DogoRangsang Research Journal
ISSN: 2347-7180

UGC Care Group I Journal
Vol-12 Issue-01 Jan 2022

Calculating the Energy Produced by Solar PV Modules: A New Mathematical Model

Dr T RAKESH[1] , D V RAMA NARSAIAH[2]

[1,2]Professor , DEPARTMENT OF EEE
KLR COLLEGE OF ENGINEERING & TECHNOLOGY
BCM ROAD, PALONCHA-507115, BHADRADRI KOTHAGUDEM DIST

Abstract

Values for the input parameters of comparable circuit models of solar modules are notoriously difficult to calculate analytically. Consequently, prior researchers favoured using numerical approaches. An enhanced mathematical model was created by combining analytical and numerical approaches to address the limits of previous methods; this was necessary since numerical methods are time-consuming and need long-term time series data that is unavailable in most developing nations. Input parameters for the model were determined analytically. The Lambert W function provided an explicit expression for the photovoltaic module's output current, while the Newton-Raphson approach provided a numerical value for the module's voltage. In addition, an algebraic model for the power output of a single-diode photovoltaic module was developed, including the form factor, which incorporates the idealist factor and the series resistance. Using local meteorological data, the results of the created model were compared with the rated power output of a solar module given by manufacturers, yielding an inaccuracy of less than 2%. The suggested model was shown to be more applicable in terms of accurate predictions of photovoltaic module power output for any given location and set of input variables.

Introduction

Manufacturers often grade photovoltaic (PV) modules using standard test conditions (STC) that include 1000 W/m2 of solar energy, a cell temperature of 25 °C, and a solar spectrum of 1.5. The local meteorological conditions determine the input parameters for the PV modules. Due to their random occurrence, weather conditions are difficult to forecast. Energy output from PV modules is thus either over- or underestimated due to these unknowns. Up to 40% of the rated power output of PV modules was observed to be overestimated [1, 2]. Researchers have been looking at every facet of photovoltaics since their popularity skyrocketed [3-5]; this includes everything from cell technology to modelling to size optimization. PV module modelling is a crucial part of making sure PV systems work as intended. The relationships between the current, voltage, and power output of PV modules may be modelled and understood [6-8]. However, the behaviour of current and voltage is influenced by a number of intrinsic and extrinsic variables, which in turn impact model estimate. Therefore, accurate modelling is crucial for predicting PV module performance over a wide range of environmental circumstances. When comparing the efficiency of several solar cell types, Hernanz et al. [9] noted that producers did not disclose information on the series and parallel resistance of their products. In order to better simulate PV systems at finer resolutions, Andrews et al. [10] suggested employing module short circuit current (Isc) at 5 min time scales. Their work was an updated version of the Sandia array performance model that included additional elements to the computation of short circuit current (Isc) to explain errors (such spectral and module power tolerance issues and instrumentation alignment errors). In order to better forecast the behavior of PV modules after they have been run for extended periods of time, Chakrasali et al. [11] compared Norton's circuit model of solar PV module with the current models using Matlab. Chouder et al. [12] used a single-diode lumped circuit to simulate a PV module and calculated the power conversion efficiency to get the module's essential characteristics. Chouder et al. [13] used the LabVIEW environment to offer a comprehensive analysis of PV system performance and dynamic behaviour. In order to solve equations, the Lambert W function has been used by researchers such as Jain and Kapoor [14], Jain et al. [15], Ortiz-Conde et al. [16], and others [17–19]. Picault et al. [17] offered an innovative approach to forecasting existing PV array output in varying environmental circumstances, with the conclusion that the Lambert W function allows for a direct link between the current and voltage of modules while drastically shortening the amount of time required to calculate the results. Parameters may be extracted from the current-voltage (I-V) characteristics of commercial silicon solar cells with the use of a polynomial curve fitting and the Lambert W function, as suggested by Chen et al. [18]. In order to convert the transcendental equation into an explicit analytical solution, the Lambert W function was used. A new technique for characterizing silicon solar cells, modules, and plastic solar cells was described by Fathabadi [19]. The I-V and P-V curves of silicon and plastic solar cells and modules were calculated using an artificial neural network and the Lambert W function [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.

