DYNAMIC PV ARRAY RECONFIGURATION FOR MAXIMIZED POWER GENERATION UNDER PARTIAL SHADING

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ABSTRACT

In the presence of partial shade, conventional solar systems encounter challenges, whereas our proposed method excels with finesse. In scenarios involving intricate shading and obstructions affecting multiple panels, it showcases substantial performance improvements, surpassing traditional configurations by up to 13.24%. Even in less complex shading patterns, it demonstrates an average improvement of 2.13%. This prowess stems not only from raw power but also from a meticulously designed architecture that minimizes connections, safeguards panels, and enables seamless scalability for larger installations. Furthermore, its isolated control architecture ensures data accuracy by eliminating the noise and interference that plague traditional systems.

1. INTRODUCTION

The increasing demand for renewable energy sources, fueled by environmental considerations and the growing need for energy, has led to a widespread adoption of solar energy. Photovoltaic (PV) panels, designed to convert solar energy into electrical power, have emerged as a prominent and sustainable solution in the quest for greener energy alternatives, gaining popularity over conventional sources.

In the typical configuration, PV modules are interconnected in series and parallel to create PV arrays [1]. However, these arrays often face the challenge of partial shading (PS) caused by various obstructions such as clouds, buildings, and trees. PS results in uneven irradiance across PV modules, causing alterations in their electrical characteristics. This inconsistency in electrical properties significantly diminishes the overall power output of the PV array and can even lead to localized hot spots [2]. Although bypass diodes are commonly integrated across each PV module to prevent damage, they introduce multiple peaks in the power-voltage (P-V) characteristics of the PV array [3-4].

The power loss induced by PS is not solely dependent on shading conditions but also on the interconnection mode of the PV array [5]. Among the prevalent interconnection modes, including series-parallel (SP), total-cross-tied (TCT), and bridge-linked (BL), TCT topology has proven effective in minimizing mismatch losses and enhancing reliability compared to other configurations [6-7]. However, despite its advantages in reducing mismatch loss, TCT and similar configurations still fall short of maximizing the output power [8].

In response to these challenges, various PV array reconfiguration techniques have been proposed. These techniques involve adjusting the interconnection of PV modules within the array based on real-time shadow conditions, with the aim of

increasing maximum power and alleviating mismatch impacts. PV array reconfiguration can be broadly categorized into static and dynamic methods [9-10]. Static methods involve altering the physical location of PV modules to distribute shading effects, offering savings on switches. However, their lack of adaptability to changing irradiance conditions due to fixed interconnection schemes is a notable drawback. On the contrary, dynamic reconfiguration adjusts electrical interconnections dynamically without altering the physical positions of modules.

The implementation of dynamic reconfiguration introduces complexity to large-scale PV systems, necessitating algorithms, controllers, switching matrices, and sensors. Achieving an optimal solution within an acceptable timeframe poses a challenge [8, 11].

To address this, heuristic algorithms such as Genetic Algorithm [12], Particle Swarm Optimization Algorithm [13], Grasshopper Optimization Algorithm [14], Social Mimic Optimization Algorithm, and Rao Optimization Algorithm [15] have been employed for PV array reconfiguration. These algorithms establish mathematical models for irradiance equalization, providing flexibility in balancing PV module irradiance. However, their computational demands may escalate with larger PV arrays [8].

This paper proposes a hierarchical PV array structure, utilizing a two-PV panel building block with automatic switches for dynamic reconfiguration in PS conditions. Beyond enhancing solar energy harvesting efficiency, the system addresses control complexities and scalability issues in current dynamic reconfiguration methods. The research contributes to the development of dynamic reconfiguration as a strategic solution for challenges in solar power generation.

The paper is structured as follows: Section II provides a comprehensive literature review. Section III describes the proposed reconfiguration scheme, while Section IV describes presents simulation results and associated discussions. The paper concludes with Section V.

2. LITERATURE REVIEW

PS in PV arrays, caused by obstructions like trees and buildings, leads to significant energy losses due to mismatch between shaded and unshaded modules. To address this, researchers have developed various mitigation techniques, including repositioning PV modules and modifying electrical connections. Dynamic reconfiguration, which involves rearranging PV units within arrays, has emerged as a promising approach to improve overall system performance under PS challenges.

