Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(Research Article)

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Determination of photoelectric characteristics of two-sided sensitive solar elements

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Global Journal of Engineering and Technology Advances, 2024, 21(02), 151–156

Publication history: Received on 07 October 2024; revised on 19 November 2024; accepted on 21 November 2024

Article DOI: https://doi.org/10.30574/gjeta.2024.21.2.0215

Abstract

Nowadays, silicon-based bifacial solar panels are being manufactured at an industrial scale and are widely used to meet the energy demands of the population. The installation and commissioning processes of these advanced solar panels are complex and require the use of specialized software to determine several photovoltaic parameters effectively.

Simulation methods play a crucial role in determining the output voltage of solar cells and assessing the usable power capacity, making them highly relevant in modern research. One of the most widely used software tools for such modeling is PVlighthouse, which offers numerous capabilities for photovoltaic analysis. Using this software, the key performance parameters of bifacial solar cells were determined as follows: Open-circuit voltage: 0.625 V, Short-circuit current density: 38 mA/cm^2, Efficiency: 19.915%. These results demonstrate the high efficiency of these solar panels and highlight their potential for industrial and consumer-level applications.

Keywords: PVlighthouse software; Silicon; Bifacial solar cell; Equivalent circuit of a solar cell.

1. Introduction

The development of silicon-based planar solar cells began several decades ago, with significant contributions from researchers such as Thomas J. Watson Sr., G. Araujo, and others, who studied key parameters of solar cells, including Isc, Voc, η and μ [1]. The approach of studying solar cells through experimental and simulation methods has gained prominence in recent years, aided by software packages such as PVlighthouse, ATLAS, Silvaco TCAD, and Sentaurus TCAD, which enable the determination of various parameters of solar cells.

PVlighthouse is an online software designed for real-time analysis, capable of simultaneously calculating multiple parameters. Its key advantage lies in its high sensitivity measurements and the continuous addition of new materials and parameters as the software evolves. The developers of this tool regularly introduce updates to improve usability and extend its capabilities. For instance, PVlighthouse has been used to optimize the thickness of anti-reflective coatings on both monofacial and bifacial solar cells[2].

The ATLAS software is a widely-used tool for analyzing the electro-physical processes in various semiconductor devices. Similarly, TCAD (Technology Computer-Aided Design) software, including Silvaco and Sentaurus, has become globally popular for solar cell simulations. Specifically, Silvaco TCAD has been used to validate physical parameters by comparing simulation results with experimental data, yielding positive outcomes [3].

Using the model developed in Sentaurus TCAD, it is possible to observe a close match between simulated results and experimental data [4]. In our study, bifacial solar panels were modeled, and simulation-based calculations were

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performed. This approach is essential for improving the efficiency of solar cells and reducing their costs, which are critical factors in modern photovoltaic research. Notably, between 2011 and 2013, the cost of solar cells decreased by approximately 50% [5].

Interestingly, the production costs of monofacial solar cells are nearly identical to those of bifacial solar cells. Previous studies have explored monofacial solar cells using both experimental and simulation methods to determine parameters such as fill factor (FF), efficiency (η\etaη), and various kinetic parameters in semiconductors [6]. Experimental findings for bifacial silicon-based solar cells show front-side efficiency at 19.4% and rear-side efficiency at 16.5% [7].

Furthermore, the performance of these solar panels was analyzed under light intensities ranging from 100 W/m² to 1000 W/m², yielding promising results, including for ground albedo effects [8]. Based on these findings, computational modeling of solar panels was conducted in this study to further explore their performance. Consequently, research on bifacial solar cells remains a promising avenue for advancing photovoltaic technologies[9].

These simulation tools have significantly advanced the understanding and optimization of solar cell performance, facilitating the development of highly efficient photovoltaic technologies.

2. Materials and Methods

Semiconductor electronic devices predominantly rely on silicon, which forms their core component. Silicon is abundantly available in nature, making its production and use economical and accessible across all countries. For this reason, bifacial solar panels are primarily composed of silicon.

The operational mechanism of solar panels is based on the interaction of light with the surface layer of the solar cell. When light strikes the panel, an internal electric field is generated within the solar cell. This electric field facilitates the movement of free electrons, generated through optical processes, toward the electrodes, where they contribute to the flow of current. Additionally, due to the electrodes and minority charge carriers, ohmic and series resistances arise, influencing the panel's performance.

