An Empirical model for Generating the IV Characteristics for a Photovoltaic System

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الملخص

نموذج اختياري لتوليد خواص الـ IV لنظام الجهد الضوئي

يقدم هذا البحث نموذج تجريبي لتوليد خواص ال IV لوحدة أو خلية تعمل بنظام الجهـد الضوئي وذلك بالاعتماد على بارامترات يقوم المنتج بتزويدها، و هذه البارامترات هي I_{sc}، V_{oc}، I_{mp} و V_{mp}.

يمتاز هذا النموذج على النماذج الأخرى بأنه لا يتطلب معرفة البارامترات الداخلية لنظام الجهد الضوئي كما أنه يتضمن جهود حسابية أقل.

الحسابات باستخدام هذا النموذج يمكن أن تمدد لتوليد منحنيـات ال I-V عنـد درجـات حرارة مغايرة لدرجة الحرارة المعيارية المذكورة.

ABSTRACT

This paper presents an empirical model for generating a PV module or a solar cell I-V curves based on the parameters provided by the manufacturer specification sheets. These parameters are I_{sc}, V_{oc}, I_{mp}, and V_{mp}. The advantage of this model over other existing models is that it doesn't require the knowledge of internal PV system parameters and involve less computational efforts. Calculations using this model can be extended to generate the I-V curves at temperatures other than the standard reporting conditions (SRC) temperature.

Keywords: solar cell, PV module, photovoltaic

PACS: 84.60.Jt

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INTRODUCTION:

Both research and technological development in the areas of renewable energy sources are necessary to account for the increase in energy demand and environmental problems in the world. Photovoltaic (PV) is one of these renewable energy sources where PV systems generate electricity by direct conversion of sun light. Much research activities has been conducted in this field over the last few decades (Karatepe : 2003, and Sukamongkol : 2002).

Many PV simulation programs have been written for years, and during this time many models have been developed (Aqkbaba : 1995, Blacomb : 2001, and Ikegami : 2001). Among these models is the four parameter model (Duffie : 1991, Ikegami : 2001, and Zacharias : 1991). This model treats a PV system as an irradiance dependent current source IL connected in

$$I = I_L - I_0\left[\exp\left(\frac{q}{\gamma k T_c}(V + IR_s)\right) - 1\right]$$

where γ is a dimensionless diode curve-fitting factor, I0 is the reverse saturation current, q is the electronic charge, k is the Boltzmann constant, and Tc is the temperature in K. A modification to this model is accomplished by adding a shunt resistor Rsh in parallel with the diode resulting in the so called five parameter model which was developed by Lehman and Chamerlin (Lehman : 1987). This model is given by:

$$I = I_L - I_0\left[\exp\left(\frac{q}{\gamma k T_c}(V + IR_s\right) - 1\right] - \frac{V + IR_s}{R_{sh}}$$

A major limitation of these models is that they depend on parameters such as Rs, Rsh, I0 , IL , and γ. These parameters are not provided by the manufacturer specification sheet and are not easily determined.

PV module manufacturers specification sheets may include I-V curves at standard reporting conditions SRC or other sets of operating conditions. The data values actually used to plot these curves are not provided. Manufacturers, usually, provide some parameters on their specification sheets. Among these parameters are four characteristic parameters associated with the I-V curves. These parameters are the short circuit current Isc, the open circuit voltage Voc, the current at maximum power Imp, and the voltage at maximum power Vmp. In this paper a model that can be used to generate a curve that accurately represents the module's I-V characteristics is proposed. This gives researchers the capability to reproduce accurate PV module I-V characteristics using only a microcomputer. The input parameters required by the model are these four parameters.

The Model:

The proposed new model for generating the I-V characteristics of a solar cell or PV module has the following form:

$$I = I_{sc} - C_1 \exp(-\frac{V_{oc}}{C_2})[\exp(\frac{V}{C_2}) - 1] \qquad (1)$$

where C1 and C2 are coefficients of the model equation. It is clear that this model fulfils the requirement for a solar cell or a PV module at a voltage equal zero since it leads to a current equal to Isc. The aim, now, is to determine the unknown coefficients C1 and C2. For zero current i.e. at V=Voc Eq.(1) becomes

$$0 = I_{sc} - C_1[1 - \exp(-\frac{V_{oc}}{C_2})]$$

which leads to the following form

$$C_1 = \frac{I_{sc}}{[1 - \exp(-\frac{V_{oc}}{C_2})]} \qquad (2)$$

Dimensional analysis of Eq.(2) indicates that C2 has units of voltage and C1 has units of current. At maximum power points Imp and Vmp Eq.(1) reduces to:

$$I_{mp} = I_{sc} - C_1 \exp(-\frac{V_{oc}}{C_2})[\exp(\frac{V_{mp}}{C_2}) - 1] \qquad (3)$$