Several studies highlight the effectiveness of different reconfiguration strategies. In [16], a Multi-Objective Grey Wolf Optimizer minimizes mismatch power loss, achieving substantial output gains. In [8] focuses on dynamic reconfiguration with irradiance equalization principles, maximizing global maximum power under PS conditions. Utilizes an Maximum Power Point Tracking (MPPT) algorithm and switch matrix for efficient power extraction in pumping applications presented in [17]. Salp Swarm Algorithm (SSA) enhances MPP controller tracking capability in [18], while [19] introduces cost-effective Current Injection converters for maximum power extraction during PS.

Optimizing array configuration is key. In [20] discusses Optimal SuDoKu re-configuration techniques for improved average maximum power and introduces a method for maximizing power generation without measuring irradiance profilesin [21]. Utilizes Coyote Optimization Algorithm to maximize global maximum power presented in [11], and presents a Ken-Ken puzzle-based reconfiguration technique for improved performance and reduced complexity in [22].

Minimizing switching operations is crucial for large-scale implementations. In [23] employs mathematical models and optimized algorithms to minimize switches, while [24] utilizes Genetic Algorithms to reduce switches and sensors, achieving significant efficiency gains. Hybrid systems are also gaining attention, with [25] presenting a dynamic PV reconfiguration approach for minimizing negative impacts of suboptimal conditions. In [1] introduces a simple approach for dynamic reconfiguration of PV cells in hybrid systems to enhance efficiency and robustness. Finally, [2] highlights the Water Cycle Algorithm as a fast and efficient approach for real-time applications involving large PV arrays.

3. PROPOSED RECONFIGURATION SCHEME

This system features solar panels interlinked in a hierarchical structure, allowing easy expansion and adaptation to diverse shading conditions. Each pair of panels is controlled by a switching block (SB) with relays that adjust the connection type (parallel/series) based on shading percentage. A microcontroller receives irradiance data from a small solar cell adjacent to the main panel and decides whether to disconnect the shaded panel based on a pre-set threshold (e.g., 50% of max power).

Normally, panels connect in parallel. When one panel is shaded and voltage drops below threshold, its relay disconnects it. Shaded panels still generate current drained through relays, preventing load on unshaded panels and voltage surges. This also protects shaded panels from temperature rise and aging.

Relay switches were used that join the two boards together and are operated by microcontrollers like Arduino. Voltage sensors are employed to gather data, which is then sent to the microcontroller as suitable instructions to govern the kind of connection between the two boards, as illustrated in Figure 1, either series, parallel, or unconnected. According to Table 1,

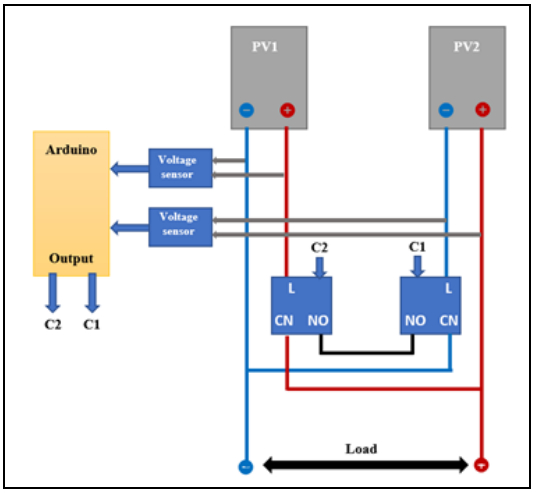


Fig.1.
The design of controlling system of Two PV array with Microcontroller.

where the NO refers to Normally open, and NC refers to Normally close, C refers to Control, L refers to line. The working conditions of Relays are; if C = 0 then L = NC otherwise if C = 1 then L = NO.

Table 1.
The Relays Status when getting instructions from microcontroller.

Shading				
PV1	PV2	C1	C2	Relay Status
NO	**NO**	**0**	**0**	Parallel
NO	**YES**	**0**	**1**	PV1 Only Working
YES	**NO**	**1**	**0**	PV2 Only Working
YES	**YES**	**1**	**1**	Series

4. RESULTS AND DISCUSSION

4.1 The parameter of the system

Implemented in MATLAB-SIMULINK, the hierarchical scheme with the proposed SB controlled a 9-panel PV array (3x3). The array consisted of 50W PV panels and integrated eight SB modules. Specifications of the PV panels used are as shown in Table 2.

