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Modified flower pollination algorithm for an off-grid solar photovoltaic system

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ABSTRACT

This Operating the solar photovoltaic (PV) system at its maximum power point (MPP) under numerous environmental conditions to extract the maximum power is a challenging task. The challenge is to track the MPP, especially under partial shading conditions (PSC), where the formation of multiple MPP occurs in the characteristic curve of a PV array. Nevertheless, achieving this would benefit us with optimal power production, reducing the payback time and initial cost of the PV system. To perform this duty, an electronic circuit ruled by an algorithm is employed. The MPP tracking (MPPT) algorithms can be categorized into conventional and nature inspired. The conventional algorithms can successfully track the MPP under uniform weather conditions (UWC), and unable to identify the global MPP (GMPP) under PSC. However, the nature inspired algorithms possess the ability to perform efficiently under all weather conditions. Considering this strength of nature inspired algorithms, one of the top performing algorithms named as Flower pollination algorithm (FPA) is selected based on its brilliant searching strategy in adjacent and distant locations. In this paper, some structural modifications have been proposed in the FPA to further improve its searching capability and get more quick, accurate and efficient results for the MPPT of solar PV system. Results have proven the superiority of the proposed Modified FPA (MFPA) over the FPA in terms of efficiency, accuracy, tracking speed, energy conservation, economic saving, and payback time. Simulation is performed in MATLAB/Simulink.

1. Introduction

The most attractive way of generating clean and cheap electricity is the solar photovoltaic (PV) technology [1]. It converts the solar illumination into electrical energy using photoelectric effect [1]. Sun as an input source makes the PV technology more reliable than any other energy generating technology [2]. A single PV cell provides a potential difference of around 0.6 V. The output power of a PV cell is directly proportional to the irradiance falls at its surface and inversely proportional to the atmospheric temperature as shown in Fig. 1 [3]. Due to the non-linear electrical characteristics (presented in Fig. 1), the PV cell cannot deliver its maximum power and depends at the load connected at the output [4-5].

To extract the maximum power, it is essential to operate the PV cell at its maximum power point (MPP). The MPP is an operating position in the characteristic curve, expressed by small circles in the Fig. 1, where a PV cell deliver its maximum power [6]. Consequently, an electronic circuit (known as MPP tracker) governed by a set of commands (algorithm) is employed to track the MPP. The position of the MPP varies with change in atmospheric conditions (temperature, illumination, and partial shading) as shown in the Fig. 1 and Fig. 2 respectively [7]. Under uniform weather conditions (UWC), the existence of single peak in the characteristic curve of a PV cell ease the MPP tracking (MPPT) for the algorithms. However, under partial shading conditions (PSC), multiple peaks occur in the characteristic curves of a PV cell as shown in Fig. 2. The peak with the highest power is known as a GMPP, whereas all the other existing peaks are called LMPPs, thus confuses the MPPT algorithms in identifying the GMPP among the several LMPPs.

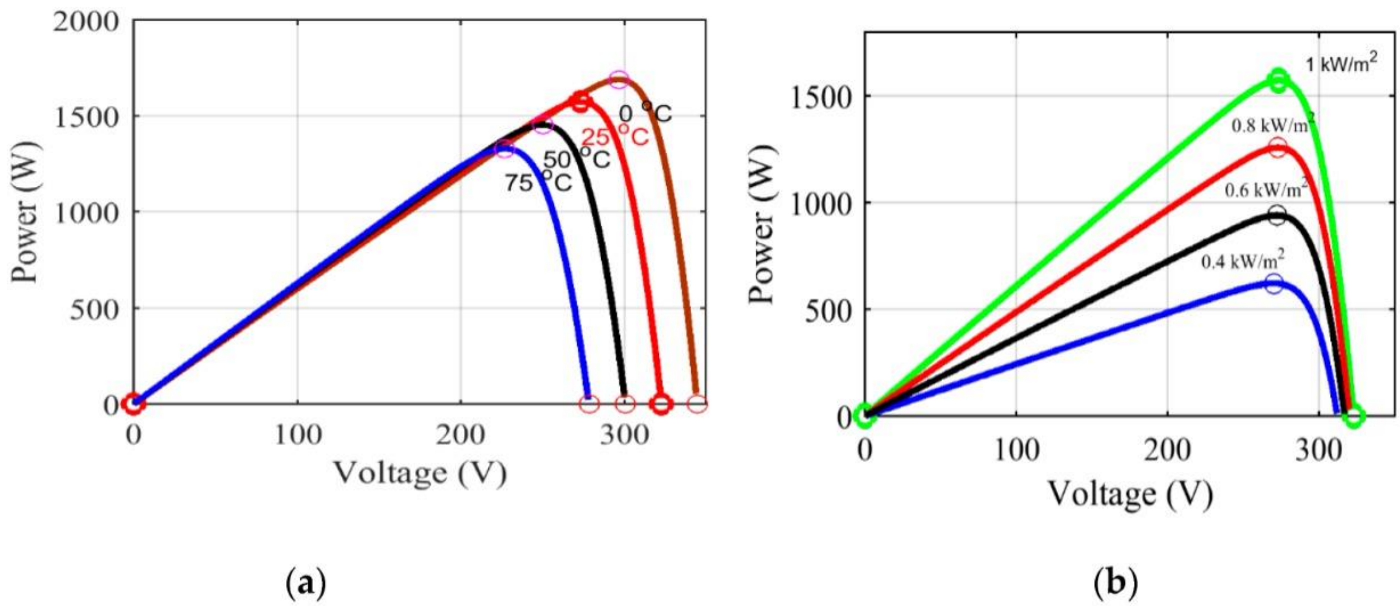


Fig. 1. Characteristic curves of a photovoltaic cell for changing temperature and illumination [3]