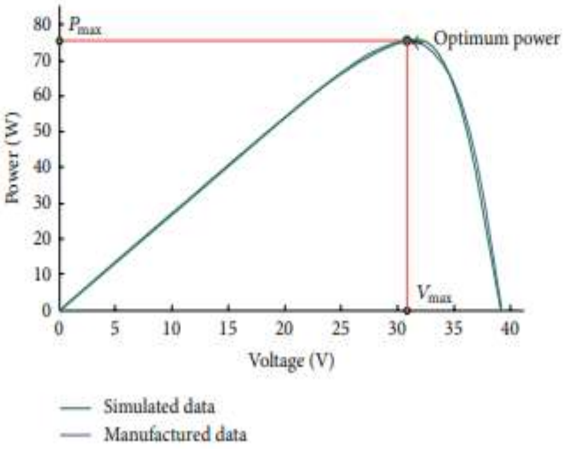

Figure 1: Typical P-V characteristic curve of a PV module

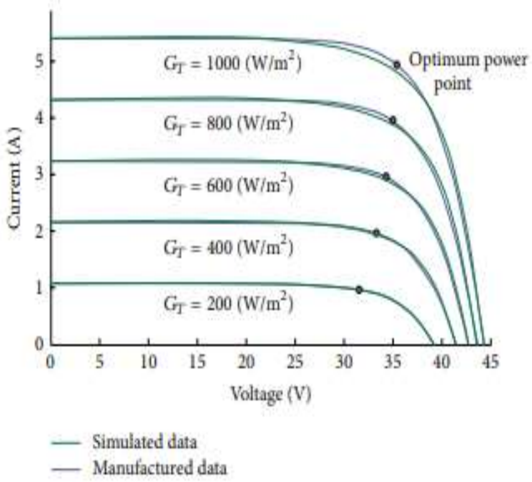

Figure 2: I-V characteristic curves at various solar radiation levels

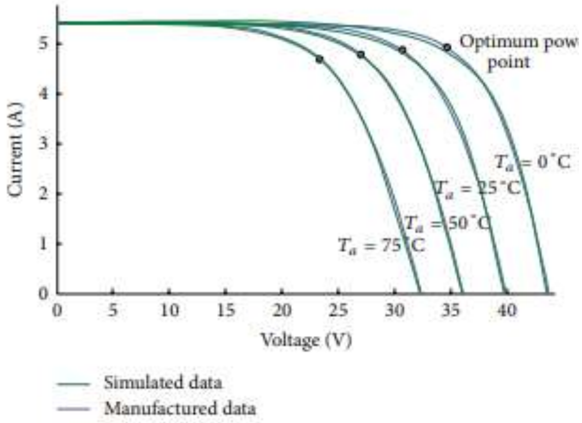

Figure 3: I-V characteristic curves at various temperatures.

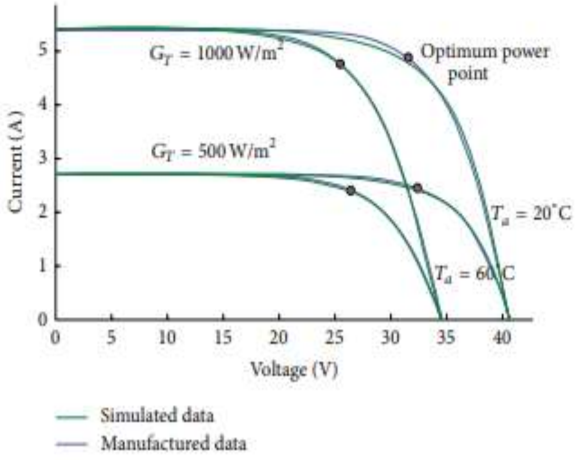

Figure 4: I-V characteristic curves for various set of solar radiation and temperature.

