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Study, Comparison and Evaluation of Model Parameters of Photovoltaic Cells

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Abstract

Modeling of photovoltaic (PV) characteristic (cell/module/panel/array) needs involvement of a lot of parameters, which can be classified into the internal and external parameters. Generally, catalogue sheet of photovoltaic module (issued by manufacturer) can be used as initial information to get model parameters. Nevertheless, only the parameter related to external parameters (i.e. current and voltage) are provided by the photovoltaic producer. As informed in the most of literatures, it is known that accuracy of the photovoltaic characteristic model is not only depend on the external parameters (light generated current and reverse saturation current) but also are influenced by the internal parameters (series resistance, shunt resistance and diode quality factor), therefore the proper estimation of internal parameters are very crucial. In our paper, comparison of two techniques in order to identify of model parameters will be discussed in, referring to "state of the art" of research in PV modeling, which available in literatures.

Keywords: modeling of PV, internal influences, external influences, crystalline technology, thin film technology.

1. Introduction

The fundamental building block of photovoltaic (PV) systems is the PV cell. A PV cell is a semiconductor diode which when exposed to light generates charge carriers. If the PV cell is connected to an external circuit, current will flow through the circuit (Siddiqui et al., 2013). A PV module, panel, or array, are composed of several of PV cells connected in series and/or in parallel.

The characteristic of PV cell/module/panel or array can be explained with an equivalent electric circuit that is similar to the device that is to be characterized. In literatures, a lot of equivalent electrical circuit models have been proposed in order to describe of the PV cell's characteristic. There are a number of more or less complex models for simulating the characteristic of a PV system (the current, I – voltage, V – *power, P*) for specific irradiance and temperature conditions (De Blas et al., 2002). In other side, accuracy of the PV characteristics system modeling (simulation) is depending on the correct calculation of the parameters such as I_l, I_o, R_s, R_{sh} and n as well, which could be expressed by generalized Shockley equation, as follow:

$$I = I_l - I_o\left[\exp\left(\frac{V + IR_s}{\frac{nkT_c}{q}}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \qquad \text{(Eq. 1)}$$

where I is PV cell output current, V is PV cell voltage, R_s and R_{sh} are the cell series and shunt resistance respectively, I_l is the photo-generated current (light generated current), I_o is the cell reverse saturation current, n is diode quality factor, k is the Boltzmann constant (k = 1.3806503 x 10^{-23} J/K), T_c is the cell temperature and q is absolute value of the electron charge (q = 1.602 x 10^{-19} C)

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Among the all adopted PV models, the one-diode and the two-diode models are the most utilized ones and the one-diode model particularly gives results since it guarantees good accuracy with a low complexity. The success of the one-diode model is also testified by its wide use within both specific software toolboxes for the estimation and the prediction of the electrical power produced by PV plants and algorithm for the Maximum Power Point Tracking (MPPT) or irradiance measurement (Laudani et al., 2014). Moreover, based on previous research which is re-written by Saloux (2011), in general, double-diode models are more accurate for polycrystalline silicon cells while single-diode ones are used for amorphous silicon cells. It is obvious that the final model application must correspond to the best compromise between simplicity and accuracy.

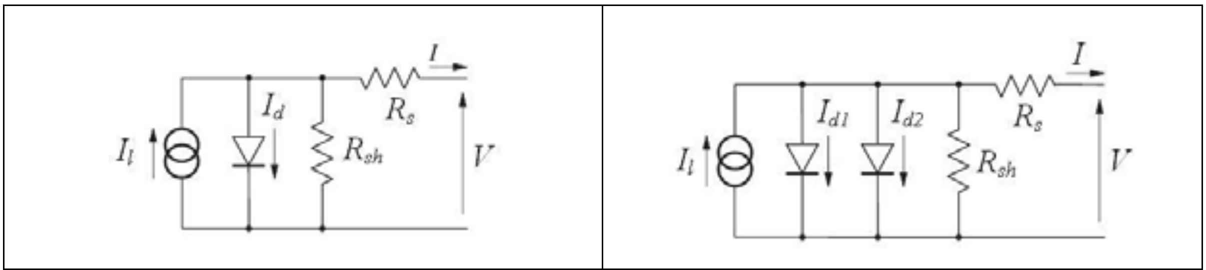
The knowledge of the parameters I_l, I_o, n, R_s, R_{sh}, which later called as "five model parameters", allows tracing the *I-V* curve for fixed temperature and irradiance values. The extraction of the five parameters model has been widely discussed in literatures by following two approaches as: (i) several authors proposed different equations/approaches to be used for the calculation of the five parameters from information provided by manufacturers in datasheets (manufacturer catalogue); (ii) many kinds of optimization techniques have been proposed to solve the inverse problem related to the extraction of the five parameters from experimental *I-V* curves (Laudani et al., 2014).

The degree of complexity of the model will determine which of the methods is most suitable in extracting the parameters that are involved in the mathematical expression of the model (De Blas et al., 2002). In this paper, comparison of two methods will be discussed referring to the "state of the art" of research in PV modeling, which available in literatures.

Nevertheless, it should be noted that the long term objectives of our research is development of photovoltaic cell/module model, especially for polycrystalline silicon (wafer based crystalline silicon technology) and amorphous silicon (thin film technology) modules, as components of grid-connected PV array system at Szent István University (SZIU), which are not discussed in this paper.

