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Experimental analysis and Modeling of Performances of Silicon Photovoltaic Modules under the Climatic Conditions of Agadir

*Abdellah Tihane[1], Mohamed Boulaid[1], Lahbib Boughamrane[1], M'barek Nya[1], Ahmed Ihlal[1].

[1]*Materials and renewable energies laboratory, Department of Physics Faculty of science, Ibn Zohr University Agadir, Morocco*
Corresponding Author: Abdellah Tihane

Abstract. *In this paper we present an experimental and modeling study of three photovoltaic modules. The influence of weather conditions on the performances of the 3 modules is assessed. Some characterization tools have been developed to interpret functioning of photovoltaic cells while determining the limiting parameters. Our study is focusing on the assessment of the performance of three photovoltaic modules available in the market: Monocrystalline, polycrystalline and amorphous silicon. We have adopted a single diode model to determine the series resistance, the shunt resistance, diode ideality factor and the photo current. This is compared to our experimental data taken in conditions of the region of Agadir, a city in southwestern Morocco.*

Keywords: *Photovoltaic modules, mathematical model, internal parameters*

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I. Introduction

Photovoltaic (PV) systems are expected to be among the largest electricity generators by 2050. Indeed, dropping of modules and systems costs are behind the development of this technology around the world. More than 137 GW of capacity is installed right now. Cumulative installations of PV modules have been growing at an average reaching 45% in 2010. This trend might be maintained or even improved during the next years. However, such energy depends on several factors: the geographical location, the orientation of solar panels, irradiation, temperature and others. Sizing a PV plant is of a crucial matter. The behavior of a PV module depends on the type of material used and several external factors. A PV module is the series association of several PV cells to increase the voltage, which can be connected in parallel to increase the current. Thus, if all the cells are identical, the resulting IV curve will be readily determined by summing the voltages of each cell. This is rarely encountered in real testing conditions, so the I-V curve depends on a complex combination of individual behavior of each cell. Several works have developed some models to study the effects of non-identical cells which are not exposed to the same conditions within a PV module [1, 2]. These effects influence the performance of a PV module. In this paper a comparative study of the performances of 3 PV modules was performed. In the first part, we focus will on the outdoor experimental characterization of PV modules in order to compare different technologies, and we modelize the I-V curves under different conditions of light and temperature.

II. Characterization And Modeling

Modeling is often described by the current-voltage characteristic which informs on the internal electrical mechanisms and technological imperfections of the fabrication [3, 4]. Whatever the model used (single diode or two diodes), the I-V characteristic depends on several electrical parameters, such as the shunt resistance R_{Sh}, the series resistance, R_S, the saturation current of the diode, I_0, and the ideality factor. The last is given by the formula $f = N_{SC} n k_B T_C / q$. N_{SC} is the number of solar cells or photovoltaic modules, n is the diode ideality factor or quality, k_B represents the Boltzmann constant, q is the electron charge and T_c represents the temperature of the solar cell or PV module in Kelvin [5].

The precise determination of all these parameters help to figure out and explain certain electrical phenomenon in these junctions [6, 7] in order to improve their performance in manufacturing and designing appropriate devices for well-defined specifications in terms of reliability, performance and consumption.

Methods of extraction parameters are numerous; they may be graphical, analytical or numerical. Each of these methods has its own, accuracy and complexity.

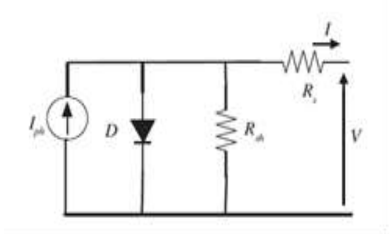
2.1 Modeling of a photovoltaic module

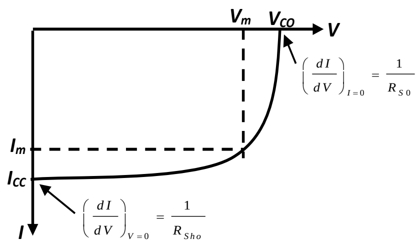
Many electric models are available in the literature to model I-V curves of PV modules, especially the simple diode model [2, 8] and the double-diode model that provides better accuracy while making it more complex modeling [9, 10]. We use first model in this study. The major advantage of the use of the model to a single diode compared to the model with two or three diodes is to simplify the equivalent circuit, and to reduce the number of equations to solve, and then calculate the parameters characterizing the operation of the PV module. The equivalent circuit is displayed in Figure 1. The characteristic equation corresponding to the simple diode model is given by equation (1):

$$I(V) = I_0\left(\exp\left(\frac{V-R_sI}{nV_{th}}\right)-1\right)+\frac{V-R_sI}{R_{sh}}-I_{ph} \qquad (1)$$

