Using the genetic algorithm to determine the parameter of photovoltaic cells and panels

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***Abstract*—Heuristic methods are used more and more often to determine the parameters of photovoltaic cells and panels. The results obtained using these methods are better than the results obtained through analytical ones. The genetic algorithm is used in this paper to determine the important parameters of the photovoltaic cells and panels for a one diode model. The current voltage characteristics of the photovoltaic cells are measured under illumination in lab conditions and for the photovoltaic panels in natural sunlight conditions.**

Keywords—photovoltaic cells and panels, genetic algorithm, parameters

I. Introduction

The performance of the photovoltaic cells and panels can be improved and estimated for different illumination and climatic conditions if their external and internal parameters are accurately determined [1]. The determination of parameters during the use of photovoltaic cells, called the ageing period, is also very important [2,3].

The external parameters of the photovoltaic cells, such as: open circuit voltage, V_{oc}, short circuit current, I_{sc}, maximum power, P_{max}, factor fill, FF, and efficiency, η, can be obtained easily using the current voltage, I-V, and power voltage, P-V, characteristics [4]. The internal parameters of the photovoltaic cells, such as: photogenerated current, I_{ph}, reverse saturation current, I_o, shunt resistance, R_{sh}, series resistance, R_s, and ideality factor of diode, n, can be determined using the I-V characteristic and some methods: analytical, deterministic and metaheuristic [3,4].

The parameters of the photovoltaic cells are determined analytically using different approximation equations [4,5] or numerical fitting methods [6,7], but the accuracy depends on the approximation and the initial value of the parameters. The metaheuristic methods, such as: genetic algorithm [8,9], particle swarm optimization and simplified particle swarm [10,11], annealing algorithm [12], cat swarm optimization algorithm [13], artificial bee swarm optimization algorithm [14] and others [15,16] increase the accuracy in determining the parameters of the photovoltaic cells and panels.

The parameters of the monocrystalline photovoltaic cells and panels are determined using the genetic algorithm in different conditions: lab and natural.

II. Methods

A. Mathematical Model and Equivalent circuit

The I-V characteristic of the photovoltaic cells is nonlinear and for its analysis the equivalent circuit and mathematical model are necessary.

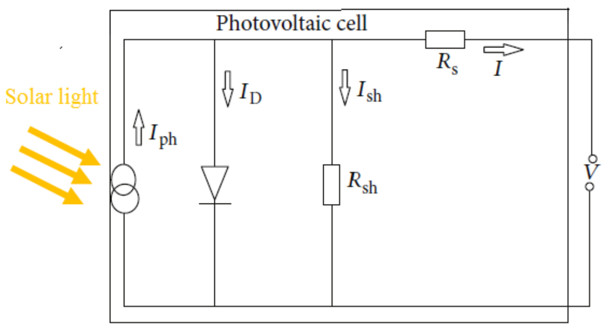

Fig. 1. Equivalent circuit of the photovoltaic cell

The mathematical model for the photovoltaic cell in the case of the one diode model equivalent circuit, Fig.1, is:

$$I = I_{ph} - I_o\left(e^{\frac{V+IR_s}{nV_T}} - 1\right) - \frac{V+IR_s}{R_{sh}} \quad (1)$$

where V_T is the thermal voltage which is equal with kT/q: T represents temperature in Kelvin, k is Boltzmann constant, and q is the elementary electrical charge.

B. Experimental setup

The measurements are made in laboratory for two photovoltaic cells: monocrystalline silicon with sizes 3 cm x 3 cm, SC1, and 8 cm x 8 cm, SC2, Fig.2a, and in outdoor conditions for one monocrystalline silicon photovoltaic panel, PV, with 18 photovoltaic cells, Fig.2b. The artificial light in laboratory is assured by nine halogen bulbs.

a) b)

Fig. 2. The experimental setup: a) laboratory condition; b) outdoor conditions

The I-V characteristics are measured with a system developed by the authors using the capacitor technique [17]. The temperature of the photovoltaic cells and panel is measured using some thermocouples. The irradiance levels are measured using two pyranometers one for the laboratory system and another for outdoor conditions.

C. Genetic algorithm

Genetic algorithms implement the bio-inspired principle of evolution and selection of the most suitable potential solution to solve problems. This strategy can be considered in a data driven approach for the parameters selection of a physical model. When the mathematical equations are part of an underdetermined system, a subject matter expert can provide reasonable intervals for parameters values in order to reduce the search space. This is sometimes a convenient alternative to the well-established search techniques from the perspective of computational time, although the solution may be sub-optimal.

The choice is to compute the model parameters by applying an evolutionary process through a genetic algorithm. This method requires first the encoding of the potential solutions or hypotheses. After that, in a loop each hypothesis is evaluated with a fitness function which is an objective criterion to promote the most suitable solutions on top, then the most promising ones are selected and are refined with genetic operators.

