Renewable Energy 97 (2016) 823–837

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Parameter extraction of solar cell models based on adaptive differential evolution algorithm

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A R T I C L E I N F O

Article history:
Received 13 August 2015
Received in revised form
27 May 2016
Accepted 8 June 2016

Keywords:
Modeling
Optimization algorithm
Parameter extraction
Photovoltaic
Differential evolution technique

A B S T R A C T

In this paper, a new approach based on adaptive Differential Evolution Technique (DET) is used to extract the parameters of solar cell models accurately. The adaption is achieved through crossover and mutation factor. It is indicated that the optimization with an objective function can minimize the difference between the estimated and measured values. In order to verify the performance of the proposed system, three different solar cell models: single diode model, double diode model, and photovoltaic module are used to extract the parameters. The analysis is performed by using the voltage and current data sets. The result shows that the proposed DET outperforms these other methods: chaos particle swarm optimization (CPSO), genetic algorithm (GA), harmony search algorithm (HSA), and artificial bee swarm optimization (ABSO). Furthermore, the DET technique is practically validated by two different solar cell types such as monocrystalline and multi-crystalline and modules. The performance of solar cell models has been verified and the outcome shows that it is an optimal method which suits the parameter extraction of solar cells and modules.

1. Introduction

Renewable energy sources such as photovoltaic (PV) and wind energy have shown significant growth over the last few decades. In particular, solar energy is promising renewable technologies due to ease of installation, very low maintenance, readily available in nature, and without pollution [1]. Renewable sources produce local heat even though the thermal reduction is achieved by avoiding CO_2 emission. The PV panels are dark and they absorb approximately 85% of incoming light whereas 15% is used to generate electricity. The remaining 70% will produce heat [2]. Various investigations on PV systems have become popular due to its significance in the past few years. However, a proper system design is also required for increasing the overall efficiency [3,4]. Several models have been introduced to analyze the above study, among the models: single diode and double diode models are the most popular [5]. In these models, the latter one is preferable because the physical module and its I-V characteristics closely resemble each other, but it has a wide range of computations [6].

There are two possible approaches such as analytical solution method and numerical method that have been developed for extracting various parameters of solar modules [7,8]. The analytical method requires different key points for I-V characteristics such as a current and a voltage at the maximum power point, open circuit voltage, short circuit current and the slope of I-V curve. It is noted that the I-V characteristic is greatly non-linear and the parameters vary dependent on the environmental conditions due to parameter changes, which leads to significant errors in the computed parameters [9]. The numerical method is more accurate than the analytical method because it is based on a certain algorithm to fit the points on the I-V curve [10]. However, the algorithm requires more computation and the accuracy depends on the cost function and the type of fitting algorithm.

Optimization and metaheuristics algorithms are widely used in parameter extraction of solar cells. Evolutionary algorithms are the natural choice for parameter extraction problems because they are capable of replacing the standard test condition. Evolution algorithm methods are preferred to solve parameter extraction regardless of gradient and information of initial conditions [11]. Various evolutionary algorithms such as genetic algorithm (GA) [12,13], particle swarm optimization (PSO) [14], simulated annealing (SA) [15] have been included in parameter extraction for solar

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http://dx.doi.org/10.1016/j.renene.2016.06.024
0960-1481/

Nomenclature

L_i	length of individual
D	p-n junction of solar cell
I_t	terminal current
k_{max}	maximum number of generation
M	number of real I-V data
m	ideality factor of the diode
R_{ser}	series resistance
q	charge of electron (1.602×10^{-19} C)
T_c	cell temperature
I_i	illuminated cell current
I_m	current of PV module
I_{ph}	cell-generated photocurrent
I_s	shaded cell current
V_s	shaded cell voltage
P_s	power dissipated by shaded cell
I_{es}	estimated cell current
C_r	crossover probability constant
F	mutation factor
k	Boltzmann constant (1.381×10^{-23} J/K)
NP	size of population
D_k	blocking diode
R_{sh}	shunt resistance
RC	rate of crossover
D_b	bypass diode
I_d	diode current
V_m	voltage of PV module
V_T	thermal voltage
V_t	terminal voltage
I_{sd}	reverse saturation current of diode
I_{sh}	shunt resistor current
I_{me}	measured cell current

Subscript

1,2	first and second

cells. The electrical characteristics of solar cells and parameter extraction using GA are computed from the maximum power point [16]. The PSO technique is used to extract various parameters of the PV module [17,18]. The modified differential evolution algorithm called penalty based DE algorithm is used to extract various parameters of solar cells [19].

