ISSN: 2583-5637 (Online)

International journal of Inventive Research in Science and Technology

Volume 4 Issue 10 October 2025

Review Paper 2

Enhancing Solar PV System Performance: A Review of Flower Pollination Algorithm-Based MPPT Under Partial Shading

Md Arif Hasnanin[1], Devendra Sharma[2], M.S.Dash [3], Vasant Acharya[4]

arifhasnain25@gmail.com[1],devendrasharma798@gmail.com[2],malaya_rec@rediffmail.com[3], vasantacharyatitc@gmail.com[4]

[1]MTech Scholar, Department of Electrical and Electronics Engineering, Technocrats Institute of Technology, Bhopal, India

[2]Assistant Professor, Department of Electrical & Electronics Engineering, Technocrats Institute of Technology, Bhopal, India

[3]Professor, Department of Electrical & Electronics Engineering, Technocrats Institute of Technology, Bhopal, India

[4]Assistant Professor, Department of Electrical & Electronics Engineering, Technocrats Institute of Technology, Bhopal, India

Abstract

This paper reviews the critical role of Maximum Power Point Tracking (MPPT) in optimizing solar Photovoltaic (PV) system output, particularly under challenging partial shading conditions (PSCs). It introduces the limitations of traditional MPPT methods, which often fail to track the Global Maximum Power Point (GMPP), and highlights metaheuristic algorithms, specifically the Flower Pollination Algorithm (FPA), as a robust solution. The review discusses advancements, such as the Modified FPA (MFPA) and Revised FPA (RFPA), that address the standard FPA's shortcomings, demonstrating improved tracking speed and efficiency. The paper examines the FPA's application, advantages, recent challenges, and future directions in this domain, providing a comprehensive overview of its potential to enhance solar energy harvesting.

Keywords: Flower Pollination Algorithm (FPA), Maximum Power Point Tracking (MPPT), Partial Shading Conditions (PSCs), Photovoltaic (PV) system, Global Maximum Power Point (GMPP), Metaheuristic Algorithms.

I. Introduction

Solar photovoltaic (PV) systems are increasingly recognized as a clean and cost-competitive source of energy, directly converting sunlight into electricity. The electrical characteristics of PV modules are inherently non-linear, with their output power varying significantly based on solar radiation and ambient temperature. To ensure maximum energy extraction, Maximum Power Point Tracking (MPPT) techniques are indispensable. MPPT controllers continuously adjust the operating point of the PV system to maintain operation at its Maximum Power Point (MPP), thereby optimizing power output. This dynamic adjustment is crucial for enhancing overall energy harvesting and system efficiency.

A significant challenge arises under partial shading conditions (PSCs), where the PV array is unevenly illuminated due to obstructions like clouds, trees, or adjacent structures. Unlike uniform irradiance, where the power-voltage (P-V) curve exhibits a single peak, partial shading introduces multiple peaks, known as local maximum power points (LMPPs). This multi-modal characteristic makes it exceptionally difficult for conventional MPPT techniques, such as Perturb and Observe (P&O) and Incremental Conductance (IC), to locate the true Global Maximum Power Point (GMPP). These traditional methods are prone to getting trapped in LMPPs, resulting in suboptimal power output, slow tracking speed, and significant oscillations around the MPP.

The persistent difficulty of traditional MPPT techniques in efficiently managing partial shading, coupled with the increasing prevalence of shading in diverse PV installations, underscores a fundamental shift in the design requirements for PV control systems. This situation necessitates a transition from simple, reactive control mechanisms to more sophisticated, adaptive, and global optimization algorithms. The adoption of metaheuristic approaches, such as the Flower

Pollination Algorithm (FPA), is not merely an incremental improvement but a strategic necessity to unlock the full energy harvesting potential and economic viability of PV systems in real-world, dynamic environments. This implies that the "intelligence" of the MPPT algorithm is becoming as critical as the efficiency of the PV panel itself.

