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Comparison between single-diode and two diodes models of a grid connected PV technologies: numerical study and experimental validation

L. Bouhaki, R. Saadani, M. Rahmoune
Laboratory of Advanced Study of Materials and applications (LEM2A), Moulay Ismail University,
Superior School of Technology, Morocco

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ABSTRACT

This article presents a simulation model comparison between a diode and two diodes of a photovoltaic cell. The simulation model created under the Matlab-Simulink environment predicts annual performances of the three photovoltaic field technologies connected to the grid. The simulation models have been validated by the experimental data of the photovoltaic system in the meteorological conditions of the city of Meknes. The interest is to inspect the closest model that allows to obtain more reliable results in order to follow the performances and the operation of the installation in the coming years, Also to compare between the efficiency of the three photovoltaic technologies (monocrystalline, polycrystalline and amorphous) in the same climatic conditions of Meknes city in Morocco which is a Mediterranean climate with very cold winters and very hot summer.

Corresponding Author:

Lamiae Bouhaki
Laboratoire d'Etude des Matériaux Avancés et Applications (LEM2A), Université Moulay Ismail, Faculté des sciences, Ecole Supérieure de Technologie Meknès,
Km 5, Rue Agouray, Meknes, 50040/B. P: 3103-Toulal, Morocco.
Email: lamiae.bouhaki1@gmail.com

1. INTRODUCTION

In 2017, according to preliminary estimates by the IEA, global energy demand grew by 2.1%, which is the double growth rate in the previous year [1]. Global energy demand reached about 14050 million tons of oil equivalent (Mtoe) compared to 10 035 Mtoe in 2000 [1, 2]. Natural gas demand reaches a record 22% of total energy, also Renewable energy grew by a quarter of global energy demand, while nuclear use accounted for 2% of the growth. In 2017, the total share of fossil fuels in energy demand reached 81%, this percentage remains stable over the past ten years even if the increase of renewable energies. the growth in global energy demand has been concentrated in Asia, China and India account for 40% of the increase. [3] Energy demand in all advanced economies accounted for more than 20% of global energy demand growth, although their share of total energy consumption decreased. An Important growth was also recorded in Southeast Asia (which accounted for 8% of global energy demand growth) and Africa (6%) [4, 5], although per capita energy consumption in these regions is still well below the global average

Nowadays, Renewable energy accounts for 25% of global electricity production [6]. China and the United States accounted for half of the increase in sales of this energy [7]. The growth of wind and photovoltaic solar energy in 2017 was unprecedented [8]; Wind energy recorded a growth of 36%, followed by photovoltaic solar (27%), hydropower (22%) and bioenergy (12%). China accounted for 40% of the combined growth of wind and solar photovoltaic energy, with record capacity additions and a reduction in the compression ratio. Nearly 40% of the increase in hydroelectric power took place in the United States, while climatic conditions in the European Union reduced hydroelectricity production by almost a tenth [9, 10].

The energy transition has become a strategy for many countries in recent years. The transition from fossil fuels to renewable energies is a constraint (administrative, political, technical barriers, financial but also in terms of professional skills) and a real opportunity (job creation, economic development, increased access to energy, response to climate change) for countries that have appeared in such developments. The energy transition considers a good control of greenhouse gas emissions, which allows energy independence in the face of increasing energy demand [11]. In particular, Morocco is included in the «African locomotive of the energy transition», Since A few years ago, they occupying the COP (COP 22) in 2016, which built on ambitious goals for an energy strategy [12]. To reduce the energy dependence and the greenhouse gas emissions, the country aims to reach 52% of installed electricity capacity with renewable energy by 2030 [13].

The main objective of this study is to present a precise method, easy to follow the parameters that influence the operation of grid-connected photovoltaic plants, the validity of the two models is obtained by comparing the simulation results of one diode and that of two diodes with the experimental results of the Meknes site.

2. PRESENTATION OF THE PROPRE.MA PROJECT

2.1. The geographical coordinates of the city of Meknes

Meknes is a city located to the north of the kingdom, whose geographical coordinates are as follows latitude: 33°53 36 North, Longitude: 5°32 50 West and Altitude relative to sea level: 531 m, which has a subtropical climate, characterized by a very hot and humid summer period, and by a very cold winter period [14].

