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DEVELOPMENT OF A SIMULINK MODEL FOR SHADING EFFECTS ON PHOTOVOLTAIC SYSTEMS

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Abstract

Photovoltaic (PV) systems are one of the most promising technologies in the field of renewable energy due to their ability to directly convert sunlight into electricity. However, these systems are highly susceptible to environmental influences, especially partial shading. Partial shading can significantly degrade the energy output of PV arrays and introduce multiple local maxima on the power-voltage (P-V) curve, complicating maximum power point tracking (MPPT). Even minimal shading can lead to hotspots and long-term damage in PV cells. Traditional analytical models often ignore these complexities, resulting in inaccurate system predictions. This paper presents a detailed MATLAB/Simulink model that simulates the impact of partial shading on PV performance.

Keywords: *photovoltaic systems, Simulink, MPPT, bypass diodes, performance analysis, dynamic modeling, power loss, series connection, modular design*

Introduction

In the current era, global energy demand continues to rise, driven by industrialization and population growth. Simultaneously, environmental concerns such as climate change necessitate a shift toward renewable energy sources. Photovoltaic (PV) systems offer a sustainable solution by converting solar energy directly into electricity. They are environmentally friendly, quiet in operation, and have low maintenance requirements. Among renewable technologies, PV has gained prominence for its modularity and scalability. However, real-world deployment of PV systems presents numerous challenges. One of the most critical among them is partial shading. Shading can occur due to trees, buildings, clouds, or dirt. Even a small amount of shading on a PV module can affect the output of the entire array. This is particularly true for series-configured systems where current mismatch occurs. The result is not just reduced efficiency but also potential damage to modules through hotspots. Conventional models often fail to account for the nonlinear behavior caused by shading. This leads to misleading predictions about energy yield and system reliability. Accurate modeling is therefore essential for performance assessment. Simulink, a graphical simulation environment by MATLAB, provides an excellent platform for modeling such dynamic systems. The use of Simulink enables integration of various subsystems, including bypass diode functionality. This paper focuses on modeling the electrical performance of PV arrays under partial shading conditions. The ultimate goal is to understand and mitigate the effects of shading. It seeks to help researchers, designers, and policymakers make informed decisions. Additionally, the model can be used for educational purposes to demonstrate the impact of shading.

Figure 1. *Current-Voltage (I–V) Characteristics of PVA*

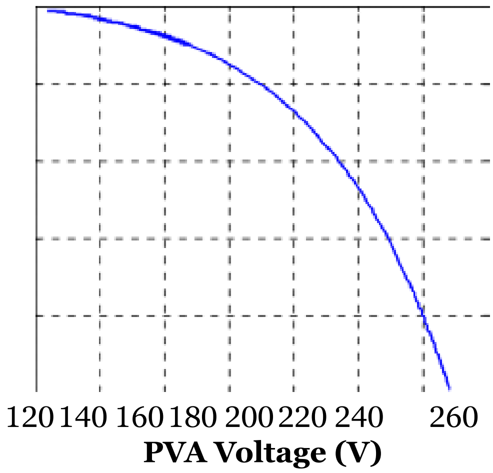
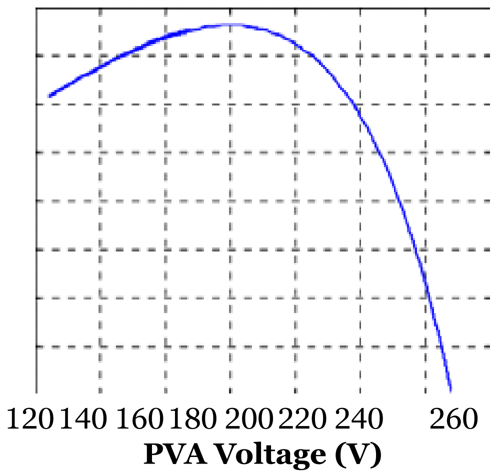


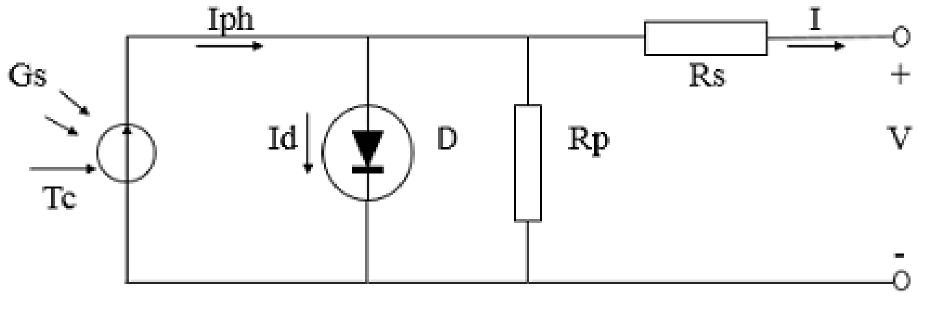
Figure 2. Power-Voltage (P-V) Characteristics of PVA



