Outdoor Photovoltaic Module Performance Comparison in Desert Climate

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***Abstract*—this paper presents the modelling verification of photovoltaic modules using five-parameter models of PV module. Based on mono-cristallin photovoltaic panel, the effects of external parameters, mainly temperature and solar irradiance have been considered in the modelling. The five parameters I_{ph}, I_0, γ, R_s and R_{sh} of a PV system are calculated. The performance of the model to calculate the current voltage characteristics was tested by comparing the results with data measured at outdoor climate in this work.**

Keywords-one diode; mono-crystalline ; performance; five parameters.

I. INTRODUCTION

Solar energy which is free and abundant in most parts of the world has proven to be an economical source of energy in many applications. Photovoltaic (PV) cells allow the energy to be transported by electromagnetic waves (i.e., photons) to be directly converted into electricity. The mechanisms that allow this energy conversion to take place are based on photon-electron interactions that occur in p–n junctions formed by appropriately doped semiconductor materials.

Several models for solar cells utilize non-linear lumped parameter equivalent circuits and their parameters are determined by experimental current–voltage characteristics using analytical or numerical extraction techniques [1–2].

The performance of a PV module largely depends on the availability of solar radiation and on the conversion efficiency; these important features are affected by many physical parameters like the site latitude, the typical weather conditions, the panel tilt and azimuth angles, the air temperature, the wind speed, the temperature of the surrounding surfaces, the obstruction and shadow effects, the electrical load, etc. [3].

There exist several mathematical models in the literature to describe photovoltaic cells [4-6].

The model with two diodes may represent more closely the observable effects on the device under consideration in various lighting condition. To simplify parameter adjustment, the two-diode model can be reduced to a one-diode model. In general, double diode models are more accurate for polycrystalline silicon cells, while single-diode ones are used for amorphous silicon cells [7]. An electrical circuit with a one diode is considered as the equivalent photovoltaic cell in the present article. Modeling of photovoltaic cells is an essential topic of research.

The simplified one diode model assumes the shunt resistance as infinite and it is neglected. Some of the used parameters are not available on the corresponding module data sheet, additional work is often necessary to compute them, empirical [8] or semi empirical [9] models are used. In some other cases, analytical resolution with no needs of any manufacturer data [10].

In general, short-circuit current, open-circuit voltage, maximum power voltage, current and power, are determined by the manufacturers under STC, i.e., irradiance of 1000 W/m^2, cell temperature of 25°C and AM 1.5 spectrum, and under Nominal Operating Cell Temperature (NOCT) conditions, i.e., irradiance of 800 W/m^2, temperature of 45 or 47°C (depending on the manufacturer), ambient temperature of 20°C, wind speed of 1 m/s and AM 1.5 spectrum.

In some cases, they also provide temperature coefficients for the short-circuit current, the open-circuit voltage and the overall PV panel efficiency. The cells number in series and the array size are also given by the manufacturers.

In this paper, a simplified PV equivalent circuit with a one diode equivalent as model is proposed.

II. THE EQUIVALENT CIRCUIT OF A SOLAR CELL

The most common model for a PV module is the five-parameters and a PV performance model that is derived from an equivalent circuit of a solar cell, which consists of a current source, a diode, and a series and parallel resistors, as it is shown in Fig. 1.

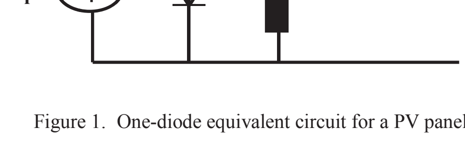

Figure 1. One-diode equivalent circuit for a PV panel.

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The model characteristic equation, given by (1).

$$I=I_{ph}-I_0\left[\exp\left(\frac{q(V+IR_s)}{\gamma kT}\right)-1\right] \quad (1)$$

Where I_{ph} is the photocurrent (A), I_0 is the saturation current (A), q is the absolute value of electron's charge (1.602 10^{-19} °C), γ represents the quality factor of the diode, k = 1.38 10^{-23} J/K is Boltzmann's constant and T is the temperature of the p–n junction (K).

The five parameters appearing in Eq. (1) corresponding to the conditions standards are: γ, I_o, I_{ph}, R_s, and R_{sh}.

The value of ideality factor γ is indicative of the recombination mechanism, they have observed for the c-Si cells, his value decreases from about 1.6 to 1.1 with increasing irradiance within the same range [11].

The ideal factor γ depends on photovoltaic technology, which is selected as 1.3 in this paper.

