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Three-diodes PV model parameters extraction using PSO algorithm

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Abstract - *In this paper, we propose a particle swarm optimization technique for the characterization of the equivalent electrical model of photovoltaic cell. The three diodes model with nine parameters is considered. The particle swarm optimization algorithm is used as a tool for the extraction of the model parameters by reaching the global minimum solution in a few iterations with a very good accuracy and short convergence time based on the minimization of the quadratic error between experimental and theoretical curves. Simulation obtained results show that the proposed approach is effective for modeling the photovoltaic cell as well as the module.*

Résumé - *Dans cet article, nous proposons une technique d'optimisation de l'essaim de particules pour la caractérisation du modèle électrique équivalent d'une cellule photovoltaïque. Le modèle à trois diodes à neuf paramètres est considéré. L'algorithme d'optimisation de l'essaim de particules est utilisé comme outil d'extraction des paramètres du modèle en atteignant la solution minimale globale en quelques itérations avec une très bonne précision et un temps de convergence court basée sur la minimisation de l'erreur quadratique entre les courbes expérimentales et théoriques. Les résultats de la simulation montrent que l'approche proposée est efficace pour modéliser la cellule photovoltaïque, ainsi que le module.*

Keywords: Photovoltaic - PV Model - Parameters Extraction - Particle Swarm Optimization - PSO.

1. INTRODUCTION

The depletion of the fossil fuel reserves and the pollution caused by the conventional energy sources has made necessitous the exploitation of renewable energy sources in order to address the global challenges of clean energy, climate change and sustainable development. Those alternative energy production systems, such as photovoltaic (PV) systems are being supported by many governments and countries on a worldwide basis [1].

Photovoltaic energy is one of the most promising emerging technologies. The cost of PV modules has been divided by five in the last six years; the cost of full PV systems has been divided by almost three. On the other hand, installations of PV systems around the world have been growing at an average annual rate of more than 44 % during the period from 2000 to 2013.

Since 2010, the world has added more solar photovoltaic capacity than in the previous four decades. New systems were installed in 2013 at a rate of 100 megawatts (MW) of capacity per day. Total global capacity overtook 150 gigawatts (GW) in early 2014 [2].

Photovoltaics is the field of technology and research related to the devices which directly convert sunlight into electricity. The solar cell made of semiconductor materials is the elementary building block of the photovoltaic technology. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination [3].

To better understand the acting physical mechanisms within the solar generator (cell, module, array), several methods have been proposed for the identification of the different parameters that affect their characteristics, not only for increase their performance, but also to simulate their behavior and optimize their different characteristics [4-10].

These methods can be classified in two categories: **a**- deterministic methods involving methods such as least squares [11], Lambert W-functions [12], and the interior-point method [13]; **b**- heuristic methods such differential evolution (DE) [14], genetic algorithm (GA) [15], simulated annealing (SA) [16].

In this paper, we propose a particle swarm optimization approach (PSO) [17] for the extraction of electrical parameters {the saturation current, the serial resistance, the parallel resistance and the ideality factor}.

The models with three, five and seven parameters respectively are considered. The PSO algorithm is used as a tool for optimization to increase the probability of reaching the global minimum solutions in a short time with a very good accuracy based on the minimization of the quadratic error between experimental and theoretical characteristics.

The simulation results show that the accuracy of the heuristic approach is effective for modeling in the case of solar modules.

The remainder of the paper is organized as follows. In Section 2, the problem of solar cell modeling is defined. Section 3 describes the PSO algorithm as well as the problem of solar cell identification translated to an optimization task using this technique. Section 4 presents the simulations results compared to experimental ones. In Section 5, the conclusions are stated.

2. THREE DIODES PV CELL MODELLING

It consists of a constant current source, in parallel with a first diode including an ideality factor accounting for the recombination in the space-charge region.

The second diode in the accounts for the carrier recombination in the space charge region of the junction and the surface recombination losses.

The third diode accounts for the contribution of added diode current due to recombination in the defect regions and grain sites.

