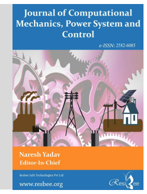
Vol.7 No.3 July 2024

Journal of Computational Mechanics, Power System and Control

Received 28 June, Revised 25 July, Accepted 31 July



A Survey on Various MPPT based Optimization Techniques for PV-grid under Partial Shading Conditions

R. Ramya

Department of Computer Science and Engineering Noorul Islam Centre for Higher Education, Thuckalay, Tamil Nadu 629180, India
rramya068@gmail.com

T. Brindha

Department of Information Technology, Noorul Islam Centre for Higher Education, Thuckalay, Tamil Nadu 629180, India

Abstract: Photovoltaic (PV) energy offers a promising solution to meet global electricity demands. However, partial shading conditions (PSCs) pose a significant challenge to PV systems. These conditions can trap the system at a local maximum power point, hindering its ability to reach the global maximum power point (GMPP). To address this issue and ensure an uninterrupted power supply, researchers have explored various MPPT-based optimization approaches. These methods aim to mitigate the negative impacts of PSCs and maintain system stability. To provide a comprehensive understanding of existing research, we conducted a literature survey focusing on the most influential articles published between 2020 to 2024 in IEEE, Google Scholar, Science Direct, and Springer journals. These studies were analyzed based on the MPPT techniques in terms of error metrics, tracking efficiency, and convergence time. By identifying current challenges and limitations, this survey aims to pave the way for future advancements in MPPT-based optimization.

Keywords: Photovoltaics; Solar System; Partial shading condition; MPPT; optimization.

Nomenclature

Abbreviation	Expansion
PV	photovoltaic
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
IncCond	**Incremental Conductance**

1. Introduction

Solar PV systems rely heavily on MPPT to optimize energy generation. Due to their nonlinear voltage-current (V-I) characteristics, solar panels produce different power outputs under varying conditions like sunlight intensity, temperature, and other environmental factors. MPPT algorithms are vital for extracting the maximum power from PV panels. Through real-time monitoring and optimization, these algorithms help to ensure maximum power extraction. Several MPPT methods are available, each offering unique advantages and considerations.

(i) Perturb and Observe (P&O) Method

The P&O method [2] determines the optimal operating point of the PV-wind hybrid system. By analyzing the I-V curve's slope, the P&O controller adjusts the PV's operating point to maximize power output. If the I-V curve slope is more negative than the stored value, the system perturbs in the opposite direction. Otherwise, it continues operating in the forward direction. The P&O algorithm is categorized by its straightforward design and easy comprehension. However, it suffers from less efficient MPP tracking, limited suitability for fluctuating irradiation and temperature conditions, and potential drawbacks as noted in [6].

(ii) Incremental Conductance (IncCond) Method

The InC method [18] initially determines the conduction slope and adjusts the converter's duty cycle accordingly. This algorithm operates based on slope values, where the duty cycle increases for positive slopes and decreases for negative or zero slopes. The process gets repeated until the MPP is located on the curve. This method computes the power derivative in terms of voltage and identifies the MPP by linking the incremental conductance ($\Delta I/\Delta V$) to the instantaneous conductance (I/V). Although it provides more precise MPP tracking, its added complexity might be a drawback for certain applications.

https://doi.org/10.46253/v7i3.a5

(iii) Constant Voltage Method

The Constant Voltage MPPT method maintains a fixed output voltage for the PV system, near its MPP under standard scenarios. This voltage is determined by empirical data or manufacturer guidelines, providing an approximation of the optimal operating voltage. Then, the constant Voltage method, which is simple and computationally efficient, often relies on experimentally determined or modeled voltage settings. These values are typically chosen to approximate the maximum power point under standard operating conditions [11]. However, this static approach can limit accuracy as the optimal voltage fluctuates with varying environmental factors and module degradation.

