Mehran University Research Journal of Engineering and Technology

https://doi.org/10.22581/muet1982.2204.12

2022, 41(4) 118-127

Adapted flower pollination algorithm for a standalone solar photovoltaic system

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Received: 05 October 2021, Accepted: 25 February 2022, Published: 01 October 2022

KEYWORDS

Solar Photovoltaic system

Maximum Power Point Tracking

Flower Pollination Algorithm

Random Walk

Partial shading

ABSTRACT

This Extraction of the maximum electrical power from a solar photovoltaic (PV) system under numerous weather conditions is required to reduce its payback time period, per unit energy price, and to compensate for the high initial price of the solar PV system. This could only be achieved by continuously operating the solar PV system at its maximum power point (MPP) under several weather conditions. Unlike under uniform weather conditions (UWC), identification of the real MPP (Global MPP) under partial shading condition (PSC) in a reasonable time is a challenging task due to the formation of multiple local MPP in the power-voltage (P-V) characteristic curve of a solar PV array. The nature-inspired MPP tracking algorithms have been proved suitable for global MPP tracking (MPPT) under PSC. In this research paper, a renowned nature-inspired flower pollination algorithm (FPA) is deeply reviewed, modified, and integrated with the random walk filter to improve its performance in terms of tracking speed, and efficiency. A comparison of the proposed ‘Adaptive Flower Pollination Algorithm (AFPA)’ and conventional FPA algorithm has been made under zero, weak, and strong PSCs for a 4S solar PV array. The proposed algorithm has produced remarkable results in tracking speed, and efficiency, for the global MPP (GMPP) tracking under different PSCs. The simulation is performed in MATLAB/Simulink software.

1. Introduction

The direct conversion of solar illumination into electrical energy using the photoelectric effect is the function of solar photovoltaic (PV) cells [1]. The output of a PV cell is directly proportional to solar illumination and inversely related to the atmospheric temperature [2]. It is the most attractive way to generate clean, cheap, and reliable electricity [3]. The PV cell has non-linear electrical characteristic curves, presented in Fig. 1 [4].

A point of operation in the characteristic curve, where a PV cell can deliver its maximum output power is called the MPP. The location of MPP varies with the level of illumination and temperature as shown in the Fig. 1. However, under PSC, multiple peaks occur in the characteristic curves of a PV array known as local MPPs (LMPPs) [5]. The LMPP with the maximum power is called the global MPP (GMPP) [5]. The characteristic curve of a solar PV array under PSC is depicted in the Fig. 2 [6].

Out of the three MPPs (A, B, and C) presented in the Fig. 2, ‘A’ is the GMPP, and ‘B’ and ‘C’ are the LMPPs. In order to extract the maximum power, from a solar PV system, it is mandatory to operate the PV system at its GMPP [7]. Therefore, the MPP trackers are employed to track the location of the MPP. These trackers are the electronic circuits, governed by a set of rules called MPPT algorithms [8]. An ideal MPPT algorithm should be able to accurately and efficiently track the MPP under numerous weather conditions [9].

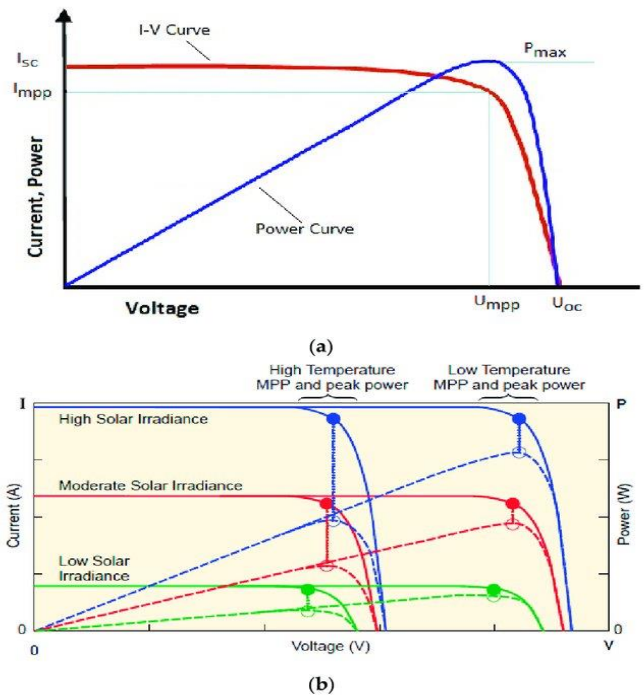


Fig. 1. Electrical characteristics of a solar photovoltaic cell [4]

Where P_{max} is Power at the MPP, I_{sc} is Short circuit current, I_{mpp} is Current at MPP, V_{oc} is Open circuit voltage, and V_{mpp} is Voltage at MPP.