Generally, available manufacturer's information are set at three points at the reference conditions: the current of I_{sc} short circuit, the tension of open circuit V_{oc} and the current and the points of maximum power (I_{mp}, V_{mp} and P_{mp}).

Fourth information results:

a) *Current of short-circuit*: I = Isc, V = 0

$$I_{sc}=I_{ph}-I_0\left[\exp\left(\frac{qR_sI_{sc}}{\gamma kT}\right)-1\right]-\left(\frac{R_sI_{sc}}{R_{sh}}\right) \quad (2)$$

b) *Tension of open circuit*: I = 0, V = Voc

$$0=I_{ph}-I_0\left[\exp\left(\frac{qV_{oc}}{\gamma kT}\right)-1\right]-\left(\frac{V_{oc}}{R_{sh}}\right) \quad (3)$$

c) *Maximum power point*: I = I_p, V = V_p

$$I_p=I_{ph}-I_0\left[\exp\left(\frac{q(V_p+R_sI_p)}{\gamma kT}\right)-1\right]-\left(\frac{V_p+R_sI_p}{R_{sh}}\right) \quad (4)$$

In [12], the Newton-Raphson method was chosen to calculate the series resistance value and the convergence for various initial values.

In this paper we used the same method for obtain the values of the four unknown I_{ph}, I_0, R_{sh} and R_s, [12].

Where:

$$A=\exp\left(\frac{q(V_p+R_sI_p)}{\gamma kT}\right)-1 \quad (5)$$

$$B=\exp\left(\frac{qR_sI_{sc}}{\gamma kT}\right)-1 \quad (6)$$

$$C=\exp\left(\frac{qV_{oc}}{\gamma kT}\right)-1 \quad (7)$$

$$I_{ph}=\det{}^{-1}(V_{oc}I_{sc}A-V_{oc}I_pB-V_pI_{sc}C) \quad (8)$$

$$I_{sc}=\det{}^{-1}(V_{oc}I_{sc}-V_{oc}I_p-V_pI_{sc}) \quad (9)$$

$$R_{sh}{}^{-1}=\det{}^{-1}[I_{sc}A-I_pB-(I_{sc}-I_p)C] \quad (10)$$

The calculation of *det* is shown in (11):

$$\det=(V_{oc}-R_sI_{sc})A+(-V_{oc}+V_p+R_sI_p)B+\cdots$$
$$(-V_p+R_s[I_{sc}-I_p])C \quad (11)$$

d) *The derivative of the maximum power point*

$$\left.\frac{d(IV)}{dV}\right|_p=I_p-V_p\left.\frac{dI}{dV}\right|_p=0 \quad (12)$$

With $dI/dV|_p$ is given by the following relation:

$$\left.\frac{dI}{dV}\right|_p=\left\{\frac{-qI_0}{\gamma kT}\exp\frac{q(V_p+I_pR_s)}{\gamma kT}-\frac{1}{R_{sh}}/\ldots\right.$$
$$\left.1+\frac{qI_0R_s}{\gamma kT}\exp\frac{q(V_p+I_pR_s)}{\gamma kT}+\frac{R_s}{R_{sh}}\right\} \quad (13)$$

The derivative of (1) compared to the tension can be expressed by:

$$\frac{dI}{dV}=-\left\{R_s+\left(\frac{qI_0}{\gamma kT}\exp\frac{q(V+R_sI)}{\gamma kT}+\frac{1}{R_{sh}}\right)^{-1}\right\}^{-1} \quad (14)$$

We introduce (12) in (14), then we define a function f_{Rs} given by:

$$f_{R_s}=I_p-(V_p-R_sI_p)\left(\frac{qI_0}{\gamma kT}\exp\frac{q(V_p+R_sI_p)}{\gamma kT}+\frac{1}{R_{sh}}\right) \quad (15)$$

As I_0 and R_{sh} depend on R_s, the function f_{Rs} is also. The Newton–Raphson method was used in the proposed iterative procedure due to the resolution of f_{Rs}=0.

III. Dependence Of The Parameters On Outdoor Conditions

The diode reverses saturation current Io depends on temperature, as well as on the material band gap energy (E_g) and the cells number in series Ns [9].

$$I_0=I_{0,ref}\left(\frac{T_c}{T_{ref}}\right)^3\exp\left[\frac{q}{\gamma k}\left(\frac{E_{g,ref}}{T_{ref}}-\frac{E_g}{T_c}\right)\right] \quad (16)$$

Where $E_{g,ref}$=1.12 eV for silicon cells the band gap energy at reference temperature $T_{c,ref}$, Egis the band gap energy at cell temperature. Ref. [13], defines the value for E_g for silicon can be described as.

$$E_g=E_g(0)-\frac{\alpha T^2}{T_c-B} \quad (17)$$

Eg(0), its value at T=0 K and a and b are constants [14].

