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RESEARCH ARTICLE

Effect and Behaviour of Photovoltaic Array Power under Intermittency

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ABSTRACT

Photovoltaic (PV) arrays are a critical component in the global transition towards renewable energy, but they face significant challenges due to intermittency, which refers to fluctuations in solar irradiance caused by environmental factors such as cloud cover, shading, and atmospheric conditions. MATLAB/Simulink environment was used to model and simulate the PV array under different intermittency scenarios. This study investigates the effect of intermittency on the performance of a PV array with a maximum power output of 3980 watts. The study analyses the impact of varying irradiance levels on the output power, voltage, and the emergence of multiple maximum power points (MPPs). The results show that under stable irradiance conditions, the PV array produces a single MPP, with optimal power and voltage outputs. However, when intermittency is introduced, multiple MPPs and voltage peaks appear, complicating the performance of conventional Maximum Power Point Tracking (MPPT) systems. Various scenarios, including partial shading on specific modules, are examined to understand the degree to which intermittency affects energy output. The findings emphasize the need for enhanced PV array management techniques to maximize energy yield and system reliability in real-world applications where solar intermittency is prevalent

***Keywords**: Intermittency; Photovoltaic Array; Maximum Power Point; MPP*

Introduction

Photovoltaic (PV) arrays are an essential technology for converting sunlight into electricity, forming the backbone of solar energy systems. As global energy demands grow and concerns over fossil fuel dependence and environmental sustainability increase, PV technology has become a critical component in the transition to renewable energy sources (Ebhota, & Jen, 2020; Al-Shetwi, 2022). Solar photovoltaic offer a clean, abundant, and increasingly cost-effective solution for electricity generation, providing power for residential, commercial, and industrial applications. In the early days, PV technology was primarily used in space applications, where solar panels powered satellites and space probes (Verduci, *et al.*, 2022). Over time, PV systems were adopted for terrestrial use, particularly in off-grid locations where connecting to traditional power grids was impractical or expensive (Ghosh, *et al.,* 2024; Salas, *et al.,* 2015). Today, PV systems are widely deployed in both grid-connected and off-grid settings, and their capacity continues to grow as governments, utilities, and businesses invest in solar energy as part of their broader renewable energy strategies. Despite their many benefits, PV arrays face certain challenges that can affect their performance and widespread adoption. Traditional energy systems are designed for consistent and predictable power output from fossil fuels, nuclear, or hydroelectric plants. However, the fluctuating nature of PV solar power can create imbalances between energy supply and demand. These imbalances can lead to frequency and voltage fluctuations in the grid, which may disrupt the reliability of power distribution. Commercial and utility-scale solar installations often have performance guarantees or power purchase agreements (PPAs) that depend on meeting specific energy output targets. The integration of PV systems into national and regional grids presents both opportunities and challenges, and one of the key challenges is the impact of intermittent power generation on grid stability and intermittency is an inherent characteristic of PV solar power (Nwaigwe*, et al.,* 2019). PV arrays depend on sunlight, and their output fluctuates with changes in solar irradiance due to weather conditions, shading, and the time of day. These fluctuations can reduce the overall energy yield of

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the system and complicate its integration with existing power grids (Heptonstall & Gross, 2021; Ahmed, et al., 2008). Intermittency also poses challenges for the power electronics used in PV systems, particularly Maximum Power Point Trackers (MPPTs), which are designed to maximize the power output of the array (Islam, *et al.,* 2018; Sarang, et al., 2024). When shading or other disruptions cause variations in the power curve of a PV array, traditional MPPT algorithms may struggle to find and track the true maximum power point, leading to inefficiencies (Nusrat, *et al.,* 2024). Intermittency is a critical challenge in solar photovoltaic (PV) systems, and effectively addressing it is essential for maximizing the performance, reliability, and integration of solar power into the broader energy grid. Without effective mitigation techniques, these systems may fail to identify and track the true maximum power point, especially when there are multiple peaks on the power curve caused by shading. Addressing intermittency helps maintain higher energy yields and improves the overall performance of PV systems. Failure to account for intermittency may lead to underperformance, resulting in financial penalties or reduced revenue. By integrating advanced technologies that mitigate intermittency, solar energy providers can offer more predictable energy generation, thereby enhancing the financial viability of solar projects and boosting investor confidence (Hussain, et al., 2023; Bakht, *et al.,* 2022). The study aims to simulate and analyse different intermittency conditions by varying solar irradiance on specific modules within a PV array. The objective is to understand how changes in irradiance on different parts of the array impact the overall output power and voltage. The study aims to improve the understanding of how PV arrays behave in real-world environments where intermittency is a common occurrence.

