A New Mathematical Model for Estimating Solar PV Module Energy Production

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Abstract

Analytical calculations of values for the input parameters of solar module circuit models that are similar to those used in practice are notoriously challenging. Therefore, past studies favored numerical methods. Because numerical techniques are time-consuming and need long-term time series data, which is unavailable in most poor countries, an improved mathematical model was built by integrating analytical and numerical approaches to meet the limitations of prior methods. The model's input parameters were solved for analytically. The output current from the photovoltaic module was given an explicit expression using the Lambert W function, and the output voltage was given numerically by the Newton-Raphson method. Also, the form factor, which includes the idealist factor and the series resistance, was included into an algebraic model for the power output of a single-diode photovoltaic module. When the developed model was compared with the rated power output of a solar module offered by manufacturers, using local meteorological data, the discrepancy was found to be less than 2%. In terms of predicting the power output of photovoltaic modules for a given location and set of input factors, the proposed model was demonstrated to be more relevant.

Introduction

Standard test conditions (STC) are used by manufacturers to assign grades to photovoltaic (PV) modules. These circumstances typically include 1000 W/m2 of solar energy, a cell temperature of 25 °C, and a solar spectrum of 1.5. The input parameters of PV modules are established by the local weather. The unpredictable nature of weather makes it difficult to plan ahead for. As a result, the power produced by PV modules is either over- or underestimated. It has been shown that the rated power output of PV modules might be overstated by as much as 40 percent [1, 2]. Since their meteoric rise in popularity [3-5], scientists have investigated every part of photovoltaics, from cell technology to modeling to size optimization. Modeling PV modules is an important step in developing reliable PV systems. It is possible to model and understand the connections between PV modules' current, voltage, and power output [6-8]. However, a variety of intrinsic and extrinsic factors alter the behavior of current and voltage, which in turn affects model estimate. Predicting PV module performance over a broad variety of environmental conditions requires reliable modeling. Hernanz et al. [9] found that manufacturers did not provide information on the series and parallel resistance of their products when comparing the efficiency of various kinds of solar cells. Andrews et al. [10] proposed using module short circuit current (Isc) at 5 min time scales for more accurate simulation of PV systems at finer resolutions. Their effort improved upon previous work with the Sandia array.

paradigm whereby extra components were added to the calculation of short circuit current (Isc) to explain mistakes (such spectrum and module power tolerance concerns and instrumentation alignment faults). Norton's circuit model of solar PV module was compared with existing models using Matlab by Chakrasali et al. [11] to better predict the behavior of PV modules after they have been operated for lengthy periods of time. Using a single-diode lumped circuit, Chouder et al. [12] were able to mimic a PV module and determine its basic properties, including its power conversion efficiency. Chouder et al. [13] employed the LabVIEW environment to provide an in-depth evaluation of the functionality and behavior of PV systems. Researchers like Jain and Kapoor [14], Jain et al. [15], Ortiz-Conde et al. [16], and others [17–19] have all employed the Lambert W function to solve equations. The Lambert W function provides a direct connection between the current and voltage of modules while significantly reducing the time required to calculate the results, as was concluded by Picault et al. [17], who presented a novel approach to forecasting the output of existing PV arrays under varying environmental circumstances. Polynomial curve fitting using the Lambert W function may be used to extract parameters from the current-voltage (I-V) characteristics of commercial silicon solar cells, as proposed by Chen et al. [18]. The Lambert W function was used to transform the transcendental problem into an explicit analytical answer. Fathabadi [19] presented a novel method for analyzing silicon solar cells, modules, and plastic solar cells. Artificial neural networks and the Lambert W function were used to determine the I-V and P-V curves of silicon and plastic solar cells and modules [20].

