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Determination of I-V curves for photovoltaic generator by an analytical method: Akbaba Model

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ABSTRACT

In order to maximize the amount of electrical energy generated and ensure effective use, the conventional I-V or V-I characteristics derived from the diode model of photovoltaic (PV) solar panels are important. Unfortunately, these features cannot be extracted using linear equations. The conventional I-V or V-I characteristics requires extremely drawn-out, time-consuming procedures. Many studies focus on calculating maximum power extraction. The analytical solutions to these equations are also nonexistent. Programming on computers can assist in solving the equations. The Akbaba Model was created specifically for the photovoltaic generator (PVG) to address these challenges. The Akbaba Model relies heavily on coefficients A, B, and C in this equation. The diode model serves as the true model in this case, and the coefficients A, B, and C are calculated. Another advantage of this model is that, because its qualities have partially deteriorated with time, the genuine I-V characteristics of the PV panels can be recovered by measuring again.

Keywords: Electrical power generation, maximum power, photovoltaic, renewable energy, solar panel

INTRODUCTION

The amount of energy consumed in the world is increasing day by day due to reasons such as global growth, the rapid increase in technology and industrial development, and therefore the way of life keeping up with this. However, the trend towards new energy sources is increasing day by day due to reasons such as traditional energy sources having limited reserves, being difficult and expensive to find and use, and causing environmental pollution. The alternative to this is renewable energy sources, which are both environmentally friendly and generally have no reserve limit. One of these, perhaps the most important; it is the sun. Because it does not pollute the environment, can be used anywhere, and is an endless source of energy. Photovoltaic (PV) solar panels are used to convert solar energy into electrical energy. PV solar panels are among the renewable energy technologies that have found the greatest development and application area. PV solar panel is a photovoltaic generator (PVG). PVs have very low maintenance costs and important advantages such as not requiring fuel, not creating pollution and not making noise. The fact that silicon, the primary raw material used in PV cells, is widely available in nature is another significant benefit. In addition, we can say that its disadvantages are high investment costs and low energy conversion efficiency. For this reason, studies to improve the efficiency of PV solar panels continue intensively (NREL).

To improve the efficiency of PV solar panels, studies are carried out either to increase the efficiency of PV solar cells or to use electrical energy at the maximum level of the output of PV solar panels (Akbaba, 2006; Brambilla; 1999, Kulaksiz, 2012). This study is about the second method. In other words, it is the study of using the electrical energy at the maximum level at the output of PV solar panels. In the literature, two ways are followed to convert solar energy into electrical energy using solar panels. These are maximum power point tracker (MPPT) (Ali et al., 2020; Motahhir et al., 2020; Yang et al., 2020; Shankar & Saravana, 2020; Karami et al., 2017; Rezk et al., 2017) and solar tracking systems methods (Hasanah et al., 2020; Zegrar et al., 2021; De Riso et al., 2024). There are many studies in the literature on these methods in different fields (Akbaba, 2007; Appelbaum & Sarma, 1989; Saied, 1988; López-Lapeña et al., 2009). It has been observed that the amount of solar radiation increases by 30% in single-axis solar tracking systems and 35% in dual-axis solar tracking systems compared to fixed solar panels.25 In MPPT systems, this ratio is much higher. Because MPPT systems provide maximum electrical power at the output by converting the maximum amount of solar radiation into electrical energy despite different environmental conditions (Akbaba, 2007). Machine learning algorithms and artificial intelligence are used in the literature (Türk, 2024; Turk, 2024).

