the diode saturation current, given by [7]:

$$I_s = \frac{I_{cc}}{\exp(qV_{co} / AkT)} \tag{5}$$

Thus, the expression of the current–voltage (I–V) characteristic is [8]:

$$I = I_{ph} - I_s \left[\exp\left\{ \frac{q(V - R_s I}{AKT} \right\} - 1 \right] - \frac{V - R_s I}{R_{sh}} \tag{6}$$

All the constants in the equations above can be determined using the manufacturer's datasheet of the photovoltaic panels and the (I-V) characteristic curves. In this study, the ENIE Solar 75 W module (2013 model) is used to illustrate and validate the proposed model. The photocurrent is directly proportional to the irradiance.
When the cell is short-circuited, a negligible current flows through the diode. The relationship between the photocurrent and temperature is approximately linear (see Equation 4) and is derived by observing the change in photocurrent with respect to temperature variation.
In dark conditions, the (I-V) characteristic of the cell follows Shockley's diode equation, as only the dark current is present. When the illuminated cell operates under open-circuit conditions, the entire photocurrent flows through the diode [9]. The saturation current at 25 °C is calculated using the open-circuit voltage and the short-circuit current at that reference temperature. The series resistance of the module has a significant influence on the slope of the (I-V) characteristic, especially in the region where the cell behaves as a voltage source.

Table 1. Electrical characteristics of the ENIE Solar photovoltaic module (2013 model).

Puissance maximale (Pmax)	75 W +/- 10%
Tension à Pmax (Vmax)	17.3 W
Courant à Pmax (Imax)	4.05 A
Tension à circuit ouvert (Vco)	21.6 V
Courant de court-circuit (Icc)	4.67 A
Tension maximal de circuit	760 V
Valeur minimal du fusible en série	10 A
NOCT (800 X/m2, 20 °C, AM1.5, 1m/s)	47°C

III. Results and Discussion

III.1 Current–Voltage and Power–Voltage Characteristics

A primary approach to evaluating the consistency of the model developed throughout this chapter is to analyze the shape of the current–voltage (I-V) and power–voltage (P-V) characteristics obtained using the equations of the electrical model presented in Figure.2. These curves provide insight into the behavior of the photovoltaic module and allow for verification of the model's ability to replicate the actual performance of the solar cell under standard test conditions.

To assess the proper functioning of the studied model, simulations were carried out to evaluate the effects of various parameters namely temperature and irradiance on the current–voltage (I-V) characteristics [10].