Power Generation from PV Modules Modelled and Calculated

A PV module's output power is affected both by its internal electrical properties (current and voltage) and by environmental factors. In order to keep things simple, scientists often only include the most crucial electrical properties and influential climatic data in their models. It's almost impossible to get a model that takes into account every factor that affects PV modules' efficiency. Parameters such as the electrical characteristics of modules under standard rating circumstances are included in the models as they are often given by manufacturers [37]. A PV cell represented by a single diode in an equivalent electrical circuit is stated as [38].

where Ish is the shunt current, ID is the current through the diode, and IL is the current produced by the light.The Shockley equation [[39, 40]] gives an expression for the diode current(ID):

In their definition of the shunt current (Ish), Petraeus et al. [41]

This complete model of an electrical equivalent circuit with a single diode and five parameters is shown visually in Figure 1. It may alternatively be written as [40, 42-44] in algebra.

Characteristic Curves of Impedance vs Voltage and Potential versus Voltage A Model of a Photovoltaic Cell

It is critical to estimate the power output of PV modules, therefore knowing the relationship between current and voltage under real-world operating conditions is essential. In order to create the necessary quantity of power, the cells are often joined into modules. Cells in a particular module may be connected in series or in parallel to provide the required current and voltage. You may choose to link the modules in a series or in a parallel array. The voltage from a series connection is additive, whereas the current from a parallel connection is additive [52–56]. It is possible to assess the PV module's power output by measuring how well the current-voltage (I-V) and power-voltage (P-V) characteristic curves perform. The power-voltage and current-voltage characteristic curves are graphically shown in Figures 2–9. The typical current-voltage (I-V) characteristic of a PV module is shown in Figure 2. The current in a circuit when the open circuit voltage (Voc) is 0 is called the short circuit current (Isc). Current typically decreases gradually up to a certain point and then rapidly afterwards until open circuit is achieved. Figure 3 depicts a power vs voltage plot. A maximum area rectangle drawn below the I-V curve indicates the greatest power available. At the optimum power point, the power output, current, and voltage are all at their highest possible levels (Pmp, Imp, and Vmp). In an ideal world, the cells would always be operating at the optimum point where their power output is directly proportional to the load's I-V characteristic. So, to get the most out of solar PV panels, load matching is essential.

