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An improved single-diode model parameters extraction at different operating conditions with a view to modeling a photovoltaic generator: A comparative study

Abdelkader Abbassi [a,*], Rabiaa Gammoudi [b], Mohamed Ali Dami [a], Othman Hasnaoui [b], Mohamed Jemli [a]

[a] University of Tunis, Higher National Engineering School Of Tunis (ENSIT), Engineering Laboratory of Industrial Systems and Renewable Energies (LISIER), 5 avenue Taha Hussein, PO Box 56, 1008 Tunis, Tunisia

[b] University of Carthage, National Institute of Applied Sciences of Tunisia (INSAT), Unit of Research (ERCO), North Urban Center, 1080 Tunis Cedex, Tunisia

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ABSTRACT

This paper proposes advanced analytical, numerical and genetic algorithm (GA) approaches for retrieving the parameters of photovoltaic (PV) panel. A comparative study for extracting the five parameters of a single diode PV model is presented. Based on the datasheet values, a numerical based Newton-Raphson algorithm is investigated for solving the current-voltage relation of a single diode solar PV model. To highlight the rigorous performance of our models, a second analytical model is proposed. For improving the accuracy of solar panel parameters, a technique based on GA is established. This approach is based on the problem of research and optimization of the extracted parameters as an objective function. To account for variation in solar radiation and temperature, these models are presented under the reference and real operating conditions. The performances of the proposed algorithms are compared by using MATLAB scripts programming, and the theoretical advantages of GA model were demonstrated. The different models are validated experimentally by various tests of temperature and solar irradiance variation. The experimental results indicate that the GA model has a very satisfactory performance compared with the two other models and it offers good compromise between accuracy and fastness.

1. Introduction

During last twenty years, solar energy, like wind energy, is one of the most attractive concerns. Due to the intensive presence of the Saharan climate especially in Africa, solar energy must be among the best renewable sources that have gained great popularity due to its high availability and predictability. With the trend to serve exponential demand for electricity as their economies grow, the production of electricity from solar energy sources has a great interest to developing countries, especially because it has many isolated and remote regions from electricity distribution networks. To solve this problem, a highest priority must be accorded to the exploitation of the solar potential must be a priority.

From its discovery, the conversion of solar energy into electrical energy using photovoltaic modules reveals an undesirable problem. The non-linearity of the photovoltaic modules outputs, presents today a very respectful occupation of the researchers.

In order to describe the behavior of photovoltaic cells, Different models based on the current-voltage curve of a P-N junction were used. Recently, various researches on the prediction of the current-voltage characteristic curve are founded in the literature (Salaux et al., 2011). In this context, the two diodes model is known as the most accurate model for representing the equivalent electrical circuit of a photovoltaic cell.

Nevertheless, additional difficulties and a longer calculation time are appended to solving the basic equation describing the two diodes model, since their parameters are defined in a nonlinear manner (Ishaque et al., 2011a, 2011b). As the most commonly used, the single diode model can be categorized into two main types (Dongue et al., 2012). The simplified four-parameter model neglecting shunt resistance by assuming it as infinite value in the equivalent electrical circuit and the five-parameter model that characterizes the current-voltage curve of the cell by maintaining the effect of the shunt resistor. The five-parameter model evaluates the photocurrent, the saturation current, the series and shunt resistors and the ideality factor of the diode.

Various methods are conceivable to determine the parameters of the equivalent electric circuit of a solar cell. However, the

* Corresponding author.
E-mail addresses: abd_abbassi@yahoo.com (A. Abbassi), medali.dami@esstt.rnu.tn (M. Ali Dami), mohamed.jemli@ensit.rnu.tn (M. Jemli).

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equation that links the different parameters which make up the current-voltage relationship is defined in a non-linear manner or implied by mathematical relationships. To solve this problem, several techniques can be considered:

Taking into account the nonlinearity relationship which cannot easily expressed of the solar panel parameters. A first approach consists to resolve this relation by the artificial neural network method (Singh et al., 2014); this approach is used to predict the parameters of the electrical equivalent circuit of a photovoltaic cell. Another approach consists on calculating the parameters of the PV cell by the Newton-Raphson method (Bogning Dongue et al., 2013; Ma et al., 2014; Chouder et al., 2012; Bellia et al., 2014; Bonkoungou et al., 2015); that operators in an iterative manner and requires the initialization of parallel and series resistors while other parameters are defined referring to the photovoltaic modules manufacturer data.

In (Ishaque et al., 2011b; Ishaque and Salam, 2011; Siddiqui and Abido, 2013; Peng et al., 2013), the authors have investigated an improved modeling version based on different types of Evolutionary Algorithms (EA) to determine the photovoltaic module parameters. Besides, three algorithms are employed such as the particle swarm optimization (PSO), the Genetic Algorithm (GA) Ismail et al., 2013 and the Differential Evolution (DE). The purpose of these algorithms was to determine the parameters of the electrical equivalent model of photovoltaic cells. A critical study makes it possible to judge the stochastic optimization method as the most efficient one. In addition, a Bird Mating Optimizer (BMO) approach was used in Askarzadeh (2015) to estimate the model electrical parameters of an amorphous silicon PV module under different operating conditions.

