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Parameter identification of solar cells using artificial bee colony optimization

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ABSTRACT

In order to improve the performance of solar energy systems, accurate modeling of current vs. voltage (*I*–*V*) characteristics of solar cells has attracted the attention of various researches. The main drawback in accurate modeling is the lack of information about the precise parameter values which indeed characterize the solar cell. Since such parameters cannot be extracted from the datasheet specifications, an optimization technique is necessary to adjust experimental data to the solar cell model. Considering the *I*–*V* characteristics of solar cells, the optimization task involves the solution of complex non-linear and multi-modal objective functions. Several optimization approaches have been proposed to identify the parameters of solar cells. However, most of them obtain sub-optimal solutions due to their premature convergence and their difficulty to overcome local minima in multi-modal problems. This paper proposes the use of the ABC (artificial bee colony) algorithm to accurately identify the solar cells' parameters. The ABC algorithm is an evolutionary method inspired by the intelligent foraging behavior of honey bees. In comparison with other evolutionary algorithms, ABC exhibits a better search capacity to face multi-modal objective functions. In order to illustrate the proficiency of the proposed approach, it is compared to other well-known optimization methods. Experimental results demonstrate the high performance of the proposed method in terms of robustness and accuracy.

1. Introduction

The increase in the cost of fossil fuels and their probable depletion, air pollution, global warming phenomenon, and severe environmental laws have resulted in renewable energy sources gaining the attention of many nations to produce electricity. Solar energy is one of the most promising renewable sources that is currently being used worldwide to contribute to meeting rising demands for electric power. It has been reported that solar PV (photovoltaic) is the fastest growing power-generation technology in the world, with an annual average increase of 50% between 2004 and 2011 [1]. PV is not only capable of directly converting solar energy to electricity but also is an emission-free distributed generation unit that would supply power at the load site.

Solar cell accurate modeling has received significant attention in recent years [2–6]. The modeling of PV cells consists in two steps: the mathematical model formulation and the accurate estimation of their parameter values. For the mathematical model, the Current vs. Voltage (*I*–*V*) characteristics that rule the behavior of a solar cell is considered. Several approaches have been proposed in order to model such a behavior from different point of views [7–12].

In practical terms, there exist two equivalent electronic circuits that model the behavior of a solar cell. Such circuits are known as SD (single diode) and DD (double diode) models [13]. Irrespective of the model selected, it is necessary to estimate or identify all its parameters such as photo-generated current, diode saturation current, series resistance, and diode ideality factor. Depending on the model (SD or DD), two different sets of parameters must be identified: five for the SD and seven for the DD. The main problem is to identify the optimal parameter values which, when applied to the selected model, produce the best possible approximation to the experimental data obtained by the true solar cell [13].

The methods employed to solve the problem of PV parameter identification can be divided in two groups: deterministic and heuristic. Some examples of deterministic methods involve methods such as least squares [14], Lambert W-functions [15], and the iterative curve fitting [16]. Deterministic techniques impose several model restrictions such as convexity and differentiability in

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order to be correctly applied [24]. Therefore, they are very sensitive to the initial solution, and most often lead to local optima. As an alternative to deterministic-based techniques, the problem of PV parameter identification has also been handled through heuristic methods. In general, they have demonstrated that they deliver better results than those based on deterministic approaches considering accuracy and robustness [12,13,17–27]. In the literature, several heuristic approaches have been proposed in order to solve the problem of solar cell parameter identification. Such methods include GA (genetic algorithms) [17,18,24], PSO (particle swarm optimization) [12,19], SA (simulated annealing) [20], HS (harmony search) [13], BFA (Bacterial Foraging Algorithm) [21], TBLO (teaching-learning based optimization) [23] and BMO (bird matting optimization) [27]. Although heuristic methods present a higher probability of obtaining a global solution in comparison with deterministic ones, they have important limits [18]. In case of GA and PSO, they maintain a trend that concentrates toward local optima, since their elitist mechanism forces premature convergence [28,29]. Such a behavior becomes worse when the optimization algorithm faces multi-modal functions [30,31]. On the other hand, due to the fact that SA and HS are single-searcher algorithms, their performance is sensitive to the starting point of the search, having a lower probability to localize the global minimum in multi-modal problems than population algorithms such as GA and PSO [32,33]. Therefore, GA, PSO, SA, and HS present a bad performance when they are applied to multi-modal and noisy objective functions.