To overcome the inherent limitations of conventional methods under PSCs, advanced metaheuristic optimization algorithms have emerged as promising solutions. These algorithms, inspired by natural phenomena, are designed to effectively explore the entire search space to locate the GMPP, even in complex multi-modal P-V curves. The Flower Pollination Algorithm (FPA) is one such bio-inspired technique that has garnered attention due to its effective distribution of local and global search capabilities.

II. Literature Review

MPPT algorithms for PV systems are broadly categorized into three main groups: traditional, advanced, and hybrid approaches. Traditional techniques, including Perturb and Observe (P&O), Incremental Conductance (IC), Constant Voltage (CV), Lookup Table (LT), and Hill Climbing (HC), are characterized by their simplicity and low computational requirements. While these methods are straightforward to implement and effective under uniform irradiation, they consistently fail to track the GMPP under partial shading conditions, exhibiting slow tracking speed, poor convergence, and high steady-state oscillations. For instance, P&O can become confined to local MPPs, and its performance is sensitive to the search starting point.

In contrast, advanced techniques are designed to adapt to complex and dynamic conditions, offering improved accuracy and efficiency. These are further divided into smart techniques, such as Fuzzy Logic Controllers (FLC) and Artificial Neural Networks (ANN), and metaheuristic techniques, including Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), Ant Colony Optimization (ACO), Flower Pollination Algorithm (FPA), and Genetic Algorithms (GA). Metaheuristic algorithms, particularly bio-inspired ones like FPA, offer superior performance in handling the complex, non-linear, multi-peak P-V curves generated under PSCs.

They are designed to avoid local optima and effectively distribute search efforts across the entire power curve, making them suitable for global optimization problems like MPPT.

Hybrid approaches represent a third category, combining multiple MPPT algorithms to leverage individual strengths and mitigate weaknesses, thereby creating more robust and adaptable tracking systems.

The continuous evolution of MPPT techniques, from rudimentary rule-based systems to sophisticated bio-inspired and hybrid algorithms, reflects a fundamental research trajectory aimed at maximizing energy yield from PV systems in increasingly complex and unpredictable real-world environments. This progression highlights a growing recognition that the initial simplicity of traditional methods is insufficient for modern PV applications, necessitating a trade-off of increased computational complexity for superior performance and adaptability. This trend implies that the research community is prioritizing the robustness and adaptability of MPPT solutions, even at the cost of increased design complexity and computational requirements. The ultimate goal is to extract every possible watt from PV systems, pushing the boundaries of what is achievable in challenging conditions.

III. Flower Pollination Algorithm (FPA) for MPPT

The Flower Pollination Algorithm (FPA), proposed by Xin-She Yang, is a metaheuristic optimization algorithm inspired by the natural process of flower pollination. It idealizes pollination characteristics into four core rules:

1. **Global Pollination (Biotic & Cross-Pollination)**: This process involves pollen being carried by pollinators, such as insects, over long distances. It is modeled using Lévy flights, which ensures a broad, global exploration of the search space. This step guides pollen towards the current best solution identified (g*).
2. **Local Pollination (Abiotic & Self-Pollination)**: This represents pollen transfer occurring over short distances, often modeled as a local random walk. This mechanism facilitates intensive exploitation of promising regions within the search space.

3. **Flower Constancy**: This rule dictates that the reproduction probability is proportional to the similarity between two flowers involved, thereby maximizing the transfer of pollen to conspecific plants.
4. **Switch Probability (p)**: A critical parameter, typically set around 0.8, this probability balances global and local pollination, allowing the algorithm to dynamically switch between exploration (finding new areas) and exploitation (refining solutions in known areas).

In its application to MPPT, the FPA controls the duty cycle of a DC/DC converter connected to the PV system. The output power of the PV array serves as the fitness function, which the FPA aims to maximize by iteratively adjusting the duty cycle (representing pollen position) until the Global Maximum Power Point (GMPP) is reached.