The MPPT algorithms can be categorized into (1) Conventional algorithms, are simple in structure, easy to implement, requires low memory space, and successful under UWC but fails under PSC in differentiating between the GMPP and LMPP. Multiple improvements have been tried in conventional techniques so far but worthless. The conventional algorithms include: Perturb and Observe [8], Incremental Conductance [9], Hill Climbing [10], Fractional Short Circuit [11], Fractional Open Circuit [12], etc. Whereas, the (2) Nature inspired algorithms, can efficiently perform under all weather conditions, but are complex in structure, hard to implement, and needs huge memory. The nature inspired algorithms include Fuzzy Logic Controller [13], Genetic Algorithm [14], Particle Swarm Optimization [15], Differential Evolution [16], Random Search Method [17], and Artificial Bee Colony [18]. A brief overview of both categories is presented in the Table 1.

A dynamic nature inspired technique named as Flower pollination algorithm (FPA) [19] has been formulated by the researchers, which has outperformed all the above mentioned conventional and nature inspired algorithms for the MPPT of solar PV system under numerous weather conditions [20]. In this paper, the detailed structure of the FPA algorithm with its strength and weaknesses is deeply studied, and then modified to get more efficient and accurate results by ensuring the effective utilization of its strengths and avoiding its weaknesses. The proposed structure is named as Modified FPA (MFPA). The rest of the paper is ordered as follows; section 2 Presents the FPA algorithm, section 3 conducts the SWOT analysis of FPA, section 4 is about formulating the problem, section 5 explains the proposed modified FPA algorithm, section 6 presents simulation and results, section 7 calculates the energy conservation and profit, section 8 is the conclusion, section 9 is the acknowledgement, and section 10 lists the references.

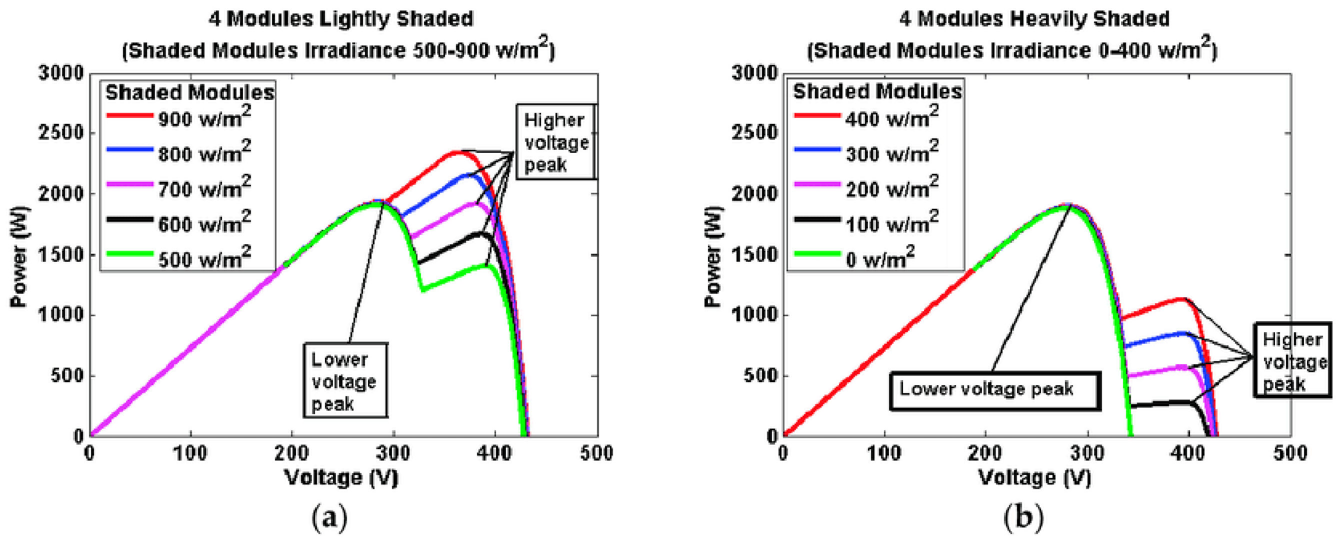


Fig. 2. Characteristic curves of four shaded photovoltaic modules [7]

Table 1

Overview of renowned conventional and nature inspired MPPT algorithms

Sr. No.	Parameter	P&O [8]	Fuzzy [21]	PSO [15]	FPA [19]
1	Steady State Oscillations	Huge	Less	Zero	Zero
2	MPP Tracking	System Dependent	Average	Average	Quick
3	Complex	No	Highly	Yes	Less
4	Procedure	Simple	Complex	Moderate	Moderate
5	Memory Needed	Less	High	Average	Average
6	Computational Complexity	Few	Large	Reasonable	Reasonable
7	GMPPT Under PSC	Flop	Efficiently	Efficiently	Efficiently
8	Execution Time	High	Reasonable	Reasonable	Low
9	PV Array Dependence	Yes	Yes	Nope	Nope
10	Steps	2	4	4	2
11	Parameters Tuning	Yes	Yes	Yes	Yes
12	Efficiency	Yes, under UWC only	Yes	Yes	Highly
13	Simple and Short	Yes	No	No	No

