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Parameter identification and sensitivity analysis of solar cell models with cat swarm optimization algorithm

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ABSTRACT

Solar cell model is used in various studies of photovoltaic system. Different methods have been developed to determine model parameters. In this paper, an optimization technique based on cat swarm optimization (CSO) algorithm is proposed to estimate the unknown parameters of single and double diode models. To investigate the effectiveness of proposed approach, comparative studies with other techniques are presented. The evaluation for the quality of identified parameters is also given. Results demonstrate the high performance of developed approach, high accuracy of estimated parameters, and calculated *I–V* curve is in good agreement with experimental *I–V* data. In addition, the sensitivity of performance to control parameter of CSO is also investigated. Results show the proposed CSO algorithm can be an effective tool to solve the optimization problem of parameter identification of solar cell models.

1. Introduction

Solar photovoltaic (PV) system has received significant attention due to its many advantages such as cleanness, abundance, sustainability and exploitation-free cost, although it also has the disadvantages including high initial investment cost and low conversion efficiency of PV modules [1]. In recent years, different works related to PV technology have been presented. Among many works, the photovoltaic thermal (PVT) system which produces not only electrical energy but also thermal energy has been addressed in the literature. In [2], a mathematical analysis has been implemented to obtain optimum PVT absorber configuration so as to reduce the cost. Based on a developed steady-state model, the optimal configuration is further validated. The authors in [3] presented a performance evaluation of a designed hybrid micro-channel PVT module under four weather conditions. Based on energy analysis and exergy analysis, the optimization of PVT water system has been performed in [4] and the optimal exergy efficiency is reported as 11.36%. In [5], a study was conducted to investigate the performance improvement of PVT system with optimized parameter, considering the climatic condition in New Delhi. The performance of glazed PVT system with optimal design parameters obtained by evolutionary algorithm has been evaluated by the authors in [6]. Study results showed that there was an increase of 69.52% in annual overall exergy gain and an increase of 88.05% in annual overall thermal gain.

Besides the efforts spent on PVT system, the work that aims to accurately model the behavior of solar cell also plays an important role in various studies of PV system due to the fact that solar cell is the basic component converting solar energy into electrical energy. Several equivalent circuit models have been developed over many years. Among circuit based models, the most popular ones are the single diode model and double diode model [7–9]. However, to describe the nonlinear current–voltage (*I–V*) characteristics of solar cell, these two models involve several unknown parameters. Thus, there is a need to provide a technique to effectively determine solar cell unknown parameters.

Many techniques have been proposed to solve such a problem, and can be grouped into two main types: analytical approaches [10–12] and numerical approaches [13–24]. In [10], solar cell model parameters were extracted from *I–V* characteristics. For the presented method, the model parameters were analytically calculated by using several key parameters including short circuit current (I_{SC}), open circuit voltage (V_{OC}), current and voltage (I_M and V_M) at maximum power point (MPP) and the slopes of *I–V* curve at short circuit point and open circuit point, and considering several approximations. Khan et al. [11] proposed an analytical method to calculate the diode parameters of solar cell subjected to high illumination. This method also uses the data obtained from *I–V* characteristics to determine the solar cell model parameters. However, only four parameters but not all five model parameters

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Nomenclature

AE	absolute error
$c1$	constant
CDC	counts of dimensions to be changed
D	number of dimensions of search space
I	output current of solar cell (A)
$I_{calculated}$	calculated current (A)
I_D	diode current (A)
I_L	photocurrent (A)
I_M	current at maximum power point
$I_{measured}$	measured current (A)
I_O,I_{O1},I_{O2}	saturation current (A)
I_P	parallel resistor current (A)
I_{SC}	short circuit current
$iter$	index of iteration
$iter_{max}$	maximum number of iterations
I–V	current–voltage
K	Boltzmann constant ($1.3806503 \cdot 10^{-23}$ J/K)
MPP	maximum power point
MAE	mean absolute error
MR	mixture ratio
MRE	mean relative error
n,n_1,n_2	diode ideality factor
N	number of points
NP	number of population
PV	photovoltaic
PVT	photovoltaic thermal
q	electron charge ($1.60217646 \cdot 10^{-19}$ C)
R_S	series resistance (Ω)
R_P	parallel resistance (Ω)
RE	relative error
$RMSE$	root mean square error
SMP	seeking memory pool
SRD	seeking range of the selected dimension
STD	standard deviation
T	cell temperature in Kelvin (K)
v	velocity vector
V	output voltage of solar cell (V)
V_{OC}	open circuit voltage
V_M	voltage at maximum power point
w	inertia weight
w_{max},w_{min}	maximum and minimum inertia weight
x	position vector
x_{best}	best position vector
$x_{bestcopy}$	best position vector for copies