In order to identify the PV parameters as an optimization problem, it is necessary to define an objective function. Such an objective function is built by using experimental data extracted from I–V measurements of the solar cell. Since experimental data contain noise as a consequence of an imperfect data collection process, the objective function obtained presents high multi-modal and noisy characteristics [34,35]. Under these circumstances, most of the heuristic approaches present a bad performance [36].

In this paper, an alternative approach using the ABC (artificial bee colony) [37] method for determining the parameters of a solar cell is presented. The ABC is an evolutionary algorithm inspired by the intelligent behavior of honey bees. The performance of the ABC has been compared to other evolutionary methods such as GA and PSO [38,39]. The results have shown that ABC produces optimal solutions when it faces multi-modal and noisy optimization problems. Such characteristics have motivated the use of ABC to solve different types of engineering problems within several fields [40–45]. One relevant advantage of the ABC method is that it does not follow a local strategy for computing new solutions. Instead, the ABC method uses a set of operators to build solutions from random operations avoiding falling into local optimal.

ABC consists of three essential components: food source positions, nectar amount, and several honey-bee classes. Each food source position represents a feasible solution for the problem under consideration. The nectar amount for a food source represents the quality of such a solution (represented by a fitness value). Each bee class symbolizes one particular operation for generating new candidate food source positions (i.e., candidate solutions). The ABC algorithm starts by producing a randomly distributed initial population (food source locations). After initialization, an objective function evaluates whether such candidates represent an acceptable solution (nectar amount) or not. Guided by the values of such an objective function, candidate solutions are evolved through different ABC operations (honey-bee types) until a termination criterion is met.

This paper presents the use of ABC to accurately estimate the parameter of solar cells. In the approach, the estimation process is considered as an optimization problem. The proposed approach encodes the parameters of the solar cell as a candidate solution. An objective function evaluates the matching quality between a candidate solution and the experimental data. Guided by the values of this objective function, the set of encoded candidate solutions is evolved by using the operators defined by ABC so that the parameters that produce the best possible approximation to the I–V measurements obtained by the true solar cell can be found. In order to illustrate the proficiency of the proposed approach, it is compared to other well-known optimization methods. Experimental evidence shows that ABC exhibits no sensitivity to noisy conditions and high performance in terms of robustness and accuracy.

The remainder of the paper is organized as follows. In Section 2, the problem of solar cell identification is defined. Section 3 describes the ABC algorithm. In Section 4, the problem of solar cell identification is translated to an optimization task. Section 5 presents the experimental results and comparisons. In Section 6, the conclusions are stated, finally an appendix with the ABC algorithm is presented.

2. Solar cell modeling

The modeling of PV cells consists in two steps: the mathematical model formulation and the accurate estimation of their parameter values. In general, there exist two models: SD (single diode) and DD (double diode) [13]. In this section these models are described and their objective functions are formulated.

2.1. Double diode model (DD)

Solar cells are ideally modeled considering a photo-generated (I_{ph}) current source which is shunted with a rectifying diode. However, in practical terms, the current source I_{ph} is shunted by another diode which models the space charge recombination current and other non-idealities. The model of solar cells also includes a resistor connected in series with the cell shunt elements [13]. Fig. 1 shows the equivalent circuit for the DD model.

According to Fig. 1, the cell terminal current is computed as follows:

$$I_t = I_{ph} - I_{d1} - I_{d2} - I_{sh}, \quad (1)$$

where I_t is the terminal current, I_{ph} the photo-generated current,I_{d1},I_{d2} is the first and second diode currents whereas I_{sh} is the shunt resistor current. In order to appropriately model the solar cell, there is used the Shockley diode equation; hence, Eq. (1) is rewritten as it is shown in Eq. (2).

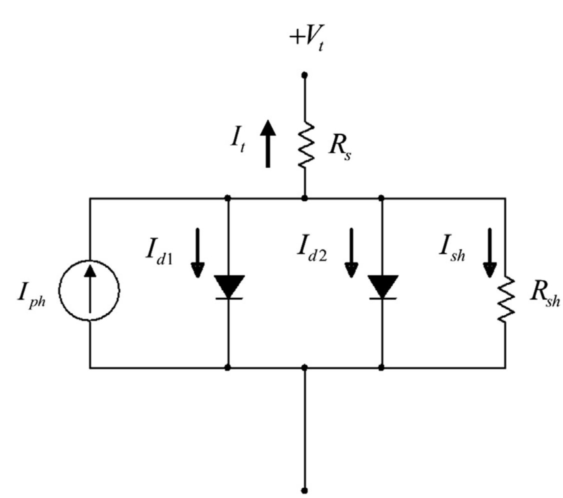

Fig. 1. Double diode model of solar cells.