Intermittency in Photovoltaic Arrays

Intermittency in photovoltaic (PV) arrays refers to the fluctuations in the solar energy output due to varying levels of solar irradiance. This variability can result from natural phenomena like passing clouds, shading from trees or buildings, weather changes, or even the movement of the sun throughout the day. These fluctuations are common in both large-scale solar farms and smaller rooftop systems and can significantly affect the performance, efficiency, and reliability of the photovoltaic arrays. There are different causes of intermittency and one of the most common causes is the presence of clouds that temporarily block the sun. This leads to sudden drops in solar irradiance, followed by rapid recovery when the cloud passes, causing power fluctuations in PV systems (Suri, *et al.,* 2014), shading is also one cause of intermittency. This happens when buildings, trees, or other solar panels can cast shadows on parts of a PV array, even partial shading on a single module can dramatically reduce the output of the entire system due to the series configuration of the modules (Kuznetsov, et al., 2020). Atmospheric Changes like fog, rain, or dust can reduce the intensity of sunlight reaching the PV modules, leading to a decrease in energy generation (Zaihidee, et al., 2016; Kazem, *et al.,* 2020). The Solar Position throughout the day, the angle of the sun changes and can alter the amount of sunlight incident on the solar panels. This diurnal variation can lead to fluctuating energy output, particularly in areas without optimized panel tilt and orientation (Kaddoura, *et al.,* 2016). The challenge of intermittency has driven significant technological advancements in the solar energy industry. Innovations in energy storage, power electronics, and system design have all emerged as responses to the need for more resilient and efficient PV systems. By addressing intermittency, the industry continues to evolve, with new technologies like smart inverters, micro-inverters, and hybrid energy systems offering greater flexibility and control over energy generation and distribution.

Methodology

Material used for the Investigation

MATLAB® is powerful mathematical software widely used in both academia and industry for solving complex numerical computations and data visualization. Its highly regarded algorithms produce accurate and reliable results. MATLAB® also includes the Simulink environment, which is applied in various fields of science and engineering. Simulink allows users to simulate and design model-based dynamic and nonlinear systems, including controllers, plants, and embedded systems. Fully integrated with MATLAB, it enables seamless incorporation of MATLAB algorithms into models and facilitates the export of simulation results for further analysis. MATLAB/Simulink is employed in this research to investigate the impact of intermittency on the PV array output power.

Methods used for the Investigation

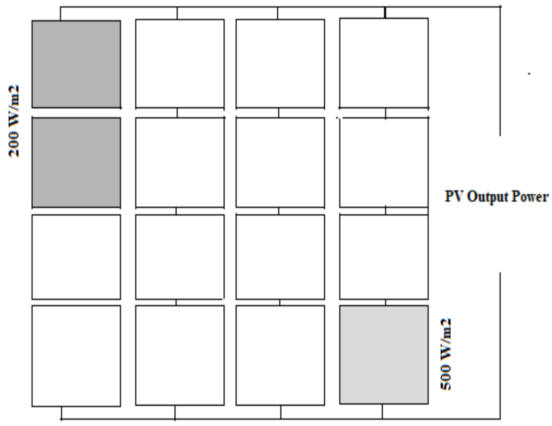
The procedures used for the analysis are as follows;

- Modelling of the PV Array
- Developing different scenarios (patterns) of clouding effects (intermittency) on the PV array