(iv) Hill Climbing Method

By analyzing the P-V curve slope, the system continuously adjusts its operating point in a feedback loop. If power increases, it will maintain the direction; otherwise, it will reverse [21]. This process is repeated after each voltage perturbation to ensure optimal power output. The algorithm iteratively adjusts the voltage, increasing or decreasing it based on whether the power output increases or decreases, respectively. Moreover, it is easy to use, but convergence can be slow and prone to local maxima**.**

(v) Ratio control method

It is a straightforward MPPT technique for solar PV systems. It operates by maintaining a constant ratio between the PV output voltage and OC voltage, assuming that the MPP occurs at a predictable fraction of the OC voltage. Implementation is easy as it avoids constant real-time MPP tracking. Instead, it relies on a predetermined relationship derived from prior measurements. However, this approach sacrifices flexibility and accuracy compared to more dynamic strategies like P&O or INC.

Table 1. *Review based on MPPT controllers for stand-alone vs hybrid PV systems*

Author [citation]	Standalone/ Hybrid system	Converter	Partial shading or not	Applications
Saibal Manna, *et al.* [1]	Standalone	Boost converter	No	❖ Aerospace
Ahmed G.Abo-Khalil, *et al.* [2]	standalone	Boost converter	Partial shading	❖ Applications that are Resilient to environmental variability.
P. Venkata Mahesh, *et al.* [3]	standalone	Boost converter	No	❖ Suitable for both grid-connected and isolated solar power generation, including large-scale solar installations.
Ruhi Sharmin, *et al.* [4]	standalone	DC-DC converter	No	❖ used in real-life settings
Deepthi Pilakkat, S. Kanthalakshmi. [5]	Hybrid	boost converter	Partial shading	❖ Suitable for smart grid and solar farm projects
Chakarajamula Hussaian Basha, *et al.* [6]	Hybrid	DC-DC converter	Partial shading	❖ used in high-voltage applications
Mohamed Bahri, *et al.* [7]	Hybrid	Boost converter	Partial shading	❖ Used in grid synchronization and fault detection/diagnosis
Sunkara Sunil Kumar & K. Balakrishna [8]	standalone	DC-DC converter	Partial shading	❖ Applied to real-time control and solar farms.
Mahmoud N. Ali, *et al.* [9]	Hybrid	boost converter	No	❖ Designed for fluctuating weather and precise solar applications
Badreddine Babes, *et al.* [10]	Hybrid	Boost converter	No	❖ arc welding machine
Sampath Kumar Vankadara, *et al.* [11]	standalone	Boost converter	Partial shading	❖ Solar panel analysis
Nouman Akram,Laiq Khan, *et al.* [12]	standalone	DC-DC converter	Partial shading	❖ Grid-tied or large-scale system
Idoko Sunday John, *et al.* [13]	standalone	Boost converter	Partial Shading	❖ Suitable for solar farms, urban, and residential PV installations
R. Sreedhar, *et al.* [14]	Hybrid	Luo converter	Partial shading	❖ Used in low to medium power applications
Haidar Islam, *et al.* [15]	Hybrid	Boost converter	Partial shading	❖ Utilized for both urban and agricultural solar projects
K. Latha Shenoy, *et al.* [16]	Hybrid	DC/DC converter	Partial shading	❖ Dynamic MPPT with irradiance compensation
Chittaranjan Pradhan, *et al.* [17]	standalone	DC/DC converter	Partial shading	❖ Used in large-scale solar farms
Sajid Sarwar, *et al.* [18]	standalone	DC/DC converter	Partial shading	❖ Large-scale solar farms and dynamic irradiance conditions
Md Tahmid Hussain, *et al.* [19]	Hybrid	DC-DC converter	No	❖ Used for Fault Detection and Diagnostics
Abdulaziz Almutairi, *et al.* [20]	Hybrid	DC-DC converter	Partial shading	❖ Used in multi-string inverters, microinverters

Table 1 reviews the various MPPT controllers for stand-alone vs hybrid PV systems. It represents the type of converter used in the PV system and their applications.