2. The Flower Pollination Algorithm

The FPA algorithm initiates five randomly generated pollens and apply to the duty cycle input of a DC-to-DC converter. Output power of a solar PV system against each pollen is measured. Pollen with the highest power is marked as a best pollen of this iteration P_{best}. Further, a randomly generated number (RAND) is compared with switching probability (P) (normally set at P = 0.8). If the RAND is greater than P, pollen will experience the Local Pollination using Eq. 1. Otherwise, it will pass through the global pollination using Eq. 2. The set of pollens obtained after first iteration will experience the same steps in the second iteration. In each iteration the P will be compared with new RAND. At the completion of twenty fifth iteration, a set of 25 P_{best} is obtained. The P_{best} with maximum power is designated as a Global best (G_{best}). The flowchart of the FPA algorithm is presented in Fig. 3.

$$X_i^{t+1} = X_i^t + \xi(X_k^t - X_j^t) \quad (1)$$

$$X_i^{t+1} = X_i^t + \gamma L(\lambda)(G_{best} - X_i^t) \quad (2)$$

Where, X_i^t, X_j^t, and X_k^t are the pollens i, j, and k in the iteration t. The term ε represents the search in the range 0 to 1, L is the levy factor that is used to spread the pollens at global positions, and λ is the standard gamma function. The symbol ɣ is a scaling factor to control step size and its value is fixed at 0.1. The value of Levy flight step size L(λ) determined using Eq. 3.

$$L(\lambda) = \frac{(\lambda.\Gamma(\lambda).\sin(\lambda))}{\pi.S^{1+\lambda}}, \qquad S > 0 \qquad (3)$$

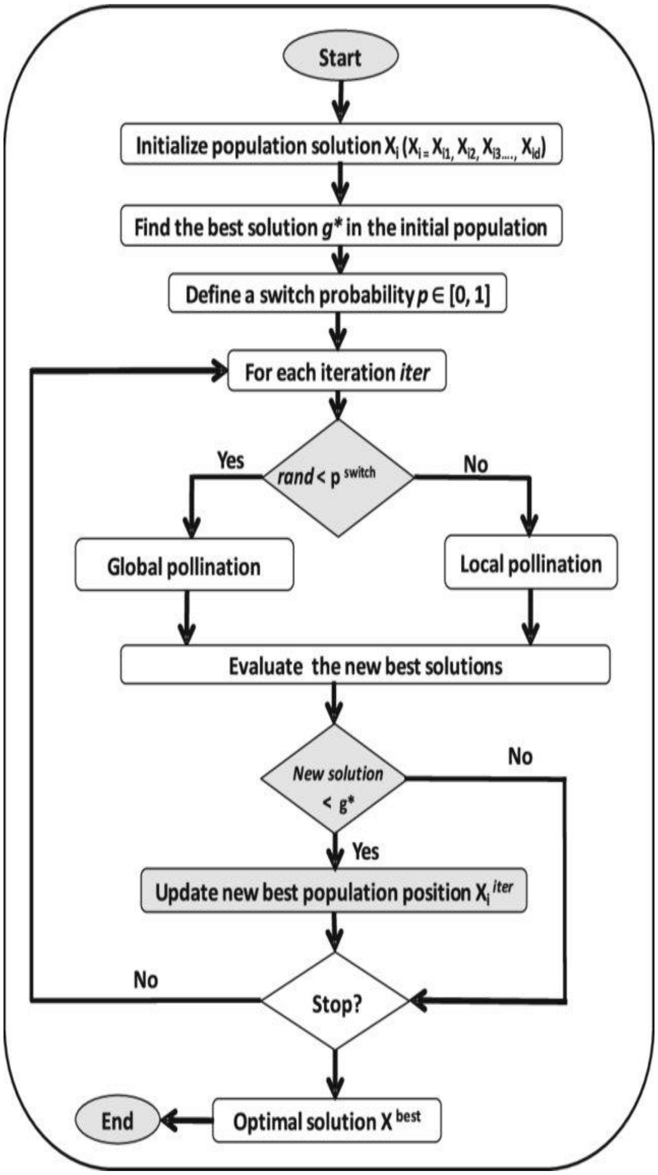


Fig. 3. Flowchart of the flower pollination algorithm [19]

Where S represents the step size and Γ(λ) represents gamma function (λ is set at 1.5, its range is 1-2). Further, the algorithm is triggered due to the change in weather, that is detected by observing the thresholds, set by the experimental trials performed in [19], for the change in voltage and current (dV and dI) shown in the Eq. 4, and Eq. 5 respectively. The thresholds vary with the size of the PV system. The value calculated by the hit and trial method for the change in voltage and current to detect the change in weather conditions are 0.2 V and 0.1amperes respectively.

$$dV = (Vpv(k) - Vpv(k-1))/Vpv(k) \geq 0.2 \qquad (4)$$

$$dI = (Ipv(k) - Ipv(k-1))/(Ipv(k)) \geq 0.1 \qquad (5)$$

Where, the Vpv(k), Vpv(k-1), Ipv(k), and Ipv(k-1) are the voltages and current of a PV array at the k^{th}, and preceding iteration respectively.

3. SWOT Analysis of the Flower Pollination Algorithm

After a deep study of the FPA algorithm, we have concluded that the strengths, weaknesses, opportunities, and threats of the FPA algorithm are as under.

Strengths

1. Fast-tracking speed
2. Able to differentiate among the LMPPs and GMPP
3. Novel concept of local and global pollination

Weaknesses

1. Huge computations
2. Needs huge memory
3. Complex structure

Opportunities

1. Novel concept of local and global pollination can be used more effectually to improve its performance.
2. Additional filters could be added to optimize the distribution of pollens at local and global positions.

Threat

The outstanding capabilities and strengths could be gone unused.