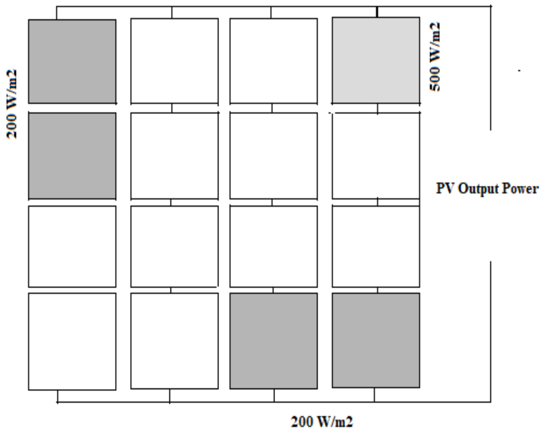
- Analysis the behaviour of the intermittency on the PV array output power.

Description of PV Array System and Scenarios

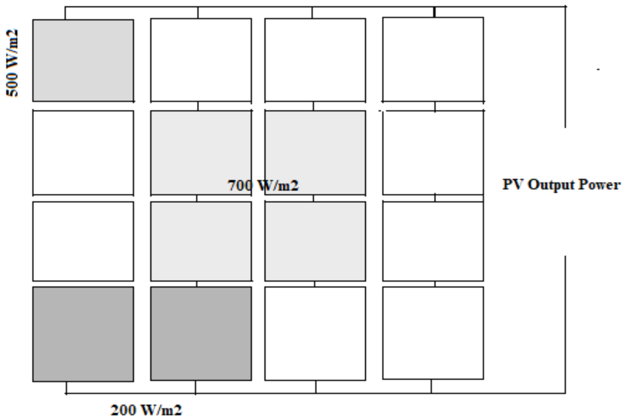
The study involved a PV array consisting of 16 modules arranged in four strings of four modules each. Each module can produce a maximum voltage of 41.6 volts, a current of 6 A, and a peak power of 249 watts. In total, the array can generate around 3980 watts, with key voltage and current points for optimizing energy production identified. This setup provides insights into how the PV array responds to varying solar radiation conditions and intermittency, aiding in evaluating the MPPT algorithm's efficiency. Figures 4.8(a) depict clouding and intermittency patterns impacting the array, where different sections receive varying levels of solar radiation. For instance, one string receives only 200 W/m² due to shading or cloud cover, significantly reducing its power output compared to other strings. On the right side, another string experiences uneven radiation, with the top module receiving 700 W/m² and the bottom module receiving 400 W/m². These real-world variations create challenges for the PV system as it strives to operate efficiently under inconsistent sunlight. Figure 1 shows the different scenarios or cases that were analysed.



(a) Scenarios 1



(b) Scenario 2



(c) Scenario 3

Fig 1: Different Scenarios of assumed Clouding effect

Results and Discussion

Simulation of PV Array Performance Without Intermittency

The analysis focused on the impact of intermittency on a photovoltaic (PV) array with a maximum power output of 3980 watts. This study aimed to understand how variations in solar irradiance, caused by intermittent shading or environmental conditions, could affect the performance of the PV array, particularly in terms of power output and voltage levels.

The PV array under ideal conditions, where solar irradiance was stable at 1000 W/m² across all modules. This represents a situation where no intermittency is present, and the system operates under optimal sunlight exposure. Under these conditions, the PV array produced a power output of 3980 watts and a voltage of 170 volts, as shown in Figure 2. The power curve exhibited a single maximum power point (MPP), meaning the system reached its highest efficiency without any disturbances. This scenario served as the baseline for comparison with cases involving intermittency.

