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Simulated Annealing algorithm for photovoltaic parameters identification

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Abstract

A Simulated Annealing based approach is proposed in this paper for optimal estimation of solar cell model parameters. Different solar cell models, namely single diode, double diode, and photovoltaic module, are used in this study to verify the proposed approach outcomes. The developed technique is used to solve a transcendental function that governs the current–voltage relationship of a solar cell, as no direct general analytical solution exists. Several cases were investigated to test and validate the consistency of accurately estimating various parameters of different solar cell models. Comparative study among different parameter estimation techniques is presented to show the effectiveness of the developed approach. Furthermore, statistical analyses are carried out to measure the accuracy of the estimated parameters and model suitability.

Keywords: Photovoltaic; Solar cell; Simulated Annealing; Parameter estimation

1. Introduction

Emerging involvement of environmental friendly energy sources in producing electricity is being sought by many nations due to possible depletion and price increase of fossil based fuels, global warming, air pollution, and strict environmental laws. Solar energy is one of the most promising renewable sources that is currently being used worldwide to contribute to meeting rising demands of electric power. It has been reported that solar photovoltaic (PV) is the fastest growing power-generation technology in the world, with an annual average increase of 60% between 2004 and 2009 (Global Status Report, 2010). 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.

PV systems comprise different parts centered around a solar panel that typically has arrays of interconnected solar cells. Several models have been proposed to describe the current–voltage relationship (I–V) in solar cells (Xiao et al., 2006; Chegaar et al., 2003; Ye et al., 2009). The I–V curve of a solar cell exhibits non-linear characteristics determined by the solar cell parameters that describe its model. To gain better understanding of the solar cell physics, a lumped parameter equivalent circuit model is commonly used to simulate its behavior under different operating conditions. In practice, there are two main equivalent circuit models used to describe the non-linear I–V relationship: single and double diode models. The key parameters that describe solar cell models behavior are the generated photocurrent, saturation current, series resistance, shunt resistance, and ideality factor. Accurate estimation of these parameters is always required to provide precise modeling and accurate performance evaluation of a given solar system.

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Various techniques have been reported to approximate different parameters of solar cells. Reference Easwarakhanthan et al. (1986) proposed a modified non-linear least error squares estimation approach based on Newton's method to calculate solar cell parameters. A major drawback of this approach is its dependency on the initial values used in the proposed iterative technique. In addition, this type of optimization method is local in nature and may reach a local solution rather than a global one if multiple solutions exist. A new analytical solution technique, using the so called "Co-content function" which is based on Lambert function, has been proposed in reference Ortiz-Conde et al. (2006) to extract the solar cell parameters. A comparative study of three different methods, namely curve-fitting method, iterative 5-point method, and analytical 5-point method, for extracting solar cell parameters is presented in reference Chan et al. (1986). Similar analytical solution methods are presented in references Jain and Kapoor (2004), Chan and Phang (1987), Saleem and Karmalkar (2009). However, these techniques, that necessitate certain modeling conditions to make it applicable such as continuity, convexity and differentiability, involve heavy computations, tedious algebraic manipulation, and finally curve fitting. The Genetic Algorithm (GA) based approach is introduced as a new evolutionary tool for extracting the solar cell parameters in reference Jervase et al. (2001). Shortcomings of reported results are the relatively high percentage of errors associated with the extracted parameters and the binary conversion pertaining to GA implementation. Particle swarm optimization (PSO) is introduced in references Ye et al. (2009), Munji et al. (2010) as a different population based optimizer for solar cell parameters extraction. A comparative study illustrated that PSO outperformed GA in extracting more accurate parameters of solar cells. Reference proposes a robust Pattern Search (PS) technique for extracting the solar cell parameters as it introduces a new objective to this estimation problem.

This paper presents a Simulated Annealing (SA) based approach for estimating solar cell parameters. Section 2 discusses the solar cell modeling and mathematical formulation of the estimation problem along with the proposed approach. Section 3 presents testing and simulation results. The paper is then concluded in Section 4.

2. Modeling and estimation by Simulated Annealing

Before proceeding to the estimation phase, it is essential to have a mathematical model that accurately represents the electrical characteristics of the solar cell and the PV module. Despite the fact that many equivalent circuit models have been developed and proposed over the past four decades to describe the solar cell's behavior, only two models are used practically. In this section the two common models are briefly presented.

2.1. Double diode model

The solar cell is ideally modeled as a current source connected in parallel with a rectifying diode. However, in practice the current source is also shunted by another diode that models the space charge recombination current and a shunt leakage resistor to account for the partial short circuit current path near the cell's edges due to the semiconductor impurities and non-idealities. In addition, the solar cell metal contacts and the semiconductor material bulk resistance are represented by a resistor connected in series with the cell shunt elements (Wolf et al., 1977). The equivalent circuit for this model is shown in Fig. 1.

In this double-diode model, the cell terminal current is calculated as follows:

$$I_L = I_{ph} - I_{D1} - I_{D2} - I_{sh} \tag{1}$$

where, I_L is the terminal current, I_{ph} the cell-generated photocurrent, I_{D1}, I_{D2} is the first and second diode currents, I_{sh} is the shunt resistor current.

The two diodes currents are expressed by Shockley equation as illustrated respectively in Eqs (2) and (3), while the leakage resistor current I_{sh} is formulated as shown in Eq. (4):

$$I_{D1} = I_{SD1}\left[\exp\left(\frac{q(V_L + I_L R_s)}{n_1 kT}\right) - 1\right] \tag{2}$$

$$I_{D2} = I_{SD2}\left[\exp\left(\frac{q(V_L + I_L R_s)}{n_2 kT}\right) - 1\right] \tag{3}$$

$$I_{sh} = \frac{V_L + I_L R_s}{R_{sh}} \tag{4}$$

where R_s and R_{sh} are the series and shunt resistances respectively; I_{SD1} and I_{SD2} are the diffusion and saturation currents respectively; V_L is the terminal voltage; n_1 and n_2 are the diffusion and recombination diode ideality factors; k is Boltzmann's constant; q is the electronic charge and T is the cell absolute temperature in Kelvin. Substituting Eqs. (2)–(4) into Eq. (1), the cell terminal current is now rewritten as shown in the following equation:

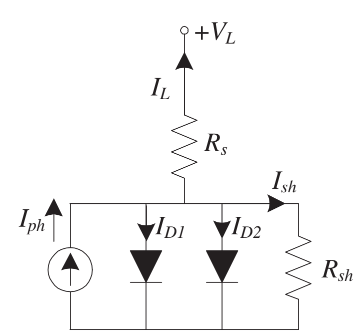

Fig. 1. Equivalent circuit of a double diode model.