Parameter identification of solar module model using a metaheuristic technique

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Abstract—**In fact that the meaningful parameters of photovoltaic (PV) module model are of major importance, they could lead to carry out a monitoring tool, so the extraction method should be accurate and quick in the same time. Due to the nonlinear and implicit nature of the circuit equivalent PV module model it is preferable to use a good optimization method; in this paper we opt for a metaheuristic based parameter identification method inspired from Artificial Bee Colony (ABC) and Differential Evolutionary (DE). The proposed method is compared with other optimization methods and then is validated with a real measured data under different meteorological conditions of several PV modules.**

Keywords-parameter extraction; metaheuristic technique; one diode model; Differential Evolutionary.

I. INTRODUCTION

Recently, photovoltaic (PV) market has experienced prominent growth, due to the political support and reduction of the costs production, and other factors which make the return on PV system investment more interesting. Thus, photovoltaic energy technologies can be a significant candidate to sub for fossil fuels in the future due to the following advantages and others; installation easiness, no pollution and no required maintenance over long periods.

Single (one) and double (two) diode based equivalent circuit model are the more used for modeling the physical behavior of PV module under different outdoor conditions [1-3], also Bishop's model is used especially in the case of non uniform (shading) condition by including the bypass diode effect in PV module [4]. Therefore, using Lambert W function to render the implicit nature of the PV module model explicit is proposed by several researchers [5, 6].

Performing a strong extraction technique to identify the unknown PV module parameters can lead to accomplish a monitoring tool. In this context, based on the data given by the manufacturer in Standard Test Condition (STC; 25°C of PV cell temperature and 1000 W/M^2 of incident irradiance) or the value of the relative current and voltage in maximum power point (MPP), there are a propositions to extract the unknown parameters analytically [7], but the effectiveness of this techniques are heavily related to the current and voltage values in MPP (if they are not precise the analytical technique cannot get a feasible solution) [8].

Also, based on Newton-Raphson or Levenberg-Marquardt algorithms, numerical techniques are used for the PV module parameters extraction [9], but they depend deeply on the initial parameters values and other conditions (such as convexity and differentiability).

While, due to their property to handle the nonlinear problems meta-heuristic algorithms are useful for the parameter extraction of PV module such as Genetic Algorithm (GA) [10], Particle Swarm Optimization (PSO) [11], Artificial Bee Swarm Optimization (ABSO) [12], Differential Evolution (DE) [3] Harmony Search (HS) [13] and Pattern Search (PS) [14], Bird Mating Optimizer (BMO) [15]

In this paper, we propose a metaheuristic technique inspired from Artificial Bee Colony (ABC) [16] and based on DE [3] to extract the unknown parameters of PV module models (one and double diode model). The results will be compared with other extraction methods in terms of their relative errors efficiency. Then, to confirm the accuracy of the proposed method, it is validated by means of real measurement of the voltage-current (V-I) characteristics of several PV module manufacturing technologies under different level of PV cells temperature and incident irradiance.

The paper is organized as follows: section II reviews the modeling practice of the PV module, section III presents the parameter extraction algorithm. Finally section IV and V draws the discussion results and the conclusion respectively.

I. CIRCUIT BASED PHOTOVOLTAIC MODEL

Several propositions have been developed for modeling the PV generator behavior under different operating conditions. Nevertheless, two models are essentially used in practice; called relatively to the representative number of diode.

A. One diode model

$$I = I_{ph} - I_0 \cdot \left(e^{\frac{V - I \cdot R_s}{n \cdot V_{th}}} - 1 \right) - \frac{V - I \cdot R_s}{R_{sh}} . \qquad (1)$$

This model is the most common representation of the PV cells behavior formulated as Eq. (1), and its corresponding equivalent circuit is shown in "Fig. 1", characterized by five unknown parameters I_{ph} (photo-generated current), R_s

(Series resistor), R_{sh} (Shunt resistor), n (ideality factor) and I_0 (reverse saturation current).