The photon-generated current I_{ph} parameter depends on the effective solar irradiance G_T, the cell temperature (Tc) and the short circuit current temperature coefficient (α_{Isc})

$$I_{ph}=\frac{G_T}{G_{T,ref}}\left[I_{ph,ref}+\mu_{Isc}(T_c-T_{c,ref})\right] \quad (18)$$

The short circuit current of the panel at a temperature T and irradiance G_T other than the reference values, the following expressions were used:

$$I_{sc}=\frac{G_T}{G_{T,ref}}I_{sc,ref} \quad (19)$$

IV. Cell Temperature T_C

In order to predict the energy production of photovoltaic (PV) modules, it is necessary to predict the module temperature. The cell temperature is influenced by the optical properties (glazing, encapsulant, back-sheets), the incoming solar irradiance, wind speed and the ambient climatic conditions [15-17].

Previous work in modelling the temperature of PV modules has focused on obtaining correlations that predict the module temperature based on the incoming solar irradiance, ambient temperature and wind speed

The PV-module temperature can also be determined using Eq. (20) given as [18]:

$$T_c=T_a+G_T\frac{NOCT-20}{0.8} \quad (20)$$

NOCT is the Nominal Operating Cell Temperature which is defined as the cell temperature when the ambient temperature is 20°C, irradiance is 0.8 kW·m⁻²and wind speed is1 m·s⁻¹. T_a ambient temperature.

Finally, one of the most common models of maximum power point methods to correct from STC to any operating conditions is:

$$P_{mp} = \frac{G_T}{G_{T,ref}} P_{mp,ref}\left[1 + \mu_{mp}\left(T_c - T_{ref}\right)\right] \qquad (21)$$

V. Results And Discussion

The SM-XXXMH1 Series, 250 Watts, mono-crystalline silicon panels are experimentally chosen to perform the characterization and modelling procedure.

The experimental data are extracted within the Research Unit in Renewable Energies in the Saharan Medium, Adrar, Algeria, in specific desert climate environment. The IV photovoltaic characteristics were measured with a MP-160 I–V curve traceras seen in Fig. 2.

Figure 2. MP-160 I–V Curve Tracer

Table.1 shows the manufacture parameters of the array obtained from the datasheet at STC. Table. 2 shows the electric parameters of the model proposed and the model at Ref. [9].

TABLE I. Results And Manufacture Data Of Pv Panels At Stc

SM-XXXMH1 Series, 250 Watts*	
I_{sc} (A)	9.15
V_{oc} (V)	[illegible]
I_p (A)	8.34
V_p (V)	30.0
Ns	60
NOCT	47
*STC : 25 C et 1KW/m²	

Figures (3) and (4) show respectively the I-V and P-V characteristics. Solid line corresponds to the reference model results and squares are experimental points. Some points are not exactly matched because the model is not perfect.

Differences between the experimental data and the calculated values occur as a result of limitations in the cell model itself, as well as in the methods used to calculate absorbed radiation. In addition, there are uncertainties inherent in the experimental data [9].

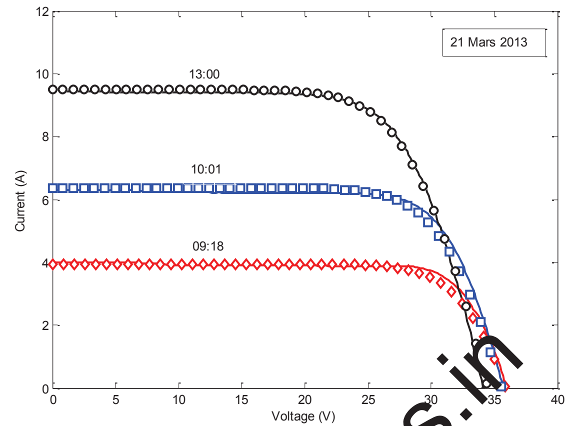

Figure 3. Current–Voltage characteristics, scattered points are experimental results and solid line is model results, 21/03/2013.

