Five PV Model Parameters Determination Through PSO and Genetic Algorithm, a Comparative Study

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Abstract. The main goal of this paper is the application of PSO (Particle Swarm Optimization) and Genetic Algorithm (GA) in Renewable energy in general and particularly photovoltaics (PV) in order to extract the five parameters that governs the PV module (the photocurrent, the serial resistance, the saturation current, the parallel resistance and the ideality factor). Indeed, PSO and GA are intelligent post-analytic global optimization algorithms that give a minimal error. The application of these algorithms aimed at comparing the experimental results of a fairly well known photovoltaic module with is the MSX 60 has given good results. This is confirmed by the calculation of statistical performance measurement factors such as RMSE (root-mean-square error) and MAPE (mean absolute percentage error).

Keywords: Optimization · Five PV parameters · PSO · GA

1 Introduction

The Photovoltaic solar energy which is a clean energy comes from the conversion of sunlight into electricity through semiconductor materials such as silicon or composite materials. These photosensitive materials have the property of releasing their electrons under the influence of an external energy (light and temperature). This junction constituting the solar cell is based on solar modules constructed by manufacturers. Modeling and simulation of PV module helps in better understanding in terms of the behavior and characteristics [1]. Many models have been developed to reflect the true behavior of the solar module such as Ideal Photovoltaic model (model of three parameters), 1D-2R model (five parameters model) and the two-diode model (the seven parameters model) [2]. The most used common model is the five parameters model for its offering a closer representation of the solar cell [3]. These five parameters are the: photocurrent (Iph)t, serial resistance (R_S), saturation current, (I_0), parallel resistance (R_{sh}) and the ideality factor (n).

There were different optimizing algorithms For evaluating and optimizing the PV model [4–8]. In general, we cal classify these algorithms in three groups: (a) analytical methods such as Newton-raphson method [9], (b) iterative methods like search fitting curves [10, 11], (c) intelligent algorithms (heuristic and metaheuristic). Among the heuristic methods it can be found the PSO algorithm and the genetic algorihms [12–14].

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The remainder of the paper is organized as follows. In Sect. 2, the problem of solar cell modeling is presented.

Section 3 describes the GA algorithm as well as PSO algorithm. The different results and discussion with validation are exposed in Sect. 4. Finally, Sect. 5 gives a summary and conclusions.

2 The Five Parameters PV Cell/Module Modeling

Due to its simplicity and acceptable accuracy, the single-diode (five parameters) model has been selected (see Fig. 1).

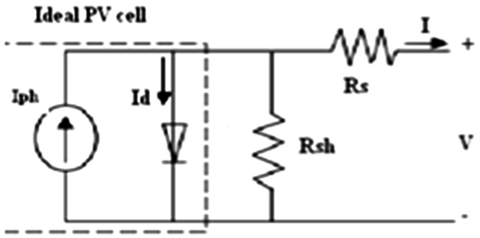

Fig. 1. Equivalent model of five parameters solar cell

From Fig. 1, it can be shown that the output current of the solar cell can be given as follows:

$$I = I_{ph} - I_{rs}\left[e^{\left(\frac{q(v+R_S.I)}{A.k.T}\right)} - 1\right] - \left(\frac{q(v+R_S I)}{R_{sh}}\right) \quad (1)$$

PV cells are connected together in series and parallel solar cell combinations to form a module the terminal equation of the PV module can be written as follows [15]:

$$I = N_p I_{ph} - N_p I_{rs}\left[e^{\left(\frac{q(v+R_S.I)}{A.k.T.N_S}\right)} - 1\right] - N_p\left(\frac{q(v+R_S I)}{N_S.R_{sh}}\right) \quad (2)$$

Where:

V is the cell output voltage; q is the electron charge ($1.60217646 \times 10^{-19}$C); k is the Boltzmann's constant ($1.3806503 \times 10^{-23}$ J/K); T is the temperature in Kelvin; I_{rs} is the cell reverse saturation current; A is the diode ideality constant; N_p is the number of PV cells connected parallel; N_s is the number of PV cells connected in series.

The generated photocurrent I_{ph} depends on solar irradiation and it's by the following equation:

$$I_{ph} = [I_{sc} + k_i(T - T_r)]\frac{G}{1000} \quad (3)$$

Where:

k_i is the short-circuit current temperature coefficient; G is the solar irradiation in W/m^2; I_{sc} is the cells short-circuit current at reference temperature; T_r is the cell reference temperature.

The cell's saturation current i_s varies with temperature according to the following equation

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{q.E_G}{k.A}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \tag{4}$$

Where:

E_G is the band-gap energy of the semiconductor used in the cell. I_{rr} is the reverse saturation at T_r.