To extract the physical parameters R_s, R_{sh}, n, I_0 and I_{ph}, a system of five equations is established by choosing three specific points of the characteristic $I(V)$: $(0, I_{cc})$, $(V_{co}, 0)$ and (V_m, I_m) as shown in Figure 2.
Using equations associated with the pairs (I, V), we obtain the following equations:

$$I_{0DR}\left(\exp\frac{V_{co}}{nV_t}-\exp\frac{R_sI_{cc}}{nV_t}\right)+\frac{V_{co}}{R_{sh}}-I_{cc}\left(1+\frac{R_s}{R_{sh}}\right)=0 \qquad (2)$$





(a) (b)

Fig. 1.a. Equivalent circuit of a solar cell developed according the first model.

Fig. 1.b. Theoretical I -V Characteristic of a solar cell used to extract the parameters R_s, R_{sh}, n, I_0 and I_{ph}, the curve is plotted according to aquation 1.

$$I_{0DR}\left(\exp\frac{V_{co}}{nV_t}-\exp\frac{V_m+R_sI_m}{nV_t}\right)+\frac{V_{co}-V_m}{R_{sh}}-I_m\left(1+\frac{R_s}{R_{sh}}\right)=0 \qquad (3)$$

By deriving I as a function of V in open-circuit ($(dI/dV)_{V=0}$), and in short circuit ($(dI/dV)_{I=0}$), we obtain the following equations:

$$(R_{s0}+R_s)\left(\frac{1}{R_{sh}}+\frac{I_{0DR}}{nV_t}\exp\frac{V_{co}}{nV_t}\right)-1=0 \qquad (4)$$

$$\frac{1}{R_{sh}}-\frac{1}{R_{sho}-R_s}+\frac{I_{0DR}}{nV_t}\exp\frac{R_sI_{cc}}{nV_t}=0 \qquad (5)$$

The values $(dI/dV)_{I=0}$, $(dI/dV)_{V=0}$ V_{co}, I_{cc} I_{max} and V_{max}, are experimentally determined and injected into the system of equations.

2.2 Testing of photovoltaic modules

The data used in this study were recorded by a data acquisition system developed in our laboratory. Figure 3 illustrates a simplified schema of this system[12]. The setup has been based on some sensors: voltage, current, temperature and irradiation. An Arduino board is used to control the variable electronic resistor we realized and acquire data from the various sensors and send them to the computer.

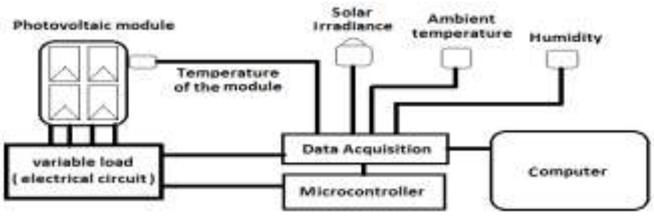


Fig. 2. Acquisition system installed to identify internal parameters of photovoltaic modules [12].

In order to measure the parameters of the tested PV modules, the experimental device has been recently installed on the roof of "Materials and Renewable Energies Laboratory" at the faculty of sciences of Agadir, with 30,406 North in longitude and 9,544 West in latitude. The climate is typically mild-coastal with usually low rainfalls. The outdoor station consists of three PV modules: crystalline, polycrystalline and amorphous silicon (Figure 4), each one represents specific technological and electrical characteristics as displayed in Table 1. The modules are installed on fixed mounting structures, at a 30° tilt angle facing the South.

Fig. 3. Picture of the tested photovoltaic modules. From the left to the right: polycrystalline, monocrystalline and amorphous silicon modules.