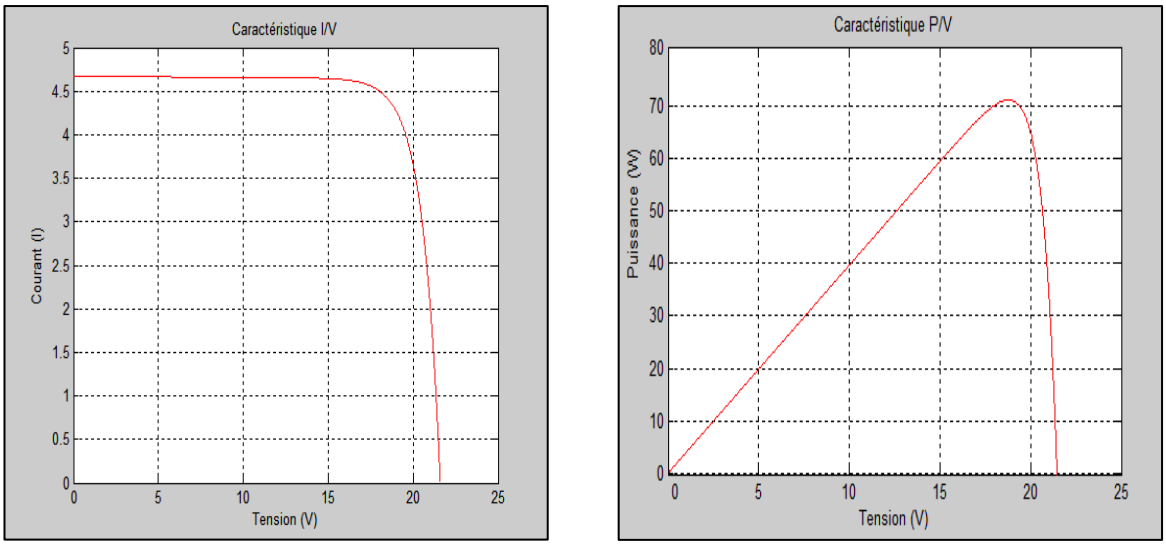
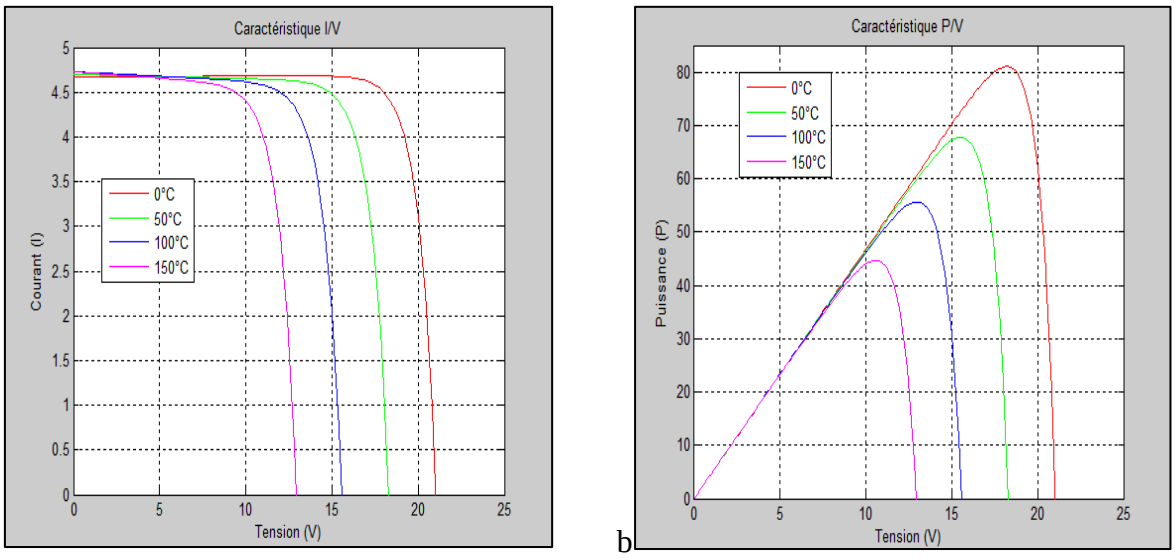


Figure 2: (I-V) and (P-V) characteristics of the photovoltaic generator.

III.2 Influence of Temperature



b

Figure 3: Influence of temperature on the (I-V) and (P-V) characteristics of the photovoltaic generator.

An increase in the junction temperature of solar cells leads to a significant rise in the dark current and slightly enhances the generation of electron–hole pairs [11]. Since the output current of the solar cell is equal to the difference between the photocurrent and the diode's dark current, there is a slight increase in the short-circuit current, accompanied by a notable decrease in the open-circuit voltage. As a result, the maximum power point shifts toward lower power values (see Figure.3) [11].

III.3 Influence of Irradiance

A decrease in solar irradiance leads to a reduction in the generation of electron–hole pairs, while the dark current remains unchanged. Since the output current of the solar cell is equal to the difference between the photocurrent and the diode's dark current, the short-circuit current decreases proportionally with the reduction in irradiance. This is accompanied by a very slight decrease in the open-circuit voltage, resulting in a shift of the maximum power point toward lower power values (see the graph below) [12].