Table 2.
PV panel specifications.

Solar cell type		Monocrystalline (670*530*25mm)		
Pm	Vmp	Imp	Voc	Isc
50W	**17.5V**	**2.85A**	**21.6V**	**3.23A**

The solar radiation is set to 1000 W/m2, and the PV temperature is fixed at 25 °C. In cases of partial shade, the solar radiation decreases from 900 W/m2 to 100 W/m2 at a temperature of 25 degrees Celsius, as illustrated in Figure 3. The shading cases are categorized as 1000 W/m2 for unshaded conditions and 500 W/m2 for shaded conditions.

To monitor MPPT performance, the simulation was conducted using MATLAB-Simulink, employing the SP, BL, and TCT configurations. Figure 2 depicts six types of shading, and Table 3 presents the tested shading cases under different irradiance values.

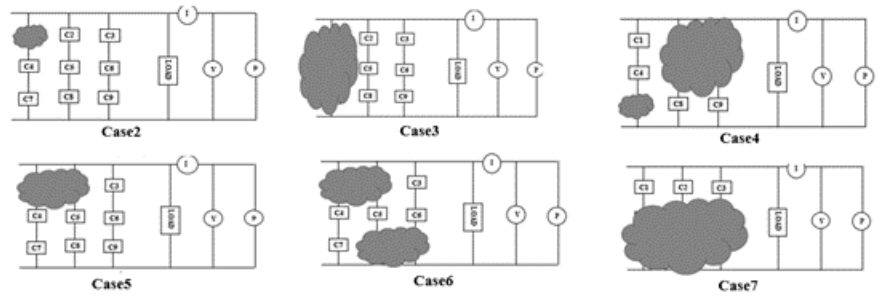


Fig. 2.
Shading patterns.

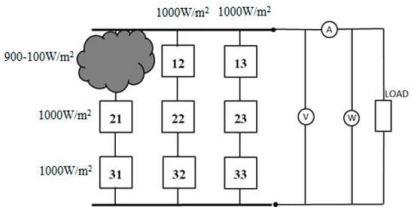


Fig.3.
Decreased solar radiation when shading occurs on solar PV cells.

4.2 Results

Table 3 shows that our proposed system outperforms conventional systems like SP, LP, and TCT in terms of maximum power under six different shading conditions.

Table 3.
MPPT performance in various PS cases for the 9-panel PV array with the SB configuration.

Shading cases	MPPT			
	SP	BL	TCT	SB
No shading	**367.9**	**367.9**	**367.9**	**330**
Case 1	**290.4**	**270.9**	**308.3**	**315.2**
Case 2	**271**	**267.2**	**261.1**	**272**
Case 3	**259.1**	**259.1**	**259.1**	**309.7**
Case 4	**232.2**	**168.1**	**171.9**	**296.3**
Case 5	**167.2**	**168.1**	**171.6**	**202.7**
Case 6	**98.6**	**98.6**	**98.6**	**158.8**

4.3 Discussion

The simulation results underscore the efficacy of the proposed approach in optimizing energy harvest. In instances of simple shading patterns, where one or two PV panels are shaded in a nine-panel simulated array (cases 1 and 2), the proposed system exhibited a 0.5% to 2.13% increase in energy percentage compared to the average of SP, BL, and TCT configurations. For cases 3 and 5, there was a notable 4.65% to 4.75% increase in power. Particularly, cases 3 and 4 displayed substantial enhancements of 12.15% and 13.24% over traditional configurations. This highlights the distinctive performance and reliability advantages offered by the proposed system's design.

5. CONCLUSION

The proposed hierarchical PV array with SB configuration significantly outperforms traditional setups under partial shading. The system consistently achieves higher energy harvest, showcasing a remarkable 0.5% to 13.24% increase in power output. This innovative approach addresses control complexities and scalability issues, presenting a promising solution for minimizing energy losses. The study contributes valuable insights to dynamic reconfiguration strategies in solar power generation, emphasizing enhanced efficiency and reliability. Future research may focus on real-world implementations for practical validation.

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