While, V_{th} (thermal module voltage = N_s*k*T/q, T (cells temperature in Kelvin), k (Boltzman's constant = $1.381*10^{-23}$ J/K), N_s (PV cell number in series), q (electron charge = $1.602\ 10^{-19}$ C), and G (incident irradiance on solar cells) represent the known parameters.

Figure 1. One diode circuit based model.

B. Double diode model

Double (two) diode model is specified by adding other diode in parallel to the first one to include the recombination losses effect in the space-charge as described in "Fig. 2". It translates more the physical behaviour of the PV module and it is characterized by seven unknown parameters (I_{ph}, R_s, R_{sh}, I_{01}, I_{02}, n_1, n_2), formulated as Eq. (2).

$$I=I_{ph}-I_{01}\cdot\left(e^{\frac{V-I\cdot R_s}{n_1\cdot V_{th}}}-1\right)-I_{02}\cdot\left(e^{\frac{V-I\cdot R_s}{n_2\cdot V_{th}}}-1\right)-\frac{V-I\cdot R_s}{R_{sh}}. \quad (2)$$

Figure 2. Double diode circuit based model

C. Objective function

The extracted parameters values depend on the objective function opted for that, in the literature the meaningful objective functions proposed are based on the difference between the measured current and the calculated one with the extracted parameters expressed either on RMSE (root mean square error) [3, 11, 12, 15] or MAE (mean absolute error) [14]. In this paper we proceed to use the RMSE expressed in Eq. (3). Where, $f(\theta, I_c, V_c)$ is identified with Eq. (4) for the one diode model and with Eq. (5) for the double diode model.

$$OF=\sqrt{\frac{1}{M}\sum_{m}^{M}f(\theta,I_c,V_c)^2}\ . \quad (3)$$

$$f(\theta,I_c,V_c)=I_c-(I_{ph}-I_0\cdot\left(e^{\frac{V_c-I_c\cdot R_s}{n\cdot V_{th}}}-1\right)-\frac{V_c-I_c\cdot R_s}{R_{sh}})\ .(4)$$

$$f(\theta,I_c,V_c)=I_c-(I_{ph}-I_{01}\cdot\left(e^{\frac{V_c-I_c\cdot R_s}{n_1\cdot V_{th}}}-1\right)-I_{02}\cdot\left(e^{\frac{V_c-I_c\cdot R_s}{n_2\cdot V_{th}}}-1\right)-\frac{V_c-I_c\cdot R_s}{R_{sh}})\ .(5)$$

Where, θ = [I_{ph}, I_0, R_s, R_{sh}, n] represents the unknown parameters in the case of one diode model and θ = [I_{ph}, I_{01}, I_{02}, R_s, R_{sh}, n_1, n_2] for the double diode model.

The ideal value of OF (Objective function) is 0, however due to the electrical noise and measurement errors, it cannot be resettled, but it will be minimized as much as possible.

III. PARAMETER EXTRACTION METHOD

To extract the unknown parameters of PV module model (either the one diode model or the two diode model) we opt for a metaheuristic technique inspired from the foraging behavior of a bee swarm to find the optimal honey sources. Where, the search strategy and the information exchange between the bees are based on DE mutation strategy, with D-dimensional honey sources, each honey source is considered as a position. When the bees return from the source navigation, they share their report in relation to the quantity of the discovered sources, where the best source is that one with biggest quantity of honey. Then, they are classified according to the sources discovered into two groups, namely, leaders and scouts, the leaders are placed in the first half of the swarm, in this case, the swarm leaders are those with smallest objective function. Based on the report of the leader bees, the scout bees abandon their sources and try to discover other honey sources with a good quantity. The best quantity means the smallest objective function; this technique is called AB-DE.

A. Initialization procedure

In order to begin the optimization process with j_{max} maximum number of iteration (generation) an initial population NI is set, the population elements are called bees, their honey sources are specified as possible solutions with D-dimensional source vectors. Where, D is the number of the unknown parameters according to the chosen PV module model. Then, to cover all the search space and to reduce the wrong solutions simultaneously, we use the following steps:

Step1: generate a random individual vector $B_{a,i}$ under the search range [X_{min}, X_{max}] for the i^{th} individual index with Eq (6). Where, *a* is the dimension index form 1 to D.

