ECE 352:
Photovoltaic Engineering

PROJECT REPORT

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2

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Comprehensive Analysis of Parameter Extraction for the Five-Parameter Double-Diode Model in Photovoltaic Systems

Abstract

This report explores an innovative approach to parameter extraction for the five-parameter double-diode model of photovoltaic (PV) cells and modules. The method relies solely on manufacturer-provided datasheet values such as open-circuit voltage (VocV_{oc}Voc), short-circuit current (IscI_{sc}Isc), and the maximum power point (Vm,ImV_m, I_mVm,Im). Analytical solutions are derived as initial estimates for numerical methods like Newton-Raphson, ensuring fast convergence. Validation against experimental data shows the approach is efficient, low-cost, and accurate, making it a practical tool for PV system design and evaluation.

Introduction

The increasing adoption of photovoltaic systems necessitates accurate modeling techniques for simulating PV performance. Two prominent models—single-diode and double-diode—are used to describe the current-voltage (I−VI-VI−V) characteristics of PV cells. While the single-diode model is simpler, the double-diode model offers enhanced accuracy, especially at low irradiation levels.

Extracting parameters for these models is challenging due to their nonlinear and implicit equations. Traditional methods often require extensive experimental data, such as entire I−VI-VI−V curves, making them impractical for industrial use. This report discusses a novel analytical -numerical technique for parameter extraction using limited datasheet information, bridging the gap between accuracy and ease of implementation.

The Five-Parameter Double-Diode Model

The double-diode model incorporates two diodes to account for diffusion and recombination mechanisms. It describes the I−VI-VI−V relationship of a PV module as:

$$I = I_{ph} - I_{s1}\left[e^{\frac{V+IR_s}{n_1 N_s V_t}} - 1\right] - I_{s2}\left[e^{\frac{V+IR_s}{n_2 N_s V_t}} - 1\right] - \frac{V+IR_s}{R_{sh}},$$

where:

- IphI_{ph}Iph: Photocurrent.
- Is1,Is2I_{s1}, I_{s2}Is1,Is2: Saturation currents for the two diodes.

- Rs,RshR_s, R_{sh}Rs,Rsh: Series and shunt resistances.
- n1,n2n_1, n_2n1,n2: Ideality factors.
- VtV_tVt: Thermal voltage.

Simplifying assumptions reduce the number of unknowns to five: Rs,Rsh,Iph,Is1,Is2R_s, R_{sh}, I_{ph}, I_{s1}, I_{s2}Rs,Rsh,Iph,Is1,Is2. These parameters must be extracted to model the I−VI-VI−V curve effectively.

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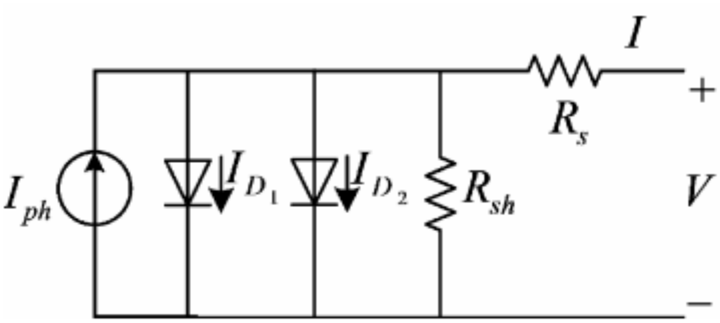
Figure 1: Double-Diode Equivalent Circuit



Proposed Methodology

Key Innovation

The proposed method uses three characteristic points on the I−VI-VI−V curve—open-circuit voltage (VocV_{oc}Voc), short-circuit current (IscI_{sc}Isc), and maximum power point (Vm,ImV_m, I_mVm,Im)—to derive initial analytical solutions. This reduces dependence on detailed experimental I−VI-VI−V data.

Analytical Solutions

Approximate analytical expressions for RsR_sRs and RshR_{sh}Rsh are derived based on simplifying assumptions like:

- Rsh>>RsR_{sh} >> R_sRsh>>Rs.
- Typical values for diode ideality factors (n1=1,n2=2n_1 = 1, n_2 = 2n1=1,n2=2).

These solutions are used as initial guesses for Newton-Raphson numerical iterations, ensuring convergence.