The fitness function *f(V,I)*, which derives from (1), is minimized by the best selection of photovoltaic cells' internal parameters given by the genetic algorithm which evaluates simultaneously a whole population of possible sets, $\{I_{ph}, I_o, n, R_s, R_{sh}\}$.

$$f(V,I)=\sum_{k=1}^{m}\left|I_k - I_{ph} + I_o\left(e^{\frac{V_k+I_kR_s}{nV_T}}-1\right)+\frac{V_k+I_kR_s}{R_{sh}}\right| \quad (2)$$

where m represents the number of measured points from photovoltaic cells or panel.

The limits for the internal parameters of photovoltaic cells and panel, low and high, are carefully chosen to minimize computing time and so as not to lose solutions, see Table I.

The Root Mean Square Error (RMSE) and Mean Absolute Bias Error (MABE) are utilized to verify the accuracy of the solution for the internal parameters (3), (4).

TABLE I. PARAMETERS RANGE

Para meters	Photovoltaic cells				Photovoltaic panel	
	SC1		***SC2***		***PV***	
	Low	High	Low	High	Low	High
I_{ph} [A]	I_{sc}	I_{sc} + 0.02	I_{sc}	I_{sc} + 0.05	I_{sc}	I_{sc} + 0.1
I_0 [A]	10^{-12}	10^{-5}	10^{-12}	10^{-5}	10^{-12}	10^{-5}
n	1	2	1	2	18	36
R_s [Ω]	0	0.2	0	0.2	0	2
R_{sh} [Ω]	0	500	0	500	0	2000

$$RMSE=\sqrt{\frac{\sum_{i=1}^{m} f^2(V,I)}{m}} \quad (3)$$

$$RMSE=\frac{\sum_{i=1}^{m}\left|I_{meas}-I_{est}\right|}{m} \quad (4)$$

III. RESULTS AND DISCUSSION

The measurements for the three photovoltaic devices are made at 1 sun = 1000 W/m^2 and different temperatures.

The genetic algorithm (GA) using Genetic Algorithms library implemented in the R programming language, offers a flexible and easy to use toolbox for stochastic optimization [18,19]. The fitness function (2) is encoded, the population size was set to 500 and the maximum number of iterations was limited to 5000.

The internal parameters of the photovoltaic cells and panels are obtained using the genetic algorithm and the five parameters method, 5P, [5] to make a comparison, see Table II.

The I-V characteristics and the absolute errors for the photovoltaic cells are presented: for SC1, Fig.3, for SC2, Fig.4, and for PV, Fig. 5. The I-V characteristics presented are: measured, estimated using the GA and five parameters method. The estimated I-V characteristics almost match the measured ones.

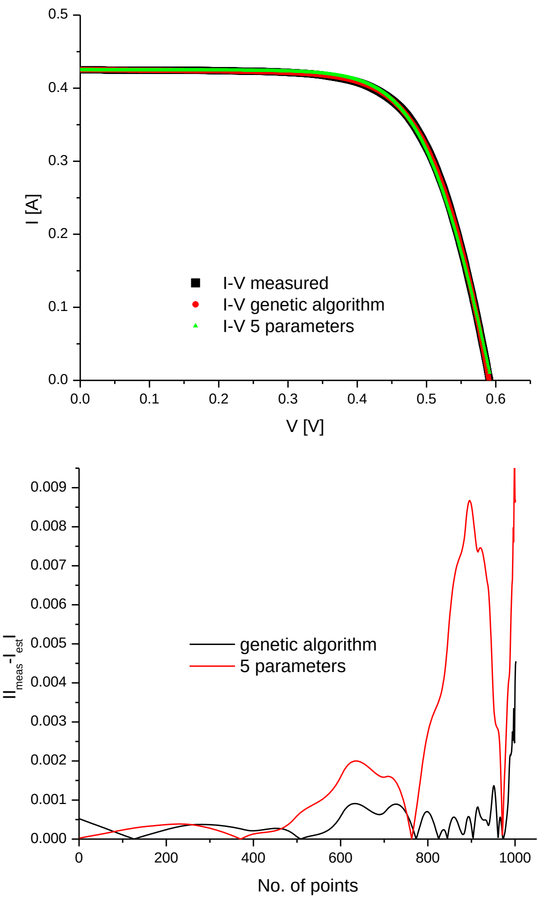

Fig. 3. a) I-V characteristics of SC1, measured and estimated with GA and 5 parameters; b) Comparison between the absolute errors

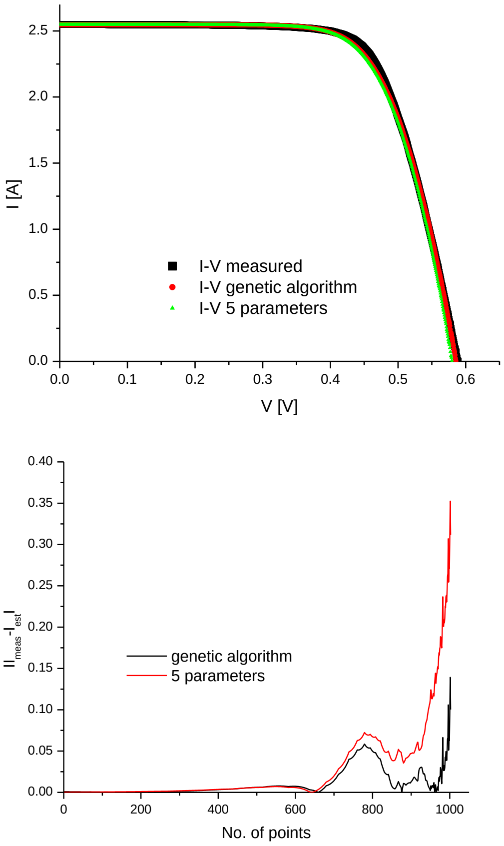

Fig. 4. a) I-V characteristics of SC1, measured and estimated with GA and 5 parameters; b) Comparison between the absolute errors