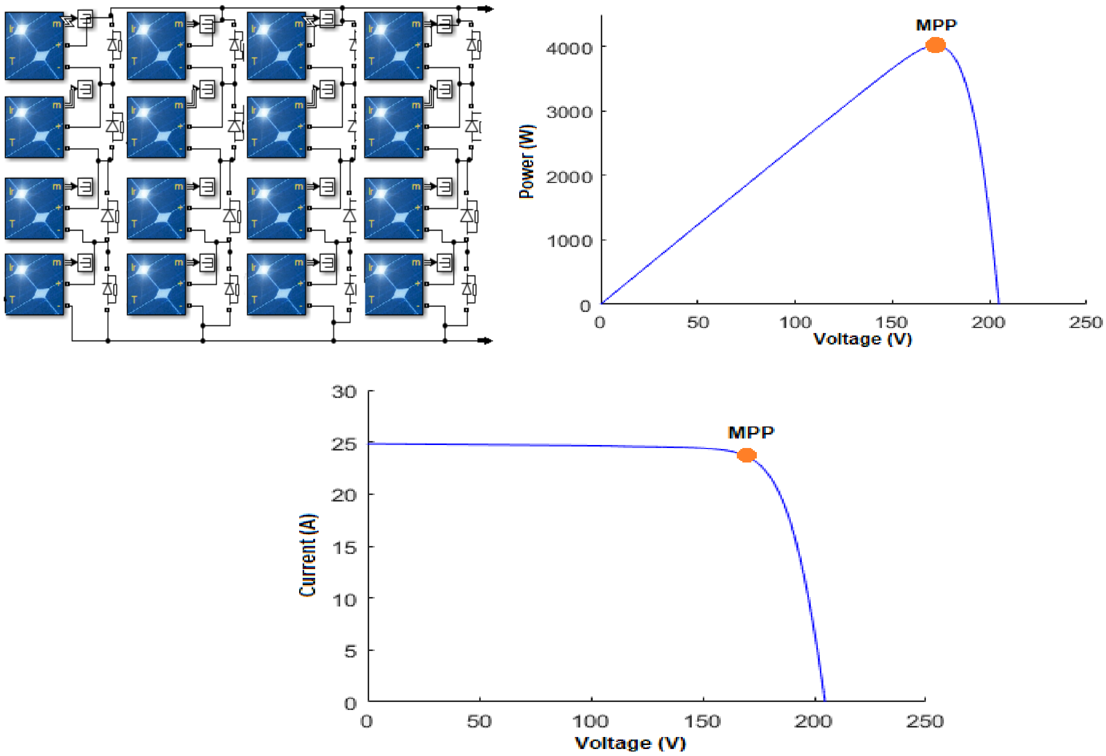


Fig 2: PV Array without Shading

Simulation of PV Array Performance Under Intermittency

Scenario 1: Partial Shading of Modules on First and Fourth Strings

In scenario one, intermittency was introduced by reducing the solar irradiance on specific modules within the array. The top two modules of the first string (on the left) experienced a reduction in irradiance to 200 W/m², while one module at the bottom of the fourth string had its irradiance reduced to 500 W/m². This setup simulated partial shading, which is common in real-world PV installations due to clouds, trees, or other obstructions. The results of scenario one show significant changes in the behaviour of the power and voltage as shown in Figure 2, instead of a single MPP, the system exhibited three distinct maximum power points (MPPs) and corresponding voltage points (MVPs). This indicated that the array was no longer operating at a single, optimal point, but rather at multiple local maxima. These multiple peaks pose challenges for traditional Maximum Power Point Trackers (MPPTs), which are typically designed to find and track only one peak. The presence of multiple MPPs can lead to inefficiencies, as the MPPT may not always track the highest power point.

