Simulation study of perovskite cell performance in real conditions of sub-Saharan Africa

Essodossomondom Anate[1], N'Detigma Kata[1,2], Hodo-Abalo Samah[1], Amadou Seidou Maiga[2]

[1] Faculté des Sciences et Techniques, Université de Kara, Togo.

[2] Laboratoire Électronique, Informatique, Télécommunication et Énergies Renouvelables,

Saint-Louis, Sénégal

Abstract. Perovskite is certainly the material of the future of photovoltaics for terrestrial applications. With high efficiencies and advances in stability, perovskite solar cells, modules and mini-modules have already made their appearance in the laboratory and are being tested under real-world conditions to evaluate their real performance. In our study, we predict the performance of perovskite-based photovoltaic panel technology under the conditions of the Sub-Saharan African region by simulation. We started from the current-voltage characteristic of a real perovskite-based module to extract the cell parameters through MATLAB analysis software. These parameters were used to model a cell and then a module in the LTSpice XVII software for simulation. The impact of temperature is studied to evaluate the performance ratio (PR) of a clear day. This study allowed us to evaluate the PR of the perovskite solar module. Displaying PR reaching 90%, perovskite is a future candidate with high potential in the list of the most suitable technologies for our sub-region.

Keywords: PV module, perovskite, simulation, extraction, performance ratio.

Introduction

This study is situated in the context of forecasting photovoltaic production in real sub-Saharan conditions. The challenge is to evaluate the influence of climatic factors, in particular temperature, on the photovoltaic performance of a perovskite-based solar photovoltaic module. To ensure the effectiveness of this new technology of photovoltaic panels in the sub-region, it is important to estimate their production in real conditions compared to standard test conditions (STC; 25°C and AM1.5 G with 1000W/m^2).

Considered as the "black gold" [1] for photovoltaic cells, the perovskite-based cell reached in 2020 an efficiency of 25.5% [2] in laboratory. The ease of its synthesis, its low production cost and its integration to various substrates make this technology one of the most accessible to a wide range of users. The crucial issue is its industrialization. Perovskite degrades at temperatures above 40°C and is soluble in water [1]. Several studies on these two aspects have been done and are being actively pursued: the introduction of 2-methylbenzimidazole (MBIm) by C. Longeaud between the electron transport layer (ETL) SnO_2 and the perovskite layer as a passivating layer has improved the stability of the cell [3], S. Sonmezoglu et S. Akin showed that the introduction of Triethyl Citrate (TEC) between the perovskite and PCBM forming the PCBM/TEC retained up to 84% of the cell performance after 1000 hours of exposure without encapsulation [4]. The improvement of the strontium titanate ($SrTiO_3$) electron transport layer by M. Neophytou et al. also shows this [5] etc. At present, perovskite-based modules/mini-modules are available in laboratories with yields, for a small module, of 17.9% (*Panasonic*) in 2020 [2] [6]. The same company having reached in May 2019 an efficiency of 16.1% with a module of 55 cells [7]. All these very encouraging results show the progress made in terms of stability and efficiency. This technology is

eagerly awaited to prove itself in real-life conditions and will soon appear on the world market. In view of all this, it seems obvious to foresee the efficiency of the perovskite solar cell technology in real conditions in the Sub-Saharan African zone.

We study the impact of temperature on the performance and the performance ratio of the perovskite solar cell in the climatic conditions of Sub-Saharan Africa. The results are presented and discussed in this paper.