While effective, the standard FPA exhibits certain limitations when applied to MPPT under PSCs. The random initialization of pollen values can lead to premature convergence, where the algorithm settles on a local maximum power point (LMPP) instead of the true GMPP. Furthermore, the standard FPA can suffer from a slow convergence rate, particularly in later stages, and may cause oscillations in the power waveform, delaying power convergence to the GMPP.

To overcome these shortcomings, various modified FPA (MFPA) strategies have been developed. These include optimized pollen initialization, where initial pollen values are set near expected peak positions, often determined by approximating duty ratios, open-circuit voltage, and DC link voltage. This reinitialization significantly reduces convergence time and enhances GMPP detection. Additionally, in MFPA, population fitness and switch probability influence the swapping between two-mode optimization. Individuals far from the global maximum undergo global pollination, while those close undergo local pollination, accelerating convergence. Some revised FPA variants, such as the Ordered FPA (OFPA), incorporate hierarchical optimization or ordering of collected pollens to minimize settling time. Strategies are also implemented to optimize pollination utilization, avoiding excessive randomness for a more effective distribution

ISSN: 2583-5637 (Online)

International journal of Inventive Research in Science and Technology

Volume 4 Issue 10 October 2025

of solutions. Finally, retriggering the algorithm based on detected changes in current and voltage (indicating weather changes) allows for dynamic adaptation to environmental shifts.

The consistent pattern of modifications to the standard FPA, leading to variants like MFPA, RFPA, and OFPA, directly addresses its core limitations: the initial randomness and the balance between exploration and exploitation. This reveals a critical optimization strategy in applying metaheuristic algorithms to real-world problems like MPPT. While initial randomness is vital for broad exploration, intelligent constraints and adaptive mechanisms are necessary to guide the search efficiently towards the global optimum, especially in the critical initial and final convergence stages. The "novelty" in these algorithms often refers to these intelligent refinements that convert a general optimization algorithm into a highly effective MPPT solution.

The performance of these algorithms under various partial shading conditions is critical for their practical application. The following table provides a comparative overview of key performance metrics:

Table: Comparative Performance of MPPT Algorithms Under Partial Shading

Algorithm	**Tracking Time (s) (Example PSCs)**	**MPPT Efficiency (%) (Example PSCs)**	**Key Characteristics**
MFPA	0.24, 0.24, 0.22, 0.23	99.98, 99.90, 99.93, 99.26	Faster, higher efficiency, minimal oscillations, optimized initialization, fitness-based mode switching
RFPA/DA-FPA	0.1018 (Zero Shading), 0.1057 (Weak Shading), 0.1058 (Strong Shading)	99.4 (Zero Shading), Same as FPA (Shading)	Significantly faster (up to 86x), optimized pollen placement, hierarchical optimization, retriggering
FPA	0.4, 0.35, 0.45, 0.37	99.93, 99.88, 99.91, 99.18	Slower than MFPA/RFPA, more oscillations, random initialization

Algorithm	Tracking Time (s) (Example PSCs)	MPPT Efficiency (%) (Example PSCs)	Key Characteristics
P&O	Slower, high oscillations	Lower efficiency, often trapped in LMPP	Simple, easy to implement, but inefficient under PSCs

This table provides a direct, quantitative comparison of the performance metrics, specifically highlighting the improvements offered by modified FPA variants over the standard FPA and traditional methods like P&O. Such empirical data is crucial for substantiating claims of superior performance in a technical review, allowing for a rapid understanding of practical benefits and validating algorithmic advancements.

IV. Advantages of FPA-Based MPPT

Employing FPA and its modified variants for MPPT in solar PV systems offers several key benefits, particularly under partial shading conditions. FPA-based MPPT, especially its modified versions, significantly enhances energy harvesting from solar panels. By accurately tracking the GMPP, these algorithms ensure that the PV system continuously operates at its optimal power output, leading to increased energy production and improved overall system efficiency. This capability translates into reduced energy consumption from other sources, lower energy bills, and increased savings for system owners.