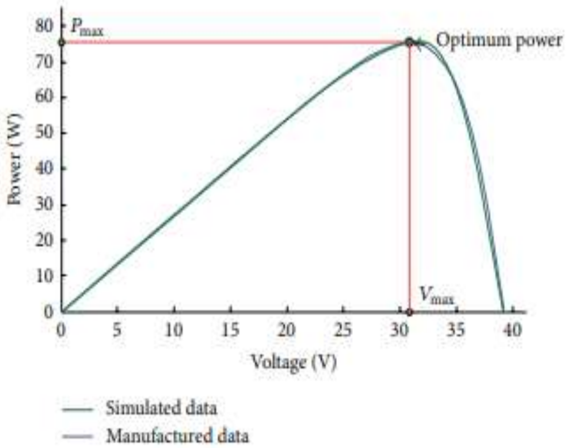

Figure 1: Typical P-V characteristic curve of a PV module

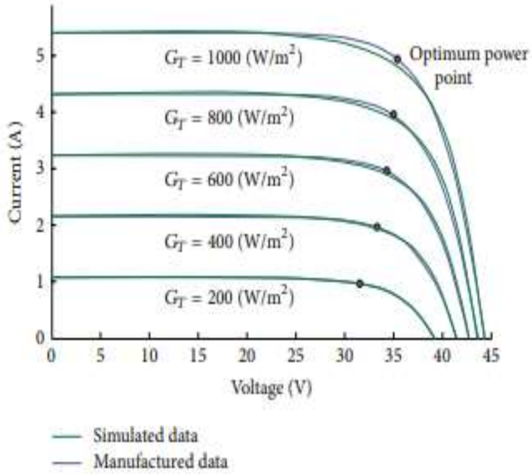

Figure 2: I-V characteristic curves at various solar radiation levels

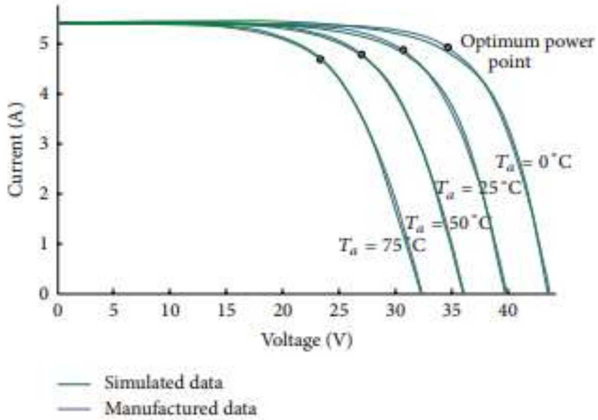

***Figure 3: I-V characteristic curves at various temperatures*.**

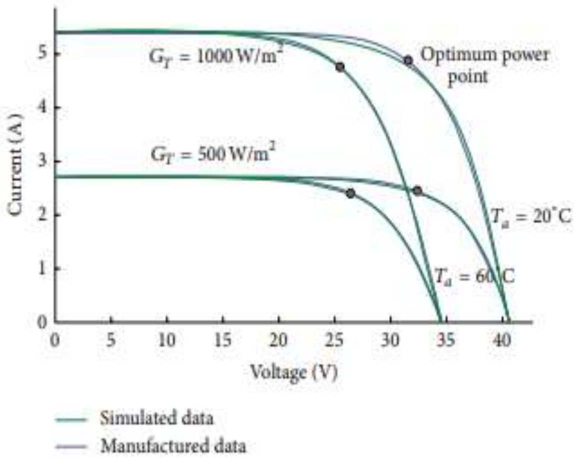

Figure 4: I-V characteristic curves for various set of solar radiation and temperature.

As a result, maximum power point tractors are favored for optimizing solar PV system output power. Figure 4 and Figure 5 depict typical I-V curves for a range of solar irradiance and temperatures. The curves show the greatest power point locus. While the open circuit voltage grows linearly with solar irradiance, the short circuit current grows at a logarithmic rate. The short circuit current is almost directly proportional to the incoming solar energy as long as the curved component of the I-V characteristic does not cross. It is possible to utilize the short circuit current as a measure of incoming solar radiation under the assumption that the solar radiation has a constant spectral distribution. Figure 6 depicts the I-V characteristics curves for various irradiance and temperature combinations. It was found that the output voltage drops linearly with temperature relative to current. As a result, at a given amount of solar irradiation, a PV module's power output drops as its voltage drops. However, when incoming solar radiation rises, the influence of temperature is more on short circuit current.Figure 7 and Figure 8 show the P-V characteristics curves for different solar irradi ation levels at constant temperature of 25 C and at multiple temperatures with constant solar irradiance of 1000 W/m2, respectively. As the temperature rises, the open-circuit voltage drops and the short-circuit current rises only little. as the cell is operated in that temperature range, the power output drops dramatically as the temperature rises. Figure 9 depicts the P-V curves that result from a given irradiance and temperature. When comparing the calculated power output of photovoltaic modules with the rated power of PV modules given by manufacturers, the developed model resulted in an inaccuracy of less than two percent. However, the model predicted results were off from the rated power of PV module at higher solar radiation and temperature levels. Since this was the case, the suggested model arbitrarily set Rsh, or shunt resistance, to infinite. The investigation showed that when temperature and incoming solar energy both increased, electricity production decreased. Energy production from photovoltaic cells