The simulation also helps in visualizing the P-V and I–V curve deviations. The presence of multiple peaks in the P-V curve under shading complicates MPPT. Standard MPPT algorithms like Perturb and Observe often fail in such cases. Understanding the behavior under different shading patterns is thus crucial. This study fills a gap in existing literature by providing a modular and customizable model. It contributes both theoretically and practically to the field of renewable energy. The model enables simulation of various real-world conditions. It can also help in optimizing the layout of PV arrays during installation. This introductory section lays the foundation for the rest of the paper. The paper is structured to guide the reader through the problem, methodology, results, and implications. The introduction makes clear why this study is timely and necessary. It ends by reaffirming the goal of improving PV system performance under shading.

The single diode equivalent circuit model is the most commonly used model for a PV module due to its simplicity. The circuit consists of a current source (Iph), a diode, a resistor in parallel (Rp), and a resistor in series (Rs).

Figure 3. *Electrical equivalent circuit diagram of single diode PV cell structure*



It is possible to increase the power output by connecting solar panels in series, parallel or mixed structure. Systems created in this way are called complex structured PV energy systems. Two important factors that determine the maximum power that can be obtained from a PV module are solar radiation and temperature. The power generated from the PV module is calculated by multiplying the module current and voltage. There is a standard test condition for evaluating efficiency in PV systems. The values under these standard test conditions are generally included in the catalogs of PV panels (Altas I. H. and Sharaf A. M., 2008).

The maximum power point provided in response to a certain voltage and current values in the power-voltage characteristic curve of PV panels is 1000 W/m^2 under standard test conditions. The radiation and temperature value is defined as 25 °C module temperature. However, these conditions may not always occur. The output current and voltage values of the PV module are also affected by this situation.

Figure 4. *Shows the current-voltage characteristic curves of the 260 W PV module under different radiation values*

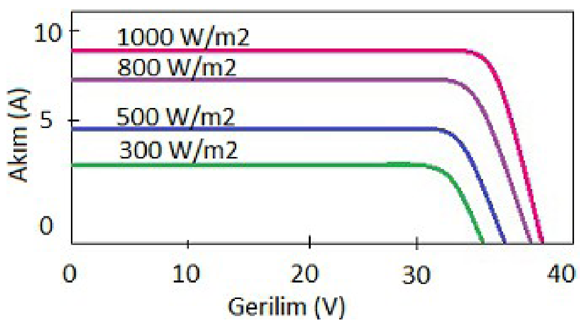
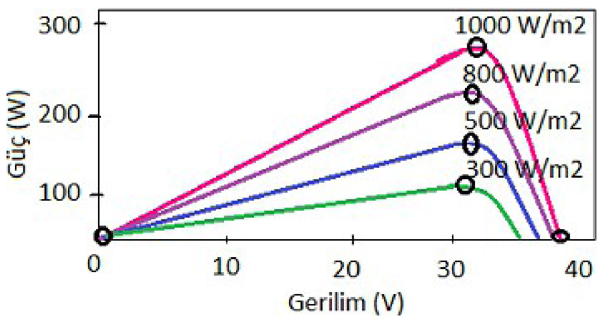


Figure 5. *Current-voltage characteristic curves of PV cell module under different radiation values*



Methodology

This study employs MATLAB/Simulink to develop a dynamic simulation model for PV systems affected by partial shading. The model is built using blocks that represent the electrical behavior of photovoltaic cells. A single-diode equivalent circuit is used to simulate the core characteristics of the PV module. The current source, diode, series resistance, and shunt resistance are configured to reflect real panel behavior. Standard test conditions (STC) are used for baseline calibration. The model allows for variation in irradiance and temperature to mimic real environmental scenarios. Shading is introduced by altering irradiance inputs to specific cells or modules. The simulation includes scenarios such as row shading, corner shading, and random shading patterns. Bypass diodes are integrated into the model in parallel with series-connected module blocks. These diodes are activated when the current drops below a threshold. This prevents damage and minimizes power losses during shading. The Simulink model also includes measurement tools to track voltage, current, and power. The block diagram is modular, making it easy to modify or expand. Parameters such as module area, temperature coefficient, and irradiance levels are user-defined. The simulation is run for a fixed time interval under each scenario. Results are collected and visualized using scopes and data displays. A key part of the methodology is comparing shaded and unshaded performance. The model does not include grid connection or battery storage systems. Emphasis is placed solely on the shading effect and its mitigation. The model is validated by comparing its outputs with known theoretical patterns. The methodology section ensures reproducibility for future studies.