Or

$$C_1 = \frac{I_{sc} - I_{mp}}{[\exp(\frac{V_{mp}}{C_2}) - 1][\exp(-\frac{V_{oc}}{C_2})]} \qquad (4)$$

Analytical solution of Eq.(2) and Eq.(4) to determine the coefficients C1 and C2 is difficult. On the other hand, For a certain product parameters (Isc, Voc, Imp, and Vmp), one can easily solve these two equations graphically for C1 and C2 where the solution is the point of intersection of the two graphs. These results are depicted in Fig.1 for Shell ST10 module with Voc=22.9 V, Isc=0.77 A, Vmp=15.6 V, and Imp=0.64 A. In this figure C1 represents the ordinate and C2 represents the abscissa.

On the other hand we can easily deduce a simplified form of the coefficients C1 and C2 by making the following assumptions:

1- Assuming that Voc/C2 >>1, we find that Eq.(2) reduces to

$$C_1 \cong I_{sc} \qquad (5)$$

2- assuming that (Vmp/C2) >>1, then, Eq.(3) reduces to

$$I_{mp} \cong I_{sc} - C_1 \exp(\frac{V_{mp} - V_{oc}}{C_2}) \qquad (6)$$

Rearranging terms, we obtain

$$C_1 = \frac{I_{sc} - I_{mp}}{\exp(\frac{V_{mp} - V_{oc}}{C_2})} \qquad (7)$$

Now, by substituting Eq.(5) into Eq.(6) and rearranging terms, we obtain

$$\frac{I_{sc} - I_{mp}}{I_{sc}} = \exp[\frac{V_{mp} - V_{oc}}{C_2}]$$

After some algebra and solving for C2 this equation reduces to:

$$C_2 = \frac{V_{mp} - V_{oc}}{\ln(1 - \frac{I_{mp}}{I_{sc}})} \qquad (8)$$

The above assumptions are valid only if they lead to a solution of Eq.(5) and Eq.(7) that is too close to the solution of Eq.(2) and Eq.(4). Plotting Eq.(5) and Eq.(7) on the same graph with Eq.(2) and Eq.(4) show that the solutions of the two sets of equations intersect almost at the same point. This behavior is depicted in Fig.1. Thus, the assumptions will not affect much the values of C1 and C2 at the point of intersection which, in turn, will not appreciably affect the behavior of the IV curve of a solar cell or a PV module when applying these approximate values to Eq.(1).

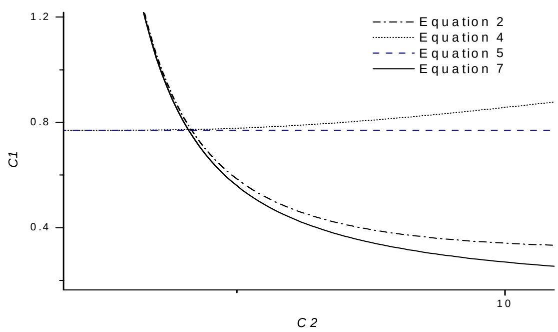

Fig. 1. The graphical solution of Eq.(2) and Eq.(4) almost coincide with the graphical solution of Eq.(5) and Eq.(7) for Shell ST 10 module.

To demonstrate how this model works, a set of module parameter values was used with Eq.(1), Eq.(5), and Eq.(8) in order to model the I-V curve of the PV module. For example, using the specification sheet parameters for Uni-Solar PV modules (US-64, US-42, US-32) which utilize the proprietary triple junction silicon solar cells. With these parameters implemented into the model one obtain the I-V curve shown in Fig.2. This figure shows that the theoretical model is in good agreement with the experimental curve. At this point, it is necessary to point out that all the measured data in this article is excerpted from the manufacturers I-V curves in the specification sheets. It is clear from the figure that the model closely models the measured performance of the three PV modules.

Again it can be seen from Fig.3 that the calculated power closely models the measured performance of the power for PV module, for bp solar 75-Watt monocrystalline BP 275 module.

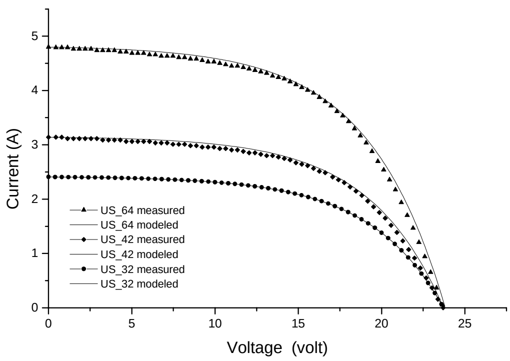

Fig. 2: Modeled (lines) and measured (points) I-V characteristic for Uni-Solar PV modules (US-64, US-42, US-32.)