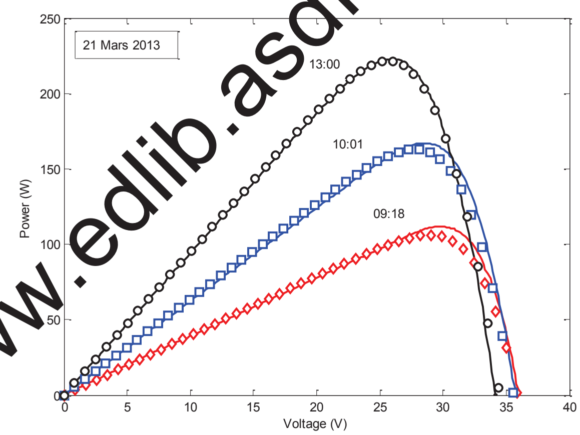

Figure 4. Power–Voltage characteristics. scattered points are experimental results and solid line is model results, 21/03/2013

TABLE II. Electric Parameters Of The Model Proposes

SM-XXXMH1 Series, 250 Watts mono-crystalline		
Parameters	**Our model**	Ref. [9]
γ	1.3	1.3
I_{ph} (A)	9.1514	9.1550
I_0 (A)	3.721e-8	3.7475e-8
R_s (Ω)	0.4001	0.39
R_{sh} (Ω)	170.17	156.48
*STC : 25 C et 1KW/m²		

Figure (5) shows a comparison between the power calculated and the experimental power recorded.

Figure (6) shows another representation of the agreement between modeled and experimental values of the power produced by a module. The correlation coefficient R^2=0.960, It can be seen that the predicted PV array maximum output power shows good correlation with the measured data.

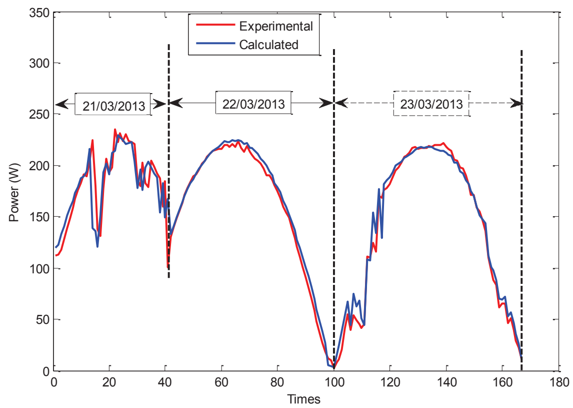

Figure 5. Temporal variation of the measured and modeled maximum power output.

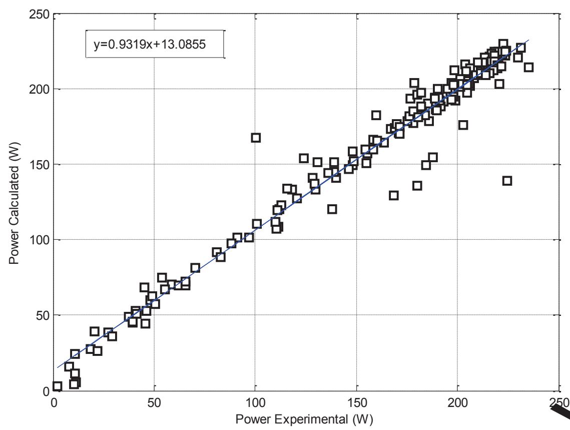

Figure 6. Calculated maximum power vs. measured maximum power 21-23/03/2013.

Figure (7) show successively the absolute error of the current according to the tension. This calculation considers the time of 08:00, 14:00, 17:00 and 18:00 P.M, for the PV Site during Mars 23, 2013.

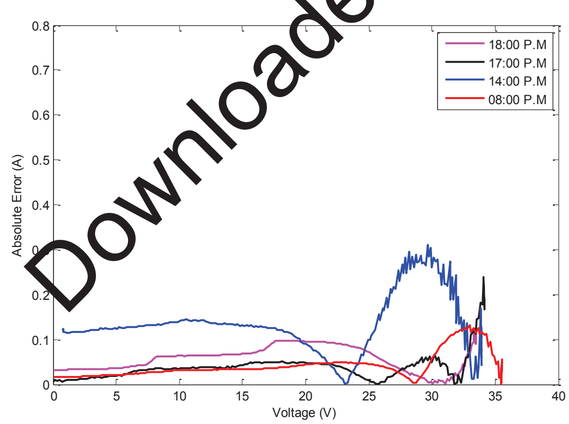

Figure 7. Absolute error for proposed model, 23/03/2013.

The model in this paper gives incorrect results in the vicinity of the open circuit tension, and at the maximum power point.