Methodology

Figure 1 presents the flow chart of the method adopted to conduct our study.
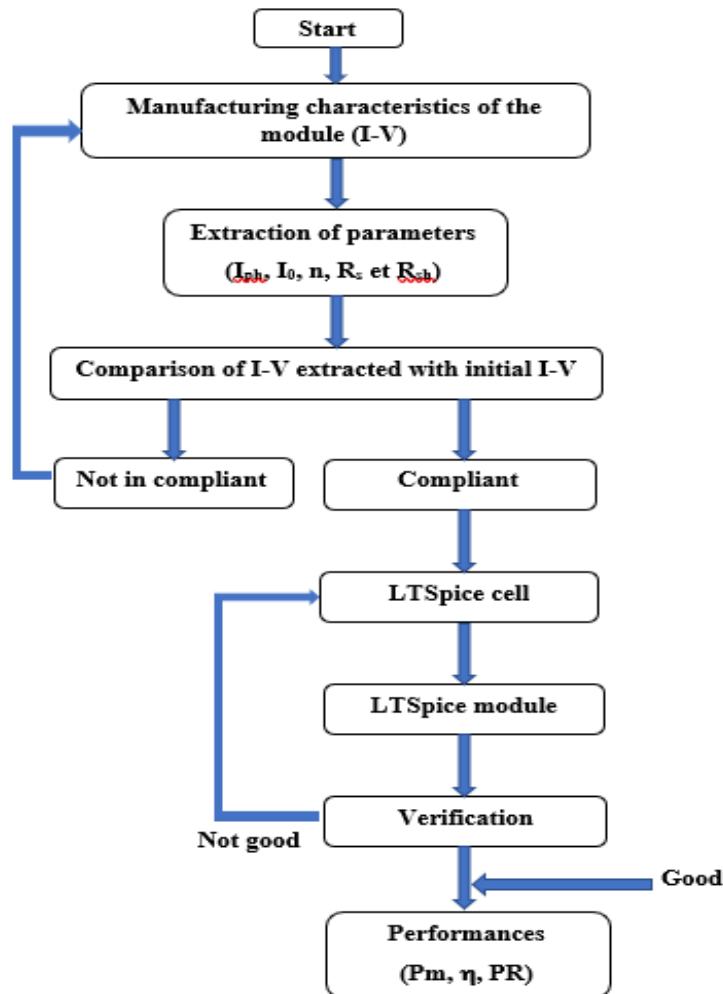

Figure 1. Organization chart of the study

From the current-voltage characteristic of the manufacturer Panasonic (Table 1.) [7], we extracted the data of the one-diode model with five parameters I_{ph}, I_0, n, R_s, and R_{sh}, respectively the photo-generated current, saturation current, ideality factor, series resistance and the parallel resistance to carry out our study. The hybrid Levenberg-Marquardt-analytical algorithm proposed by Kata et al. [8] is used to extract these parameters. This algorithm combines the analytical [9] and empirical method to calculate the initial values needed by the Levenberg-Marquardt algorithm making it not only fast and robust but also accurate as shown in [8].

Table 1. Manufacturing characteristics of the module

Open circuit voltage of the module (Voc)	57.3 V
Short circuit current (Isc)	321 mA
Module efficiency (η)	16.1 ± 0.5 %
Fill factor (FF)	70.3 %
Module area (S)	802 cm^2

At the end of the extraction the algorithm plots the I-V characteristic corresponding to the extracted data and compares it with the initial I-V characteristic. The algorithm resumes the extraction if there is no conformity of the new I-V characteristic with the initial one. In case of conformity, the data are collected to go to the next step.

This new step consists in modeling a photovoltaic cell in the LTSpice software. The algorithm at the beginning is adapted to the electrical model of the cell with one diode (figure 2.), it is thus this model which will be made in LTSpice, model which we call the "LTSpice cell". This model is shown in Figure 3. Using this model, the current delivered by the cell to a load is given by the equation (1).
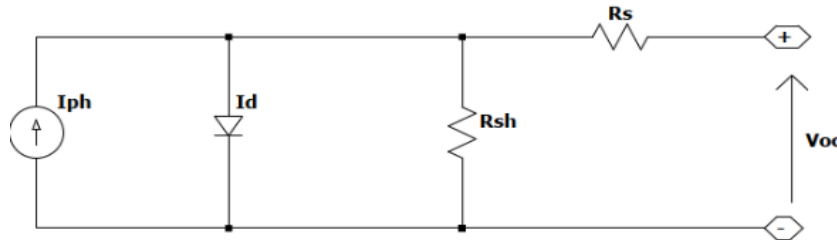
Figure 2. Electrical model equivalent to a diode of a solar cell

$$I = I_{ph} - I_0\left[exp(q\frac{V_{Cell}+I_{Cell}R_s}{nk_BT}) - 1\right] - \left(\frac{V_{Cell}+I_{Cell}R_s}{R_{sh}}\right) \qquad (1)$$