Unlike traditional methods that frequently become trapped in local maxima, FPA and its variants are designed to effectively explore the multi-peak P-V curves under partial shading conditions, ensuring robust and accurate tracking of the Global Maximum Power Point (GMPP). This capability is crucial for maximizing power output in challenging real-world scenarios. Modified FPA algorithms (MFPA, RFPA) demonstrate significantly faster tracking times and reduced oscillations around the MPP compared to both the standard FPA and conventional methods like P&O. For instance, RFPA has shown an 86% improvement in tracking speed over standard FPA under various shading conditions. This rapid convergence ensures that the system quickly adapts to changing environmental conditions, minimizing power losses. Furthermore, the inherent design of FPA, integrating both global (Lévy flights) and local (random walk) search mechanisms, provides a strong capability to avoid getting stuck in local optima. This robustness is a key advantage for MPPT in complex, multi-modal search spaces.

The technical superiority of FPA-based MPPT, particularly its enhanced efficiency and significantly faster GMPP tracking under partial shading, directly translates into substantial economic benefits for solar PV system stakeholders. By maximizing energy yield, these algorithmic advancements contribute to a quicker return on investment, reduced operational costs, and increased financial attractiveness of solar energy. This accelerates its broader adoption and impact on sustainable energy transitions. This connection highlights that algorithmic improvements in MPPT are not merely academic achievements but crucial drivers for the economic viability and widespread deployment of solar PV technology, demonstrating tangible financial and societal ripple effects that contribute to overall sustainability goals.

V. Recent Challenges and Limitations

Despite its advantages, FPA-based MPPT techniques, particularly the standard FPA, face certain challenges and limitations that warrant ongoing research. A primary issue with the standard FPA is the random initialization of pollen values, which can lead to the algorithm converging prematurely to a local maximum power point (LMPP) instead of the true Global Maximum Power Point (GMPP) under partial shading conditions. Additionally, the standard FPA can suffer from a slow convergence rate, especially in later stages of tracking, and may generate oscillations in the power waveform. This is often attributed to its reliance on switching between global and local pollination and suboptimal randomness generation.

More broadly, advanced metaheuristic techniques, including FPA, often come with increased computational complexity and higher memory requirements compared to traditional methods. This can pose challenges for implementation in resource-constrained embedded systems. The effectiveness of metaheuristic algorithms is also highly dependent on the careful tuning of their control parameters, such as switch probability and population size. Improper tuning can lead to suboptimal performance or slow convergence. Furthermore, despite extensive research, there remains a recognized lack of clear guidance on selecting the most suitable MPPT algorithm for a particular solar system application, given the inherent trade-offs between tracking speed, accuracy, complexity, and cost.

While metaheuristic algorithms like FPA offer superior performance in tracking the GMPP under complex partial shading conditions, their inherent computational complexity, higher resource demands, and sensitivity to parameter tuning represent a critical trade-off. This suggests that enhanced performance often comes with increased design and implementation challenges. This highlights a persistent need to balance algorithmic sophistication with practical deployability and cost-effectiveness for wider commercial adoption. The field is not just about achieving higher performance but also about making these high-performing algorithms practical and affordable. This implies that future research will increasingly focus on optimization for embedded systems and simplification of algorithmic structures, rather than just raw performance metrics.

VI. Future Directions

Future research in FPA-based MPPT for solar PV systems should focus on addressing existing limitations and exploring new avenues for enhanced performance and practical implementation. Continued efforts are needed to refine FPA variants and explore novel hybrid approaches. Integrating FPA with other optimization techniques or filtering mechanisms, such as random walk and solution ordering, has already demonstrated significant improvements in tracking speed and efficiency. Future work could investigate more sophisticated hybridization strategies to further enhance robustness and convergence.

A crucial future direction involves conducting detailed economic analyses of FPA-based MPPT systems, focusing on aspects like payback period and overall cost-effectiveness. This will provide valuable insights into their real-world viability and justify the initial investment compared to simpler, less efficient solutions. Rigorous comparative studies are also essential to assess the performance of FPA-based algorithms against newly developed Global Maximum Power Point Tracking (GMPPT) algorithms. This ensures that FPA remains competitive and its strengths and weaknesses are thoroughly understood in the context of the latest advancements.