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 irradiation 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

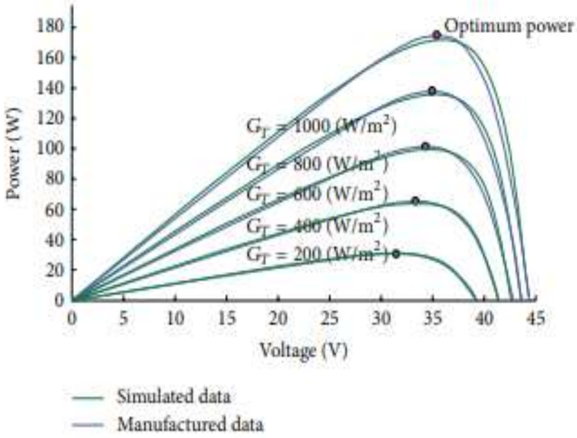

Figure 7: P-V characteristic curve at constant temperature of 25∘C.

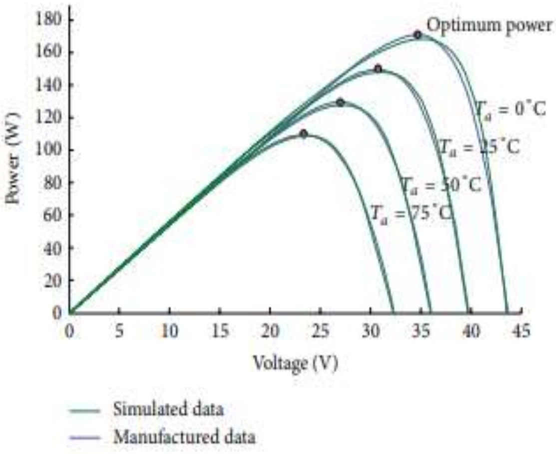

Figure 8: P-V characteristic curve at constant solar radiation of 1000 W/m2 .

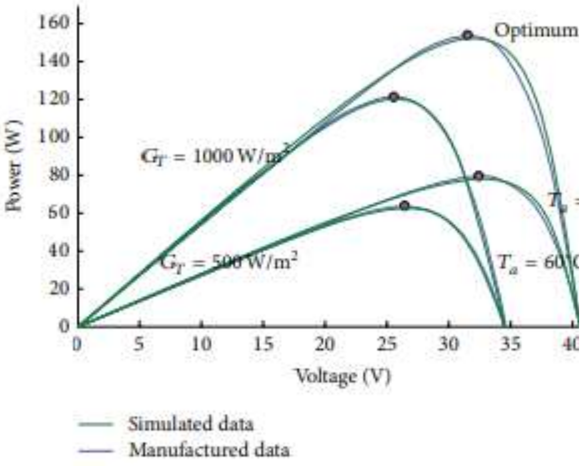

Figure 9: P-V characteristic curve at various set of solar radiation and temperature.

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.

References

[1] W. Durisch, D. Tille, A. Worz, and W. Plapp, "Characterisation ¨ of photovoltaic generators," Applied Energy, vol. 65, no. 1–4, pp. 273–284, 2000.

[2] A. Q. Jakhrani, A. K. Othman, A. R. H. Rigit, S. R. Samo, and S. R. Kamboh, "A novel analytical model for optimal sizing of standalone photovoltaic systems," Energy, vol. 46, no. 1, pp. 675– 682, 2012.

[3] A. N. Celik, "A simplified model based on clearness index for estimating yearly performance of hybrid pv energy systems," Progress in Photovoltaics: Research and Applications, vol. 10, no. 8, pp. 545–554, 2002.

[4] A. H. Fanney and B. P. Dougherty, "Building integrated photovoltaic test facility," Journal of Solar Energy Engineering, vol. 123, no. 3, pp. 194–199, 2001.

