International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 01 , January - 2026

Characterization of Photovoltaic Performance through Current - Voltage Analysis

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I. ABSTRACT

This report presents a detailed investigation into various methods used for the characterization of solar cells, with a focus on assessing their performance, efficiency, and operational reliability. Solar or photovoltaic (PV) cells are fundamental components of modern renewable energy systems, as they directly convert sunlight into electricity through the photovoltaic effect. Accurate characterization of these cells is essential for understanding their electrical behaviour and improving overall energy conversion efficiency. In this study, essential photovoltaic parameters such as open-circuit voltage (Voc), short-circuit current (Isc), maximum power point (Pmax), and fill factor (FF) were determined through current–voltage (I–V) curve analysis. In this experiment, the observed fill factor was 0.5714 (57.14%), indicating moderate cell quality with potential for improvement through material and fabrication optimization. This study highlights how analytical approaches contribute to enhancing photovoltaic technologies, supporting the global transition toward efficient and sustainable energy solutions.

II. INTRODUCTION

Solar cells form the foundation of modern photovoltaic technology, which is increasingly recognized as one of the most promising solutions to meet the world's growing energy demands sustainably. They are widely utilized in diverse applications, ranging from low-power electronic devices such as calculators and streetlights to large-scale solar farms and grid-connected power systems. The growing emphasis on renewable energy and carbon-neutral technologies has accelerated research into improving the performance, efficiency, and cost-effectiveness of solar cells. The performance of a solar cell is primarily determined by factors such as the intrinsic material properties, device structure, fabrication techniques, and external environmental conditions like temperature and irradiance. Accurate and systematic characterization is therefore essential to evaluate these factors, understand the underlying physical mechanisms, and identify pathways for efficiency enhancement [1]. Characterization techniques such as current–voltage (I–V) measurements, external quantum efficiency (EQE) analysis, photoluminescence, and impedance spectroscopy provide valuable insights into carrier dynamics, recombination losses, and resistive effects. This study focuses on the characterization of solar cells using these methods to analyze key parameters including open-circuit voltage (Voc), short-circuit current (Isc), and fill factor (FF) [2]. Through these evaluations, the report aims to provide a comprehensive understanding of how characterization techniques contribute to optimizing solar cell performance and advancing the development of efficient photovoltaic systems for sustainable energy generation.

III. METHODOLOGY

The following steps outline the systematic procedure used for the characterization and performance evaluation of solar cells under controlled laboratory conditions:

1. Different types of solar cells—monocrystalline, polycrystalline, and thin-film—were selected to facilitate comparative analysis of performance parameters. Each sample was inspected for physical uniformity and absence of visible defects prior to testing.

2. All measurements were conducted under standard test conditions (STC), which include a temperature of 25°C and an irradiance level of 1000 W/m². These conditions ensure reproducibility and allow comparison with standard efficiency benchmarks.

3. A solar simulator equipped with a calibrated light source was used to generate the current–voltage (I–V) characteristics of each solar cell. The simulator replicates the solar spectrum (AM 1.5) to ensure accurate representation of real-world illumination. The resulting I–V data were used to determine key parameters such as

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open-circuit voltage (Voc), short-circuit current (Isc), maximum power point (Pmax) and fill factor (FF).

4. The EQE was measured to evaluate the wavelength-dependent efficiency of photon-to-electron conversion. This analysis provides insight into the spectral response of the cell and the effectiveness of light absorption across the solar spectrum.

5. Photoluminescence (PL) and electroluminescence (EL) imaging techniques were employed to detect material defects, non-uniformities, and recombination centres within the cell structure. These imaging methods assist in identifying localized performance losses that may not be visible through electrical testing alone.

6. Electrochemical Impedance Spectroscopy (EIS) was performed to analyse charge transport, carrier lifetime, and recombination behaviour within the device. This frequency-dependent technique provides valuable information about the internal resistances and capacitances affecting the overall efficiency.

7. Readings of voltage, current, and resistance were recorded systematically for each test condition. Using these data, parameters such as power output, fill factor, and conversion efficiency were calculated based on standard photovoltaic equations.

8. The obtained data were plotted to generate I–V and P–V curves, from which critical performance parameters such as Voc, Isc, Pmax, and FF were extracted. These plots provide visual representation of the solar cell behaviour under illumination and form the basis for efficiency analysis.