Some analytical propositions are also suggested in this subject. In fact, an efficient analytical approach for obtaining a five parameters model of photovoltaic modules using only reference data is proposed by Lo Brano (2013), Chikh and Chandra (2015). Herein, the electrical behaviors of the photovoltaic model depending on the operation conditions of temperature and solar irradiance were described analytically. In (Batzelis and Papathanassiou, 2016; Hejri et al., 2014), various analytical solutions for approximating the parameters of the single diode and the double diode models of a photovoltaic module have been presented, respectively. Based on manufacturer's datasheet, various numerical algorithms are investigated for solving the current-voltage equation of a single diode solar PV model (Ayodele et al., 2016; Silva et al., 2016). Other numerical methods, which are based on Newton-Raphson and Levenberg-Marquard algorithms, are proposed in Appelbaum and Peled (2014).

In addition, based on the parameters extraction of solar cells, review papers have also addressed this issue (Humada et al., 2016; Jordehi, 2016; Lineykin et al., 2014; Ciulla et al., 2014). These works have focused on the extraction of the DC parameters of solar cells by a set of techniques based on both single-diode and double-diode models is described and discussed. Moreover, the existing research works on solar cell model parameter estimation problem are classified in a fair manner into different categories.

In this paper, a single diode model which depends on the solar irradiance, the temperature and five characteristics parameters is established. Analytical and numerical studies were developed to solve the nonlinearity behavioral in order to determine the five parameters of PV panel. A technique based on GA model is proposed for improving the accuracy of the extracted parameters describing the electrical equivalent model of the solar panel. Some experimental tests have been conducted in order to better choose the most suitable model. After comparison of the different proposed models with the experimental data, the results show that the GA model is almost confused with these data. This model offers a good compromise between fastness and accuracy.

The rest of this paper is structured as follows. Section 2 is related to a preface on the modeling of the PV system. Section 3 describes the parameters extraction under reference conditions, which includes the different models used in this study. In Section 4, the parameters determination under real conditions is demonstrated. Section 5 discusses the obtained results and their comparison with experimental ones. Finally, Section 6 outlines the main conclusions.

2. Mathematical modeling of a photovoltaic module

Although a multitude of models and techniques have been published in the literature, the modeling of a photovoltaic generator remains a complex undertaking. In order to resolve this problem electrically, various models are used to describe the I-V curve variation, on which we look at three characteristic points to improve the relationship between all components of electrical equivalent circuit.

In this work, based on the variation of solar radiation and temperature, different models are discussed to get the current-voltage and the power-voltage characteristics. Analytical, numerical and GA based evolutionary computational approaches have been used. The synoptic scheme of PV parameters extraction is depicted in Fig. 1.

This one shown below was judged as the most appropriate, following an exhaustive research on this subject (Abbassi and Chebbi, 2012; Ma et al., 2014; Abbassi et al., 2017; Mares et al., 2015). The objective of this segment is not only to describe in detail the equations of this model, but also to highlight the shortcomings with respect to this research theme and to propose modifications to enable them to be filled.

Fig. 2 shows the equivalent electrical circuit of a single diode model of photovoltaic generator. It consists of a current source I_{ph}, a diode D, a series resistor R_s and a shunt resistor R_{sh}.

The current-voltage relation of photovoltaic cell is given by:

$$I = I_{ph} - I_D - I_{sh} = I_{ph} - I_0\left(e^{\left(\frac{V+R_sI}{V_t}\right)} - 1\right) - \frac{V + R_sI}{R_{sh}} \tag{1}$$

The diode thermal voltage at reference conditions is given by:

$$V_t = \frac{AkT}{q} \tag{2}$$

where I_{ph} is the photo current (A); I_0 is the diode saturation current (A); A is the diode ideality factor; k is the Boltzmann constant ($1.38 \cdot 10^{-23}$ J/K); q is the electron charge ($1.6 \cdot 10^{-19}$ C); T is the cell temperature (K); R_s is the series resistance (Ω) and R_{sh} the shunt resistance (Ω).

In Eq. (1), the five parameters which defined the current-voltage relation of photovoltaic cell, vary in accordance with the solar irradiance, the cell temperature and necessary with their reference values.

The particulars points of current voltage, power-voltage characteristics of the solar panel used in this work are represented in Fig. 3.

3. Calculating parameters procedure under reference conditions

3.1. Analytical approach

The current voltage relation which described by Eq. (1), in the reference conditions, as follows:

$$I = I_{phref} - I_{0ref}\left(e^{\left(\frac{V+R_{sref}I}{V_{tref}}\right)} - 1\right) - \frac{V + R_{sref}I}{R_{shref}} \tag{3}$$