GA has limitations like low speed and degradation [20]. The trade-off between temperature, cooling schedule and inconsistencies are the major issues making SA less suitable for parameter extraction problems [21]. To improve the consistency of the estimation, PSO is introduced in conjunction with cluster analysis. The PSO is also used to estimate the parameters and the cluster analysis for filtering the non-feasible solution [22,23]. This increases the consistency and reliability, even though it requires all previous points to be stored. It increases the computational burden and therefore the simulation speed will be greatly impacted. The searching space of the parameters should be broadened to avoid convergence problems and the extraction processes satisfy different boundary conditions. A fast and accurate two-diode model for photovoltaic modules has been studied by Ishaque et al. [24]. The control parameters are changed randomly in to a self-adaptive evolutionary algorithm so that the convergence is difficult and the selection process has not been impacted by the evolution [25,26]. To increase the efficiency of the control parameters such as F and RC, an adaptive algorithm has been introduced [27]. Differential evolution using adaptive methods have been studied by Tvrdik using a numerical comparison [28].

Unlike conventional differential evolution (DE), the solution of adaptive DE is always in the feasible region and unconstrained in nature. Therefore, it is reliable to include the adaptive DE. As a result, a greater number of solutions will be created. The solution takes part in the evolution process and in the accuracy of the method, where diversity and consistency will be improved. In this work, the performance of DET is investigated for individual solar cells in each module parameter extraction process and is compared with four methods namely GA, CPSO, HAS, and ABSO. Finally, to ensure the practical use of the proposed DET method, it is validated by two different solar cells and modules such as monocrystalline (SM55) and multi-crystalline (KG200GT). The remnants of this paper is organized in the following ways: section 2 describes the problem formulation of parameter extraction with single diode model, double diode model, and model of PV module; section 3 describes the DE and adaptive DE algorithm; section 4 explains the simulation and experimental results; and the conclusion is discussed in section 5.

2. Problem formulation

The main objective of the parameter extraction for solar cell models is to minimize the difference between measured and simulated current. Two circuit models (single and double diode) are typically used to describe the performance of solar cells. The single diode model provides better performance under normal operating condition, but the performance is very less at low irradiance [29]. On the other hand, the two diode model modifies the current equation by including the recombination losses in space-charges by incorporating an additional diode.

2.1. Single diode model

The equivalent circuit model of a solar cell using single diode model is shown in Fig. 1. In Fig. 1, the index D, R_{sh}, R_{ser}, and I_{ph} represents the p-n junction of a solar cell, shunt resistance, series resistance, and photocurrent due to solar irradiation respectively. The diffusion current, diode ideality factor, and recombination currents are combined together in the single diode model. The governing equation for this equivalent circuit is formulated using Kirchoff's current law for current I_t and it is given as:

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

In single diode model, I_d is modeled using Shockley equation,

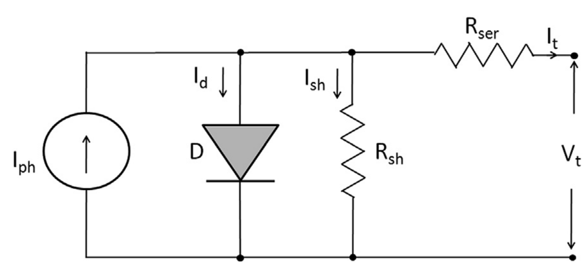

Fig. 1. Equivalent circuit model of solar cell using single diode model.