4. Problem Formulation

The FPA algorithm is an efficient technique with a brilliant concept of local and global pollination that makes it superior over other existing MPPT techniques. But, this strength of the FPA has been put at the back. However, the concept of pollination along with a levy flight could be optimized to build a more effective and efficient approach for the better utilization of the strengths of the FPA algorithm to achieve better results in terms of accuracy, efficiency, and tracking speed. The global pollination distributes the pollens at far locations to ensure the covering of maximum possible area, and the local pollination plays its role to cover all the peaks that could occur close to the global positions. This strategy has forced us to think for the opportunities lie in this amazing concept. Either, multiple techniques exist in parallel as a solution for the MPPT problem but this appeals the most. Keeping this in mind, we have proposed some structural changes in the FPA algorithm for the better utilization of its strengths and to avail the opportunities lies inside. The proposed structure is named the Modified FPA (MFPA) algorithm.

5. Modified Flower Pollination Algorithm

The ineffective use of the earlier mentioned strengths (local and global pollination), unnecessary computations, and the impulsive convergence of pollens adversely affects the ability of the FPA algorithm in MPPT of solar PV system. Therefore, this paper focuses on the structural modification of the FPA to achieve better results in minimum time.

In the proposed MFPA algorithm, each pollen experiences both the local and global pollinations to ensure proper distribution of pollens at the close and distant positions, which reduces the chance of losing GMPP. Afterward, the filtered set of pollens is routed to the probability switch strategy to attain the G_{best}. Unlike FPA the proposed MFPA is a single iteration algorithm. The flowchart of the proposed Modified FPA is shown in Fig. 4.

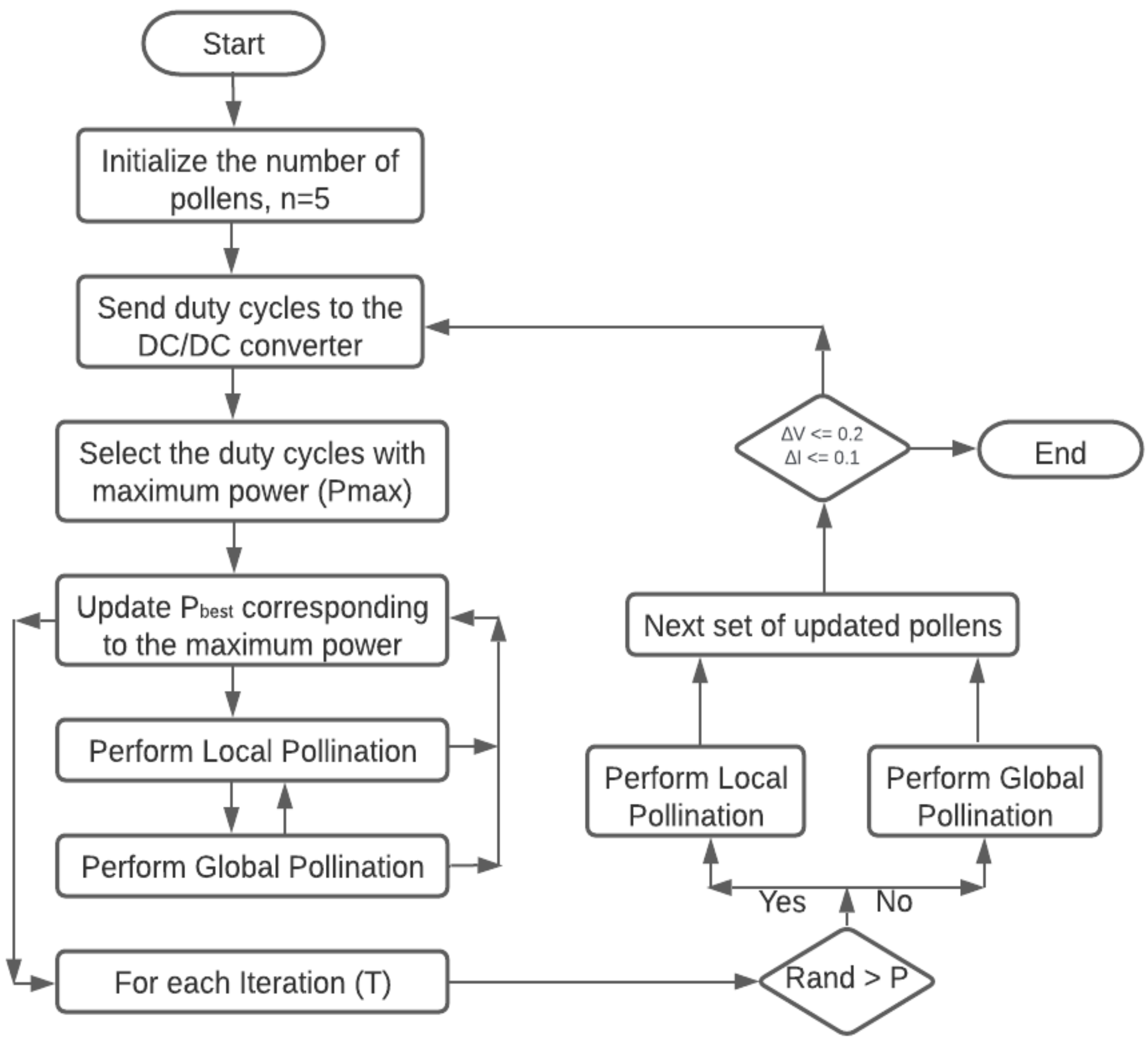


Fig. 4. Modified flower pollination algorithm

1. Initially a set of five randomly generated pollens are generated.
2. Then applied them one after another to the DC/DC converter.
3. Duty cycle with the maximum power is selected as the P_{best}.
4. Further avoiding the step of RAND vs P, the received set of pollens passes through the local pollination process to get the second P_{best}.