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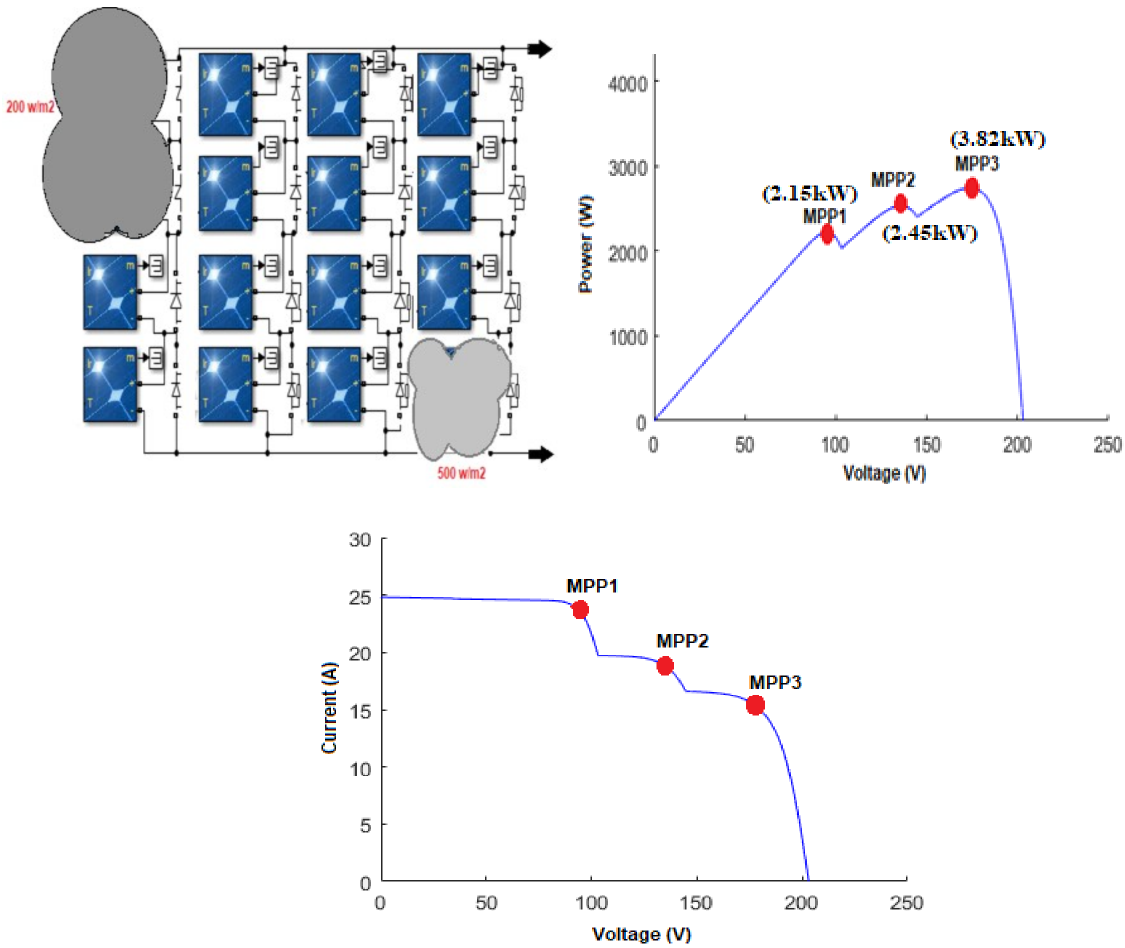


Fig 3: (Scenario 1) Impact and Shading Pattern on PV Array

Scenario 2: Increased Shading on Multiple Strings

The second scenario further explored the effects of intermittency by altering the irradiance levels on different modules. In this case, the irradiance was reduced to 200 W/m² on the top two modules of the first string, as well as on the last modules of the third and fourth strings. Additionally, the irradiance on the first module of the last string was lowered to 500 W/m². This more complex shading pattern resulted in even more pronounced power fluctuations. The array's output displayed four different power and voltage peaks, indicating an even greater number of local maxima compared to scenario one. The increased number of peaks further complicated the task of tracking the maximum power point, as traditional MPPT algorithms struggle to differentiate between local and global maxima in such conditions.