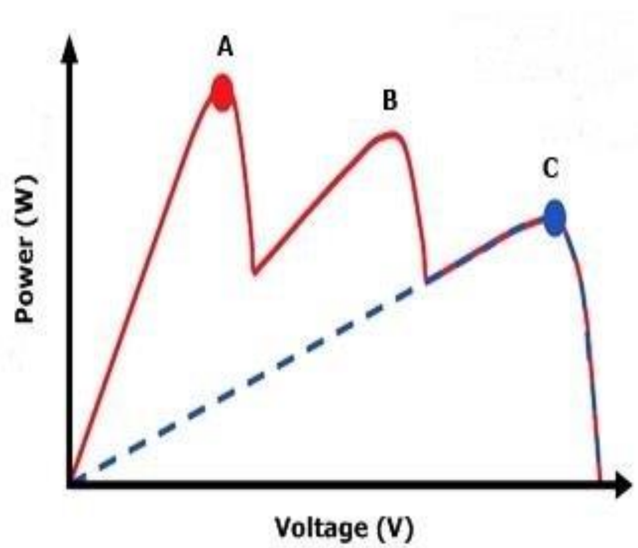


Fig. 2. Electrical characteristics of a solar photovoltaic cell under partial shading [6]

The existing MPPT algorithms can be categorized as follows.

1. The Conventional algorithm includes, Perturb and Observe [10], Incremental conductance [11], Hill climbing [12], Fractional short circuit [13], Fractional open circuit [14], etc. These are simple structured, easy and cheap to implement, but fails to track the GMPP under PSC, as get trapped by the nearest LMPP [15].
2. The Nature-inspired algorithms includes, Artificial bee colony [16], Ant colony optimization [17], Fuzzy logic control [18], Grey wolf optimization [19], Particle swarm optimization [20], Flower pollination algorithm [21], Fusion firefly [22], Butterfly optimization [23], and Slap swarm algorithm [24] etc. These are complex structured, hard and costly to implement, and perform better in tracking the GMPP under PSC [25].

After reviewing the strategy of nature inspired MPPT algorithms under PSC, it is realized that the FPA is the most opportunistic algorithm with a smart distribution strategy at the close and far positions. An intelligent utilization of the existing strengths of the FPA with additional filtration of random walk, could provide fantastic results for the MPPT of solar PV system. Keeping this as a target, an adaptive FPA algorithm has been proposed in this research paper.

The paper is further divided into sections as follows, section 2 explains the adaptive FPA, section 3 presents results and comparison, and also presents energy conservation and price, section 4 is conclusion, and section 5 is the references list.

2. Adaptive Flower Pollination Algorithm

The impulsive convergence adversely affects the ability of FPA to achieve the G_{best}. Therefore, the paper focuses on the development of an algorithm for the attainment of a better-quality solution compared to the FPA. The flowchart of the AFPA algorithm is presented in Fig. 3.

In the proposed AFPA, two additional filters namely 'random walk' and 'cross-pollinator' are applied on the set of pollens. These two initial filters take the set of pollens close to the G_{best}. Afterward, a filtered set of pollens is routed to the conventional FPA to attain the G_{best}. The proposed AFPA is a double iteration algorithm.

1. Initially a set of five randomly generated pollens are applied to the DC/DC converter.
2. Duty cycle with the maximum power is selected as the current best (C_{best}).
3. Further this set passes through a filter 'Random Walk' for the effective distribution at close and far

positions simultaneously and then applied to the DC/DC converter to get a second C_{best}.

4. The set received then experience a local Pollination to locate the GMPP around each random position and prove the third C_{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 fourth C_{best}.
6. This local search at random positions, and global search at local positions assures the effective distribution of pollens. Further, to assure the effective scanning, a local pollination is applied at the received global pollens and get the fifth C_{best}.
7. Finally, the five received set of pollens experience a local or global pollination based on the comparison of RAND vs P to obtain the fifth C_{best}. Here, Rand and P are the random numbers between 0 and 1.
8. The C_{best} with the maximum power is considered as GMPP.
9. Dimensions of flowers are then updated using the random walk to make them ready for use in case of change in weather. This would also help the proposed algorithm to reduce its tracking time for the next cycle.