The structural design of a bifacial solar cell, including its key components, is illustrated below (Figure 1).

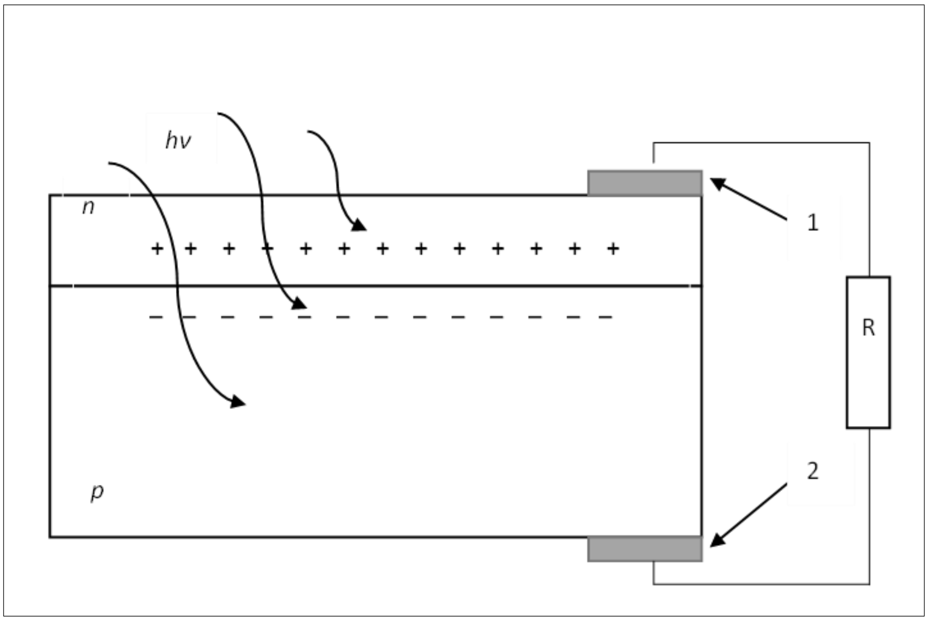

Figure 1 Operational Diagram of a Bifacial Solar Cell

The schematic illustrates the working principle of a bifacial solar cell, showing key components and processes: 1- Anode – The positive electrode facilitating current collection, 2 - Cathode – The negative electrode completing the circuit, R – Series resistance arising due to material and contact resistances. hν – Incident light energy that generates electron-hole pairs.

The diagram demonstrates how light energy (hν) interacts with the solar cell's surface, creating an internal electric field. This field drives the generated charge carriers toward the anode and cathode, enabling current flow while overcoming the series resistance (R).

The operational mechanism of this bifacial solar cell is illustrated, highlighting the critical processes of light absorption, reflection, and transmission. These phenomena play a pivotal role in the device's overall efficiency. In addition, it is essential to account for various electrical resistances during energy generation, as these resistances directly influence the open-circuit voltage Voc and short-circuit current Isc that the solar cell can achieve.

To fully describe the electro-physical processes occurring in the solar cell, including those in the dark, its behavior can be represented using an equivalent circuit model. The main photovoltaic parameters, such as open-circuit voltage and short-circuit current density, can be determined by analyzing the current-voltage (I-V) characteristics. These characteristics enable the calculation of shunt and series resistances, both in ideal and practical conditions.

Below is the equivalent circuit diagram of the solar cell, illustrating its operational mechanism (Figure 2).

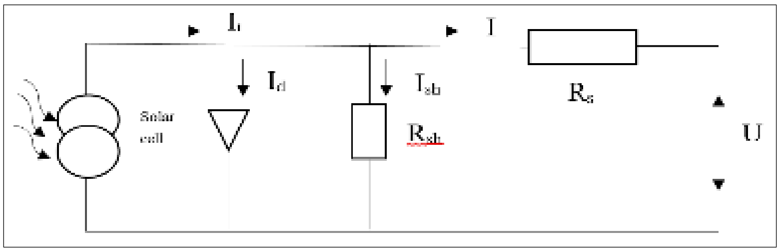

Figure 2 Circuit Diagram for Measuring the Current-Voltage (I-V) Characteristics of a Solar Cell

In this diagram, the following parameters are defined: I_t - Photocurrent generated by the solar cell, I_d - Current through the diode mode of the solar cell, I_{sh} - Current passing through the shunt resistance, I_{sc} - Short-circuit current, U - Output voltage of the solar cell.