Similarly (Voutsinas et al., 2023; González et al., 2021; Sardar et al., 2024; Hocine et al., 2021; Oliva et al., 2014), emphasize the necessity of evaluating V-I characteristics to improve PV system efficiency, fault detection, and overall performance. They use innovative techniques such as machine learning, imaging, and optimization algorithms to improve the dependability of solar energy generation (Voutsinas et al., 2023). Investigates the use of machine learning techniques for defect detection in PV systems using I-V curve data. Support vector machines (SVMs) and deep neural networks are used to detect typical problems such as line-to-line and ground faults. The work focuses on the accuracy of ML models in diagnosing defects in real-time systems, which improves total PV system dependability (González et al., 2021). focuses on creating an IoT-based I-V curve tracer for real-time monitoring of solar panels. The tracer allows for extensive investigation of V-I characteristics, which improves PV array performance and problem identification while also giving vital data for operational modifications (Sardar et al., 2024). focuses on how series resistance impacts the efficiency of silicon solar cells. The researchers use advanced imaging techniques to assess the relationship between resistance, voltage, and current in order to optimize cell design. The I-V curve is critical in determining the energy losses due by excessive resistance in cells. In (Hocine et al., 2021), a combination of thermal imaging and I-V curve analysis is used to detect flaws in PV modules, such as microcracks and hot spots. This technique allows for early detection of performance decline, especially under changing temperature conditions (Oliva et al., 2014). describes the artificial bee colony (ABC) algorithm for optimizing the I-V properties of PV cells. The method accurately predicts the maximum power point (MPP) under changing temperatures and irradiance, increasing the total efficiency of PV systems.

Methodology

The analysis of the effectiveness of systems powered by PV generators depends heavily on the mathematical model of the electrical properties of PV generators. Because it must be used in design for maximum energy use. Therefore, the mathematical model of the I-V characteristic is one of the most important key elements in the performance analysis of loads operated with PV generators (Akbaba, 2007). All published literature utilizes a consistent mathematical model to describe the current-voltage (I-V) or voltage-current (V-I) characteristics of PV cells or PV cell generators. This model is based on the traditional p-n junction, which has been widely employed in electronic devices for a long time. The I-V characteristic model accurately captures the relationship between the current output and the voltage of PV cells under various conditions, providing crucial insights into their performance and efficiency (Appelbaum & Sarma, 1989).

I can be formulized as given in equation (1). Traditional I-V characteristic of solar panels is obtained by using equation (1).

$$I = I_{ph} - I_0\left[e^{L(V+IR_s)} - 1\right] \tag{1}$$

And, to obtain V-I characteristic, equation (1) can be written as in equation (2) by leaving V alone;

$$V = IR_s + \frac{1}{L}\ln\left[\frac{I_{ph}-I+I_0}{I_0}\right] \tag{2}$$

It is shown with equations. Here, I_{ph} is produced light current, I_o is reverse saturation current, L is PV generator constant, and R_s is series resistance of the PV generator. The equations given above with the traditional I-V and V-I characteristics are quite non-linear. As a result, the solution requires difficult, extended, and complex methods. The following model, referred to as the Akbaba Model in the PVG literature, is proposed in order to eliminate suggested problems (Akbaba & Alattawi, 1995).

The current, can be formulized by Akbaba Model as in equation (3) as following:

$$I = \frac{V_{OC}-V}{A+BV^2-CV} \tag{3}$$

The Akbaba Model relies heavily on coefficients A, B, and C. The real diode model is utilized to obtain the A, B, and C coefficients.

It is found with $A = \frac{V_{oc}}{I_{sc}}$. Here, V_{oc} is the open circuit voltage and I_{sc} is the short circuit current. The other two coefficients will be calculated using the values at point "a", which is on the I-V Characteristic and corresponds to 94% of the short circuit current, and point "b", which corresponds to 68% (Akbaba & Alattawi, 1995). B and C coefficients can be obtained by using the mathematical operations as follows.

$$B = \frac{K_1-K_2}{K_3} \tag{4}$$

$$C = \frac{K_1V_a-K_2V_b}{K_3} \tag{5}$$

where,

$$K_1 = V_aI_a(V_{oc} - V_b - AI_b) \tag{6}$$

$$K_2 = V_bI_b(V_{oc} - V_a - AI_a) \tag{7}$$

$$K_3 = V_aI_aV_bI_b(V_b - V_a) \tag{8}$$

For the calculation of PVG power, to be used in P=VI and the power is calculated by equation (9).