2. MPPT controller for standalone Vs hybrid PV system

(i) Standalone System

Standalone systems rely on MPPT controllers to exclusively optimize power extraction from PV panels, ensuring maximum energy transfer to the connected load or battery. These systems operate independently of the grid, allowing the MPPT controller to focus solely on maximizing power generation without regard for grid-related constraints. Standalone PV systems typically rely on DC-DC converters that serve as voltage bridges, connecting SPV panels, batteries, and loads while ensuring a harmonious flow of power. Some of the researches on stand-alone PV systems are listed below:

In 2023, Saibal Manna, *et al.* [1] developed an innovative adaptive control framework to improve MPPT efficiency, reducing system complexity and mitigating the impact of environmental and PV system uncertainties. MPPT and overall system stability are achieved through decoupling the MPPT algorithm with MRAC techniques. This approach is employed in aerospace applications.

In 2023, Ahmed G. Abo-Khalil, *et al.* [2] introduced a novel MPPT algorithm designed to overcome the issue of partial shading. While the P&O algorithm is a better selection for MPPT systems due to its simplicity, it can struggle in scenarios with partial shading. To enhance its robustness and optimize power extraction, we have integrated SA into the P&O algorithm, creating a novel approach that leverages the strengths of both techniques. Moreover, it is robust to environmental variability applications.

In 2022, based on PV panel specifications, P. Venkata Mahesh, *et al.* [3] developed a machine learning model using MLR to predict the optimal operating point for maximizing power output. This MLR algorithm predicts the MPP under varying irradiance and temperature values. It is suitable for both grid-connected and isolated solar power generation, including large-scale solar installations.

In 2022, Ruhi Sharmin *et al.* [4] developed a supervised ML-based MPPT algorithm for solar PV systems in 2022. Their approach leverages NN to analyze solar cell output characteristics and accurately track the MPP. It is utilized in real-life settings.

Sunkara Sunil Kumar & K. Balakrishna [8] made a significant contribution in 2024 by developing an MDSGWO algorithm coupled with an Adaptive FLC. This innovative approach was designed to optimize power extraction from RES in a wide range under PSCs. However, it can be applied to real-time control and solar farms.

In 2022, Sampath Kumar Vankadara, *et al.* [11] created a novel MPA-based MPPT technique, specifically designed to optimize the performance of SPV systems operating under PSC. This method is tested on various PS scenarios and outperformed existing algorithms for convergence speed, efficacy, accuracy, and extracted power. It is used in Solar panels and COVID-19 image analysis.

Nouman Akram, *et al.* [12] proposed FA in 2022 that significantly enhanced the energy output of solar PV systems operating under PSC. FA's efficient MPP tracking and rapid convergence led to substantial improvements in overall system performance. This technique can be utilized most commonly in grid-tied or large-scale applications.

In 2023, Idoko Sunday John *et al.* [13] presented a novel FA approach-based controller that significantly enhances the efficiency of DC-DC boost converters. The MATLAB simulations showcased its ability to accurately track the MPP, even under fluctuating solar irradiance circumstances. This innovative approach is particularly promising for large-scale solar farms and smaller residential PV systems.

In 2022, Chittaranjan Pradhan, *et al.* [17] framed a bio-inspired RIO technique. Moreover, it is designed to maximize power output from PV systems in which the RIO demonstrated superior search capabilities compared to PSO across various benchmark functions. Its effectiveness in finding optimal solutions and rapid convergence makes it a promising candidate for large-scale solar power installations.

In 2022, Sajid Sarwar, et al. [18] established a hybrid MPPT method called InC-DFO. This technique combines InC with Bio-inspired DFO to efficiently track the highest power from SPV systems. The InC-DFO algorithm demonstrated superior performance, particularly in dynamic irradiance conditions and under partial shading or cloudy sky conditions. Its simplicity, quick power tracking, and reduced oscillations near the MPP make it well-suited for large-scale solar farms.