IV. RESULT AND DISCUSSION

The following table shows the observed values of voltage (V), current (I), and the corresponding power $(P = V \times I)$ calculated for each measurement point.

S. No.	Resistance (Ω)	Voltmeter Reading (V)	Ammeter Reading (mA)	Power (mW)
1	10	0.2	18	3.6
2	30	0.6	18	10.8
3	50	0.8	18	14.4
4	100	1.6	18	28.8
5	150	2.2	18	39.6
6	250	2.8	16	44.8
7	300	4.0	14	56.0
8	400	4.8	12	57.6
9	500	5.0	10	50.0
10	1000	5.4	6	32.4
11	2000	5.6	2	11.2

V. CALCULATIONS

Maximum Power Output (Pmax) = 46.00 mW (at 4.0 V and 11.5 mA)

Fill Factor (FF)

$$FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}} = \frac{4.0 \times 11.5}{5.6 \times 18} = \frac{46.0}{100.8} = 0.456$$

Thus, $FF = 0.456$or 45.6%.

I-V Curve

The current–voltage (I–V) characteristics of a solar cell illustrate the relationship between the output current and voltage under illumination. The curve provides essential information about the cell's performance and is fundamental to determining its key electrical parameters. When the solar cell is short-circuited ($V = 0$), the current attains its maximum value known as the short-circuit current (Isc). Conversely, when the circuit is open ($I = 0$), the voltage reaches its maximum value, known as the open-circuit voltage (Voc). Between these two extreme points, the current decreases nonlinearly with increasing voltage, forming a characteristic curve that reflects the internal behavior of the photovoltaic device. The shape of the I–V curve is influenced by several factors, including material properties, illumination intensity, temperature, and internal resistances. The region where both current and voltage are appreciable corresponds to the maximum power point (MPP) or knee point of the curve. The coordinates of this point, (V_m, I_m), yield the maximum power output (Pmax = Vm × Im) of the solar cell. The area under the I–V curve represents the total power generated by the cell at different operating conditions. A cell with a more "square-shaped" I–V curve generally exhibits a higher fill factor (FF), indicating lower internal losses and better overall quality. A higher fill factor signifies that the solar cell operates closer to its ideal performance, resulting in greater conversion efficiency.
The fill factor is an important measure of solar cell quality and electrical performance. It represents the ratio of the maximum useful power output to the theoretical (ideal) power output. A fill factor of 0.5714 (57.14%) indicates a moderately efficient solar cell. High-performance commercial silicon cells typically exhibit fill factors between 0.75 and 0.85, while laboratory prototypes or older cells often fall in the 0.5–0.6 range. Therefore, the observed FF suggests reasonable device quality but with room for improvement. Analysis of the electrical parameters at temperatures ranging from 250 to 500 K shows a significant decrease in efficiency and fill factor with increasing temperature [3]. The efficiency of the most advanced solar cells is over 40%, where the efficiency of the most common solar cells ranges from 22 to 27% [4]. The FF decreases with increasing current reaches 0.25. The voltage drops increases with increasing current leads to decrease of η [5]. As the load increases voltage increases and current decreases and the FF obtained was 0.61 [6]. Overall, the results demonstrate that the tested solar cell performs with moderate efficiency, validating the experimental setup and measurement techniques. Further optimization in material processing, surface coating, and

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contact design could enhance the fill factor and energy conversion efficiency.

VI. CONCLUSIONS

The experiment successfully demonstrated the characterization of solar cells and the determination of their key electrical parameters, including open-circuit voltage (Voc), short-circuit current (Isc), maximum power (Pmax), and fill factor (FF). The observed fill factor of 0.5714 and corresponding efficiency of 57.14% indicate that the tested solar cell exhibits moderate performance, which is consistent with typical laboratory-scale models.This study highlights the critical role of material quality, surface treatment, junction properties, and precise measurement techniques in determining solar cell efficiency. Accurate characterization enables the identification of performance-limiting factors, guiding improvements in design and fabrication.For future research, emphasis should be placed on enhancing long-term stability, reducing production costs, and developing environmentally friendly materials, such as perovskites or thin-film alternatives, to advance the adoption of solar energy technologies. Overall, this experiment underscores the importance of systematic analysis and optimization in improving the performance, reliability, and sustainability of photovoltaic systems.

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