$$P=V(Voc-V)/A+BV^2-CV \tag{9}$$

By taking the derivative of equation (9), equation (10) is obtained for the maximum point with $\frac{dP}{dV} = 0$.

$$V_{max}^2 - Q_1V_{max} + Q_2 = 0 \tag{10}$$

And, maximum voltage V_{max} is formulized by solving equation (10);

$$V_{max} = 0{,}5\left(Q_1 - \sqrt{Q_1^2 - 4Q_2}\right) \tag{11}$$

where,

$$Q_1 = \frac{2A}{C-BV_{OC}} \tag{12}$$

$$Q_2 = \frac{AV_{OC}}{C-BV_{OC}} \tag{13}$$

To obtain the maximum current equation from here, if we write the Vmax value instead of V in the Akbaba Model equation in equation (3), the maximum current is obtained as in equation (14).

$$I_{max} = \frac{V_{OC}-V_{max}}{A+BV_{max}^2-CV_{max}} \tag{14}$$

As a result, maximum power can be calculated with the equation $P_{max}=V_{max}I_{max}$.

Thus, I-V characteristic curves of PV generators can be easily drawn by analytical analysis method using the Akbaba model. For this reason, the method presented as the Akbaba Model is a new and simpler, but accurate model for the I-V characteristic curve (Goksenli & Akbaba, 2016). The accuracy, flexibility, and simplicity of this new model have been proven by comparing it with the traditional model. In (Akbaba & Alattawi, 1995), Akbaba Model is proposed in the PV generators literature, by comparing it with the traditional model in a simulation environment, they proved that there is a negligible difference of around 1-2% between the traditional and the Akbaba model.

Application Method and I-V Plotting the Characteristic Curve

In this study, measurements of PV solar panels at different solar radiations are made for the first time, calculations are made, and the I-V characteristic curve is drawn analytically. Another advantage of this study is that since some electrical properties of the solar panels used may change over time, this method allows the I-V characteristic curve to be drawn by re-measurement.

To draw the I-V characteristic curve of the solar panel, the V_{oc} (open circuit voltage), I_{sc} (short circuit current) of the solar panel, and the current and voltages at different loads were measured under real solar radiation by connecting a rheostat to the output. The values obtained as a result of measurements at different solar irradiance values were substituted into the Akbaba Model equation (3), calculations were made and compared with the measurement results, and very close results were obtained. These results showed insignificant differences of around 1-2 percent, as in the study simulated in the literature (Akbaba & Alattawi, 1995). Some of the data obtained as a result of measurements and calculations are shown in Table. In Table, some of the current (I) and voltage (V) values from numerous measurements at different solar irradiances are given in separate columns.

Table. I and voltage V values measured at different solar radiation

Solar irradiance 35%		Solar irradiance 50%		Solar irradiance 85%		Solar irradiance 100%	
V_1 (Volt)	I_1 (Amper)	V_2 (Volt)	I_2 (Amper)	V_3 (Volt)	I_3 (Amper)	V_4 (Volt)	I_4 (Amper)
0.00	0.35	0	0.50	0.00	0.59	0.00	0.68
3.00	0.35	5.55	0.50	2.00	0.59	1.00	0.68
4.78	0.35	8.15	0.49	3.00	0.59	2.00	0.68
6.30	0.35	11.06	0.49	4.00	0.59	3.00	0.68
8.95	0.35	12.10	0.49	5.00	0.59	4.00	0.68
10.20	0.35	13.10	0.49	6.00	0.59	5.00	0.68
11.00	0.35	14.00	0.48	7.00	0.59	6.00	0.68
13.12	0.34	14.85	0.47	8.00	0.59	7.00	0.68
14.18	0.33	15.37	0.45	8.50	0.59	8.00	0.68
15.27	0.31	15.72	0.44	9.00	0.59	8.79	0.68
15.95	0.28	16.05	0.42	9.70	0.58	10.57	0.68
16.48	0.25	16.32	0.40	10.33	0.58	11.83	0.68