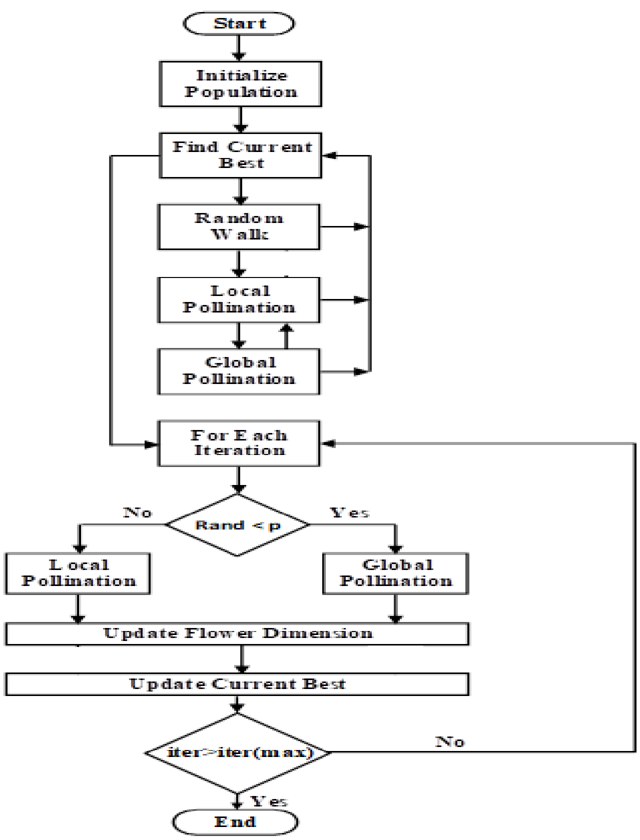


Fig. 3. Adaptive flower pollination algorithm

The filter of random walk is used once to provide a better start by distributing the randomly generated pollens at mixed positions (close and far). So, the pair of local and global pollinations could be applied at distinct locations, despitf just local pollination at global positions and vice versa. The mathematical expression of local pollination is as follows.

$$X_p^{k+1} = X_p^k + \alpha.\varepsilon.\left(X_i^k - X_m^k\right) \quad (1)$$

Where X_i^k and X_m^k represent two pollen '*I*' and '*m*' at iteration k from different flowers of the same class, and ϵ is a random number range 0 to 1.

The mathematical equation for global flight is given as under.

$$X_p^{k+1} = X_p^k + \alpha.L(\lambda).\left(P_{best} - X_p^k\right) \quad (2)$$

Where α is a scaling factor (with a fix value of 0.1) to control step size. The value of Levy flight step size $L(\lambda)$ is as follows.

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

Where S and $\Gamma(\lambda)$ are the step size and gamma function respectively. The value of λ is set at 1.5 (its range is 1 to 2). The random walk could be obtained as follows.

$$X_p^{k+1} = X_p^k + w_1.\alpha.L(\lambda).\left(g^* - X_p^k\right) + \gamma.\varepsilon.w_2.\left(X_l^m - X_m^k\right) \quad (4)$$

Where w_1 and w_2 are weights and are defined as follows.

$$w_1 = w_1^{max} - k.\frac{w_1^{max} - w_1^{min}}{k_{max}} \quad (5)$$

$$w_2 = \frac{min[F(k), F_{avg}]}{max[F(k), F_{avg}]} \quad (6)$$

Where w_1^{max} and w_1^{min} are the upper and lower bounds respectively, k_{max} represents the maximum number of iterations, $F(k)$ and F_{avg} are the fitness function at iteration k and average respectively, γ and ε are arbitrary scaling factors set at 0.1 and randomly between 0 and 1, respectively.

3. Results and Comparison

System specifications are 64-bit operating system, core-i3 processor 1.7 GHz, and 4.00 GB RAM. The FPA and the proposed AFPA are tested at a standalone solar PV system simulated in MATLAB/Simulink, displayed in Fig. 4.