Figure 6.

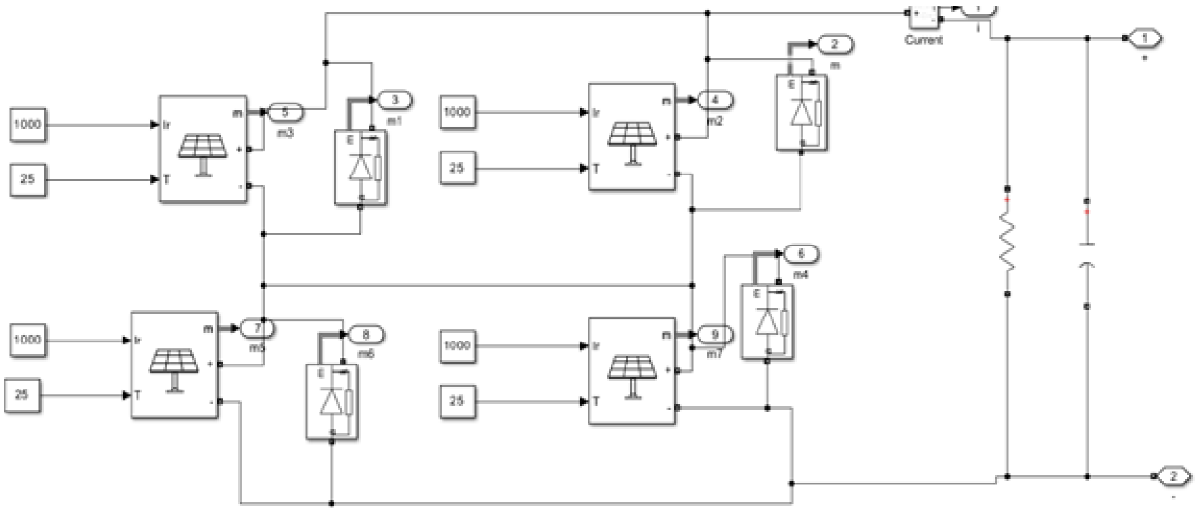
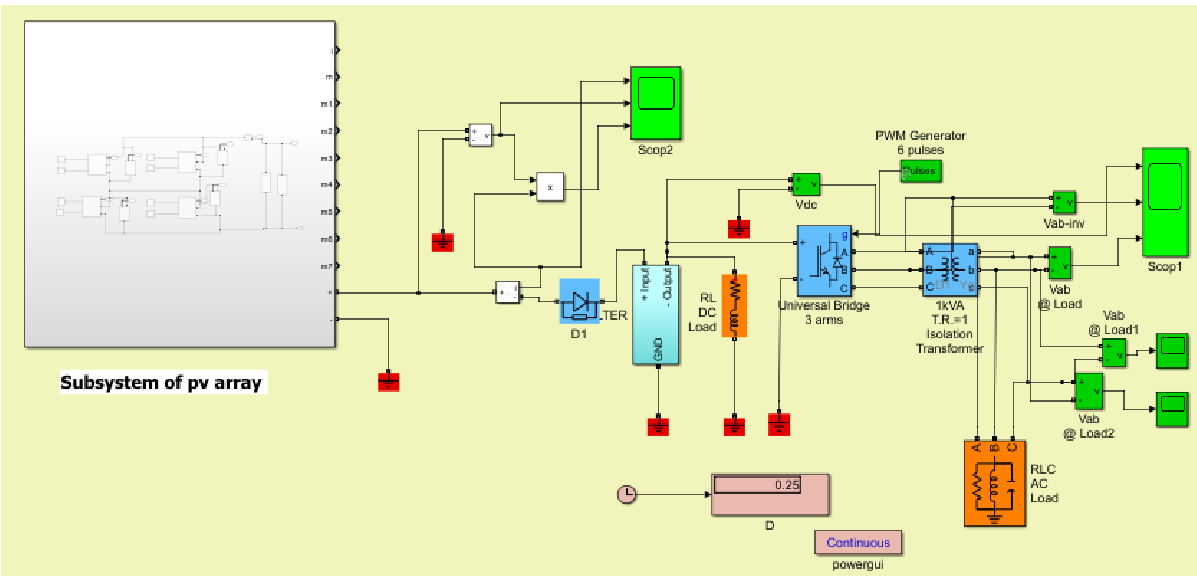