2.2. Photovoltaic Installation

The project installed within the ESTM consists of three south-facing photovoltaic technologies with an angle of bank of 30°, assumed to be close to optimal value to provide maximum annual yield, with an installed power of 2,040 kWc for monocrystalline, 2,040kWc for polycrystalline and 1,086kWc for amorphous [15].

2.3. Photovoltaic field

Monocrystalline and polycrystalline is composed of 8 panels in series, for amorphous consisting of two chains totaling 12 modules [15].

Figure 1. Monocrystalline panel

Figure 2. Amorphous panel

Figure 3. Polycrystalline panel

Table 1. Characteristic of the photovoltaic park

Photovoltaic installations	Polycristalline	Monocristalline	Amorphous
Number of strings per plane	1	1	2
Number of modules per string	8	8	6
Nominal Power	2040W	2040W	1860W
Tension open circuit (Voc)	304V	302,4	513V
Tension maximal (Vmax)	247,2V	251,2V	391,2
Short-circuit curent (Icc)	8,88A	8,66	5,12A
Maximal curent (Imax)	8,32A	8,15A	4,76A
Orientation		South	
Incline of panels		30°	

3. MATHEMATICAL MODEL OF A PHOTOVOLTAIC CELL

To find the model of the photovoltaic generator, it is first necessary to define the electrical circuit equivalent to this source. Many mathematical models have been developed to represent their very strongly non-linear behavior which results from that of semiconductor junctions which are the basis of their achievements [16]. This part compares two models of the GPV:

- Model with one diode,
- Model with two diodes.

3.1. One diode equivalent circuit

The equivalent plan of a photovoltaic cell, which corresponds to a generator of current I connected in parallel with a diode [16], two parasitic resistances are introduced in this diagram Rs series resistance is the internal resistance of the cell -Rsh shunt resistance is due to a leakage current at the junction [17-18], this is the model chosen for the simulation of the characteristics of photovoltaic panels.

$$I = (\Delta T.\mu + I_{cc}).\frac{G}{Gref} - I_0\left(exp^{\left(\frac{I.Rs+V}{Ns.A.n.T.K}\right)^{q}} - 1\right) - \frac{V+I.Rs}{Rp} \quad (1)$$

I_{sc} : Short circuit current (A),
μ_{sc}: Temperature coefficient supplied by the short-circuit current manufacturer (A/°C),
T : Operating temperature (K),
G : Solar irradiation (W/m²),
G_{ref}, T_{ref} : Solar irradiation reference and temperature.

3.2. Equivalent circuit of two diodes

The operation of a solar cell can be modelled by considering the equivalent electrical diagram below, this is the case of an ideal solar cell comprising a current source and two diodes in parallel [19]. The Iph current source models the photo current generated [20]. The branches of each diode represent the diffusion current in the base and the transmitter (Id1) respectively, and the recombinant generation current (Id2) in the Junction Space Load Area (ECA). To consider the case of a real solar cell, the equivalent circuit must include, A resistance series Rs, which models the resistive losses within the photo pile and therefore the metallization, a parallel resistance Rsh, modelling the currents that short-circuit the junction (leaks by the edges of the cell and at the junction) [21].
The output current is expressed as follows:

$$I = I_{ph} - I_{d1}\left[\left(exp^{\frac{q(V+(I*Rs))}{KT}}\right) - 1\right] - I_{d2}\left[\left(exp^{\frac{q(V+(I*Rs))}{\gamma KT}}\right) - 1\right] - \frac{V+(I*R_S)}{R_p} \quad (2)$$

I_{d1}: Current passing through diode d1 and d2.
I_{d2}: Reverse saturation current of diode d1 and d2.
I_{ph}: Photo-Solar cell current.
V: Thermodynamic potential of diode d1 and d2.
γ: Quality factor (: ideal junction, 1 2 depends on polarization, Schrockley model, recombinated by leakage currents).
Rs : The Resistance series.
R_p: The Shunt Resistance.