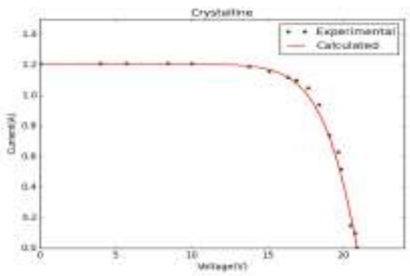
Table 1. Different characteristics of the tested PV modules.

Nominal characteristics	**Modules**		
	C-Si ET Solar ET-53630	**Poly-Si bp Solar SX-330J**	**a-Si FREE 14-12 Solar panel**
Nominal Power,[Wp]	30	30	14
Area, [m^2]	0,1881	0,23393	0,2610
Open circuit voltage, [V]	21,52	21	22
Short circuit current, [A]	1,80	1,94	1,05
Voltage at max power, [V]	17,72	16,8	16
Current at max power,[A]	1,69	1,78	0,87

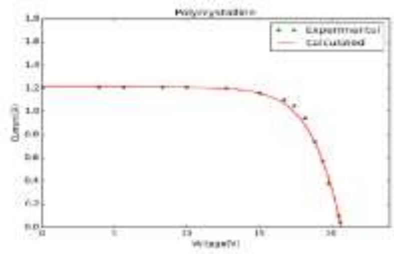
III. Results And Discussion

3.1 Modeling characteristics-five-parameter model

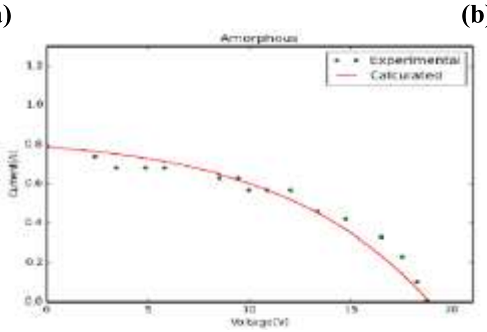
In Figures 5, 6 and 7, we present the experimental and modeled I-V characteristics of various photovoltaic modules. The solution of the system of equations is based on the Newton-Raphson method. The extracted parameters of photovoltaic modules are gathered in the following table 2:



(a)



(b)



(c)

Fig. 4.a. The Current-voltage I-V characteristics of the monocrystalline photovoltaic modules.
Fig. 4.b. The current-voltage characteristics of the polycrystalline photovoltaic module.

Fig. 4.c. The current-voltage characteristics of the amorphous photovoltaic module.

TABLE 2. Different Modeling extracted parameters.

	I_{ph}(A)	I_0(A)	Rs(Ω)	R_{sh}(Ω)	n
C-Si	1.0399	$1.24761e^{-5}$	0.114453	$1.37311e^{+9}$	65.653
P-Si	1.9063	$5.8958e^{-4}$	0.274625	$2.65768e^{+9}$	92.393
a-Si	0.6895	0.019968	0.162357	$8.71954e^{+12}$	203.97

Table 3. Experiment calculated data values.

	I_{pm}(A)	V_{pm}(V)	P_{max}(W)	I_{sc}(A)	V_{oc}(V)	FF	η%
P-Si	1.1	16.72	18.4	1.2	20.58	0.745	16.7
C-Si	1.1	16.87	18.56	1.21	20.87	0.734	19.42
a-Si	0.42	14.73	6.19	0.8	18.7	0.413	3.86

We present in figures 5, 6 and 7 some examples of measured and modeled curves I-V and in tables 2 and 3, the parameters calculated based on experimental data (temperature, irradiation ...) which are of the same size order than those given by the manufacturer. We note that the single diode model is in good agreement with the experimental data for polycrystalline and monocrystalline modules.