Based on this schematic, the equation for determining the current-voltage (I-V) characteristics of the solar cell can be derived as follows:

$$I = I_t - I_d - I_{sh}$$

Where:

I_t is the photocurrent generated by the solar cell.

I_d is the current through the diode, which depends on the voltage and the diode's characteristics.

I_{sh} is the current passing through the shunt resistance, representing leakage current.

In the case of an ideal solar cell, the equation simplifies further, but real-world considerations (such as series and shunt resistances) lead to more complex expressions, involving parameters like the diode saturation current and ideality factor. This I-V equation is used to calculate the electrical output of the solar cell under various operating conditions.

$$I = I_t - I_0\left[\exp\left(\frac{U-IR_s}{nkT}q\right) - 1\right] - \frac{U-IR_s}{R_{sh}} \quad (1)$$

this equation is used for the circuit in Figure 2 above. But certain conditions must be entered into the volt-ampere characteristic for the solar cell. According to this, the voltage of the solar cell is ideally represented by the tendency I=Isc=0 and R=0. After satisfying this condition, U=Uoc takes its maximum value. This can be seen through the following equation (Formula 2).

$$0 = I_t - I_0\left[\exp\left(\frac{qU_{oc}}{nkT}\right) - 1\right] - \frac{U_{oc}}{R_{sh}} \quad (2)$$

Taking into account this equality, we create the following equation for the photocurrent (formula 3).

$$I_t = I_0\left[\exp\left(\frac{qU_{oc}}{nkT}\right) - 1\right] + \frac{U_{oc}}{R_{sh}} \quad (3)$$

By calculating this equation, the operating voltage of the solar cell can be determined. These above equations are sufficient to determine the volt-ampere characteristic for a solar cell. We determine the volt-ampere characteristic of the solar cell by means of the empirical formulas determined by experimental research and by the modeling method combining the fundamental formulas for the solar cell. For this, we need the PVlighthouse program, based on the capabilities of this program, we determine the photoelectric quantities through the sufficient size and light intensity values for the solar cell. For the study, the two-way sensor was determined for the simple and non-reflective state.

3. Results and discussion

At the beginning of the study, a light intensity of 1000 Wt/m^2 was applied vertically to the front of the double sensitive solar cell. The experiment was carried out for the case of an external temperature of 300 K. According to this, the volt-ampere characteristic was determined for the double sensitive solar cell as follows.

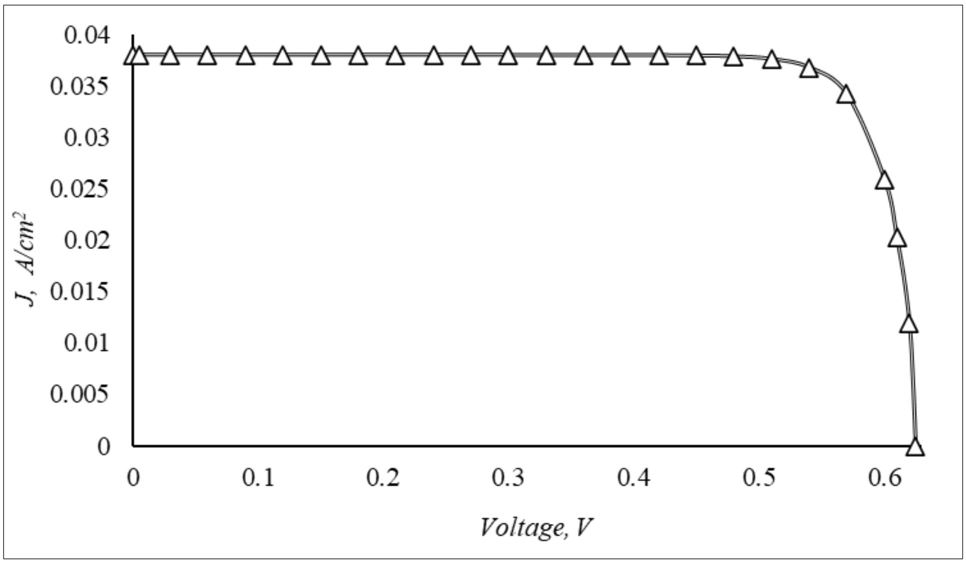

Figure 3 I-V characteristics for a double sensitive solar cell.