Where I_{ph} is the photo-generated current, I_0 the saturation current, n the ideality factor, T the temperature of the cell, q the elementary charge (1,602 *10^{-19}C), V_{Cell} the voltage at the terminals of the cell and k_B the Boltzmann constant (1,38*10^{-23}J/°K).
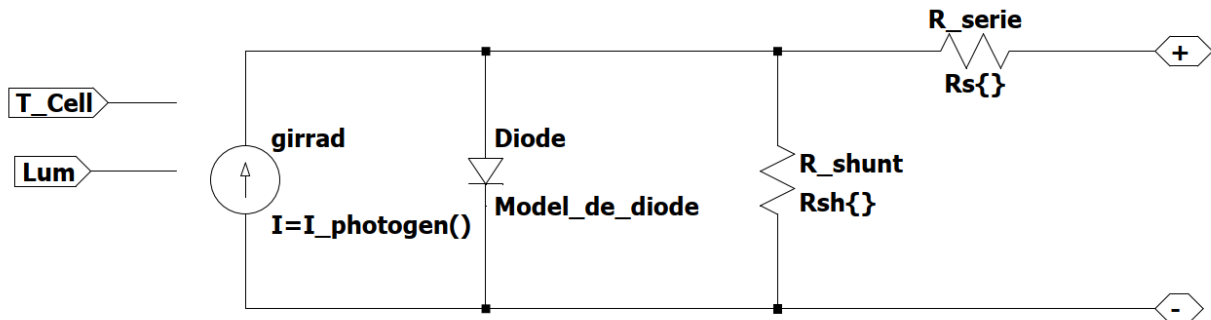
Figure 3. Behavioral model of a photovoltaic cell under LTSpice.

As the maximum power and the arrangement mode were not given, we obtained them (Table 2) by using the relation (2) for the maximum power and the relation (3) for the cell arrangement mode.

$$\eta_{STC} = {P_m}/{S_{Module*}} \; G_{STC} \qquad (2)$$

$$\begin{cases} I_{ph} = N_p * I_{scCell} \\ V_{oc} = N_s * V_{ocCell} \end{cases} \quad (3)$$

Table 2. Module details

Maximum power (Pm)	12.9 W
Arrangement of the cells	Serial

The LTSpice cells are then connected in series to form an LTSpice module.

It is in this module that we introduce the temperature and irradiance measurements. The measurements are made during a clear day with a measurement time step of 5 minutes on which we assume that the measured value is a constant.

Results and discussion

The real performance (η_{real}) of the LTSpice module is determined for each measurement of the day using equation (4). Like the yield, the performance ratio allows the comparison of performances between different technologies and also within the same technology with respect to the conditions in which they are installed. It is defined as the ratio between the real performance under real conditions and the performance under STC conditions (η_{STC}) in equation (5).

$$\eta_{réel} = \frac{P_{mréel}}{S * G_{réel}} \quad (4)$$

$$PR = \frac{\eta_{réel}}{\eta_{STC}} \quad (5)$$

Figure 4 shows the evolution of the performance ratio, temperature and irradiance as a function of time of day.
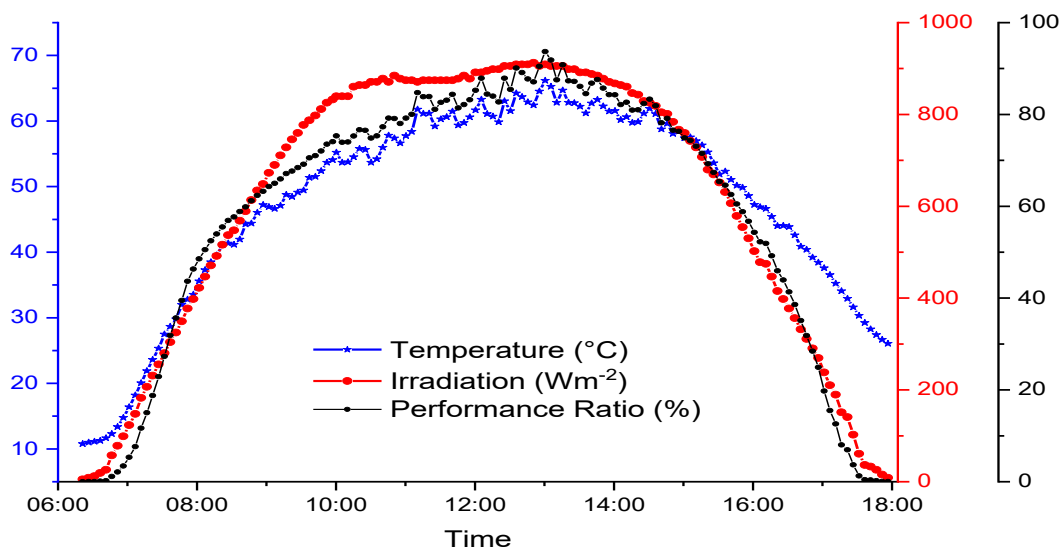