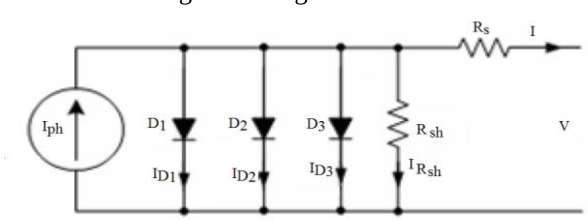

Fig. 1: The triple diode model

The internal series resistance represents the contacts and interconnections between cells and modules losses; while the shunt resistance represents the leakage currents across the junction and within the cell due to crystal imperfections and impurities losses [18]. Figure 1 shows the electrical equivalent model.

The model parameters are I_{s1}, I_{s2}, I_{ph}, A_1, A_2, R_s and R_{sh} as given below:

$$I_{pv} = I_{ph} - I_{s1}\left(\exp\left(\frac{V_{pv} + I_{pv} E_s}{A_1.k.T}\right) - 1\right) - I_{s2}\left(\exp\left(\frac{V_{pv} + I_{pv} E_s}{A_2.k.T}\right) - 1\right) - I_{s3}\left(\exp\left(\frac{V_{pv} + I_{pv} E_s}{A_3.k.T}\right) - 1\right) - \frac{V_{pv} + I_{pv} E_s}{R_{sh}} \quad (1)$$

With, I_{ph}, The photocurrent, A ; $I_{si\,(i=1,2,3)}$, the diode saturation currents in standard test conditions, A ; $A_{i\,(i=1,2,3)}$, the ideality factors ; R_s, the PV series resistor, Ω ; R_{sh}, the PV parallel resistor, Ω ; k is the Boltzman's (1.381 x 10^{-23} J/K), T is the temperature of cell, K.

3. PSO-BASED PV CELL PARAMETERS EXTRACTION

Particle swarm optimization is a population-based swarm intelligence algorithm. It was originally proposed by Kennedy and Eberhart as a simulation of the social behavior of social organisms such as bird flocking and fish schooling [19].

PSO uses the physical movements of the individuals in the swarm and has a flexible and well-balanced mechanism to enhance and adapts to the global and local exploration abilities. Because of its easy implementation and inexpensive computation, its simplicity in coding and consistency in performance, PSO has proved to be an effective and competitive algorithm for the optimization problem in continuous spaces.

Most applications of PSO have concentrated on the optimization in continuous spaces while recently some works have been done to the discrete optimization problem.

The PSO algorithm first randomly initializes a swarm of particles. The position of each individual (called particle) is represented by a d-dimensional vector in problem space $S_i = (S_{i1} + S_{i2} + \ldots + S_{id})$, $i = 1, 2, \ldots, N)$ (N, is the population size), and its performance is evaluated on the predefined fitness function.

Thus, each particle is randomly placed in the d-dimensional space as a candidate solution. The velocity of the i_{th} particle $v_i = (v_{i1} + v_{i2} + \ldots + v_{id}))$ is defined as the change of its position. The flying direction of each particle is the dynamical interaction of individual and social flying experience.

The algorithm completes the optimization through following the personal best solution of each particle and the global best value of the whole swarm.

Each particle adjusts its trajectory toward its own previous best position and the previous best position attained by any particle of the swarm, namely p_i and p_g. In each iteration, the swarm is updated by the following equations:

$$v_i(t+1) = v_i(t) + c_1 \, rand_1 (p_i - s_1(t)) + c_2 \, rand_2 \quad (2)$$

$$s_i(t+1) = s_i(t) + v_i(t+1) \quad (3)$$

where $p_i = (p_{i1},\ldots,p_{iN})$ is the best position encountered by i_{th} particle so-far; p_g represents the best position found by any member in the whole swarm population; t is iteration counter; c_1 and c_2 are acceleration coefficients; $rand_1$ and $rand_2$ are two uniform random numbers in [0,1].

The acceleration coefficients control how far a particle will move in a single iteration. Low values allow particles to roam far from target regions before being tugged back, while high values result in abrupt movement towards, or past, target regions.

