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Determination of photovoltaic modules parameters at different operating conditions using a novel bird mating optimizer approach

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ABSTRACT

The main goal of this paper is to provide a framework to accurately estimate the electrical equivalent circuit parameters of photovoltaic arrays by use of an efficient heuristic technique. Owing to the non-linearity of the current vs. voltage (*I–V*) characteristics of PV modules, using a superior optimization technique helps to effectively find the real electrical parameters. Inspired by the mating process of different bird species, bird mating optimizer (BMO) is a new invented search technique which has shown superior performance for solving complex optimization problems. In this paper, the original BMO algorithm is simplified and used to estimate the electrical parameters of the module model for an amorphous silicon PV system at different operating conditions. The simplified BMO (SBMO) eliminates tedious efforts of parameter setting in original BMO and also modifies some rules. The usefulness of the proposed algorithm is investigated by comparing the obtained results with those found by two particle swarm optimization (PSO) variants, two harmony search (HS) variants as well as seeker optimization algorithm (SOA). Based on the investigated situations of this paper, SBMO yields more accurate results than the other studied methods.

1. Introduction

Solar energy offers a clean, climate-friendly, very abundant, and in-exhaustive energy resource to mankind. Solar power generation by PV technology is an active area which is studied worldwide from various aspects such as modeling and control [1], combination with other renewable sources [2], power forecasting [3], maximum power point (MPP) tracking [4] and parameter optimization [5]. In order to understand the characteristics, evaluate the performance and consequently optimize photovoltaic (PV) systems, an accurate mathematical model is a key tool for researchers. Modeling includes the mathematical description of the non-linear behavior of current vs. voltage (*I–V*) characteristics.

A number of mathematical models have been represented to clarify the behavior of PV system under different operating conditions. They vary from models with simple assumptions to advanced models accompanied with many physical variables. However, the single and double diode models are the most common models which are used in practice [6]. Though the double diode model slightly yields more accurate results than the other one, the ability of providing a good compromise between simplicity and accuracy causes the single diode model becomes more popular [7]. By the optimum value of the parameters, the model results can fit the experimental data as well as possible.

Various techniques have been used to extract the optimum parameters. In some Refs. [8–11], conventional methods have been employed. Because of their global search ability, metaheuristic algorithms can be appropriate choices to conquer the difficulty of the problem. In recent years, metaheuristic optimization algorithms such as genetic algorithm (GA) [6], simulated annealing (SA) [12], pattern search (PS) [6], differential evolution (DE) [7], harmony search (HS) [13] and artificial bee swarm optimization (ABSO) [14] have been used to solve the parameter estimation issue. The main differences between this paper and the recently published papers by the author [13,14] are (1) In [13,14], an optimization framework has been developed to find the parameters of a single solar cell while in this paper the formulation has been extended to a PV array consisting a number of series and parallel solar cells, (2) In [13,14], only one operating condition has been considered while here, parameter identification is conducted at

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different operating conditions, (3) In [13,14], the parameter estimation is conducted for a commercial silicon solar cell while this paper studies an amorphous silicon PV system.

Recently, a heuristic technique named bird mating optimizer (BMO), has been developed based on the idea of mimicking the breeding process in birds' society. BMO belongs to the category of evolutionary algorithms (EAs) which borrows some idea from the other heuristic techniques. Though BMO has been successfully applied to the engineering optimization problems [15,16] in comparison with a variety of optimization techniques, it suffers from some drawbacks. The main disadvantages of the original BMO are (1) numerous numbers of adjustable parameters and (2) numerous types of birds. In order to cope with the mentioned drawbacks, this paper proposes a simplified BMO algorithm, named SBMO, which reduces the types of the birds and eliminates tedious and experience-requiring parameter assigning efforts. In fact, these modifications make a user friendly optimization technique.

The ultimate aim of this paper is to propose an efficient methodology to estimate the electrical equivalent circuit parameters of photovoltaic modules. The solar system considered in this paper is an amorphous silicon module which is an attractive solar cell for PV researchers. For this system, parameter identification is conducted at different operating conditions. Operating conditions affect the model parameters and so, in each operating condition parameter identification is necessary. In order to evaluate the search power of the proposed algorithm, the performance of SBMO is compared with the results found by some well-known heuristic techniques.