are determined for single diode model. An analytical method to extract single diode model parameters was proposed in [12]. In order to solve the equations established by using information on there points (short circuit point, open circuit voltage point and MPP) on I–V curve, a piecewise curve-fitting method, together with a simplified solar cell model consisting of only four parameters, was developed to calculate the derivative of the V with respect to I at short circuit point and open voltage point. In general, for analytical approaches [10–12], model parameters are explicitly computed by the help of some particular point values on I–V curve of solar cell. Despite simplicity and relatively little time cost, the accuracy of analytical solution greatly relies on the values of selected points. Inaccurate values may lead to a solution with significant error in some cases. In addition, analytical approaches often need to make some assumptions and/or approximations. This may also cause a loss in solution accuracy.

To avoid the potential disadvantages of analytical approaches, many numerical approaches have been suggested, including Newton method [13], various heuristic algorithms such as Genetic Algorithm (GA) [14,15], Particle Swarm Optimization (PSO) [16,17], Simulated Annealing (SA) [18], Harmony Search (HS) [19], two variants of HS, Grouping-based Global Harmony Search (GGHS) [19] and Innovative Global Harmony Search (IGHS) [19] Pattern Search (PS) [20], bee swarm based algorithms including Artificial Bee Colony (ABC) [21] and Artificial bee swarm optimization (ABSO) [22], Differential Evolution (DE) [23], Levenberg–Marquardt algorithm based on simulated annealing (LMSA) [24]. As for Newton method based technique, a major deficiency is its sensitivity to initial parameter value [18]. It may fail to find global optima when solving a multimodal problem, if initial value is inappropriate. Besides, its application requires some necessary conditions such as convexity, continuity and differentiability [19]. On the other hand, heuristic algorithms, based on stochastic search technique which has no requirements for gradient information and accurate estimation of initial value, are more suitable to solve nonlinear optimization problem, and present better results than Newton method. However, most of the heuristic algorithms mentioned above have limitations. Although GA has been widely utilized as an optimization tool, it often suffers from the problem of local optimum [25], especially when low quality chromosomes are initialized or inappropriate control parameters are adopt. SA is a search technique imitating a physical process in which a metal is firstly heated to a given temperature and is then forced to cool down slowly. For this technique, an optimal cooling schedule is difficult to design, and it requires heavy computation burden during iterative search process [26]. LMSA also encounters the same problem as SA. Compared to SA, HS based algorithms produced better results [19]. However, HS based algorithms show a low ability to conduct local search, when used for numerical computation [27]. PSO and DE are the most popular heuristic algorithms, and have many advantages such as simplicity, easy programming and high convergence performance. However, due to fast convergence speed, the probability of premature convergence is also increasing [25,28]. For bee swarm based algorithms and PS, they also have to face the problem of getting trapped in local optimum [29,30].

Therefore, it is necessary to find a new algorithm with a more powerful ability to avoid local optima, which is a problem in the use of most of above mentioned algorithms. Cat swarm optimization (CSO) [31] is a recently devised heuristic algorithm, which mimics the behavior of a swarm of cats. By combining two different search strategies, CSO has the advantages of flexibility, fast convergence and producing highly consistent results. But it is slightly more complex than PSO. As a numerical optimization tool, CSO has been applied to different application domains [32,33]. To our knowledge, there are no reports on the application of CSO algorithm to the problem of parameter identification of solar cell model. In this work, we propose a CSO based optimization method to estimate the unknown parameters of sole cell models.

The main aim of this paper is to investigate the performance of proposed method. For this purpose, results are compared with other reported results. The quality of identified parameters is further evaluated. In addition, the effect of control parameter on the performance is also investigated.