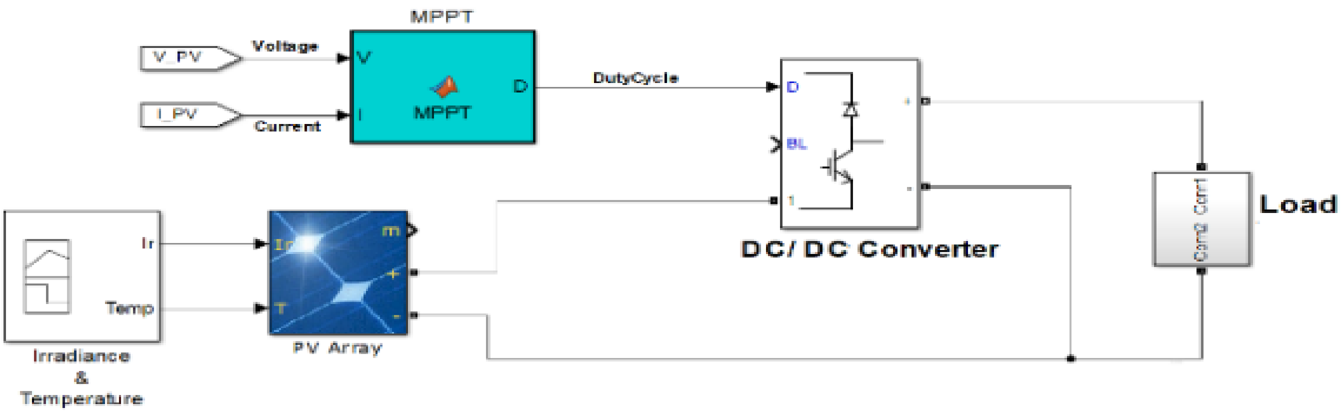
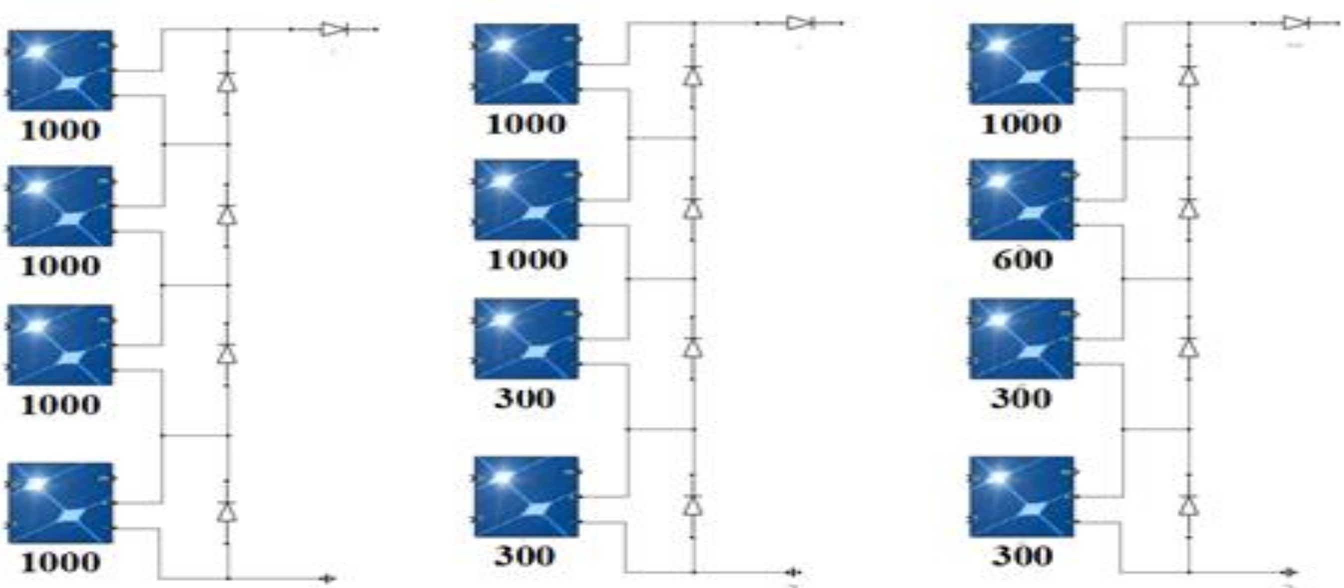


Fig. 4. Standalone solar photovoltaic system



Zero Weak Strong

Fig. 5. A 4S PV array with zero, weak, and strong partial shading conditions [3]

A PV array with four modules connected in series (4S) is taken as a test system for the performance evaluation of FPA and AFPA MPPT algorithms. The three atmospheric conditions of Zero, Weak, and Strong PSCs (depicted in Fig. 5) are applied at the 4S PV test system [3, 13]. Starting the analysis and comparison of FPA and the proposed AFPA algorithms from the zero shading, we will proceed to the weak and strong PSCs.

3.1 Zero/Uniform Shading Condition

In this case, all the modules of 4S PV array are receiving the same illumination level, therefore only one MPP occurs in the P-V curve. The P-V and I-V (current-voltage) characteristic curves of the 4S PV array for zero shading conditions are displayed in Fig. 6.