5. After the scanning of close sites, these pollens are then pushed to the global pollination process to attains various global positions and provide the third P_{best}.
6. This global search at local positions assures the effective global distribution. Further, to assure the effective scanning, a local pollination is applied at the received global pollens and get the fourth P_{best}.
7. Finally, the four received set of pollens experience a local or global pollination based on the comparison of RAND vs P to obtain the fifth P_{best}. But here P has no specific value, in fact it will attain a random value.
8. The G_{best} will then be extracted from a set of five received P_{best}.

This efficient distribution of pollens at the local and global positions in a single iteration provided remarkable results (discussed in the results section). Further, the MFPA algorithm utilizes the same equations (Eq. 4 and Eq. 5) of FPA algorithm for the detection of change in weather conditions.

6. Concepts of FPA and the MFPA Algorithms

Conceptual comparison of the FPA and MFPA algorithms is presented in the

Table 2, where it explains the inefficient utilization of local and global pollination by the FPA algorithm. A huge space of 80% is allocated to the local pollination and left 20% for the global pollination by setting P = 0.8. This imbalance in the pollination process effects the performance of the FPA algorithm. Effective utilization of the pollination process is assured in the proposed MFPA algorithm by balancing the contribution of local and global pollination. Moreover, the MFPA algorithm has saved a noticeable time in GMPP tracking by reducing the number of pollens from 125 to just 40 and limiting the number of iterations to one instead of 25.

Table 2

Logical comparison of FPA and the proposed MFPA algorithms

Benchmarks	FPA [19]	Modified FPA
Generated Pollens	125	40
Switching Probability (P)	0.8	Random
Pollens pass through Global Pollination	Probably 80%	Confirm = 5 Random (For last 20 pollens)
Pollens pass through Local Pollination	Probably 20%	Confirm = 10 Random (For last 20 pollens)

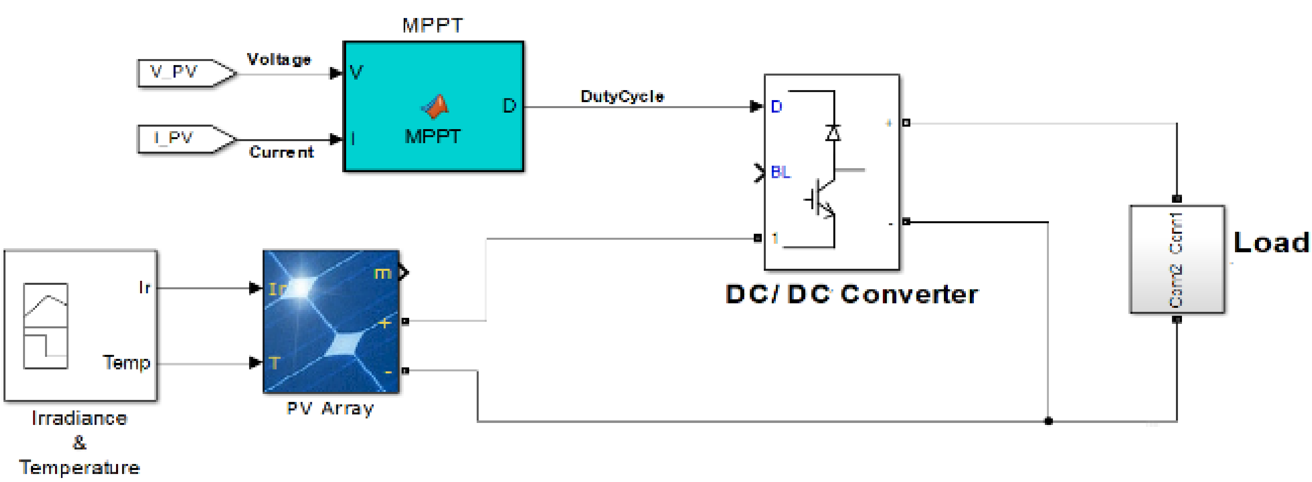


Fig. 5. Off-grid solar photovoltaic system.