3 PV Module Parameters Extraction Based on GA & PSO Algorithms

Using the objective function well defined by the Eq. (1), it can be easily implemented on the heuristic algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) for determining the five parameters of our chosen model 1D–2R.

3.1 Genetic Algorithm (GA)

The genetic algorithm is a search heuristic inspired by the process of natural selection (well reputed as Darwin's theory). Its principal application is to generate useful solutions to optimization and search problems. The Genetic Algorithm was originally proposed by Holland (Holland 1975). After that, many authors (Goldberg 2000; Michalewicz 1994) have modified the existing one and improved genetic algorithms are proposed) [16]. Procedure of the GA starts from a seed and generates a set of individuals. Each of these individuals can extract a group of parameters, the best-fitted parameters are selected to form the new population when the process has been repeated 50 000 times until this iterations procedure been accomplished [17].

The basic components common to almost all genetic algorithms are [18]:

- a fitness function for optimization
- a population of chromosomes
- selection of which chromosomes will reproduce
- crossover to produce next generation of chromosomes
- random mutation of chromosomes in new generation.

For the implementation of GA to perform PV module parameters extraction the fitness function has the role of optimizing the objective function defined above (I–V curve) and the population of chromosomes express the five electrical PV cell parameters (Iph, I0, A, Rs and Rsh). The task of selection and crossover is to promote chromosome with high fitness. On the other hand, the random mutation ensures diversification of solutions by creating another generation.

3.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is an heuristic optimization (sometimes called metaheuristic), invented by Russel Eberhart and James Kennedy in 1995, inspired by the behaviour of social organisms in groups, such as bird and fish schooling or ant colonies [19]. This optimization method is based on the collaboration of individuals with each other. Elsewhere this method has many similarities with the genetic algorithm except for the use of a group (swarm of particles) instead of an individual (chromosome) in the search.

Just the algorithm starts each particle is positioned randomly in the search space of the problem. Each iteration moves the particles according to 3 components: (1) Its current velocity $v_i = (v_{i1}, v_{i2}, \ldots, v_{id})$ with i is the rank of the particle. (2) Its best positions (or solution) namely p_i. (3) The best solution obtained before (previous best position) which is p_g. This gives the following equations [4]:

$$v_i^{n+1} = w * v_i^n + C_1 * r_1 * \left(Pbest_i - x_i^n\right) + C_2 * r_2 * \left(Gbest - x_i^n\right) \tag{4}$$

$$x_i(j+1) = v_i(j+1) + x_i(\mathrm{j}) \tag{5}$$

Where: x_i is the position of the particle, C_1 and C_2 are acceleration factors r_1 and r_2 are two uniform random numbers between 0 and 1. w is an inertia weight (had a high value for searching global solution). v_i is the initial velocity. j is the iteration index. *Pbest* and *Gbest* are respectively: personal and global best fitness of each particle. The global solution is indeed represents the desired solution of the solar cell equation.

4 Results and Discussions

The GA and PSO algorithms were implemented on the MSX 60 PV module (polycrystalline) by using the Matlab software (see Table 1).

Table 1. Manufacturing datasheet of MSX 60

Characteristics	Value
Open-Circuit Voltage (V_{oc})	21.1 V
Optimum Operating Voltage (V_{mp})	17.1 V
Short-Circuit Current (I_{sc})	3.8 A
Optimum Operating Current (I_{mp})	3.5 A
Maximum Power at STC* (P_{max})	60 W
Number of cells	36
Temp. coefficient of V_{oc}	−80 m V/°C
Temp. coefficient of I_{sc}	0.0024 A/°C

For measuring the efficiency of the proposed algorithms, we opted for statistical tools by calculating the errors: *RMSE* (root-mean-square error) and *MAPE* (mean absolute percentage error).

RMSE is defined by [20]:

$$RMSE = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N} f_i(V_m, I_m, x)^2} \quad (6)$$

Where, N is the number of the experimental data.

The formula of the mean absolute percentage error (MAPE) is as follows:

$$MAPE = \frac{1}{N}\sum\nolimits_{i=1}^{N} \left|\frac{A_i - F_i}{A_i}\right|.100 \quad (7)$$

Where A_i is the actual value and F_i is the forecast value, N is the number of the experimental data.

In this section, the proposal methods (PSO & GA) are applied to extract the five parameters governing the MSX60 solar module under standard test conditions (STC: 1000 W/m^2, 25 C°). Referring to the experimental I–V curve and the manufacturer's given datasheet, a statistical study performed by calculating the RMSE, the MAPE and the execution time was done. The different results can be shown in Table 2.