(ii) Hybrid System

To fully leverage the potential of PV systems in hybrid configurations, MPPT controllers serve a crucial function in optimizing power output and enabling efficient integration with other energy sources. The controller's complexity arises from managing interactions between multiple power sources and the grid. Hybrid PV systems typically employ bidirectional DC-DC converters and multi-level inverters to connect with DC storage and the AC grid. These converters allow for flexible power management, enabling energy storage during surplus and discharge during shortages.

Deepthi Pilakkat and S. Kanthalakshmi [5] developed the ABC-PO MPPT algorithm in 2020 to extract maximum power from photovoltaic modules, even under partial shading conditions. A DC/AC inverter with an LC filter and PLL was employed for grid synchronization. However, it is suitable for smart grid and solar farm projects.

In 2024, Chakarajamula Hussaian Basha *et al.* [6] framed a hybrid MPPT controller designed to optimize solar PV system performance under varying PS conditions. Comparative simulations demonstrate that the proposed GWO-based ANFIS hybrid MPPT consistently achieves superior performance when contrasted with existing techniques. It is utilized in high-voltage applications.

In 2022, Mohamed Bahri, *et al.* [7] designed a novel ANN-driven control strategy for optimizing power extraction from three-phase grid-connected PV systems under PSC. Additionally, a conventional controller was utilized to manage the three-phase inverter, resulting in the injection of a synchronized sinusoidal current into the grid that exhibited a lower threshold of 1.23%. Used in grid synchronization and fault detection/diagnosis.

In 2021, Mahmoud N. Ali, *et al.* [9] developed an FL-based technique to adjust the step size of the INC-based MPPT method for PV systems. This algorithm dynamically determines the step size depending on the P-V curve slope. A fuzzy logic controller modulates the duty cycle's step size according to the input's proximity to five distinct regions. Furthermore, fuzzy inputs were derived from the P-V slope, and corresponding membership functions and fuzzy rules were created. It is designed for fluctuating weather and precise solar applications.

To improve the MPP delivered by PV arrays and to overcome the drawbacks in the conventional MPPT method under irradiation variation, Badreddine Babes, *et al.* [10] 2021 established a hybrid MPPT controller in which the input parameters include the PV array voltage and current, and the output parameter is the duty cycle of the DC/DC boost converter. The ANN-ACO MPPT controller utilizes an ACO technique to train the ANN. This optimization process iteratively adjusts the ANN's connection weights and biases to determine the optimal duty cycle for the converter, ensuring maximum power output from the PV array. It is used for arc welding machines.

In 2024, R. Sreedhar, *et al.* [14] suggested a Hybrid GWO with ANFIS will effectively track the Maximum Power Point when compared to the conventional hybrid MPPT methods. A Luo converter, a type of DC-DC converter, is utilized to regulate the fluctuating DC voltage output from the solar panel to a consistent, nominal DC level. This stabilized DC voltage is then fed into a single-phase VSI which in turn, the inverter connects this DC power to the grid. To maintain grid-connected inverter stability, an AOA-tuned FOPI controller is employed. It is utilized for low to medium-power applications.

In 2021, Haidar Islam, *et al.* [15] proposed an improved PI-coordinated MPPT algorithm to enhance the conversion efficiency of a PV system under PSC with fast-tracking speed and reduced power oscillations. At this time, PI controllers are employed to reduce steady-state errors in the output voltage and current of the PV system. Subsequently, an INC algorithm adjusts the duty cycle of a DC-DC boost converter to achieve rapid MPPT. Utilized for both urban and agricultural solar projects

In 2021, K. Latha Shenoy, *et al.* [16] adopted a solar PV system under variable irradiance, variable temperature, and partial shading condition of the array. Grid-connected PV systems can experience reduced efficacy under PSC. To address this issue, a fuzzy controller was developed to implement MPPT for an 11 kW PV system which aims to optimize power output even when the system is partially shaded. The proposed grid-integrated PV system underwent load testing and simulation in MATLAB Simulink. A fuzzy controller was successfully implemented to ensure seamless synchronization with the power grid. This technique is commonly used for Dynamic MPPT with irradiance compensation.

