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Systematic derivation of parameters of one exponential model for photovoltaic modules using numerical information of data sheet

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ABSTRACT

Modeling of photovoltaic (PV) modules is an important issue studied in the literature. The appropriate equivalent circuit is widely used to model the PV module in order to evaluate its performance as well as estimate its behavior with other parts of a system in interconnected employment. Estimation of the parameters of equivalent circuit poses challenges which has been addressed in the literature. Determining the parameters of a PV model is generally based on experimental results but the approach which only uses the available information provided by the manufacturer is practically preferred. Since data sheets provide limited information, accurate and explicit determination of parameters would be a favorite procedure. Sometimes, specific tests are performed to obtain more data to overcome this problem which of course has its own limitations. In this paper, a set of equations required for derivation of five parameters of one exponential PV model is extracted and a systematic approach for derivation of these parameters is developed based on basic data sheet numerical information. Performance of the proposed approach for different types of PV modules is evaluated through comparing the results with experimental measurement and results of the previous works.

1. Introduction

With the increasing penetration of PV arrays into the electrical systems to generate electricity, adopting an effective method to design and control PV systems has been a challenging issue for designers especially in residential applications. The most important problem is decision making on type of PV module and the properties of requirements. Hence, designers should have the ability of estimating the performance of some typical PV modules in their systems so that they can choose the proper one. This issue needs the simulation of the performance of PV modules which requires accurate model parameters. Manufacturers present I–V characteristics which represent the performance of the PV module as a black box. In this case, the PV module can be considered as a non-linear resistor in the circuit. With I–V curves users can predict the behavior the module, but they cannot obtain accurate information about internal behavior such as effect of shading phenomenon in which the role of some cells in generation is removed and the output is dropped. On the other hand, electrical model is more suitable for circuit analysis of modules integrated with other elements in user's system or project especially for control purposes.

Since the one exponential photovoltaic model is effective for analytical evaluating of the performance of PV modules, it has been applied in a large number of literature as acceptable and reliable model. One exponential model consists of three kinds of electrical elements: a current source which represents the photocurrent which is function of radiation and environmental conditions, a diode, and two resistances which represent losses. Total loss of a module is modeled with a series resistance and a shunt (parallel) resistance. Photocurrent, reverse saturation current, quality factor of diode, and two resistances are five parameters of the one exponential model. This model is usually classified to two general types including four-parameter single diode and five-parameter single diode. The difference between these two types of one exponential model is considering the shunt (parallel) resistance. Four- and five-parameter analytical models have been used to calculate the operating current of a typical photovoltaic module in Ref. [1] and it is demonstrated that the complete five parameter model predicts the operating current better than the simplified four-parameter model where the shunt resistance is neglected.

The classical and the modified single-diode models have been used to model the electrical characteristics of PV cells and modules

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in Ref. [2]. A model has been presented in Ref. [3] based on the fundamental circuit equations of a PV cell taking into account the effects of physical and environmental parameters such as the radiation and cell temperature. Simulation of PV modules based on one exponential model has been done in Refs. [4–6]. Neural network has been adopted in Ref. [7] to predict PV panel behavior under realistic weather conditions.

To extract the parameters, some papers have focused on a specific parameter. For instance, to determine the series resistance some methods are proposed in Refs. [8–10]. References [11] and [12] have presented review of methods to determine the series resistance. On the other hand, determination of shunt resistant has been discussed in Refs. [13] and [14]. Numerical calculation of series and shunt resistances has been discussed in Refs. [15] and [16]. Several methods (up to about 22 methods) for determination of the solar cell quality factor have been presented in Refs. [17] and [18]. A numerical calculation of two resistances and the quality factor has been performed in Ref. [19]. The saturation current and the photocurrent have been discussed in Refs. [20] and [21] respectively. In some studies, a dynamic resistance of a PV cell is defined from I–V characteristics. This auxiliary parameter is normally taken to be the slope of the I–V characteristic of a module. Determination of the dynamic resistance has been discussed in Refs. [22] and [23]. To analyze the effect of external conditions which vary the photocurrent in the model and influence the I–V curve [24], predicts how the I–V characteristic changes with environmental parameters such as temperature and irradiance. The proposed tool of [24] estimates the two unknown parameters (series and shunt resistances) obtaining the best-fit of the measured I–V characteristic. Reference [25] defines a circuit-based simulation model for a PV array in order to estimate the electrical behavior with respect to changes on environmental parameter of temperature and irradiance.