Figure 4. Evolution of the performance ratio during the day under clear sky

We can notice through the graph of figure 4 a performance ratio exceeding 70% between 10 am and 3 pm, period on which often appear high irradiation and high temperatures of the day. The highest PR is obtained at the highest temperature point of the day with of course an irradiation close to the maximum of the day. This means that the perovskite-based solar cell shows only a small decrease in efficiency with high temperature and thus agrees with the finding of Tress et al. in [10]. These results seem obvious when we know that perovskite is not very sensitive to temperatures above ambient [11]
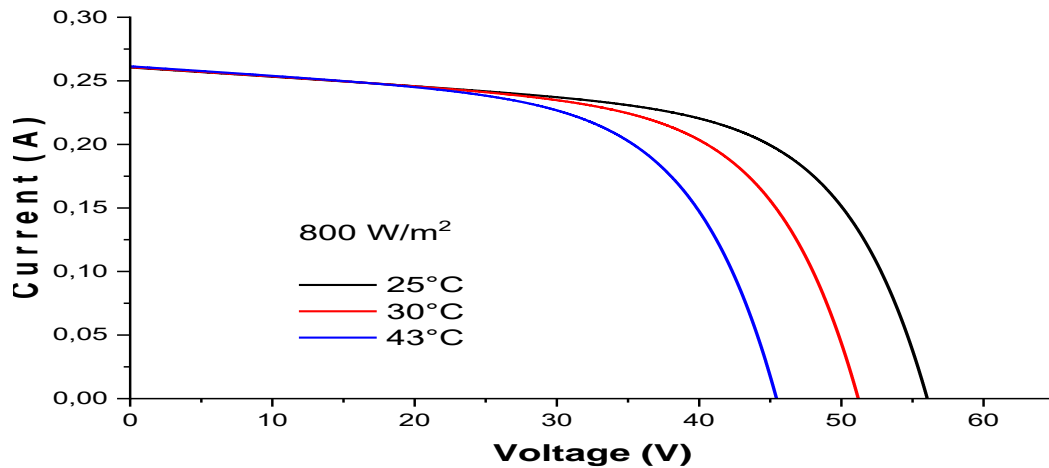
Figure 5. I-V curve showing the effect of temperature
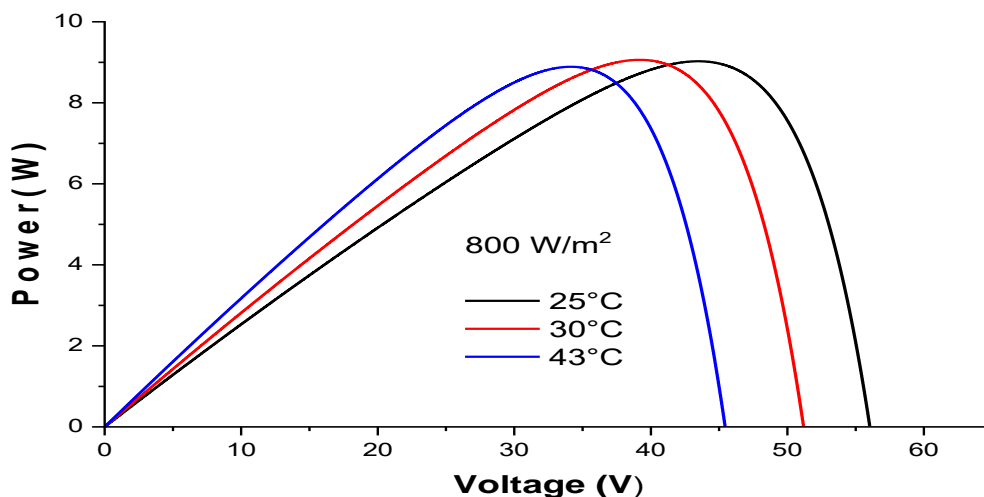
Figure 6. P-V curve showing the effect of temperature

We show here the effect of temperature on the voltage and also on the power. By fixing the irradiation we see that it is the voltage that is responsible for the decrease in performance when the temperature increases in the cell. The current remaining constant and a decreasing voltage leads to a decrease of the power according to equation (6).

$$P_m = V_m * I_m \qquad (6)$$

As shown by J. A. Schwenzer et al., the voltage decreases with temperature. This is justified by a negative temperature coefficient of the voltage. [12] [13]

Conclusion

In this paper we have evaluated the performance of a perovskite based photovoltaic module in the climatic conditions of Sub-Saharan Africa by simulation. We used the Levenberg-Marquardt-analytical hybrid extraction method proposed by Kata et al. to retrieve the data that allowed us to model a LTSpice PV module. Thus, we have collected the performances that we compare with those of the STC conditions. These results are inferior to those of STC conditions but remain encouraging for a young and very promising technology. With low temperature coefficients, perovskite is a potential future candidate of the most suitable technologies for our sub-region

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