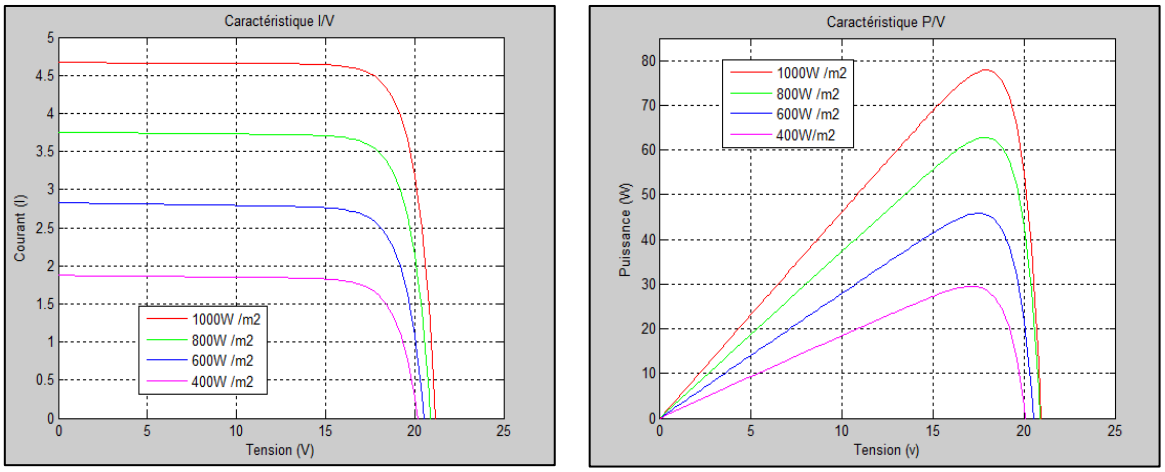


Figure 4. Influence of irradiance on the (I-V) and (P-V) characteristics of the photovoltaic generator.

III.4 Influence of Series Resistance

The series resistance represents the internal resistance of the solar cell. It mainly depends on the resistance of the semiconductor material, the contact resistance of the collector grids, and the resistivity of these grids. Fig.4 illustrates the effect of increasing series resistance on the I-V characteristic. This influence manifests as a decrease in the slope of the I-V curve in the region where the module operates as a voltage source, that is, to the right of the maximum power point [13].

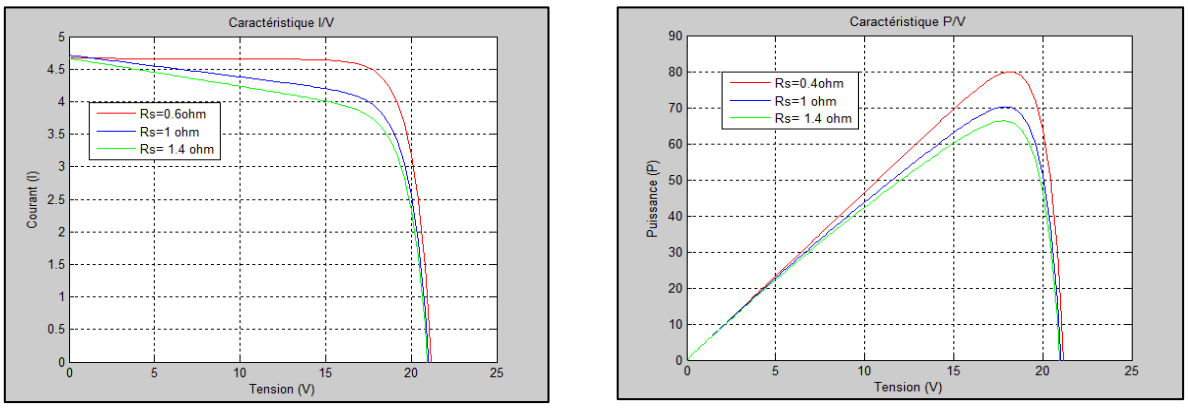


Figure 5. Influence of series resistance on the (I-V) and (P-V) characteristics of the photovoltaic generator.

III.5 Influence of Shunt Resistance

The shunt resistance accounts for the inevitable leakage currents that occur between the opposite terminals of a photovoltaic cell [14]. This resistance is directly related to the manufacturing process, and its effect becomes noticeable primarily at very low current values near the short-circuit current. Figure. 6 shows that this influence results in an increase in the slope of the (I-V) curve in the region where the module operates as a current source [14].

