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Parameters estimation of the single and double diode photovoltaic models using a Gauss–Seidel algorithm and analytical method: A comparative study

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ABSTRACT

In the photovoltaic (PV) panels modeling field, this paper presents a comparative study of two parameter estimation methods: the iterative method called Gauss Seidel, applied on the single diode model, and the analytical method used on the double diode model. These parameter estimation methods are based on the manufacturer's datasheets. They are also tested on three PV modules of different technologies: multicrystalline (kyocera KC200GT), monocrystalline (Shell SQ80), and thin film (Shell ST40). For the iterative method, five existing mathematical models classified from 1 to 5 are used to estimate the parameters of these PV modules under varying environmental conditions. Only two models of them are used for the analytical method. Each model is based on the combination of the photocurrent and the reverse saturation current's expressions in terms of temperature and irradiance. In addition, the results of the models' simulation are compared with the experimental data obtained from the PV modules' datasheets, in order to evaluate the accuracy of the models. The simulation shows that the I-V characteristics obtained are matching to the experimental data. In order to validate the reliability of the two methods, both the Absolute Error (AE) and the Root Mean Square Error (RMSE) were calculated. The results suggest that the analytical method can be very useful for monocrystalline and multicrystalline modules, but for the thin film module, the iterative method is the most suitable.

1. Introduction

1.1. Context

Like some countries, Morocco has experienced a great development regarding the production of solar energy, which is growing rapidly given its significant potential considered as a source of renewable energy. Since 2009, Morocco has put in place a 6000 MW plan of installed capacity, equally divided between wind, hydroelectric and solar energy [1]. This includes the Moroccan solar plan, a 2000 MW solar power project launched on November 2, 2009[2]. In the middle of COP22 (Conference Of Parties) in Marrakech, Morocco's ambitions for renewable energies are being realized. Renewable energies reaching 42% of installed capacity will meet our needs for the year 2020, with an estimate of 52% for 2030 [3]. Morocco is one of the countries of Africa that were selected for the installation of large solar power plants with two predisposing conditions: the first is that it has a strong and daily solar insolation, especially in the southern regions, the second is that the National Office of Electricity and Potable Water (ONEE) tariff becomes more expensive as the consumption increases. For example, Noor I solar power plant near Ouarzazate, which has been in operation since February 2016, is the first installment of a 160 MW solar power plant that has just been put into production [3,4]. Noor I is the first step in a much larger project that is expected to provide electricity to one million households. This project uses half a million solar panels 12 m high. Three other units, which are part of the project Noor, are being constructed: Noor II, III and IV which can produce, respectively, 200 MW, 150 MW, and 80 MW [1,4]. Noor would then become the largest solar complex in the world with a total capacity of 580 MW [3]. MASEN (the Moroccan Agency for Sustainable Energy) aims to pilot the five sites that have been identified to house the facilities [2]. These sites are Ouarzazate pilot site (500 MW) which was expected to generate a total of 1150 GWh by 2015, the Ain Beni Mathar site, which in principle had to be the second site to be constructed, with a total capacity of 470 MW [4], the third site is Foum el-Oued

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Nomenclature

PV	photovoltaic
STC	standard test conditions (T_n = 25 °C and G_n = 1000 W/m^2)
I	output current (A)
I_d	diode current (A)
I_0	diode reverse saturation current (A)
I_{ph}	photocurrent generated by the module (A)
I_{phn}	photocurrent current at STC (A)
I_{0n}	diode reverse saturation current at STC (A)
I_{sc}	short circuit current at (A)
I_{01}	reverse saturation current of 1st diode in double diode PV cell model (A)
I_{02}	reverse saturation current of 2nd diode in double diode PV cell model (A)
I_{scn}	short circuit current at STC (A)
V	the output voltage (V)
V_t	thermal voltage (V)
V_{tn}	thermal voltage at STC (V)
V_{oc}	open circuit voltage (V)
V_{ocn}	open circuit voltage at STC (V)
K	Boltzmann's constant (=1.3806 × 10^{-23} J/K)
K_I	current temperature coefficient (A/°C)
K_v	voltage temperature coefficient (V/°C)
Q	electron charge (=1.602 × 10^{-19} C)
ω	weighting factor
P_{mpp}	maximum power (W)
V_{mpp}	voltage at maximum power point (V)
I_{mpp}	maximum power current (A)
R_S	series resistance (Ω)
R_{sh}	Shunt resistance (Ω)
R_{shi}	initial value of shunt resistance (Ω)
R_{shn}	Shunt resistance at STC (Ω)
R_{si}	initial value of series resistance (Ω)
R_{sh0}	value of R_{sh} (Ω) at short circuit point (0, I_{sc})
A	diode ideality factor
A_1	ideality factor of 1st diode in double diode model of PV cell
A_2	ideality factor of 2nd diode in double diode model of PV cell
T	temperature of the PV module (K)
T_n	temperature of the PV module at STC (=298 K)
dT	temperature difference (T-T_n) (K)
G	irradiance of the PV module
G_n	irradiance of the PV module at STC (=1000 W/m^2)
N_S	number of cells in series
E_g	band gap energy (eV)
AE	absolute error
RMSE	root mean square error