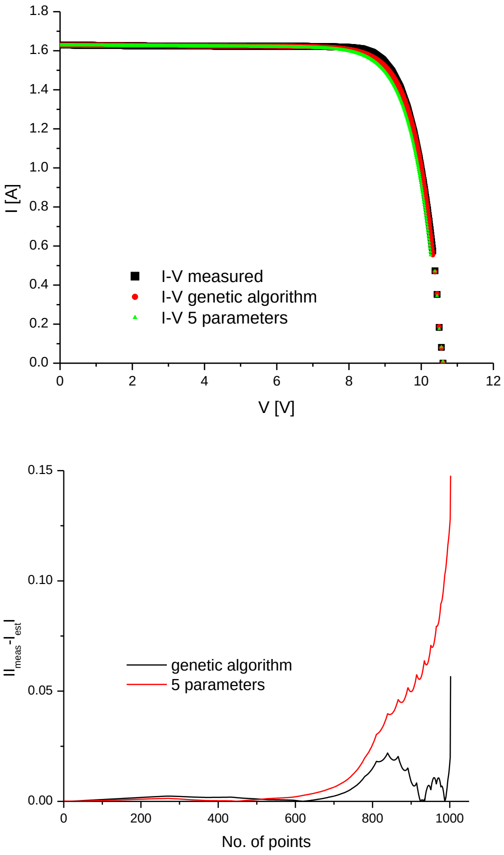

Fig. 5. a) I-V characteristics of SC1, measured and estimated with GA and 5 parameters; b) Comparison between the absolute errors

TABLE II. PARAMETERS OF PHOTOVOLTAIC DEVICES

Para meters	**Photovoltaic cells**				**Photovoltaic panel**	
	SC1		***SC2***		***PV***	
	5 P	GA	5 P	GA	5 P	GA
I_{ph} [A]	0.425	0.4256	2.549	2.5478	1.6291	1.62905
I_0 [A]	$3.68*10^{-7}$	$8.38*10^{-7}$	$8.2*10^{-7}$	$5.1*10^{-8}$	$6.82*10^{-9}$	$3.13*10^{-9}$
n	1.64	1.73	1.31	1.28	20.235	19.503
R_s [Ω]	0.107	0.083	0.022	0.0241	0.101	0.07578
R_{sh} [Ω]	212	122	181	378	804.71	1130.68

The absolute errors analyzed show that the GA gives better results than the five parameters method in all cases taken into account.

The values of the RMSE and MABE error by both methods for the photovoltaic cells and panel are given in Table III.

The curves obtained for the absolute errors show that it increases closely to the open circuit voltage for the photovoltaic cells and panel under test, especially for the five parameters method.

The region, close to the open circuit voltage from the I-V characteristic is strongly influence by the series resistance and the ideality factor of diode and less by the shunt resistance. Therefore, it is very important that these two parameters are determined accurately.

The pair number of the I-V characteristic is high, over 1000. This number can improve the determining of the photovoltaic cells and panel parameters using the genetic algorithm, but can negatively influence the determination of the series and shunt resistance through the five parameters method due to its use of the linear fitting of the I-V characteristic closely to the open circuit voltage and short circuit current points.

IV. CONCLUSION

The measurements are made under both conditions: in laboratory under artificial illumination and outdoors in natural sunlight conditions.

The internal parameters for two photovoltaic cells, SC1 and SC2, and one photovoltaic panel are determined through two methods, genetic algorithm – stochastic method and five parameters method – analytic method.

The comparison between the results obtained by two methods, through graphs, absolute errors and RMSE error show that the genetic algorithm gives more accurately the results for (V,I) pairs. Therefore the genetic algorithm can be used to accurately and efficiently determine the parameters of the photovoltaic cells and panels.

The RMSE obtained for the genetic algorithm is lower than the RMSE for the five parameters method, the difference varying from 2.7 for the SC2 to 4.6 for SC1. This difference is almost the same for the MABE errors, the difference varying from 2.35 for the SC2 to 3.9 for SC1.

TABLE III. RMSE ERROR

Error	Photovoltaic cells				Photovoltaic panel	
	SC1		***SC2***		***PV***	
	5 P	GA	5 P	GA	5 P	GA
RMSE	0,00266	5.79 E-4	0.0534	0.0193	0.0286	0.00694
MABE	0.0016	4.1 E-4	0.025	0.0106	0.0138	4.1 E-3

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