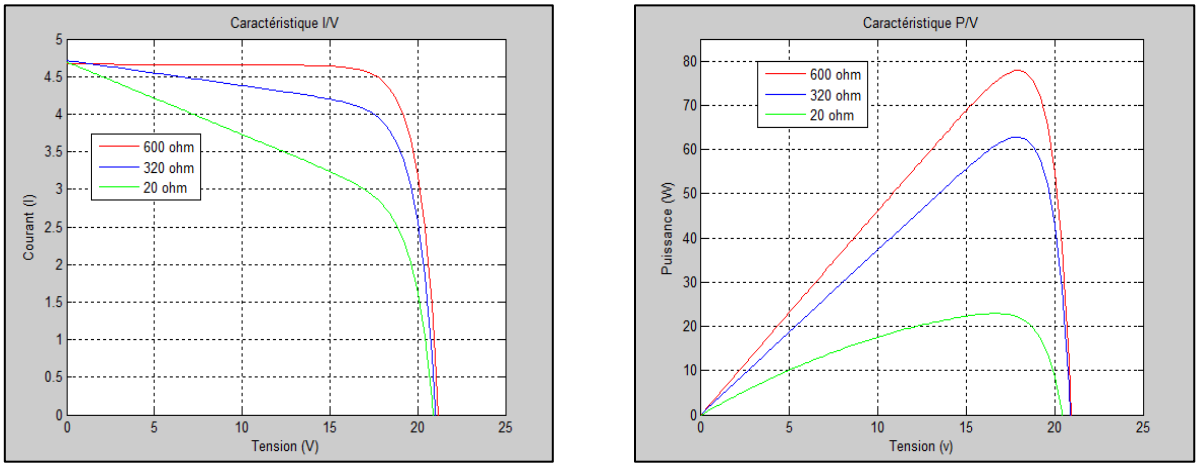


Figure .6 Influence of shunt resistance on the (I-V) and (P-V) characteristics of the photovoltaic generator.

III.6 Influence of the Diode Ideality Factor

An increase in the ideality factor leads to higher recombination losses within the junction, which negatively impacts the electrical behavior of the PV cell [15]. Specifically, as n increases, the diode's forward current increases more rapidly for a given voltage, which causes a reduction in the open-circuit voltage. Since the output power of a PV cell is the product of current and voltage, a drop in voltage—especially near the maximum power point (MPP) translates to a significant reduction in power output. This shift is clearly observed in the (I-V) and (P-V) characteristics, where the maximum power point is displaced toward lower voltage and power valus, as illustrated in Figure.7. Therefore, minimizing the diode ideality factor through improved cell design and manufacturing processes is essential for enhancing the overall performance and energy yield of photovoltaic systems [15].

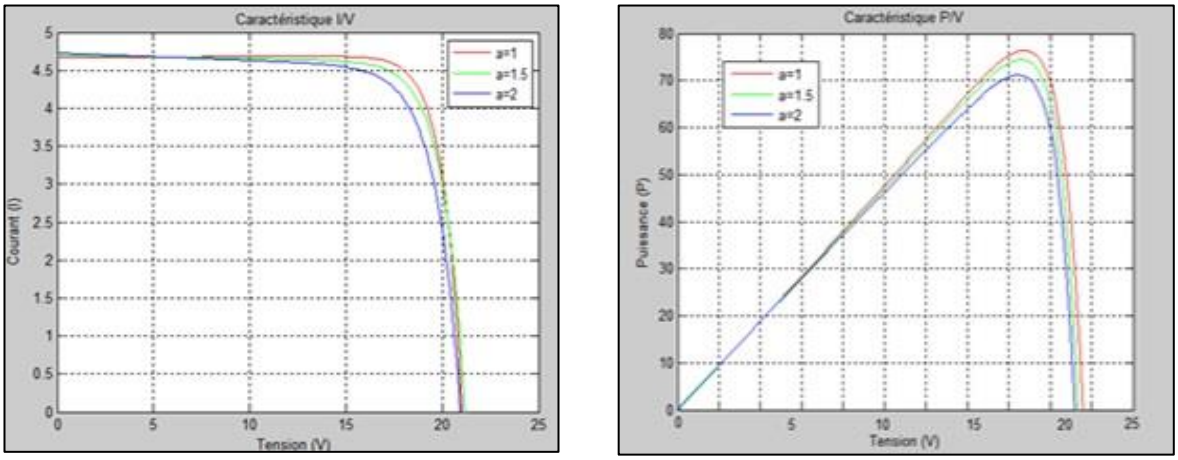


Figure. 7. Influence of the diode ideality factor on the (I-V) and (P-V) characteristics of the photovoltaic generator.

IV. Conclusion

In this study, a single-diode model was implemented using MATLAB to simulate and analyze the electrical behavior of a photovoltaic (PV) cell. The influence of key physical and environmental parameters including temperature, irradiance, series resistance, shunt resistance, and the diode ideality factor on the I-V and P-V characteristics was thoroughly investigated. Simulation results have shown that increases in temperature significantly reduce the open-circuit voltage, slightly increase the short-circuit current, and ultimately lower the maximum power output. Similarly, reductions in irradiance lead to proportional decreases in photocurrent and power output. The effects of internal resistances were also highlighted: higher series resistance lowers the fill factor and reduces efficiency, while low shunt resistance increases leakage currents and degrades performance. Additionally, an increase in the diode ideality factor was found to negatively impact the maximum power point. Overall, the modeling approach provides a reliable tool for evaluating PV cell performance under various operating conditions. Such analysis is essential for optimizing the design and deployment of photovoltaic systems in real-world applications, contributing to the broader goal of efficient and sustainable energy generation.

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