VI. CONCLUSION

In this paper, a general approach on modeling photovoltaic modules using single diode five parameters model is presented. This approach is based on datasheet parameters with the aid of independent equation of material properties of the solar cell. The accuracy of the proposed model is evaluated using mono-crystalline PV-panel. Simulation results were verified by comparing on the experiment results of three days at outdoor tested.

The agreement between the theoretical estimates of the maximum power and the experimental data is very good even in days at low solar irradiance.

VII. REFERENCE

[1]. D.SH. Chan and JCH. Phang, "Analytical Methods for the Extraction of Solar-Cell Single- and Double-Diode Model Parameters from *I- V* Characteristics," IEEE transaction on electron devices, Vol. 34, No. 2, February, pp. 286-293, 1987.

[2]. L. Sandrolini, M. Artioli and U. Reggiani, "Numerical method for the extraction of photovoltaic module double-diode model parameters through cluster analysis," Applied Energy, Vol. 87, pp. 442–451, 2010.

[3]. Valerio LoBrano, Aldo Orioli, Giuseppina Ciulla,Alessandra DiGangi," An improved five-parameter model for photovoltaic modules," Solar Energy Materials & Solar Cells, Vol. 94, pp. 1358–1370, 2010.

[4]. W. Pleciano,'' Determination of the Solar Cell Equation Parameters, Including Series Resistance, from Empirical Data,'' Energy Conversion, Vol. 9, pp. 1-6, 1969.

[5]. M. Chegaar, Z. Ouennoughi and A. Hoffmann," Anew method for evaluating illuminated solar cell parameters," Solid-State Electronics, Vol. 45, No. , pp. 293-296, 2001.

[6]. P. Rodrigues, J. R. Camacho and F. B. Matos," The application of Trust Region Method to estimate the parameters of photovoltaic modules through the use of single and double exponential models," International Conference on Renewable Energies and Power Quality, ICREPQ'11, 13-15 April, 2011.

[7]. JA. Gow, CD. Manning,''Development of a photovoltaic array model for use in power–electronics simulation studies'', *IEE Proc-Electric Power Appl*, Vol. 146, No. 2, pp. 193–200, 1999.

[8]. D. King, W. Boyson and J. Kratochvill," Photovoltaic Array Performance Model," SAND2004-3535, Albuquerque, NM: Sandia National Laboratories, 2004.

[9]. M.G. Villalva, J.R. Gazoli and E.R. Filho,"Comprehensive approach to modeling and simulation of photovoltaic arrays," IEEE Trans. power electron, Vol.24, pp. 1198–1208, 2009.

[10]. F.J. Toledo, José M. Blanes, Ausiàs Garrigós and José A. Martínez," Analytical resolution of the electrical four-parameters model of a photovoltaic module using small perturbation around the operating point," Renewable Energie, Vol. 43, pp. 83-89, 2012.

[11]. M.A. de Blas, J.L. Torres, E. Prieto and A. Garcı´a," Selecting a suitable model for characterizing photovoltaic devices," Renewable Energy, Vol. 25, pp. 371–380, 2002.

[12]. B. Mustapha, ''Modélisation et simulation d'un système de pompage photovoltaïque,'' Thèse de Magister. Université D'Oran, Algérie, 2006.

[13]. Y.P. Varshni,'' Temperature dependence of the energy gap in semiconductors,'' Physica, Vol. 34, pp. 149–154, 1967.

[14]. P. Singh and N. M. Ravindra,'' Temperature dependence of solar cell performance—an analysis,'' Solar Energy Materials & Solar Cells, Vol. 101, pp. 36–45, 2012.

[15]. M. Fuentes, G. Nofuentes, J. Aguilera, D.L. Talavera, M. Castro,'' Application and validation of algebraic methods to predict the behaviour of crystalline silicon PV modules in Mediterranean climates,'' Solar Energy, Vol. 81, pp. 1396–1408, 2007.

[16]. Durisch, W., Bitnar, B., Mayor, J.-C., Kiess, H., Lam, K.-H., Close, J., 2007. Efficiency model for photovoltaic modules and

demonstration of its application to energy yield estimation. Sol. Energy Mater. Sol. Cells 91, 79–84.
[17]. Topic, M., Brecl, K., Sites, J., 2007. Effective efficiency of PV modules under field conditions. Prog. Photovoltaics Res. Appl. 15, 19–26.
[18]. E. Skoplaki, A.G. Boudouvis, J.A. Palyvos,''A simple correlation for the operating temperature of photovoltaic module of arbitrary mounting,'' Solar Energy Materials & Solar Cells, Vol. 92, pp. 1393–1402, 2008.