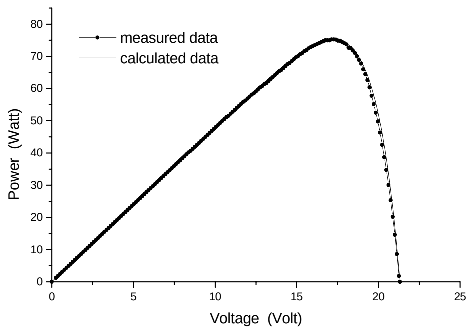

Fig. 3. Calculated and measured power for PV module, for bp solar 75-Watt monocrystalline BP 275 module.

To predict a PV module or solar cell I-V characteristics curve at temperatures where data or I-V curves are not available, parameter temperature coefficients are necessary. Temperature coefficients are the rate of change of different photovoltaic parameters with respect to temperature. These coefficients can be determined for Isc (αIsc), Voc (βVoc), Imp (αImp), and Vmp (βVmp). It has been published that these four temperature coefficients are necessary to accurately model the effect of temperature on the I-V characteristics of a module (King : 1997). The set of equations necessary to calculate the module parameters at temperature values other than SRC are:

$$V_{oc}(T) = V_{oc}(T_r) - \beta_{Voc} V_{oc}^{SRC}(T_r - T) \tag{9}$$

$$I_{sc}(T) = I_{sc}(T_r)[1 - \alpha_{Isc}(T_r - T)] \tag{10}$$

$$I_{mp}(T) = I_{mp}(T_r)[1 - \alpha_{\mathrm{Im}\,p}(T_r - T)] \tag{11}$$

$$V_{mp}(T) = V_{mp}(T_r) - \beta_{Vmp} V_{mp}^{SRC}(T_r - T) \tag{12}$$

where VocSRC and VmpSRC are the module values expected at SRC and can be obtained directly from the specification sheet. It is necessary to modify Eq.(9) and Eq.(12) in order to generate the behavior of the I-V characteristics at various temperatures different than that at SRC. The modified form of these equations are:

$$V_{oc}(T) = V_{oc}(T_r) - \beta_{Voc}(T_r - T) \tag{13}$$

$$V_{mp}(T) = V_{mp}(T_r) - \beta_{Vmp}(T_r - T) \tag{14}$$

Sandia National laboratory provides an online Microsoft Access database for various PV modules and arrays (Sandia : 2001). This database contains values of various temperature coefficients as well as values of other parameters. For example, applying Eq.(10), Eq.(11), Eq.(13), and Eq.(14) to BP 275 module with SRC parameter values Isc(Tr), Voc(Tr), Imp(Tr), and

Vmp(Tr) at temperature Tr = 25 ºC, one can determine Isc(T), Voc(T), Imp(T), and Vmp(T) at various temperatures. Then, by applying the calculated values into Eq.(1), Eq.(5), and Eq.(8) the I-V curve at the corresponding temperature can be generated. Figure 4 shows the result of generating these curves at three different temperature values (0 ºC, 50 ºC, and 75 ºC) from the data at SRC (T = 25 ºC). It is clear from the figure that the calculated curves match well the measured ones. Conclusion

A new empirical model that can generate the I-V curves for a PV module or a solar cell using parameters provided by the manufacturers data sheet is developed. This model can be used to generate the I-V curves at temperatures other than SRC.

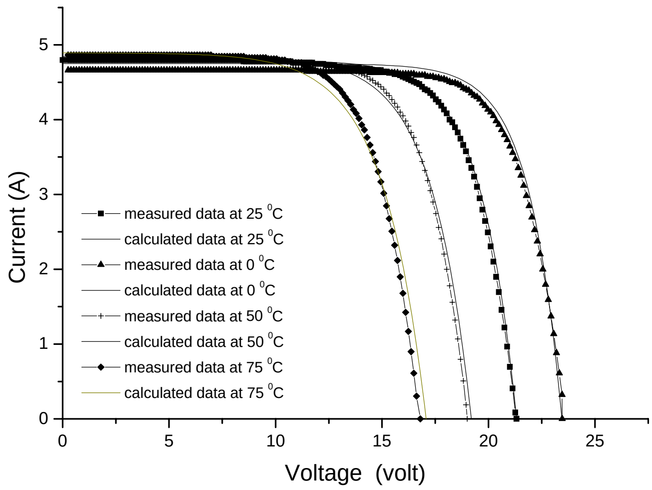

Fig. 4. Measured and Modeled I-V characteristics for bp solar 75-Watt monocrystalline BP 275 module at various temperatures.

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