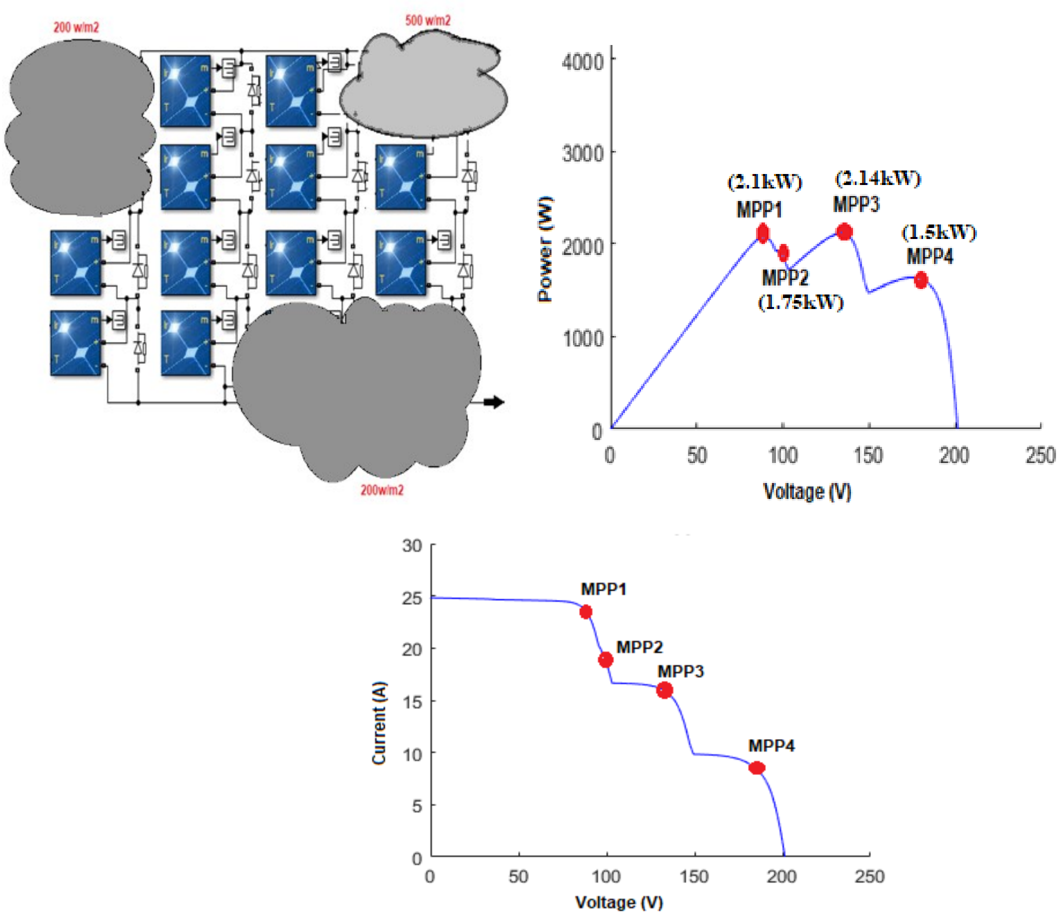
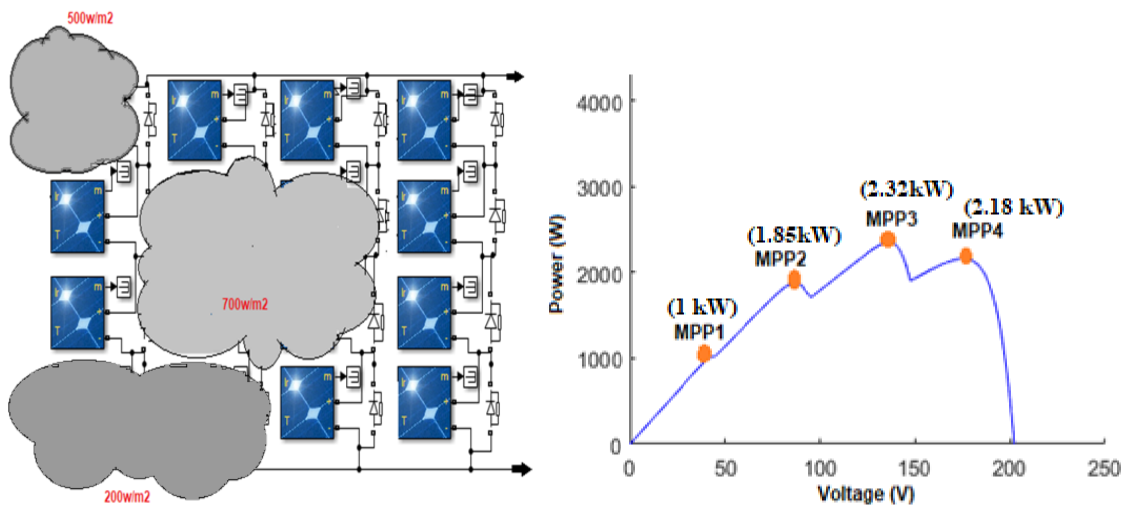