Step2: generate the opposite individual vectors $B_{b,in}$ for the i^{th} individual index with Eq (7).

Step3: evaluate the corresponding objective functions (OF).

Step4: rank the individual vectors according to their OF and select the best from them like the initial population B_i

$$B_{a,in} = X_{min} + rn\,(X_{max} - X_{min})\,. \tag{6}$$

$$B_{a,io} = X_{min} + (X_{max} - B_{a,i}). \tag{7}$$

Where, *rn* is a random number between 0 and 1.

B. *Search strategy*

After the initialization procedure, inspired from DE, the search strategy of the i^{th} bee is assured by Eq. (8). Where, Mu_i, is the mutation report which is based on the reports of the other bees.

$$Mu_i = B_g + Qk_i \cdot (B_{h1} - B_{h2}) + Qk_i \cdot (B_{h3} - B_{h4}). \tag{8}$$

Where, h_1, h_2, h_3 and h_4 are indices of bees from the swarm different from *i*. While, B_{h1}, B_{h2}, B_{h3} and B_{h4} are their corresponding honey sources. Qk_i is a random number between -1 and 1. B_g is the best honey source already found by all the bees. Then, The mutation report will be evaluated against the best honey source found by the corresponding i^{th} bee.

Role assignment

The role of each bee (leader or scout) will be adjusted based on the probability factor, calculated using Eq. (9), the bees with smallest probability factors are considered as leaders, while the rest of swarm as scouts.

$$P_i = F(B_i) / \textstyle\sum_{i=1}^{NI} F(B_i). \tag{9}$$

Where, P_i is the probability factor, B_i is the honey source (position) reached by the i^{th} bee and $F(B_i)$ is the objective function of the corresponding bee.

C. *Exchange report*

After the role assignment of each bee the leaders chair their reports with the scouts to converge to the best honey source, the exchange report is assured by the uniform strategy.

Until the stop criteria are met, B_g is considered as the global optimum (the optimal parameters). The flowchart of the proposed algorithm is shown in “Fig. 3”.

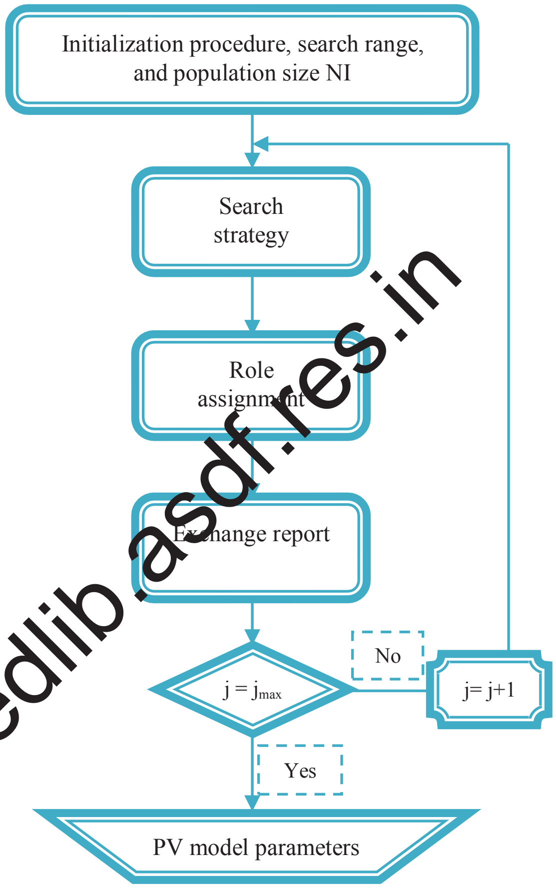

Figure 3. Flowchart of AB-DE algorithm.