2. Problem formulation

2.1. Module model

PV systems are broadly characterized by circuit-based approaches. For modeling a PV system under the illumination, the simplest way is to consider a current source in parallel to a diode. Consequently, three unknown parameters, namely, photo-generated current (I_{ph}), diode saturation current (I_{sd}) and diode ideality factor (n), make the parameters of the equivalent circuit model. For considering the PV cell metal contacts and the semiconductor material bulk resistance, an improved model, called R_s-model, takes into account a series resistance (R_s) to the model. Though R_s-model is more accurate, it shows serious deficiencies under high temperature variations since it does not account for the open circuit voltage coefficient. In addition, R_s-model is suitable for crystalline PV cell and leads to significant inaccuracy when it is applied to the thin-film technology. Another modification was suggested by adding a shunt resistance (R_{sh}) to the diode to consider the partial short circuit current path near the cell's edges resulted from the semiconductor impurities and non-idealities. This type of the model is known as the single diode model (or R_{sh}-model).

In the single diode model, shown in Fig. 1, the terminal current, I_t, can be formulated as follows [17,18]:

$$I_t = I_{ph} - I_d - I_{sh} \tag{1}$$

where I_d is the diode current and I_{sh} denotes the shunt resistor current.

By use of Shockley equation for the diode current and substituting the shunt resistor current, Eq. (1) is rewritten as given in the following equation [17,18]:

$$I_t = I_{ph} - I_{sd}\left[\exp\left(\frac{q(V_t + R_s I_t)}{nkT}\right) - 1\right] - \frac{V_t + R_s I_t}{R_{sh}} \tag{2}$$

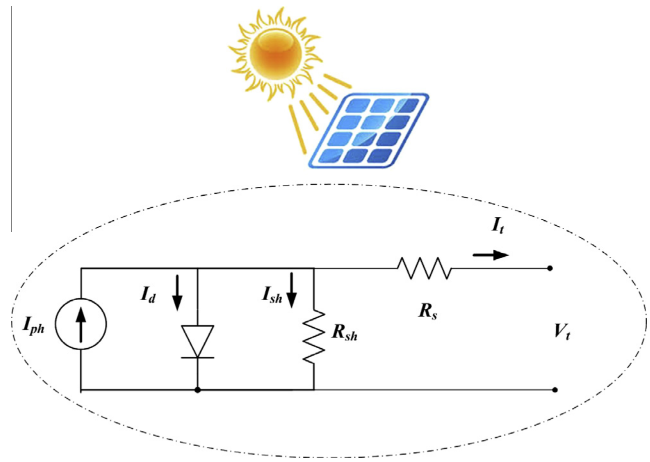

Fig. 1. The single diode model of PV cell under illumination.

where I_{sd} is the diode saturation current, V_t is the terminal voltage, q is the electronic charge, k denotes the Boltzmann constant, n is the diode ideality factor and T (K) is the cell temperature. When insolation drops, short-circuit current of cell drops in direction proportion.

A PV module consists of series and parallel PV cell combinations. If we consider a PV module with N_s cells connected in series and N_p strings connected in parallel, the mathematical formulation of a PV module can be formulated by Eq. (3) [17,18].

$$I_t = N_p \times I_{ph} - N_p \times I_{sd} \times \left[\exp\left(\frac{q(V_t/N_s + R_s I_t/N_p)}{nkT}\right) - 1\right] - \frac{N_p V_t/N_s + R_s I_t}{R_{sh}} \tag{3}$$

The equivalent circuit parameters of the single diode model which needs to be determined are photo-generated current, series resistance, shunt resistance, diode saturation current and diode ideality factor (I_{ph}, R_s, R_{sh}, I_{sd}, and n). Due to the fact that irradiance and temperature strongly affect the behavior of a PV module, it is necessary to determine all the model parameters simultaneously. This aim can be achieved by the help of a superior optimization technique.

2.2. Fitness function

In order to quantify the difference between the model results and the experimental data, root mean square error (*RMSE*) is used as the fitness function. For this aim, all the terms of Eq. (3), are moved to one side and the value of f is calculated for each pair of the experimental data by Eq. (4). Indeed, f denotes the error whose value is zero if the optimal values of the parameters are put into the right side. In this equation, I_t and V_t are the experimental data obtained from the PV system:

$$f(V_t, I_t, \vec{x}) = I_t - N_p \times I_{ph} + N_p \times I_{sd} \times \left[\exp\left(\frac{q(V_t/N_s + R_s I_t/N_p)}{nkT}\right) - 1\right] + \frac{N_p V_t/N_s + R_s I_t}{R_{sh}} \tag{4}$$

where f is the value of the homogeneous form of Eq. (3), $\vec{x} = [R_s\ R_{sh}\ I_{ph}\ I_{sd}\ n]$ is the vector of decision variables and M is the number of the experimental data.