Fig 4: (Scenario 2) Impacts and Shading Pattern on PV Array

Scenario 3: Complex Shading Patterns across Several Modules

In the third scenario, a different shading configuration was introduced. The solar irradiance on the top module of the first string was reduced to 500 W/m², while the last modules of the first and second strings were reduced to 200 W/m². Additionally, the second and third modules of both the second and third strings experienced a reduction in irradiance to 700 W/m². This scenario represented a more distributed shading pattern, affecting multiple strings in different ways. The simulation results revealed four distinct maximum power and voltage points, similar to scenario 2. However, the specific distribution of peaks and the overall power output varied, illustrating how the location and severity of shading can significantly influence the array's performance.



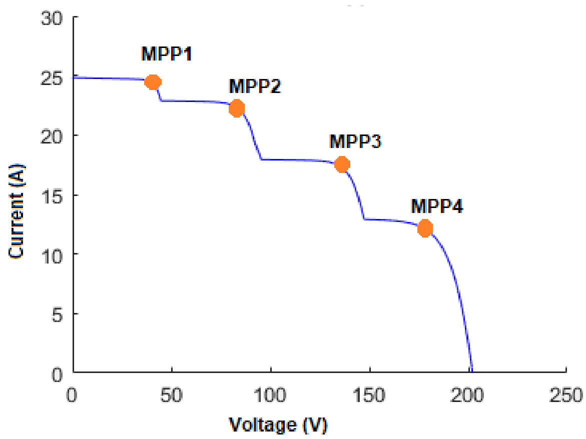


Fig 5: (Scenario 3) Impacts and Shading Pattern on PV Array

The results of these simulations clearly demonstrate that intermittency can have a profound impact on the output power of a PV array. When solar irradiance is unevenly distributed across the modules due to shading or other factors, the array produces multiple maximum power points, leading to a more complex power curve. This complexity makes it difficult for conventional MPPTs to accurately track the true maximum power point, as they are often designed to handle a single peak. In cases where multiple peaks exist, the MPPT may lock onto a local maximum, resulting in suboptimal power extraction and reduced overall efficiency. Overall, this analysis highlights the importance of addressing intermittency in PV systems, particularly in regions where shading is common. Advanced MPPT techniques, such as those incorporating machine learning or hybrid algorithms, may be required to effectively track the global maximum power point in the presence of multiple peaks. Additionally, system designers should consider the impact of shading when planning PV installations, potentially incorporating shading mitigation strategies such as module-level power electronics (e.g., power optimizers or micro-inverters) to minimize the effects of intermittency and maximize system performance.

Conclusion

The study of intermittency in photovoltaic (PV) arrays highlights the significant challenges posed by fluctuating solar irradiance on the overall performance and efficiency of solar energy systems. The analysis demonstrates that even minor variations in irradiance, caused by factors such as shading, cloud cover, or atmospheric changes, can lead to multiple maximum power points (MPPs) and voltage peaks, thereby reducing the total power output of the array. In scenarios where the PV array experiences intermittent conditions, conventional Maximum Power Point Tracking (MPPT) systems struggle to consistently track the true maximum power point due to the presence of multiple peaks. This results in suboptimal energy capture, decreased system reliability, and potential operational inefficiencies. Moreover, the impact of intermittency extends to voltage instability and increased stress on system components, which can shorten the lifespan of the equipment. Several strategies have been proposed to mitigate the adverse effects of intermittency, including the use of advanced MPPT algorithms, the integration of energy storage systems, and the optimization of array design with technologies like micro-inverters and bypass diodes. These solutions can help smooth out power fluctuations, improve energy yield, and ensure more reliable operation of PV systems in real-world environments. Addressing intermittency is crucial for the sustainable and efficient operation of PV arrays, especially as the world shifts towards increased reliance on renewable energy. Continued research and innovation in PV system design and energy management are essential to overcoming the challenges posed by intermittency and ensuring the long-term viability of solar energy as a key component of the global energy mix.

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