To facilitate wider adoption, especially in resource-constrained embedded systems, future research should focus on optimizing FPA algorithms to reduce their computational burden and memory footprint. Simplifying the structural and procedural complexities of these nature-inspired algorithms is also a key area. Exploring more cost-effective implementation strategies for FPA-based MPPT systems, perhaps through optimized hardware designs or simpler software architectures, will be vital for commercialization and mass deployment. Furthermore, ongoing research in developing more accurate mathematical models for PV cells is crucial. These models can better predict PV behavior under varying environmental conditions, which in turn can lead to more precise and adaptive MPPT algorithm designs.

The future trajectory of FPA-based MPPT research is clearly shifting from solely focusing on algorithmic performance enhancement, such as speed and efficiency, towards practical considerations including economic viability, computational efficiency, and ease of implementation. This indicates a maturing field where theoretical advancements are increasingly being subjected to rigorous testing against real-world constraints, aiming for broader commercial adoption and integration into mainstream solar PV systems. This pivot reflects a recognition that even the most advanced algorithms must be economically and practically deployable to achieve widespread impact.

VII. Conclusion

This review has highlighted the critical role of Maximum Power Point Tracking (MPPT) in maximizing energy harvest from solar PV systems, particularly given the challenges posed by partial shading conditions that lead to multiple power peaks. Traditional MPPT methods have proven insufficient under these complex conditions, often failing to track the Global Maximum Power Point (GMPP). The Flower Pollination Algorithm (FPA), a bio-inspired metaheuristic approach, has emerged as a robust solution, capable of effectively navigating the multi-modal P-V curves.

Significant advancements through Modified FPA (MFPA, RFPA, OFPA) have addressed the limitations of the standard FPA, notably by optimizing pollen initialization, implementing fitness-based mode switching, and incorporating hierarchical optimization. These modifications have led to substantial improvements in tracking speed, with some variants achieving up to 86% faster convergence, and MPPT efficiency, approaching 99.98%, compared to the standard FPA and conventional methods.

While FPA-based methods offer superior performance, challenges such as computational complexity, memory requirements, and parameter tuning persist. Future research directions are focused on further algorithmic optimization, comprehensive economic feasibility studies, comparative analyses with new GMPPT algorithms, and critically, the reduction of computational burden and implementation costs to facilitate wider adoption and real-world impact. Ultimately, the evolution of FPA-based MPPT techniques represents a promising pathway towards more efficient, reliable, and economically viable solar energy systems in diverse environmental conditions.

References

[1] M. A. El-Dine, H. M. Hassan, and M. A. El-Shazly, "A new flower pollination algorithm strategy for MPPT of partially shaded photovoltaic arrays," *Intelligent Automation & Soft Computing*, vol. 38, no. 3, pp. 55481–55481, 2024.

[2] M. A. Khan, A. Hussain, and A. Khan, "Revised flower pollination algorithm for maximum power point tracking of photovoltaic systems under partial shading conditions," *Xian Shi You Da Xue Xue Bao (Natural Science Edition)*, vol. 12, no. 13, pp. 2846–31, 2023.

[3] X.-S. Yang, "Flower pollination algorithm for global optimization," in *Unconventional Computation and Natural Computation*, vol. 7921, M. J. Pérez-Jiménez, A. Romero-Jiménez, and F. San Segundo, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 240–249.

[4] M. A. El-Dine, H. M. Hassan, and M. A. El-Shazly, "A comprehensive review of maximum power point tracking techniques for photovoltaic systems under uniform and partial shading conditions," *Applied Sciences*, vol. 15, no. 3, p. 1031, 2025.

[5] M. A. Khan, A. Hussain, and A. Khan, "Ordering technique for the maximum power point tracking of an islanded solar photovoltaic system," *Sustainability*, vol. 15, no. 4, p. 3332, 2023.