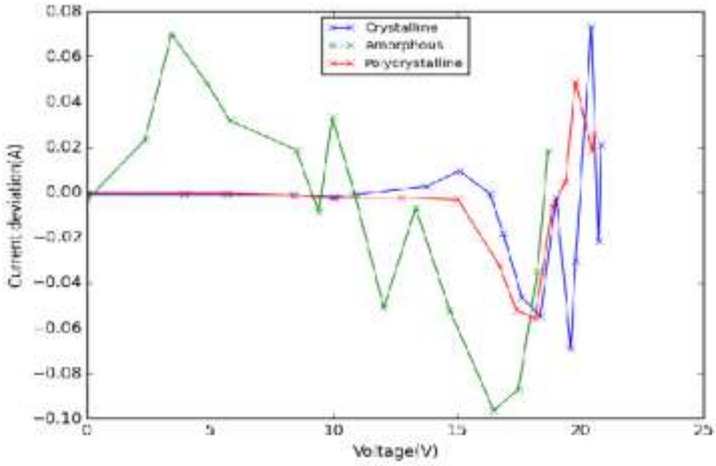


Fig. 5. Current deviation between the experimental and calculated characteristics.

Figure 8 shows the difference between the measured and calculated current for all values of associated tensions represented in the I-V characteristics. The study of the current deviation shows a good agreement between the experimental and calculated characteristics, especially for polycrystalline and monocrystalline modules.

3.2 Effects of radiation intensity and temperature

Figures 9, 10 and 11 show the evolution of the performance of photovoltaic modules studied in terms of temperature and irradiation under real test condition after modeling.

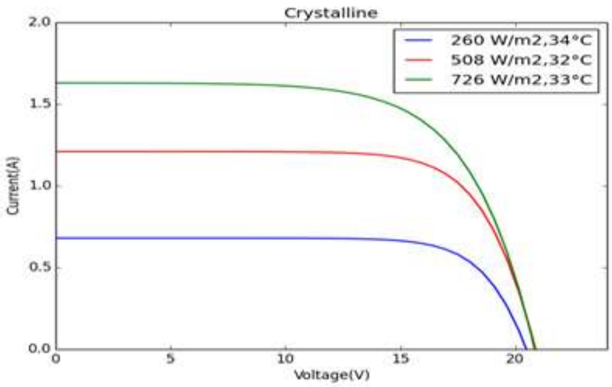


Fig. 6. I-V characteristics of the crystalline photovoltaic module.

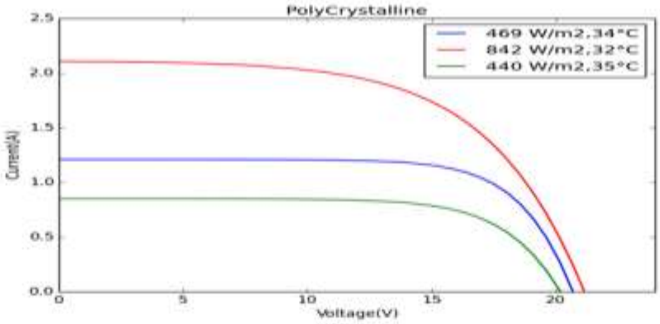


Fig. 7. I-V characteristics of the polycrystalline photovoltaic module.

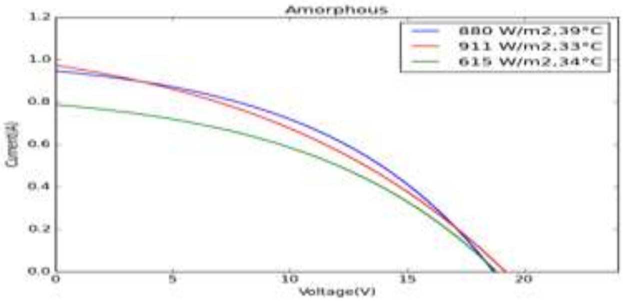


Fig. 8. I-V characteristics of the amorphous photovoltaic module.

From the curves we can see that the radiation strongly affect the current and that the influence of temperature on the voltage is negligible.

IV. Conclusion

This paper was devoted to the modeling and experimental analysis of the performance of three photovoltaic silicon modules manufactured by different technologies (monocrystalline, polycrystalline and amorphous). We have used iterative method of Newton to solve the system of equations obtained from a single exponential model to calculate the internal parameters of each photovoltaic module. The conclusion to make about our study is that a single diode model is satisfactory to describe the behavior of the modules studied under different climatic conditions in the region of Agadir. Experimental results show that the crystalline module is more efficient which is consistent with the data provided by the manufacturer. In our next studies, we plan to model experimental data using two or three diodes in order to make a comparative study between the different modules.

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