2. Model of PV cell

Generally, equivalent circuit model of PV cell composed of a photocurrent source, a diode, a shunt/parallel resistance and series resistance, and can be analyzed by single or double diode models. Fig. 1 shows equivalent electrical schematics based on single and double diode ideal of PV cell models (Saloux et al., 2011 and Ma et al., 2014).



(a) single diode	(b) double diode

Fig. 1: General model of equivalent electrical circuits with internal resistances

In case single diode model, based on Kirchhoff's current law and Shockley diode equation, the mathematical model of the PV cell has been described in Eq. 1. Note that Eq. 1 is a transcendental equation which cannot be solved by direct analysis. In the simple case, which does not include internal electrical resistances, the *I-V* characteristic curve is given by:

$$I = I_l - I_o \left[\exp\left(\frac{V}{\frac{nkT_c}{q}} \right) - 1 \right] \qquad \text{(Eq. 2)}$$

From the characteristic *I-V* curve of a given PV cell, three key physical quantities are defined: the short-circuit current, the open-circuit voltage and the values of current and voltage that permit the maximum power to be obtained. These variables correspond to well define points in the *I-V* plane. The determination of these points is essential to develop appropriate PV cell models. The nonlinear and implicit relationships that exist between them, however, necessitate using tedious iterative numerical calculations. Furthermore, most of the parameters depend on both the cell temperature and the solar irradiance; thus, the knowledge of their behavior is crucial to correctly predict the performance of PV cells and arrays (Saloux et al., 2011).

To further extract I_l, I_o, n, R_s, R_{sh} some complicated methods were proposed in the past years. In the literatures, many calculation methods such as genetic algorithm (GA), particle swarm optimization (PSO), simulated annealing (SA), explicit model, Lambert W-function, pattern search (PS), harmony search (HS) have been explained in order to identify a solar cell parameter, and generally built based on experimental of *I-V* characteristics through the extract parameters (Askarzadeh and Rezazadeh, 2013; Ghani et al., 2013).

3. Parameter extraction methods

The determination of model parameters plays an important role in PV cell design and fabrication, especially if these parameters are well correlated to known physical phenomena. A detailed knowledge of the PV cell parameters can be an important way for the control of the PV cell manufacturing process, and may be a mean of pinpointing causes of degradation of the performances of panels and photovoltaic systems being produced. For this reason, the model parameters identification provides a powerful tool in the optimization of PV cell performance (Sellami et al., 2014)

In Eq. 1, there are totally five unknown parameters to be determined: I_l, I_o, n, R_s and R_{sh}. Ma et al. have performed the research in order to solve the five parameters based on product's datasheet provided by its manufacturer. To find the five parameters, at least five equations are needed, and can be derived based on the three characteristic points under Standard Test Condition (STC), as can be seen in Fig. 2.

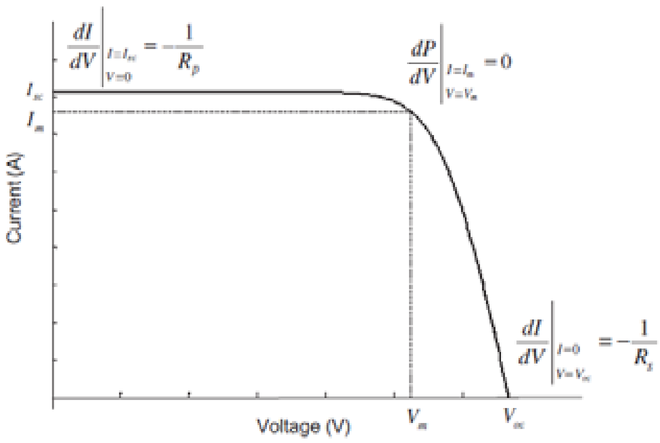


Fig. 2: The relationship between *I-V* curve, R_s and R_{sh}

This method/approach offered a good compromise between simplicity and accuracy. Detail procedures and results related to this method available in the literature (Ma et al., 2014).

Related to PV modeling, Ghani et al. have worked using the Lambert W-function in order to determine internal parameters, such as R_s, R_{sh} and n. In this method, the diode value is assumed constant and should be known. The advantage of this method is simple to apply, accurate and can be carried out using data provided the manufacturer. The algorithm method can be seen in the literature (Ghani et al., 2012, 2013). Lambert *W* function is implemented to convert the *I–V* characteristic implicit equation to an explicit one, so the output current and voltage of photovoltaic cells can be obtained by substituting the five parameters into the explicit *I–V* equation (Xu et al., 2014)

4. Concluding remarks

This paper elaborated the method of extracting of the PV cell parameters which directly affects on the conversion efficiency, the power conversion and characteristics curve of the PV cell. Principally, there are two possible approaches to extract the solar module parameters i.e. analytical and numerical extraction techniques .The former requires information on several key points of the *I–V* characteristic curve, i.e. the current and voltage at the maximum power point (*MPP*), short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), and slopes of the *I–V* characteristic at the axis intersections. The numerical extraction technique is based on certain mathematical algorithm to fit all the points on the *I–V* curve. More accurate results can be obtained because all the points on the *I–V* curve are utilized (Venkateswarlu et al., 2013).

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