In 2023, Md Tahmid Hussain, *et al.* [19] conducted a study to compare the performance of six different ANN algorithms in MPPT for solar PV systems. The authors trained a two-layer feedforward neural network on simulated solar data using MATLAB's ANN toolbox. Moreover, it is used for Fault Detection and Diagnostics.

In 2020, Abdulaziz Almutairi, *et al.* [20] developed a GWO method to track the global maximum power point and to maximize the energy extraction of the PV system. Opposition-based learning is synergistically integrated with the GWO to enhance the efficiency of the MPPT search. Used in multi-string inverters, microinverters

3. Partial Shading Effects

Partial shading is a significant challenge in PV systems as it causes multiple local maxima on the P-V curve, making it difficult for traditional MPPT techniques to accurately monitor the global MPP. Numerous works in the literature have focused on addressing partial shading conditions (PSC) through innovative MPPT techniques, algorithms, and hybrid approaches.

- **Non-linear Power Loss**: In a series-connected string of solar cells or modules, even a small amount of shading on one panel can significantly reduce the overall power output of the entire string. Shaded cells produce less current, and since the cells in a string share the same current, the overall output of the string is reduced to match the current of the most shaded cell.
- **Multiple Peaks on the Power-Voltage Curve**: Normally, PV systems exhibit a single MPP on their P-V curve, where they produce the most power. Under partial shading, the curve becomes more complex, with multiple local maxima and one global maximum, making it difficult for traditional MPPT algorithms to find the optimal operating point.

Table 2. *Performance based on Tracking efficiency*

Author [citation]	With or without Partial shading	Tracking efficiency
Saibal Manna, *et al.* [1]	Without PS	99.7%
AhmedG.Abo-Khalil, *et al.* [2]	Partial shading	-
P. Venkata Mahesh, *et al.* [3]	Without PS	More than 96%
Ruhi Sharmin, *et al.* [4]	Without PS	99.8%
Deepthi Pilakkat, S. Kanthalakshmi. [5]	Partial shading	99.93%
Chakarajamula Hussaian Basha, *et al.* [6]	Partial shading	97.22%
Mohamed Bahri, *et al.* [7]	Partial shading	99.73%
Sunkara Sunil Kumar & K. Balakrishna [8]	Partial shading	97.19%
Mahmoud N. Ali, *et al.* [9]	Without PS	-
Badreddine Babes, *et al.* [10]	Without PS	99.2%
Sampath Kumar Vankadara, *et al.* [11]	Partial shading	99.84%
Nouman Akram,Laiq Khan, *et al.* [12]	Partial shading	>99%
Idoko Sunday John, *et al.* [13]	Partial Shading	99.93%
R. Sreedhar, *et al.* [14]	Partial shading	98.74%
Haidar Islam, *et al.* [15]	Partial shading	99.96%
K. Latha Shenoy, *et al.* [16]	Partial shading	-
Chittaranjan Pradhan, *et al.* [17]	Partial shading	99.19%
Sajid Sarwar, *et al.* [18]	Partial shading	99.98%
Md Tahmid Hussain, *et al.* [19]	Without PS	-
Abdulaziz Almutairi, *et al.* [20]	Partial shading	-

- **Reason for high tracking efficiency in INC-based DFO technique:** To provide a reasonable assessment of all suggested approaches, the Dragonfly Optimization (DFO) technique is involved due to its distinctive features such as enemy avoidance, coherence, and closely spaced swarm interactions. These features enable the DFO to minimize oscillations and deliver optimized solutions for PV systems. Notably, the hybridized INC-based DFO algorithm demonstrates superior efficacy compared to other methods, maintaining a consistent, oscillation-free output across various weather conditions. Hence, it is concluded that the developed model provides rapid settling time, which significantly reduces power losses and boosts the PV system efficiency.