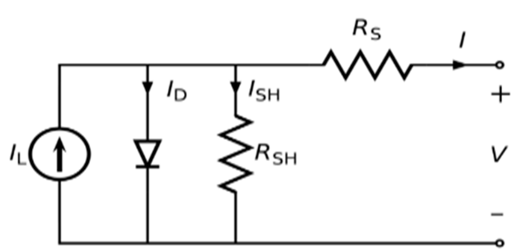

Figure 4. Equivalent circuit of a diode

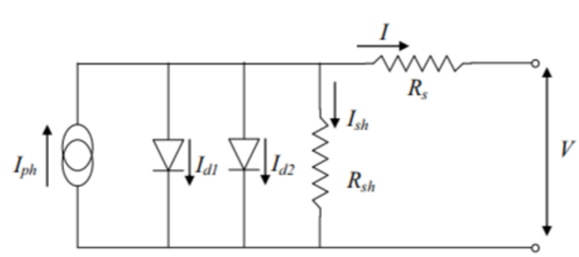

Figure 5. Equivalent circuit of two diodes

4. RESULTS AND DISCUSSION

4.1. Characteristic I-V, P-V

Under the Matlab-Simulink environment, a simulation model of the output current of a diode and two diodes as a function of voltage is devoloped in the form of subsystems [15].

The basic characteristic of the photovoltaic generator for a given irradiance and temperature is presented by the curve I = f (V). The load value within the generator limits will determine the operating point of the photovoltaic system.

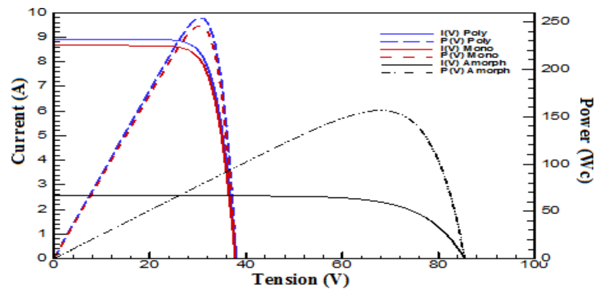

Figure 6. Characteristic I-V-P

We identify three areas:

- Zone I: Whatever the voltage for this region the current remains constant, so this zone the photovoltaic generator works as a current generator.
- Zone II: The intermediate region between the two zones corresponding to the bend of the characteristic which represents the preferred region for the operation of the generator, where the optimal point (MPP) [15] which is characterized by a maximum power can be determined.
- Zone III: This is the region which is distinguished by a current variation corresponding to an almost constant voltage, in this case the generator is similar to a voltage generator, This curve passes through a maximum which is the product of Imax * Vmax.

4.2. Comparative study between one-diode and two diode models.

After the simulation of grid-connected photovoltaic panels with Matlab / Simulink software [22]-[23], we compare the power generated by the PV systems, in order to have an approximate vision on the model closest to the results of the experience.

- ***Daily solar irradiation & Temperature***

Our acquisition system installed on the roof of the school building, allows us to recover the solar irradiation received on the panel, as well as the ambient temperature and the temperature of the cells.

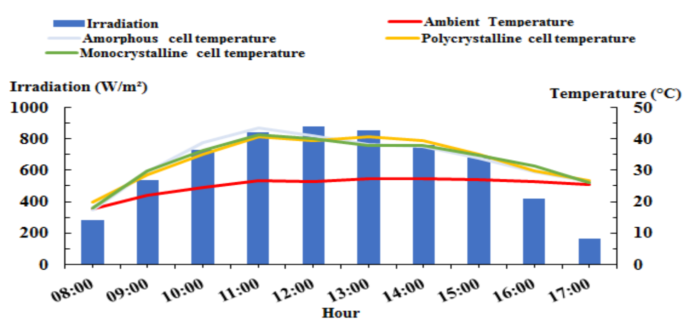

Figure 7. Irradiation and temperature profile for a particular day

According to the graph, it is recognized that solar irradiation reaches a maximum value of 880 W/m² at noon and the cell temperature follows the same rate of ambient temperature, the hourly solar radiation varies between a maximum at noon and a minimum at sunset and sunrise.

- ***Daily production profile***

In order to quantify the influence of solar irradiation and temperature on the operation of the PV system, we follow the productivity of these three photovoltaic panels (monocrystalline, polycrystalline and amorphous) during a day of the year, then we compared the simulated results in the case of a one diode and two diodes.