Photoelectric quantities can be seen from this volt-ampere characteristic as follows.

Table 1 Photoelectric parameters of a two-side sensitive solar cell

T/R	U_{oc} V	J_{sc} mA/cm^2	U_{mpp} mV	J_{mpp} mA/cm^2	FF, %	η, %
1	0.629	38	0.549	36.25	83.22	19.915

The data from this table shows that the bifacial solar cell operates with a voltage of 0.629 V, which is a key indicator of its performance under light exposure. Additionally, the short-circuit current density is measured at 38 mA/cm^2, reflecting the amount of current the solar cell can generate when the terminals are shorted, indicating its ability to harness and convert solar energy into electrical current.

With an efficiency of 19.915%, this bifacial solar cell surpasses the typical efficiency of monofacial solar cells. The higher efficiency can be attributed to the bifacial design, which allows the solar cell to capture light from both the front and the rear sides, enhancing its overall energy output. This advantage is particularly noticeable in environments where the solar panels can receive reflected light from surrounding surfaces, further improving their energy conversion efficiency.

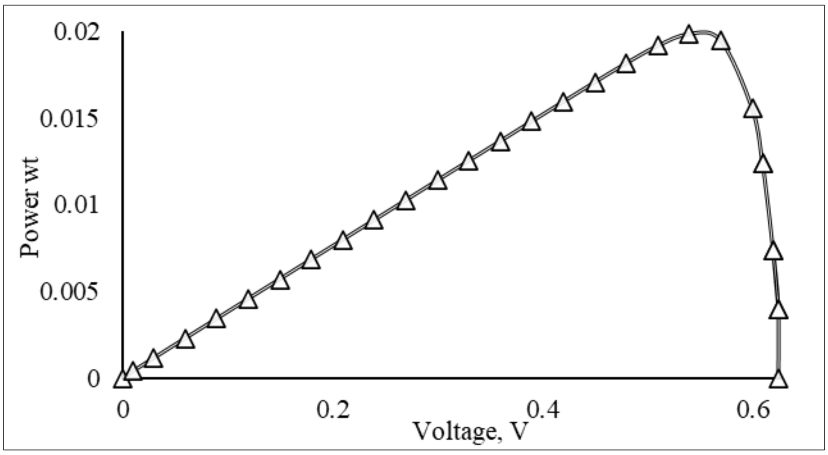

Figure 4 Volt-watt characteristic for a double-sensitized solar cell.

In comparison to monofacial solar cells, which only collect light from one side, bifacial solar cells offer a significant boost in performance, especially in conditions with high albedo (reflected light), such as snowy or sandy environments. This makes bifacial solar cells a more viable option for maximizing energy generation, particularly in regions with high levels of sunlight and reflection.

4. Conclusion

Many significant results have been obtained through experiments on bifacial solar cells. From the collected data, it is clear that the short-circuit current density was measured at 38 mA/cm^2, the operating voltage was 0.629 V, and the efficiency was 19.915%. In addition to this study, Professor Imran KANMAZ from Skya University also investigated the output power of solar panels and solar elements at various temperatures, as well as the useful work coefficients.

The experimental findings revealed that when the short-circuit current density was 32.07 mA/cm^2, the useful work coefficient was 18.02%. The results obtained using the PVlighthouse software showed a strong correlation with the experimental values, indicating a high degree of accuracy. Based on this data, it was determined that the useful work factor exceeded 1.895%, and the short-circuit current was greater than 5.93 mA/cm^2.

These findings highlight the promising potential of solar panels for future energy generation. The ability to capture and utilize solar energy efficiently opens up significant opportunities for sustainable energy solutions, especially considering the increasing global demand for renewable energy sources. The ongoing advancements in solar panel technology, including the optimization of their efficiency and energy output, point towards a more energy-efficient and environmentally friendly future.

Compliance with ethical standards

Acknowledgement

The authors would like to thank the staff of the Renewable Energy Sources Laboratory for their assistance in completing this research. This work was supported by Project #04-12 of Andijan State University, approved on February 7, 2024, focusing on the advancement of digital scientific research.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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