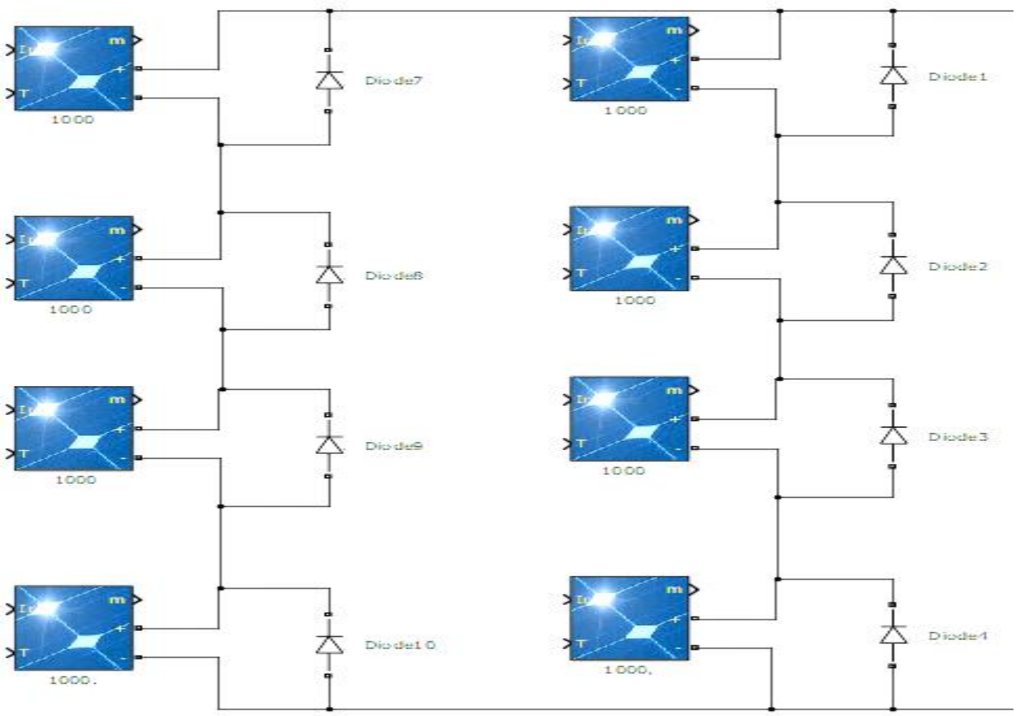


Fig. 6. A 4S2P solar photovoltaic test system

7. Simulation and Results

System specifications are 64-bit, core-i3-1.7 GHz, and 4-GB RAM. The FPA and the proposed MFPA algorithms are tested at an off-grid PV system, simulated in the Simulink as presented in Fig. 5. A PV string of two arrays four modules each (4S2P) is adopted as a trial system for the performance evaluation of FPA and the proposed MFPA algorithms as shown in Fig. 6. The three atmospheric conditions of zero, weak, and strong PSC are applied to the 4S2P PV test system as depicted in the Fig. 7.

7.1 Zero Shading Condition

In the case of zero or no shading, all the cells of 4S2P PV string are experiencing the uniform illumination, therefore just one MPP occurs in the P-V and voltage-current (V-I) characteristic curves of PV string, as shown in the Fig. 8. The MPP for the 4S2P PV test system occurs at 240 W as shown in the Fig. 8. The proposed MFPA algorithm has attained 239.9 W in 0.2578 s with 99.96% efficiency in a single iteration with just 40 pollens, whereas the FPA has extracted 238.3 W in 0.7552 s with an efficiency of 99.29% in 25 iterations with 125 pollens. The results presented in Fig. 9 have proved the dominance of the proposed MFPA algorithm over the FPA algorithm in the efficiency and tracking speed under UWC or zero shading conditions. The intelligent utilization of the concept of pollination applied in the proposed MFPA algorithm has proved its strength by achieving better efficiency in a single iteration with just 40 pollens in a time less than the FPA algorithm.

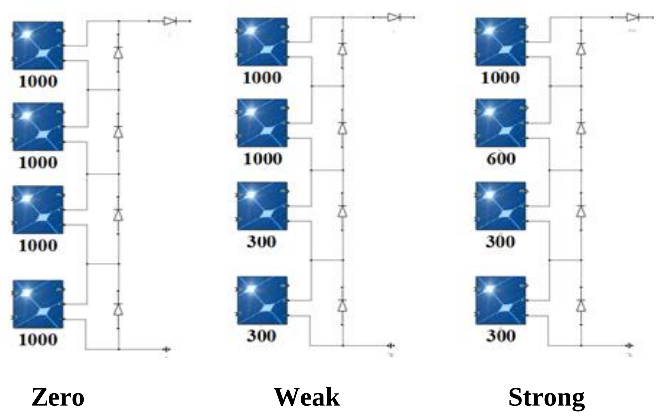


Fig. 7. An array of four modules with Zero, Weak, and Strong partial shading conditions

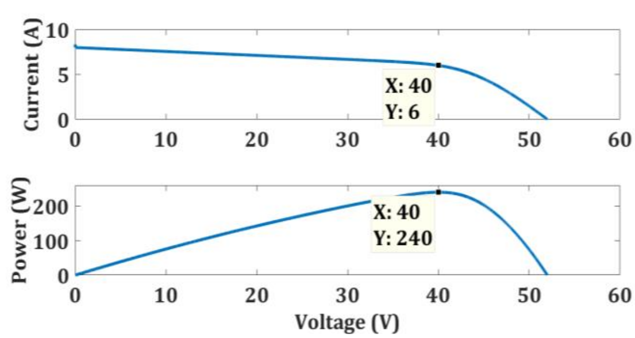
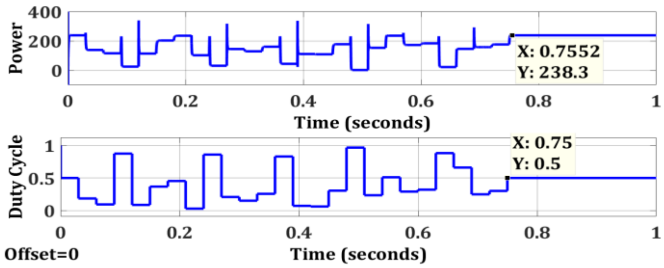


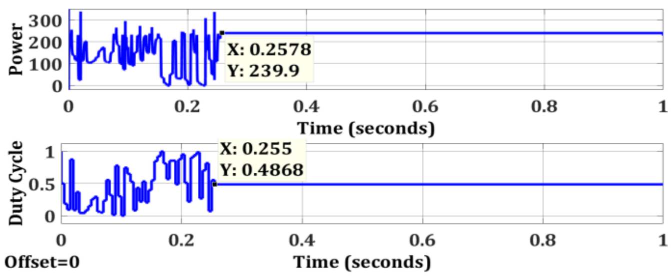
Fig. 8. Characteristic curves of a 4S2P PV string under Zero or Non-Shading

7.2 Weak Partial Shading

In the case of weak PSC, not all the cells of 4S2P PV array are receiving the same illumination level. Therefore, multiple LMPP appeared in the characteristic curves as displayed in the Fig. 10. These multiple peaks trouble the algorithms in identifying the global MPP (GMPP).