TABLE I. COMPARISON OF SEVERAL PARAMETER EXTRATION METHODES USING ONE DIODE MODEL

Item	*PS ref. [14]*	*Ref.[17]*	*Ref.[18]*	*AB-DE*
I_{ph} (A)	1.0313	1.0318	1.0339	1.03181
I_0(μA)	3.1756	3.2875	3.0760	0.32773
R_s(Ω)	1.2053	1.2057	1.2030	1.20611
G_{sh}(Ω^{-1})	0.0014	0.0018	0.0018	1/845.249
N	48.2889	48.4500	48.1862	1.3437*36
RMSE	0.0118	0.7805	0.6130	2.4266e-3

III. RESULTS AND DISCUSSION

The extraction algorithm is implemented using Matlab code and it was validated in two steps:

- Firstly, by using the V-I characteristic taken from [17]. Then, the results are compared with other methods as it is shown in table (1).
- Secondly, by using the measured V-I characteristic of four types of PV module. Where, “Module 1”: SG Mono GF245F monocrystalline with 60 series PV cell, “Module 2”: PHOTOWATT 1650

polycrystalline with 72 series PV cell, “Module 3”: SILIKEN SLK60P6 polycrystalline with 60 series PV cell, “Module 4”: SOLARFUN monocrystalline with 60 series PV cell, applied with the same AB-DE parameters (number of iteration j_{max} = 250, population size NI = 60) and the same search range

The following relatively large search ranges for the PV modules have been chosen: $R_s = [1e\text{-}3, 5]$, $R_{sh} = [10, 1e5]$, $I_{ph} = [0, I_{ph0} * 3]$, $I_0, I_{01}, I_{02} = [1e\text{-}12, 1e\text{-}4]$, $n, n_1, n_2 = [0.5, 4]$. While, the value of I_{ph0} is calculated starting from I_{phSTC} of each PV module, using Eq. (10), that is the photo-generated current in STC (it is given by the manufacturer).

$$I_{ph0} = \left(\frac{G}{G_0} + \alpha_{I_{SC}} \cdot (T - T_0) \right) \cdot I_{phSTC} \cdot \qquad (10)$$

Where, $\alpha_{I_{SC}} = 0.039\,[1/K]$ that is the short circuit current temperature coefficient, T (K) represents the cells temperature, T_0 = 298.15 K, G (W/m^2) is the incident irradiance on PV cells and G_0 = 1000 W/m^2.

In Table II, is shown in two tests (V-I curves) taken under different meteorological conditions from Module 2. So we can deduce that either using one or two diode model we get approximately the same results, but relatively two diode model need more computational time even than one diode model as it shown in “Fig. 4”. Therefore, we can limit to use one diode model to get a sufficient result with less computational time

TABLE II. PARAMETER EXTRATION UNDER SEVERAL TEMPERATURE (KELVIN) AND IRRADIANCE (W/M^2) BY ONE DIODE AND DOUBLE DIODE MODEL.

	T = 304.2, G = 526		*T = 299.3, G =844*	
Item	***One diode model***	***Double diode model***	***One diode model***	***Double diode model***
I_{ph} (A)	2.7967	2.7966	4.4632	4.4632
I_0(μA)	0.92349		1.7790	
I_{01}(μA)		0.92166		1.7790
I_{02}(μA)		1.9156		2.4537
R_s(Ω)	0.5236	0.5236	0.4970	0.4907
R_{sh}(Ω)	216.1097	216.3176	170.4101	170.4102
n	1.4537		1.5407	
n_1		1.4535		1.5407
n_2		3.9781		3.9874
RMSE	0.0088	0.0088	0.0109	0.0109

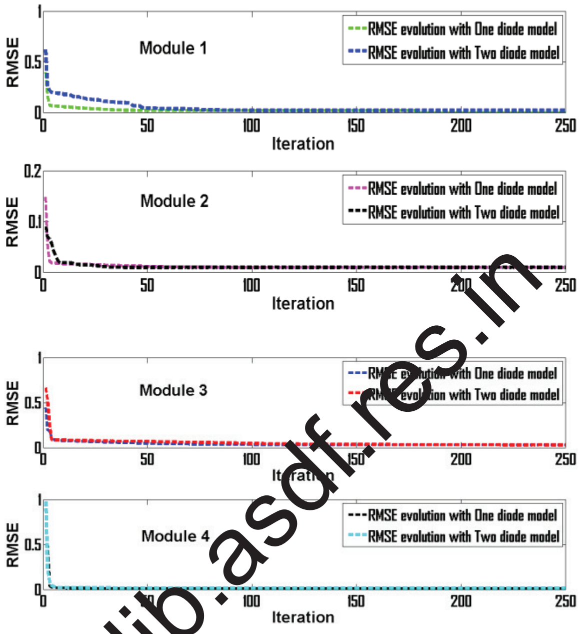

Figure 4. RMSE evolution with One and Two diode models of the PV modules.

