JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Experimental Investigation and Reliability Analysis of Shading Effects on Monocrystalline and Thin-Film Photovoltaic Panels

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Abstract

Energy development is a critical factor in national growth, with rising populations and energy demands driving significant research into renewable alternatives. Solar energy stands out as a clean, sustainable, and environmentally friendly power source, making research into photovoltaic (PV) panel efficiency increasingly crucial. Panel efficiency is heavily influenced by environmental factors such as dust, humidity, pressure, wind, rain, and shading caused by debris or structural obstructions. This experimental study evaluates the impact of artificial shading on outdoor PV panel performance. Cells on both monocrystalline and thin-film panels were sequentially covered both horizontally and vertically to simulate shadowing effects.

Results indicate that optimal power values for both panel types drop significantly to 0.1 W after three to four cells are obstructed. Furthermore, reliability analysis using the Weibull distribution demonstrates that shading severely compromises system efficiency.

Keywords: Photovoltaic panels, Shading effect, Weibull distribution, Reliability analysis, Panel efficiency.

1.Introduction

Energy production and consumption patterns serve as vital indicators of a nation's economic and industrial development. Renewable energy sources reduce fossil fuel dependency, promote domestic resources, and facilitate electricity supply to remote geographic regions. Turkey possesses high solar energy potential, averaging an annual global solar radiation of 1, 527 kWh/m^2 due to its geographical location. However, localized environmental factors frequently diminish operational efficiency. Obstructions such as clouds, neighboring buildings, trees, and chimneys cast shadows on solar modules, resulting in unequal radiation distribution across the system. Cells exposed to lower levels of radiation fail to produce expected output and actively drain system power.

Previous literature extensively addresses partial and continuous shading. Gao et al. examined series- and parallel-

connected PV panels under varying shadow ratios (5%, 12.5%, 25%, and 50%), concluding that parallel configurations exhibit higher resilience against shading.

Similarly, Zegaoui et al. developed physical models of PV cells under direct and reverse modes to study hotspots and bypass diode protection. Ando et al. investigated instantaneous and continuous shadowing, pollution, and aging anomalies utilizing sensor arrays placed across panels.

Despite numerous simulation and experimental studies, comprehensive reliability modeling regarding specific cell obstruction patterns remains necessary. This study evaluates the impact of localized shading on monocrystalline and thin-film panels in an open-field environment, utilizing Weibull distribution models to quantify reliability parameters.

2. Material and Methods

The experimental setup utilized two distinct photovoltaic technologies: industry-standard **monocrystalline panels** and **thin-film panels**.

Solar irradiance and electrical characteristics were measured using a **Benning PV 2** testing device (voltage measurement sensitivity: ± 5 V; maximum DC voltage capability: 1000 V; short-circuit current measurement up to 15 A DC). All outdoor measurements were

conducted under a stable solar radiation level of 1000 W/m^2.

Panels were aligned perpendicularly to incident solar rays. For the region, an azimuth angle of 40° was applied. To simulate precise localized shading, custom opaque cardboards (12.5 cm × 12.5 cm) were systematically placed to obstruct individual cells sequentially in both horizontal and vertical directions.

3 Results and Discussion

3.1 Measurement Results of Monocrystalline Panel

3.1.1 Vertical Cell Obstruction

Current-voltage (*I-V)* curves were recorded as 1 through 7 cells were successively obstructed vertically. Maximum Power Point (MPP) coordinates shifted inward and downward with each obstructed cell, illustrating a progressive reduction in output current.

3.1.2 Horizontal Cell Obstruction

Similar current degradation patterns were observed during horizontal obstruction tests. MPP values dropped significantly as shaded cell counts increased.

3.2 Measurement Results of Thin-Film Panel

Thin-film modules demonstrated distinct current-voltage behavior under vertical and horizontal shading. Due to inherent module architecture, thin-film variants exhibited robust baseline performance metrics compared to monocrystalline counterparts under identical obstruction conditions.

3.3 Reliability Analysis

Weibull distribution analyses were conducted on voltage levels across four operational cases:

Case 1: Monocrystalline (Horizontal Shading)

Case2: Monocrystalline (Vertical Shading) **Case 3:** Thin-Film (Horizontal Shading) **Case 4:** Thin-Film (Vertical Shading)

Parameters were estimated using both the Graphical Method (GM) and Maximum Likelihood Method (MLM).

Table 1: Efficiency Calculations for Shading Modes

Shading Percentage	Horizontal Mode Efficiency (%)	Vertical Mode Efficiency (%)
0%	0.149%	15.10%
25%	0.147%	0.148%
50%	0.146%	0.136%
75%	0.126%	0.134%
100%	0.124%	0.133%

4. Conclusion

Shading caused by environmental obstacles significantly degrades photovoltaic panel efficiency. Experimental evaluations confirm that optimum power outputs for both monocrystalline and thin-film panels collapse to 0.1 W once three to four cells are fully obstructed. Weibull reliability models successfully captured system degradation trends, demonstrating that thin-film modules maintain stable reliability curves across varied shading orientations compared to monocrystalline configurations. Regular cleaning protocols and careful spatial planning are essential to mitigate severe partial-shading losses in field installations.

Acknowledgements:

We would like to express our sincere gratitude to the Department of Biotechnology (DBT),New Delhi, for providing financial support under Project No. 0150, DBT Star College Scheme, for A.D.M. College for Women (Autonomous), Nagapattinam. We gratefully acknowledge the valuable support and encouragement extended by DBT towards the successful completion of this research work.

Funding:

This research was partly funded by the Department of Biotechnology (DBT), Ministry of Science and Technology, Government of India, under the DBT Star College Scheme, (Project No. 0150).

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