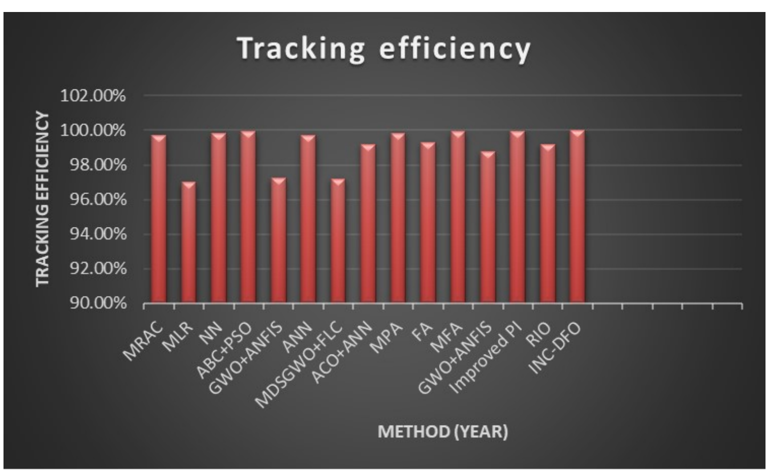


Fig. 1. *Analysis based on tracking efficiency*

The performance listed in Table 2 and Fig. 1 are based on the data published in the respective sources. This visualization can be considered as a base for choosing the way of research and the characteristics of the methodology against other methods.

4. Conclusion

This paper provides a comprehensive review of various MPPT-based optimization techniques for PV-grid systems under PSC, by examining 20 selected research papers. Each solution is thoroughly analyzed in terms of its concept and performance, particularly in tracking efficiency.

- The study examines a range of MPPT controller techniques, including P&O, INC, fuzzy logic control, and so on.
- A comprehensive comparison of technological solutions was undertaken, focusing on tracking efficiency, accuracy, and convergence time.
- This survey provided researchers with a roadmap for future MPPT research by outlining specific future scopes.

Future research should investigate how MPPT systems can maintain their high efficiency and reliability in challenging environments, guaranteeing long-term optimal performance for solar power installations.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

References

[1] Manna, Saibal, Deepak Kumar Singh, Ashok Kumar Akella, Hossam Kotb, Kareem M. AboRas, Hossam M. Zawbaa, and Salah Kamel., "Design and implementation of a new adaptive MPPT controller for solar PV systems." *Energy Reports* 9, 1818-1829, 2023.

[2] Abo-Khalil, A.G. El-Sharkawy, I.I. Radwan, A. Memon, S., "Influence of a Hybrid MPPTTechnique, SA-P&O, on PV System Performance under Partial Shading Conditions", Energies, Vol.16, 577, 2023,. https://doi.org/10.3390/en16020577.

[3] Mahesh, P. Venkata, S. Meyyappan, and Rama Koteswara Rao Alla., "A new multivariate linear regression MPPT algorithm for solar PV system with boost converter", *ECTI Transactions on Electrical Engineering, Electronics, and Communications* 20, no. 2, 269-281, 2022.

[4] Sharmin R, Chowdhury SS, Abedin Fand Rahman KM, "Implementation of an MPPT technique of a solar module with supervised machine learning", Front. Energy Res. 10:932653, 2022. doi: 10.3389/fenrg.2022.932653.

[5] Pilakkat, Deepthi, and S. Kanthalakshmi. "Single phase PV system operating under Partially Shaded Conditions with ABC-PO as MPPT algorithm for grid connected applications", *Energy Reports* 6, 1910-1921, 2020.

[6] Hussaian Basha, Chakarajamula, Madhu Palati, C. Dhanamjayulu, S. M. Muyeen, and Prashanth Venkatareddy, "A novel on design and implementation of hybrid MPPT controllers for solar PV systems under various partial shading conditions", *Scientific Reports* 14, no. 1, 1609, 2024.

[7] Bahri, Mohamed, Mohamed Talea, Hicham Bahri, and Mohamed Aboulfatah. "A New Control Strategy for Three Phase Grid Connected PV System Under Severe Partial Shading Conditions." *International Journal of Intelligent Engineering & Systems* 15, no. 2 (2022).