(500 MW), the fourth is Sebkha tah (500 MW), and finally the fifth site which is Boujdour (100 MW) [1].

1.2. Research framework and objective

The object of this study is the comparison of two methods of estimating the five and seven parameters, in order to choose which estimation method is most suitable for each PV module technologies. The two estimation methods used are the iterative method based on the Gauss-Seidel iterative resolution algorithm applied to the single diode model, and the analytical method based on the analytical resolution applied to the double diode model. Single diode model is simple and easy to implement, whereas double diode model has better accuracy, which acquiesced for more precise forecast of PV systems performance.

The main contribution of this work is to compare the single and double diode model, as well as two aforementioned estimation parameter methods and evaluate their effect on the PV model's I–V characteristics. This work provides also a comparative analysis of the five mathematical models for the single diode and two mathematical models for double diode classified below in order to choose which method/model combination is better for each PV module technology. Another advantage of the study is envisaged to be as a useful reference for both new and experienced researchers in the field of PV systems designing who require a simple, fast and accurate PV simulator, in which accuracy of the model is of prime concern. Furthermore, the results from each model were first verified for correctness against the results produced by their respective authors. The simulation results obtained in the MATLAB environment for all methods and mathematical models are validated against data in the datasheets of the PV modules.

The estimation of the five and seven unknown parameters can be obtained by exploiting the three remarkable points of the I–V characteristic at the Standard Test Conditions (STC). The values of these three points are extracted from the manufacturer's datasheets. They are used in order to estimate the values of the five parameters, namely, A, R_s, R_{sh}, I_0 and I_{ph} using the Gaussian iterative method at STC [5,6]. This is also true for the analytical method [7], for which we assume that $R_{sh} = R_{sh0}$ [8], and we take into consideration the approximation of the Schokley-Read-Hall recombination phenomenon $A_1 = 1$ and $A_2 = 2$ [9,10], in order to reduce the seven unknown parameters of the model to only five parameters R_s, R_{sh}, I_{01}, I_{02}, and I_{ph} at STC. For the various mathematical models developed in Section 3, the following hypothesis is used: $I_{ph} = I_{sc}$ [8,11]. It is noteworthy that each model is based on the combination of two equations translating the dependence of the photocurrent and the reverse saturation current on temperature and irradiance. We are interested in the effect of temperature and incident solar irradiance on the I-V characteristics of the three PV module technologies: multicrystalline (Kyocera KC200GT) [12], monocrystalline (Shell SQ80) [13], and thin film (Shell ST40) [14]. The accuracies of the estimation methods and the different models listed below were evaluated through comparing the simulation results to the experimental data taken under varying environmental conditions by means of the RMSE and the AE. The simulation results were obtained after developing computer programs in the Matlab environment to plot the I-V characteristics, to calculate the RMSE and AE in order to be able to judiciously examine the performance of the PV parameters' estimation methods. According to the literature, several methods have been developed to estimate the five parameters for the single diode model and the double diode model. These methods include the Newton Raphson iterative method for adjusting the series resistance, used by Sera et al. [15], and the analytical method based on the Lambert W function, used by Nassar-eddine et al. [16].

After having determined the five main PV parameters at STC, a thorough review on the literature based on the PV system modeling, has established that there are five unique combinations of photocurrent (I_{ph}) and reverse saturation (I_0) currents. The five existing models, which translate the values of the parameters to any irradiance and temperature operating condition, are implemented. Each model is based on the combination of I_{ph} and I_0. To