I: Current, V: Voltage

By using the data obtained as a result of numerous measurements made at different solar radiations, the I-V characteristic curves of the PV solar panel were calculated analytically and easily drawn with the Akbaba Model equation (3) (Figure). Thus, there is no need for the tedious, time-consuming, and difficult calculations required in equations (1 and 2), which are quite non-linear and are traditionally used in I-V characteristic drawings for PV solar panels. Figure shows the I-V Characteristic curves plotted at different percent solar irradiances according to the measurements made in Table. Thus, the I-V characteristic curve according to different solar radiation in Table is plotted as in the literature.

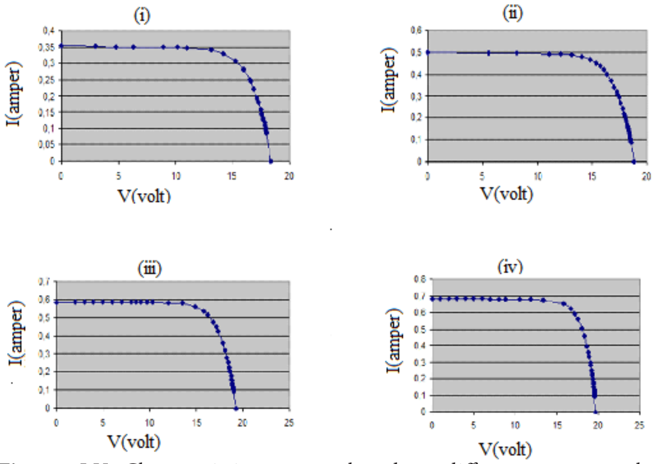

Figure. I-V Characteristic curves plotted at different percent solar irradiances; i) Radiation 35% ii) Radiation 50% iii) Radiation 85% iv) Radiation 100%

Defining the I-V curves of PV panels involves measuring current and voltage at various loads, typically using a solar simulator or real sunlight. Engineers adjust the load to record data points, creating the I-V curve, which shows how the panel performs under different conditions. In real-world applications, engineers use I-V curves to assess the panel's efficiency, identify its MPP, and ensure optimal operation in solar installations. This helps in system design, fault detection, and maximizing energy output in varying environmental conditions.

CONCLUSION

Traditional I-V or V-I characteristics determined from the diode model of PV solar panels are critical in determining maximum power points and utilizing the generated electrical energy efficiently. Because these features reveal the point of maximum energy. However, the equations commonly utilized to derive these features are non-linear. As a result, the solution necessitates lengthy, time-consuming processes. Furthermore, these equations lack analytical solutions. Thus, equations can be solved using computer programs. To address these issues, the Akbaba Model has been used. This approach is simpler and better suited for application and calculation than standard equations. Most importantly, in our study, it has been shown that this model can also be examined analytically.

Another advantage of the suggested model is that due to the partial loss of electrical properties in PV solar panels over time, the true I-V characteristics of PV solar panels may be identified by numerous measurements. In this way, values that were previously used but had lost their accuracy due to electrical changes over time-especially MPP values-can be recalculated and determined as real values once again. This recalibration ensures that the performance and efficiency of photovoltaic cells are accurately assessed, accounting for any variations or degradations that may have occurred over time.

It is advised to extract the I-V characteristics of solar panels independently, even if they have the identical manufacture features. Thus, the effect of even minor deviations will be reflected in the feature through measurement. It is hoped and suggested that this study will find a wide application area by demonstrating its usability in processes that require further study and application of I-V characteristic curves related to PV solar panels.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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