(a) FPA



(b) MFPA

Fig. 9. Performance Assessment of (a) FPA and (b) MFPA under Zero Shading/UWC

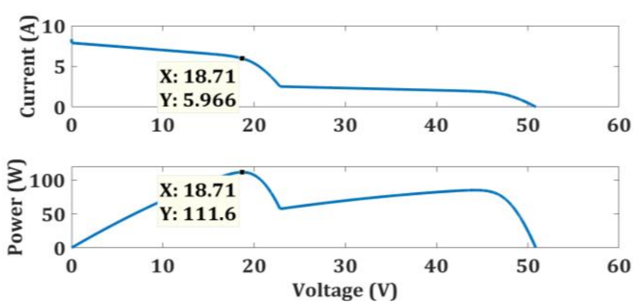
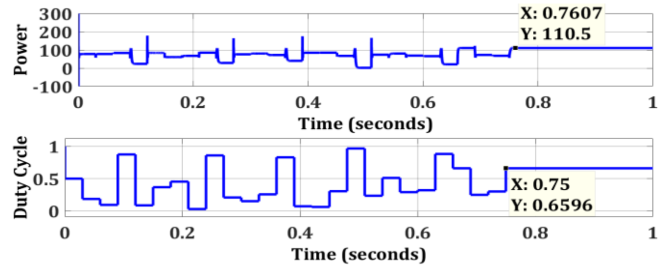
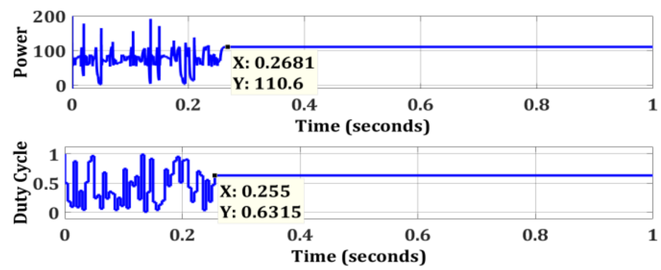


Fig. 10. Characteristic curves of a 4S2P PV array under weak PSC

The GMPP for the 4S2P PV test system under weak PSC occurs at 111.6 W as shown in the Fig. 10. The proposed MFPA has achieved 110.6 W in 0.2681 s with 99.10% efficiency in a single iteration with just 40 pollens, whereas the FPA has extracted 110.5 W in 0.7607 s with an efficiency of 99.01% in 25 iterations with 125 pollens. The results presented in **Error! Reference source not found.** have proved the dominance of the proposed MFPA over the FPA in efficiency and tracking speed. The intelligent utilization of the concept of pollination applied in the proposed MFPA algorithm has proved its strength by achieving better efficiency in a single iteration with just 40 pollens in time less than the FPA algorithm.



(a) FPA



(b) MFPA

Fig. 11. Performance assessment of (a) FPA and (b) MFPA under weak PSC

7.3 Strong Partial Shading

In the case of strong PSC, the illumination pattern of 4S2P PV array is worse than the weak PSC. Increase in the number of LMPPs complicate the characteristic curves and add to the hurdles of the MPPT algorithms as depicted in Fig. 11. The GMPP for the 4S2P PV test system under strong PSC occurs at 84.32 W as shown in the Fig. 11. The proposed MFPA algorithm has obtained 84.3 W in 0.2573 s with 99.98% efficiency in a single iteration with just 40 pollens, whereas the FPA has extracted 84.11 W in 0.7526 s with an efficiency of 99.75% in 25 iterations with 125 pollens. The results presented in Fig. 12 have proved the dominance of MFPA over the FPA in efficiency and tracking speed. The intelligent utilization of the concept of pollination applied in the proposed MFPA algorithm has proved its strength by achieving better efficiency in a single iteration with just 40 pollens in a time less than the FPA algorithm.

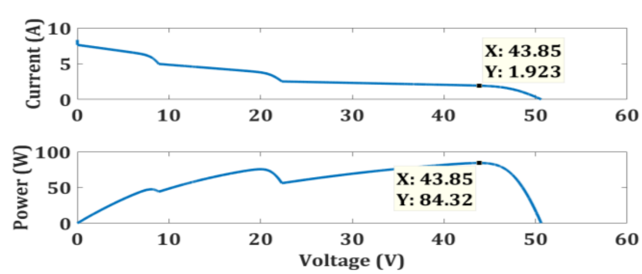
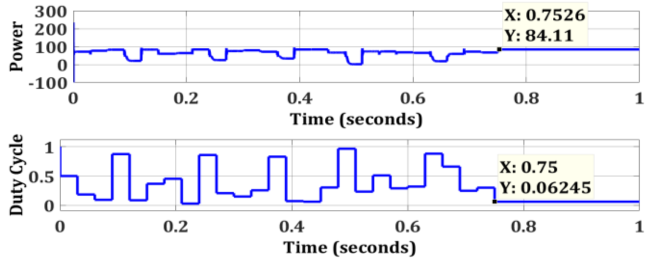
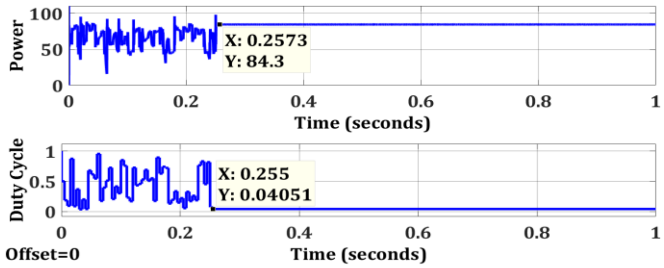