Numerical Refinement

Equations are solved numerically to refine the parameters:

1. RsR_sRs and RshR_{sh}Rsh are calculated iteratively.

2. Photocurrent (IphI_{ph}Iph) is estimated from IscI_{sc}Isc.
3. Saturation currents (Is1,Is2I_{s1}, I_{s2}Is1,Is2) are obtained from simplified relationships.

Numerical Solution and Validation

Case Studies

1. **KC200GT Module:** Exhibits high series resistance. Analytical solutions provided accurate initial estimates, enabling successful convergence of numerical methods.
2. **GEPV110 Module:** Demonstrated low series resistance. A zero-resistance initial condition was used, highlighting the robustness of the approach.

Table 1: Identified Parameters for KC200GT Module

Parameter	Analytical Solution	Numerical Solution	Relative Error (%)
RsR_sRs	0.213	0.212	0.47
RshR_{sh} Rsh	435.5	436.1	0.14

Figure 2: Experimental vs. Theoretical I-V Curves (KC200GT Module and GEPV110)

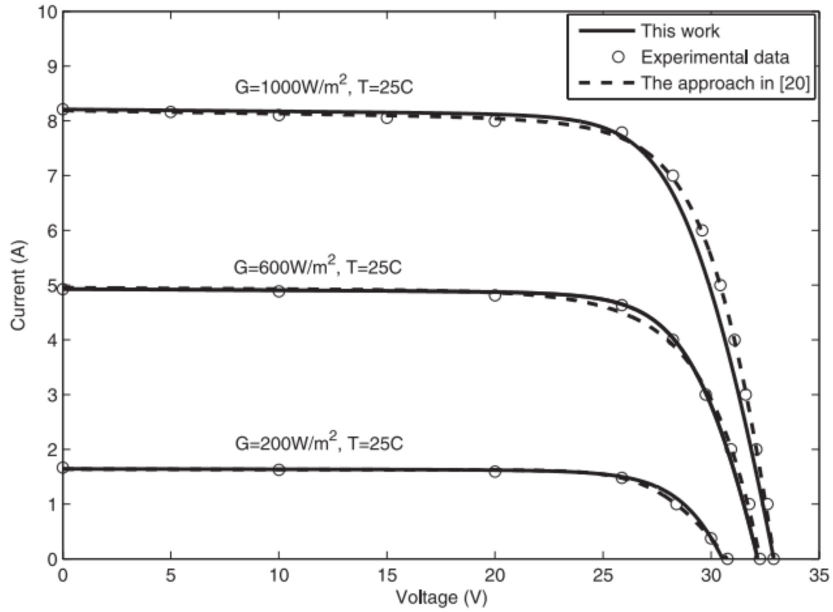
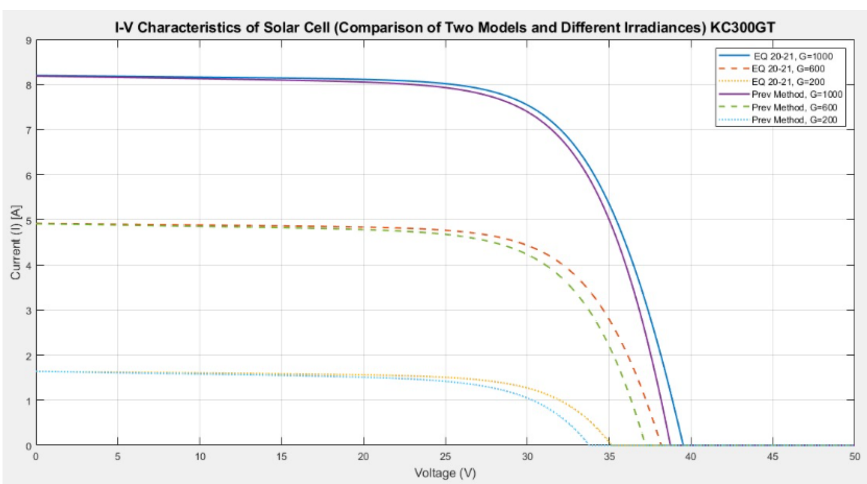


Fig. 2. Experimental data and theoretical *I*–*V* curves for the PV module KC200GT.