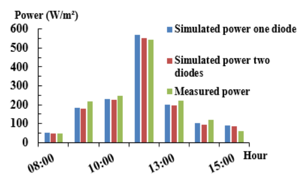

Figure 8. Output power of the monocrystalline panel for a typical day

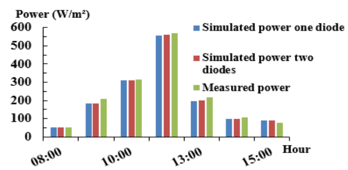

Figure 9. Output power of the polycrystalline panel for a typical day

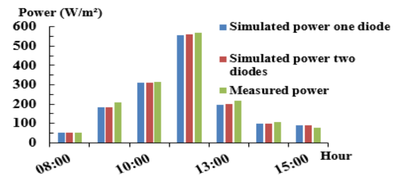

Figure 10. Output power of the amorphous panel for a typical day

The variation of the daily output power is presented in Fig.8-9-10. It can be seen that for high solar radiation, the a-Si and p-Si modules have an output power greater than that delivered by the a-Si, by against the a-Si module generates better output power for low solar radiation due to its better light absorption characteristic. For the models developed under Simulink, there is a good agreement between the results simulated by a single diode and two diodes and the experimental measurements.

- ***Monthly production profile***

In the following of this study we propose to generalize our modeling over three months of the year (October, January and May), the Fig11-12-13 shows the energy produced by the three PV technologies, using single diode and two diode models.

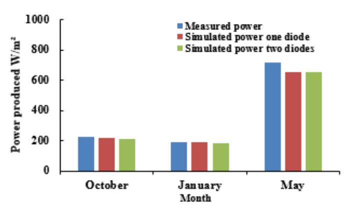

Figure 11. Production profile produced for monocrysttaline panel

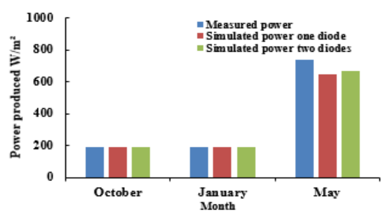

Figure 12. Production profile produced for polycristallin panel

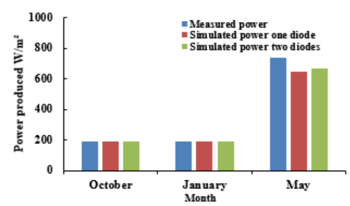

Figure 13. Production profile produced for amorphous panel

As shown in Figure 11, Figure 12 ad Figure 13, the production generally varies according to the irradiation received, the models developed under Simulink for a single diode and two diodes gives almost the same results.

5. CONCLUSION

In this article, we present the model that will allow us to monitor the operation of a photovoltaic installation connected to the grid which is the model with two models and the model with an only one diode, Based on the data from the data sheet of the photovoltaic installation taking place on the roof of the ESTM, the simulation is carried out based on the non-linear equation of the current, we determine the characteristics I-V and P-V of photovoltaic panels, the comparison between the results of the simulated output of a diode and two diodes gives a good accuracy.

Therefore, the choice of an equivalent electric model between these two models is based on a study of the characteristics of solar cells. The model with a single diode is more recommended because it saves parameters and calculation time.

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BIOGRAPHIES OF AUTHORS

Lamiae BOUHAKI is a Ph.D student at Moulay Ismail University. She received the Engineering Degree Energy at Faculty of Science and Technology. her Ph.D subject is about photovoltaic technologies.

Rachid SAADANI is a full professor at University Moulay Ismail, Morocco. Was born in Morocco in 1977. He received the MSc. Degree (Magister) in thermal and energetic system from the Université Marne La Vallée, Paris Est, Paris, France and the Ph.D degree in science for engineers from the Université Paris Est, Créteil, Paris. He is an active researcher at Thermal & Material Research Unit (advanced materials and energy system). His area of research includes Thermal Comfort, Building Thermal Simulation, renewable energy and Porous Media.

Miloud RAHMOUNE is a full professor at Moulay Ismail University. He received his Msc. Degree in applied mechanics from Université Montpellier 2 (France) and his Ph.D. degrees in Mechatronics from Université Montpellier 2 (France) and Université Hassan II – Mohammedia, in 1993 and 1996 respectively. His research interests include structural Dynamics, active control, and smart materials.