[8] Kumar, Sunkara Sunil, and K. Balakrishna. "A novel design and analysis of hybrid fuzzy logic MPPT controller for solar PV system under partial shading conditions." *Scientific Reports* 14, no. 1 (2024): 10256.

[9] Ali, Mahmoud N., Karar Mahmoud, Matti Lehtonen, and Mohamed MF Darwish. "An efficient fuzzy-logic based variable-step incremental conductance MPPT method for grid-connected PV systems." *Ieee Access* 9 (2021): 26420-26430.

[10] Babes, Badreddine, Amar Boutaghane, and Noureddine Hamouda. "A novel nature-inspired maximum power point tracking (MPPT) controller based on ACO-ANN algorithm for photovoltaic (PV) system fed arc welding machines." *Neural Computing and Applications* 34, no. 1 (2022): 299-317.

[11] Elbarbary, Zakaria Mohamed Salem, and Mohamed Abdullrahman Alranini. "Review of maximum power point tracking algorithms of PV system." Frontiers in Engineering and Built Environment 1, no. 1 (2021): 68-80.

[12] Akram, N.; Khan, L.; Agha, S.; Hafeez, K. Global Maximum Power Point Tracking of Partially Shaded PV System Using Advanced Optimization Techniques. Energies 2022, 15, 4055. https://doi.org/ 10.3390/en15114055.

[13] John, Idoko Sunday, Abubakar Abdulkarim, and Gbenga A. Olarinoye. "Maximum power point tracking of a partially shaded solar photovoltaic system using a modified firefly algorithm-based controller." *Journal of Electrical Systems and Information Technology* 10, no. 1 (2023): 48.

[14] Sreedhar, R., K. Karunanithi, and S. Ramesh. "Design, implementation and empirical analysis of a cascaded hybrid MPPT controller for grid tied solar photovoltaic systems under partial shaded conditions." *Measurement: Sensors* 31 (2024): 100961.

[15] Islam, H.; Mekhilef, S.; Shah, N.M.; Soon, T.K.; Wahyudie, A.; Ahmed, M.Improved Proportional Integral Coordinated MPPT Controller with Fast Tracking Speed for Grid-Tied PV Systems under Partially Shaded Conditions. Sustainability 2021, 13, 830. https://doi.org/10.3390/su13020830.

[16] Shenoy, K. Latha, C. Gurudas Nayak, and Rajashekar P. Mandi. "Effect of partial shading in grid connected solar pv system with FL controller." *International Journal of Power Electronics and Drive Systems* 12, no. 1 (2021): 431.

[17] Pradhan, C.; Senapati, M.K.; Ntiakoh, N.K.; Calay, R.K. Roach Infestation Optimization MPPT Algorithm for Solar Photovoltaic System. Electronics 2022, 11, 927. https://doi.org/10.3390/ electronics11060927.

[18] Sarwar, S.; Javed, M.Y.; Jaffery, M.H.; Arshad, J.; Ur Rehman, A.; Shafiq, M.; Choi, J.-G. A Novel Hybrid MPPTTechnique to Maximize Power Harvesting from PV System under Partial and Complex Partial Shading. Appl. Sci. 2022, 12, 587. https://doi.org/10.3390/ app12020587.

[19] Hussain, M.T.; Sarwar, A.; Tariq, M.; Urooj, S.; BaQais, A.; Hossain, M.A. An Evaluation of ANNAlgorithm Performance for MPPTEnergy Harvesting in Solar PV Systems. Sustainability 2023, 15, 11144. https://doi.org/10.3390/su151411144.

[20] Almutairi, Abdulaziz, Ahmed G. Abo-Khalil, Khairy Sayed, and Naif Albagami. "MPPT for a PV grid-connected system to improve efficiency under partial shading conditions." *Sustainability* 12, no. 24 (2020): 10310.

[21] Podder, Amit Kumer, Naruttam Kumar Roy, and Hemanshu Roy Pota. "MPPT methods for solar PV systems: a critical review based on tracking nature." *IET Renewable Power Generation* 13, no. 10 (2019): 1615-1632.