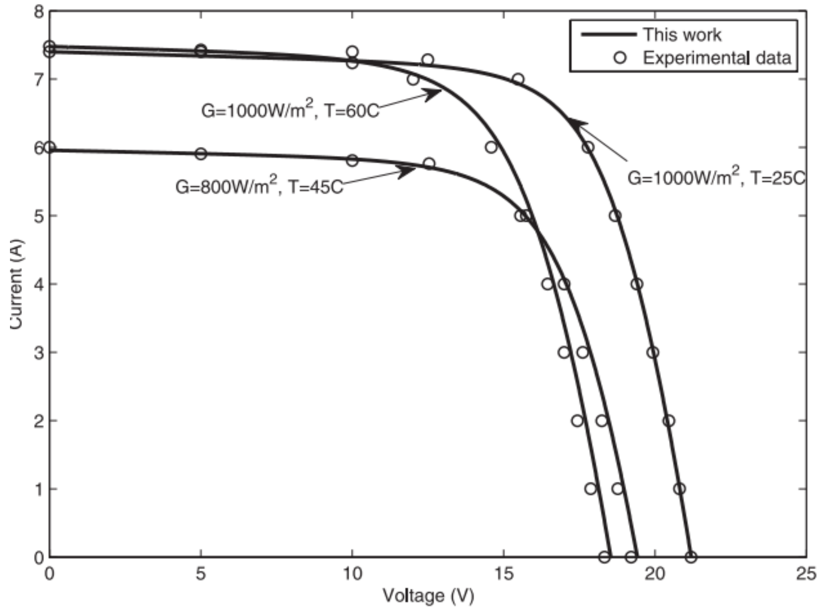
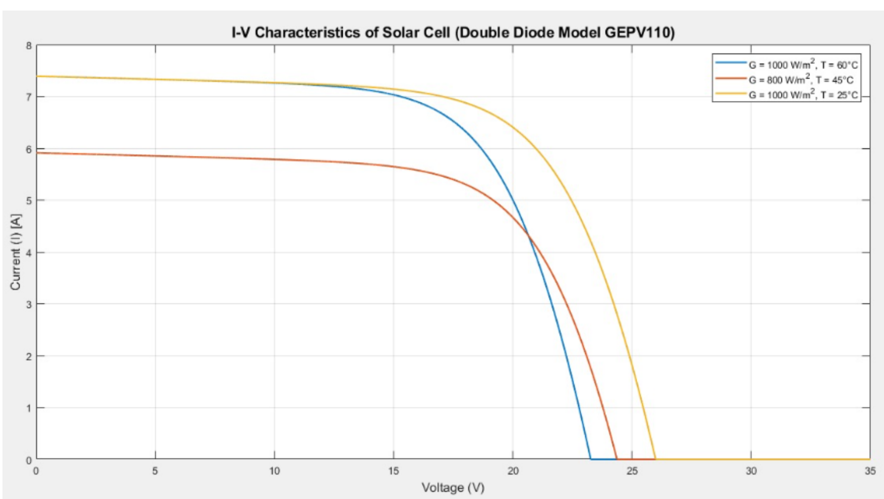


Fig. 3. Experimental data and theoretical *I–V* curves for the PV module GEPV110.



Experimental Validation

Simulated I−VI-VI−V curves closely matched experimental data, confirming the model's validity. Normalized root mean square error (nRMSE) values were within acceptable ranges, demonstrating the technique's accuracy.

Comparison with Existing Techniques

The proposed method offers several advantages over traditional approaches:

- **Efficiency:** Requires only datasheet information, reducing data collection costs.
- **Simplicity:** Eliminates the need for full I−VI-VI−V curve data or complex optimization.
- **Accuracy:** Comparable to curve-fitting methods that use the entire I−VI-VI−V curve.

However, the method may show limitations in extreme conditions, where assumptions like Rsh>>RsR_{sh} >> R_sRsh>>Rs might not hold.

Applications and Extensions

The method is applicable to:

- PV system design: Rapid parameter extraction enables efficient simulations.
- Industrial applications: Minimal data requirements make it suitable for large-scale evaluations.

Future work could involve extending the approach to multi-junction PV cells and incorporating more complex environmental dependencies.

Conclusion

This report presents an efficient and accurate method for extracting parameters of the five-parameter double-diode model using limited datasheet data. Analytical solutions provide robust initial estimates, ensuring numerical convergence and reducing computational overhead. Validation confirms the technique's suitability for industrial and research applications, marking a significant step forward in PV modeling.

References

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2. Villalva, M.G., Gazoli, J.R., Filho, E.R. *"Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays."* IEEE Transactions on Power Electronics, 2009.