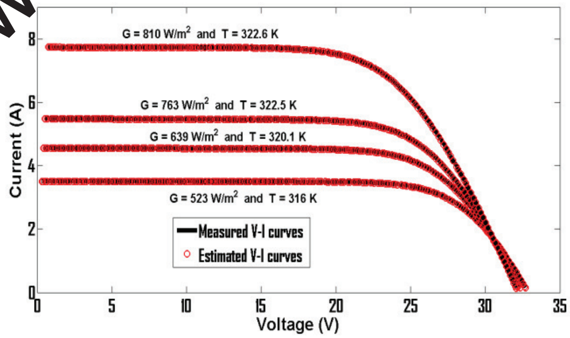

Figure 5. Examples of curves estimated using AB-DE algorithm of Module1.

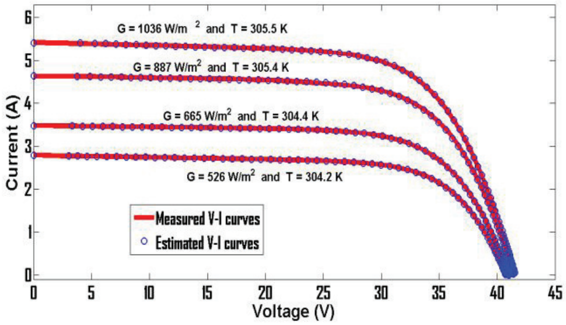

Figure 6. Examples of curves estimated using AB-DE algorithm of Module2.

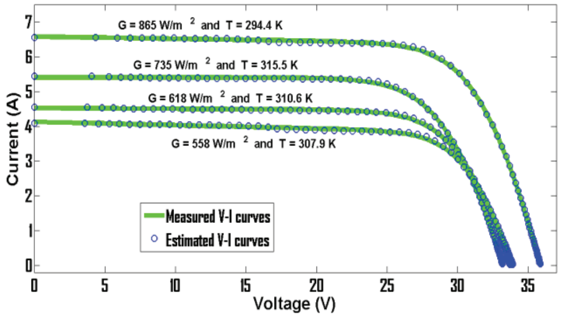

Figure 7. Examples of curves estimated using AB-DE algorithm of Module3.

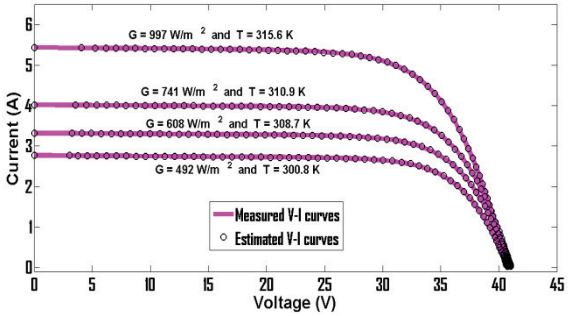

Figure 8. Examples of curves estimated using AB-DE algorithm of Module4.

The "Figs. 5, 6, 7 and 8" show same examples of estimated V-I curves using one diode model under different PV cell temperature and irradiance.

IV. CONCLUSION

In this paper, we have applied a proposed metaheuristic algorithm to extract the electrical parameters of PV module model.

The proposed algorithm presents a significant accuracy when it is compared with other techniques taken from literature under the same conditions.

Among the advantages of the proposed algorithm, the easiness implementation of several proposed PV module models, of different technologies and manufacturers, and the rapidity of converging to the global optimum under relatively a large parameters search range.

Finally, the results show that this algorithm could be used to extract the electrical parameters of PV module with a significant accuracy on line and to perform a monitoring tool.

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