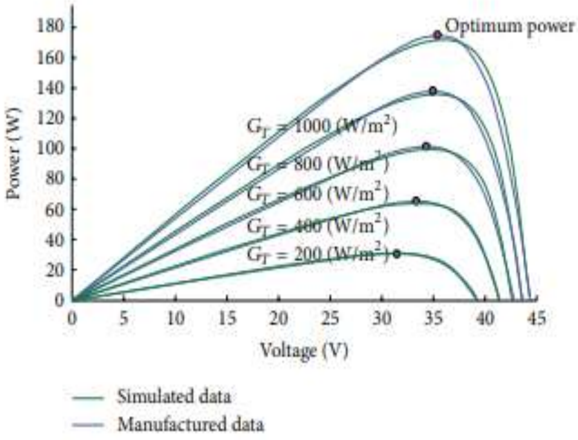

Figure 7: P-V characteristic curve at constant temperature of 25∘C.

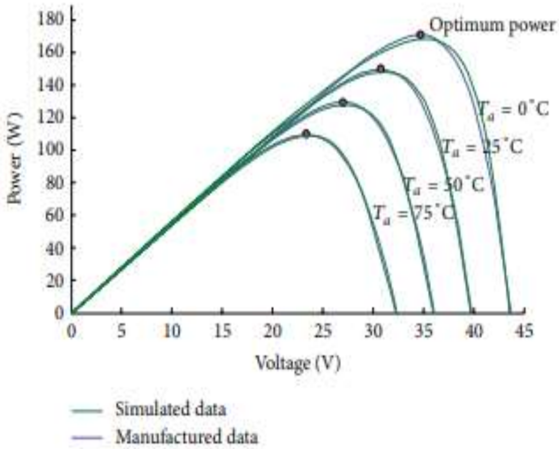

Figure 8: P-V characteristic curve at constant solar radiation of 1000 W/m2 .

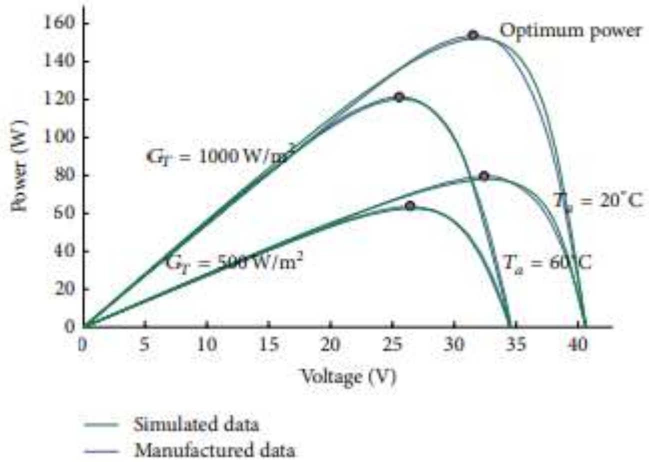

Figure 9: P-V characteristic curve at various set of solar radiation and temperature.

Conclusions

Combining analytical and numerical techniques, the suggested mathematical model is developed. Light-generating current, diode reverse saturation current, shape parameter, and series resistance are among the essential elements of the current-voltage (I-V) curve that may be calculated analytically. The Lambert W function provides an explicit formula for the PV module's output current, while the Newton-Raphson technique is used to calculate the module's voltage output numerically. Algebraic derivation of equations for the shape factor () using the ideality factor (A) and the series resistance (Rs) of the single diode model of PV module power output is the primary contribution of this paper. These equations will provide an easy and accurate method of estimating the power output of PV modules. Under normal test settings, the suggested model's estimates of the current-voltage (I-V) and power-voltage (P-V) characteristic curves were consistent with those acquired directly from the PV module. Power output from PV modules was found to change mostly due to variations in incoming solar radiation and temperature. When all other variables were held constant, researchers found that the power output of PV modules was linearly related to the quantity of incoming solar radiation. Manufacturer-reported rated power output for PV modules is used to verify the proposed model's predicted findings, which were shown to be accurate to within 2%. The model is more realistic due to its reduced reliance on a large number of independent factors and its ability to reliably forecast PV module performance.

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