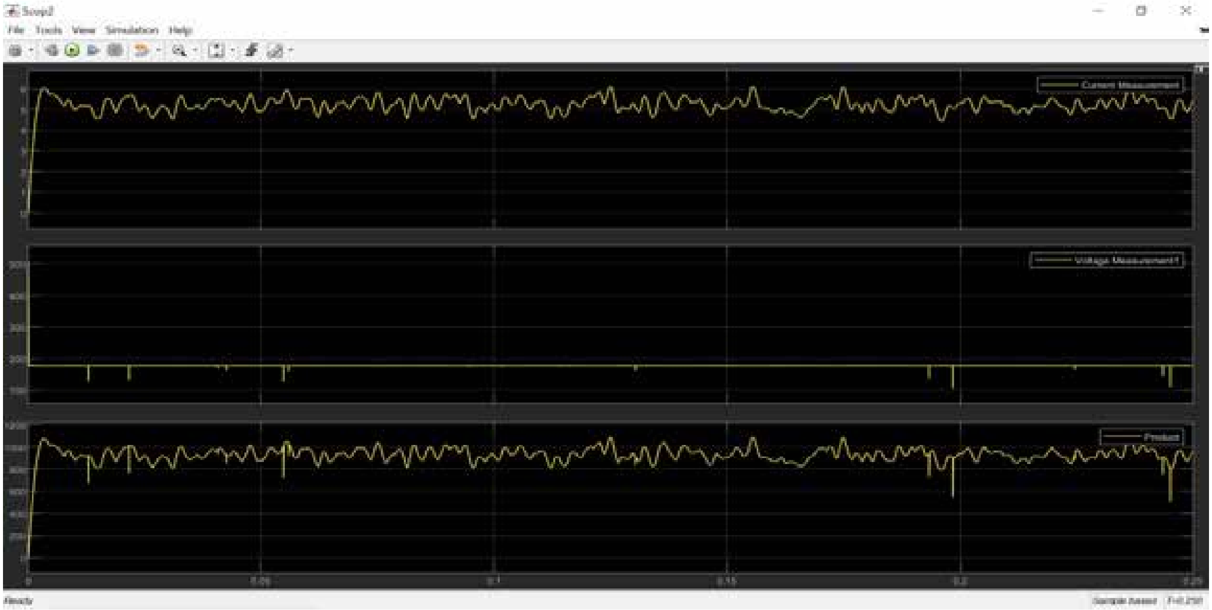
Figure 7.



Results and Discussion

Simulation results show that shading significantly affects PV performance. Even slight shading of one cell reduces the current of the entire string. The I–V and P-V curves demonstrate clear deviations from standard conditions. Multiple peaks emerge in the P-V curve under partial shading. This makes it difficult for MPPT algorithms to locate the global maximum power point. Without bypass diodes, shaded modules absorb excess heat, creating hotspots. The inclusion of bypass diodes mitigates this issue by redirecting current. When bypass diodes activate, power output is partially restored. However, energy is still lost compared to fully illuminated conditions. Different shading patterns produce different loss levels.

Figure 8.



Conclusion

This study successfully developed a Simulink-based model to evaluate the effects of partial shading on PV systems. The model accurately replicates the electrical behavior under different irradiance conditions. Partial shading was shown to cause significant efficiency losses and introduce multiple power peaks. The integration of bypass diodes helped reduce these losses. Simulation results align with established theories and real-world observations. The model is useful for both academic research and engineering design. It allows for the testing of various shading scenarios and their effects. One key contribution is the modularity of the model for future expansion. It can be adapted for different PV technologies or layout configurations. The model also assists in educational contexts to illustrate shading phenomena. It emphasizes the need for thoughtful array design in real installations. Future research may include real-time validation or integration with MPPT algorithms. Real hardware implementation could enhance the findings. The model could also benefit from incorporating weather data for temporal analysis. Dynamic irradiance profiles would improve realism further.

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