The extraction of all parameters of model has been discussed in Refs. [26–36]. Reference [26] has applied a numerical technique based on genetic algorithms to identify the electrical parameters. The harmony search-based parameter identification method has been proposed in Ref. [27] to identify the unknown parameters of the solar cell single diode model. A comparative study of four methods for extracting solar cell parameters of the single diode lumped circuit model has been presented in Ref. [28]. An application of pattern search optimization technique for extracting the parameters has been proposed in Ref. [29]. Reference [30] has proposed a Cuckoo Search-based parameter estimation method to extract the parameters of single-diode models for commercial PV generators. In Refs. [31], an optimized method on the basis of polynomial fitting and Lambert W function has been presented to extract parameters from the current–voltage (I–V) characteristics of commercial silicon solar cells. A method for identifying the parameters of photovoltaic cells/modules with the help of curve fitting by using both analytical and statistical methods is proposed in Ref. [32]. Reference [33] has presented an approach which involves the use of an auxiliary function and a computer-fitting routine. In Ref. [34] a technique has been developed that includes the presentation of a standard function and determination of three factors of this function that provide the calculation of the illuminated solar cell parameters.

Sometimes a valid assumption can help to derivate parameters. For instance [35], has proposed a stable method for deriving all the parameters from a single I–V curve, which requires a valid assumption for a solar cell. Reference [36] has presented a methodology for estimating the model parameters and a new seven parameter PV model based on the results of a sensitivity analysis. In this procedure a sensitivity analysis has been carried out to identify the relative importance of the five model parameters. Using the results of sensitivity analysis, the electrical model is improved by including two additional parameters.

This paper proposes an approach using numerical information to determine five required parameters of one exponential electrical model of PV modules considering error propagation due to one approximation. In this paper, the extraction of all unspecified parameters of one exponential model in one procedure is preferred where a systematic approach is developed with acceptable accuracy. The proposed method is based on only three manufacturer data represent coordinates of three significant points of I–V curve including the short circuit point, the open circuit point and the maximum power point. The proposed methodology is exclusively based on analytical relationships besides a valid assumption about the I–V curve which is exploited geometrically and its accuracy has been verified with practical data. The proposed procedure doesn't involve any simplification applied in previous works. This viewpoint is based on the fact that approximation and simplification may affect the reliability of the outcomes. The procedure uses only the standard numerical information of module data sheet and it doesn't use the curves presented by manufactures. The proposed procedure in this paper aims to provide a simple MATLAB-based program so that the user can only enter the primary guesses and required variables to extract the parameters. Moreover error propagation caused by approximations is discussed as an important issue in the suggested procedure.

2. Model analysis and theory

Initially one of the main features of the proposed method in this paper is the distinction between two policies in modeling of a PV module in the form of one exponential model that cause either single diode lumped circuit model or cell-based single diode circuit model. Generally single diode lumped circuit model is used in the literature for PV modules [37–46]. Nevertheless the cell-based model is preferred in this paper because of its advantages. In cell-based model each cell is individually modeled and model of a module consist of n cascade cell models and n is the number of cells in the module. The main advantage of this method is distinction photocurrent of each cell because practically all of the cells aren't under the same radiation. Moreover, in order to consider the effect of shading phenomenon, we can remove shaded cell(s) from the model conveniently.

The one exponential model of each PV cell is shown in Fig. 1. The equivalent circuit of cell consists of a current source, a diode and two resistances. Five parameters in this electrical model are the magnitude of the current source, reverse saturation current and quality factor of the diode, shunt resistance, and series resistance.

Normally, all cells have same condition of radiation and temperature. Thus the values of the current source in the models of all cells are the same. Since the module voltage is the sum of individual voltages of each cell, the output voltage of a module is determined by:

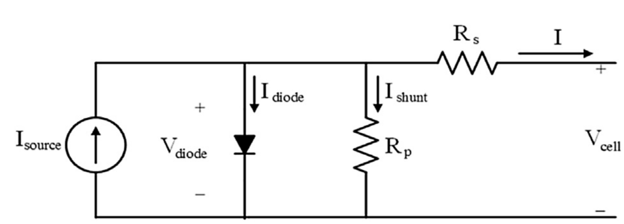

Fig. 1. The one exponential model of a PV cell.