In this study, the electrical PV cell nine parameters, $\{ I_{ph}, I_{01}, A_1, I_{02}, A_2, I_{03}, A_3, R_s$ and $R_{sh} \}$ are encoded into binary strings known as chromosomes. The length of strings is set to 144 (9×16).

4. RESULTS AND DISCUSSION

The PSO algorithm parameters used are defined in **Table 1**.

Table 1: PSO parameters

Description	Parameters
Population size	20
Maximum iteration	50
c_1	2
c_2	2

The PSO implemented using Matlab software was tested using the PV module defined in **Table 2**.

Table 2: Module parameters

Description	30XLS	30XLS1
Module temperature, T_{mod} (°C)	30.01	29.75
Efficiencies insolation, E_{eff} (W/m^2)	908.79	870.28
Short circuit current, I_{sc} (A)	5.13	4.80
Open circuit voltage, V_{oc}, (V)	21.65	21.59
MPP current, I_{pmax}, (A)	4.69	4.36
MPP voltage, V_{pmax}, (V)	17.25	17.30
Short circuit current at STC, I_{sco}, (A)	5.65	5.52
Open circuit voltage at STC, V_{oco} (V)	22.21	22.30
MPP current at STC, I_{pmaxo}, (A)	5.16	5.012
MPP voltage at STC, V_{pmaxo}, (A)	17.74	17.90
Maximum power, P_{max}, (W)	91.73	89.75

Figures 2 to 3 show the computed and the experimental IV characteristics for the two considered modules.

From the obtained figures, we can see that the theoretical $I-V$ characteristics are very close to the experimental measured $I-V$ characteristics. The results prove the effectiveness of the proposed technique to extract with good precision the parameters of the equivalent circuit model.

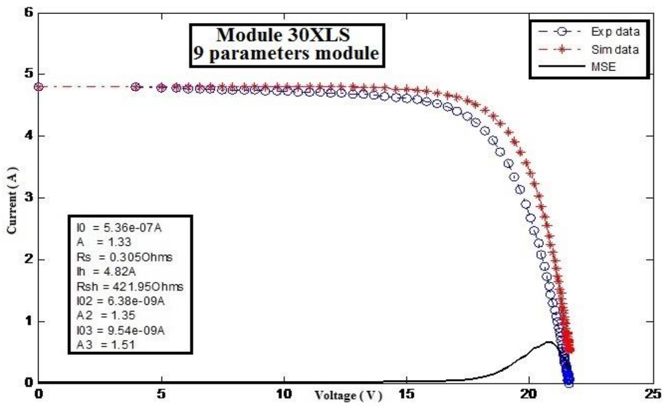

Fig. 2: 30XLS module: Nine parameters model

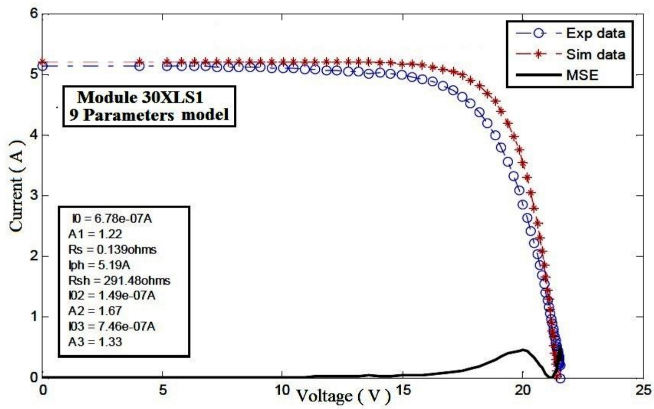

Fig. 3: 30XLSs module: Nine parameters model

5. CONCLUSION

In this paper, we propose a new technique based on particle swarm optimization for the extraction of electrical parameters of PV cell. The model with nine parameters is considered.

The particle swarm optimization is used as a tool for optimization to increase the probability of reaching the global minimum solutions in a short time with a very good accuracy based on the minimization of the quadratic error between experimental and theoretical characteristics.

The simulation results show that the accuracy of the heuristic approach is effective for modeling in the case of solar modules.

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