Fig. 11. Characteristic curves of a 4S2P PV array in strong partial shading condition



(a) FPA



(b) MFPA

Fig. 12. Performance comparison of (a) FPA and (b) MFPA under Strong PSC

7.4 Changing Weather Conditions:

The zero, weak, and strong PSCs are applied at the 4S2P PV array one after another to observe the performance of MFPA algorithm under continuously changing weather. The 4S2P PV test system experienced continuous transitions in illumination after each second. Starting from the zero on unshaded condition it turns to weak PSC after one second and further faced a strong PSC after another second. The proposed algorithm has successfully detected the change in weather and retained its performance as displayed in Fig. 13.

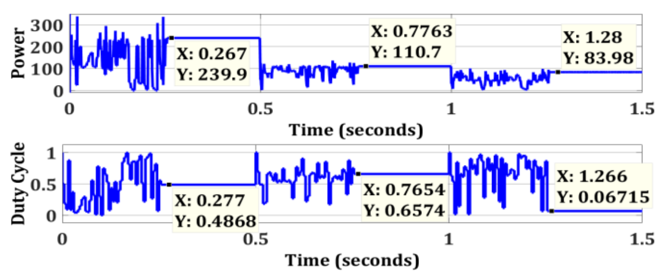


Fig. 13. Performance of MFPA under continuous changing weather

The performance of FPA and MFPA algorithms for the 4S2P PV system is summarized in the Table 3 for zero, weak, and strong PSC. The MFPA has outperformed the FPA algorithm in terms of efficiency and tracking speed under numerous weather conditions. Furthermore, an excellent improvement of 65.86% in tracking speed and 0.67% in efficiency is achieved. Finally, the standard benchmarks [22] used for the performance evaluation of the MFPA and FPA algorithms are presented in the Table 4.

Note: The intelligent utilization of the concept of pollination applied in the proposed MFPA algorithm has proved its strength by achieving better efficiency in a single iteration with just 40 pollens in time less than the FPA algorithm. A structural comparison of FPA and the proposed MFPA algorithm in number of iterations and pollens is presented in the

Table 2.

The benchmarks are used for analyzing the MPPT algorithms [22]. The comparison is based on these benchmarks is presented in Table 4. In addition to the mentioned standard benchmarks, several other important parameters are also included Table 4 for the performance and structural comparison of the proposed MFPA algorithm with the renowned MPPT algorithms.

The comparison has proved that the proposed MFPA algorithm has outperformed the renowned MPPT algorithms in tracking speed, efficiency, accuracy and GMPPT ability under PSC. Just proper handling of the concept of local and global pollination has improved the performance of the MFPA algorithm to a noticeable point.

8. Conclusion

Structural modifications have been proposed in the FPA algorithm. The proposed MFPA algorithm has improved the distribution strategy for the pollens at local and global positions. Initially it marks the local positions and run global search for each local position. Secondly after attaining the global positions, it conducts a local search around each global position to increase the probability of achieving the GMPP. The intelligent utilization of the concept of pollination applied in the proposed MFPA algorithm has proved its strength by achieving better efficiency in a single iteration with just 40 pollens in less time compared to the FPA algorithm. The proposed MFPA has demonstrated its dominance over the FPA under all shading and non-shading weather conditions in terms of efficiency and tracking speed.

9. Acknowledgment

I would like to thank my Family and Supervisor for their support and guidance.

Table 3

Performance Assessment of FPA and MFPA Algorithms

Cases	Algorithms	Power (W)	Rated Power (W)	Efficiency (%)	Efficiency Improvement (%)	Tracking Speed (s)	Improvement in Tracking Speed
Case-1	FPA	238.3	240	99.29	0.67	0.7526	0.4953 (s) 65.81 %
	MFPA	239.9		99.96		0.2573	
Case-2	FPA	110.5	111.6	99.01	0.09	0.7607	0.4926 (s) 64.76 %
	MFPA	110.6		99.10		0.2681	
Case-3	FPA	84.11	84.32	99.75	0.23	0.7552	0.4974 (s) 65.86 %
	MFPA	84.3		99.98		0.2578	

Table 4

Benchmarks Based Analysis of the Proposed MFPA algorithm

S. No.	Parameter	Fuzzy [21]	PSO [15]	FPA [19]	MFPA
1	Steady State Oscillations	Less	Zero	Zero	Nil
2	MPP Tracking	Average	Average	Quick	Faster
3	Complex	Highly	Yes	Less	Reasonable
4	Procedure	Complex	Moderate	Moderate	Reasonable
5	Memory Needed	High	Average	Average	Few
6	Computational Complexity	Large	Reasonable	Reasonable	Reasonable
7	GMPPT Under PSC	Efficiently	Efficiently	Efficiently	V. Good
8	Execution Time	Reasonable	Reasonable	Low	Low
9	PV Array Dependence	Yes	Nope	Nope	No
10	Steps	4	4	2	2
11	Parameters Tuning	Yes	Yes	Yes	No
12	Efficiency	Yes	Yes	Highly	Good
13	Simple and Short	No	No	No	No

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