[5] M. A. Green, "Short communication: price/efficiency correlations for 2004 photovoltaic modules," Progress in Photovoltaics: Research and Applications, vol. 13, pp. 85–87, 2005.

[6] A. Q. Jakhrani, A. K. Othman, A. R. H. Rigit, and S. R. Samo, "Model for estimation of global solar radiation in Sarawak, Malaysia," World Applied Sciences Journal, vol. 14, pp. 83–90, 2011.

[7] A. Q. Jakhrani, A. K. Othman, A. R. H. Rigit, and S. R. Samo, "Assessment of solar and wind energy resources at five typical locations in Sarawak," Journal of Energy & Environment, vol. 3, pp. 8–13, 2012.

[8] R. Ramaprabha and B. L. Mathur, "Development of an improved model of SPV cell for partially shaded solar photovoltaic arrays," European Journal of Scientific Research, vol. 47, no. 1, pp. 122–134, 2010.

[9] J. A. R. Hernanz, J. J. C. ampayo Martin, I. Z. Belver, J. L. Lesaka, E. Z. Guerrero, and E. P. Perez, "Modelling of photovoltaic module," in Proceedings of the International Conference on Renewable Energies and Power Quality (ICREPQ '10), Granada, Spain, March 2010.

[10] R. B. Andrews, A. Pollard, and J. M. Pearce, "Improved parametric empirical determination of module short circuit current for modelling and optimization of solar photovoltaic systems," Solar Energy, vol. 86, pp. 2240–2254, 2012.

[11] R. L. Chakrasali, V. R. Sheelavant, and H. N. Nagaraja, "Network approach to modeling and simulation of solar photovoltaic cell," Renewable and Sustainable Energy Reviews, vol. 21, pp. 84–88, 2013.

[12] A. Chouder, S. Silvestre, N. Sadaoui, and L. Rahmani, "Modeling and simulation of a grid connected PV system based on the evaluation of main PV module parameters," Simulation Modelling Practice and Theory, vol. 20, no. 1, pp. 46–58, 2012.

[13] A. Chouder, S. Silvestre, B. Taghezouit, and E. Karatepe, "Monitoring, modeling and simulation of PV systems using LabVIEW," Solar Energy, vol. 91, pp. 337–349, 2013.

[14] A. Jain and A. Kapoor, "A new approach to study organic solar cell using Lambert W-function," Solar Energy Materials and Solar Cells, vol. 86, no. 2, pp. 197–205, 2005.

[15] A. Jain, S. Sharma, and A. Kapoor, "Solar cell array parameters using Lambert W-function," Solar Energy Materials and Solar Cells, vol. 90, no. 1, pp. 25–31, 2006.

[16] A. Ortiz-Conde, F. J. Garc´ıa Sanchez, and J. Muci, "New method ´ to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I-V characteristics," Solar Energy Materials and Solar Cells, vol. 90, no. 3, pp. 352–361, 2006. [17] D. Picault, B. Raison, S.

Bacha, J. de la Casa, and J. Aguilera, "Forecasting photovoltaic array power production subject to mismatch losses," Solar Energy, vol. 84, no. 7, pp. 1301–1309, 2010.

[18] Y. Chen, X. Wang, D. Li, R. Hong, and H. Shen, "Parameters extraction from commercial solar cells I-V characteristics and shunt analysis," Applied Energy, vol. 88, no. 6, pp. 2239–2244, 2011.

[19] H. Fathabadi, "Novel neural-analytical method for determining silicon/plastic solar cells and modules characteristics," Energy Conversion and Management, vol. 76, pp. 253–259, 2013.

[20] Y. Chen, X. Wang, D. Li, R. Hong, and H. Shen, "Parameters extraction from commercial solar cells I-V characteristics and shunt analysis," Applied Energy, vol. 88, no. 6, pp. 2239–2244, 2011.