Table 2. Extracted parameters for the MSX 60 PV module under STC

Parameters	GA algorithm	PSO algorithm
Rs [Ω]	0.4843	0.4821
R_{sh} [Ω]	2.0001×10^4	2×10^4
A (ideality factor)	1.0001	1
I_{ph} [A]	3.7999	3.7999
I_0 [A]	4.6314×10^{-10}	4.6121×10^{-10}
RMSE	0.0723	0.0707
MAPE	1.8035	1.7734
Time execution [s/run]	4529.5486	1468.2126

The results in Table 2 show that statistically the results of the PSO are much better than those of the GA (see values of RMSE and MAPE). Another advantage of the PSO is its relatively low execution time compared to the algorithm GA.

The Figs. 2 and 3 shows experimental model (curve I–V) and the estimated characteristics (computed model with PSO and GA) applied on the MSX 60 PV module.

It can be seen from Figs. 2 and 3 the acceptable matching curves between experimental and proposal models. It's due also for the integration of Nelder-Mead algorithm in the main PSO-GA programms in order to resolve the non linear objective function. That's the reason of the enhancement of results.

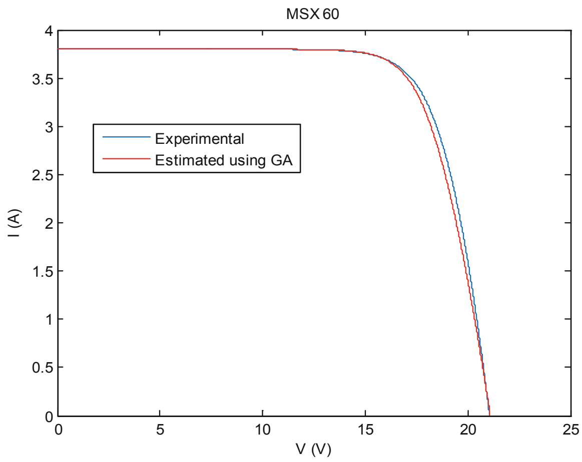

Fig. 2. GA model of the five parameters PV MSX60 module

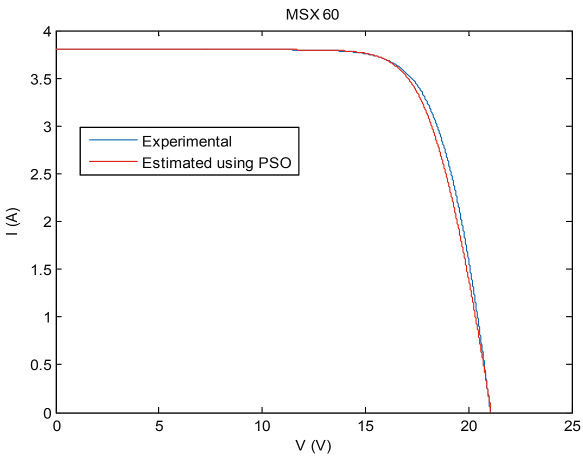

Fig. 3. PSO model of the five parameters PV MSX60 module

Figure 4 depicts the comparison between the convergence characteristics of GA and PSO algorithms depending on number of iterations. As an initial solution GA algorithm is the best but in terms of accuracy and speed of convergence it's very clear that the PSO algorithm is better than GA. In general both PSO and GA methods converge towards the global solution, which is an advantage.

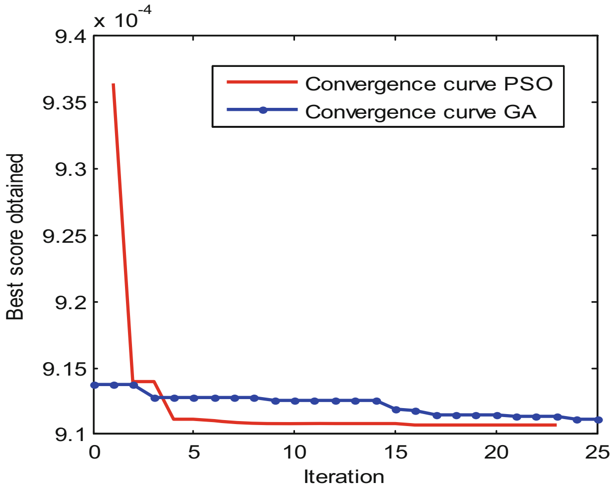

Fig. 4. Comparison between the convergence characteristics of GA and PSO algorithms

5 Conclusion

In this paper, a comparison study between the GA algorithm and PSO for extraction of PV parameters was done. this comparison confirms the power of PSO compared to GA as a modeling tool. The speed of convergence towards a global optimum is clearly in favor of the PSO. The integration of the Nelder-Mead method in order to solve the nonlinearity of the objective function solve the non-linearity of the objective function helped us to avoid falling into the local solutions and it has contributed to have precise results.

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