The MPP occurs at the 40 V, 3 A, and '120 W' in Fig. 6. The AFPA algorithm attained '119.3 W' in 0.2483-sec with 99.42% efficiency, whereas the FPA has extracted '119.2 W' in 0.7835 s with an efficiency of 99.33%. The results are presented in Fig. 7. Results have shown the superiority of AFPA over the FPA algorithm in the efficiency and tracking speed.

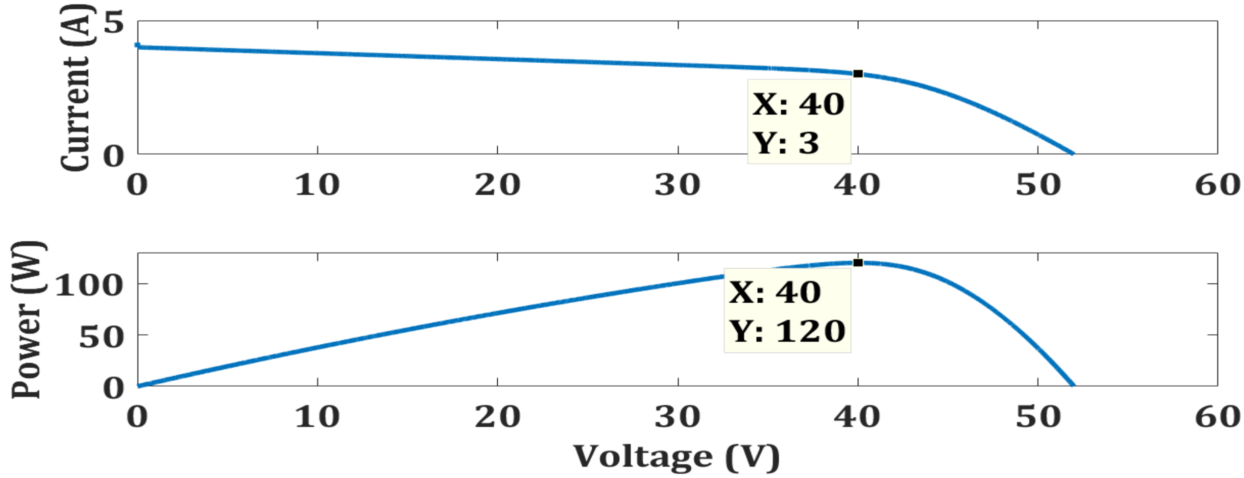
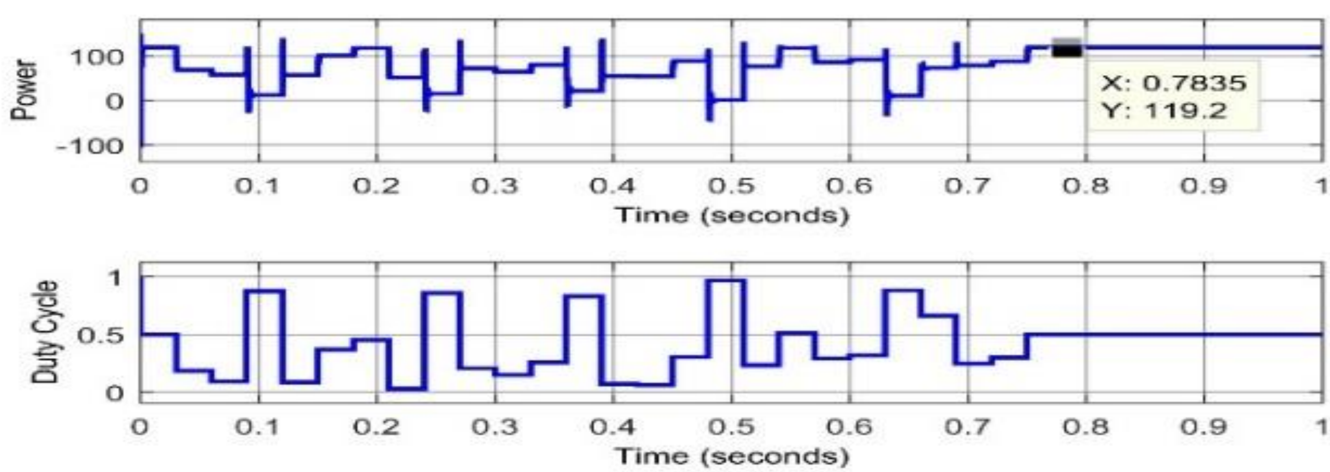
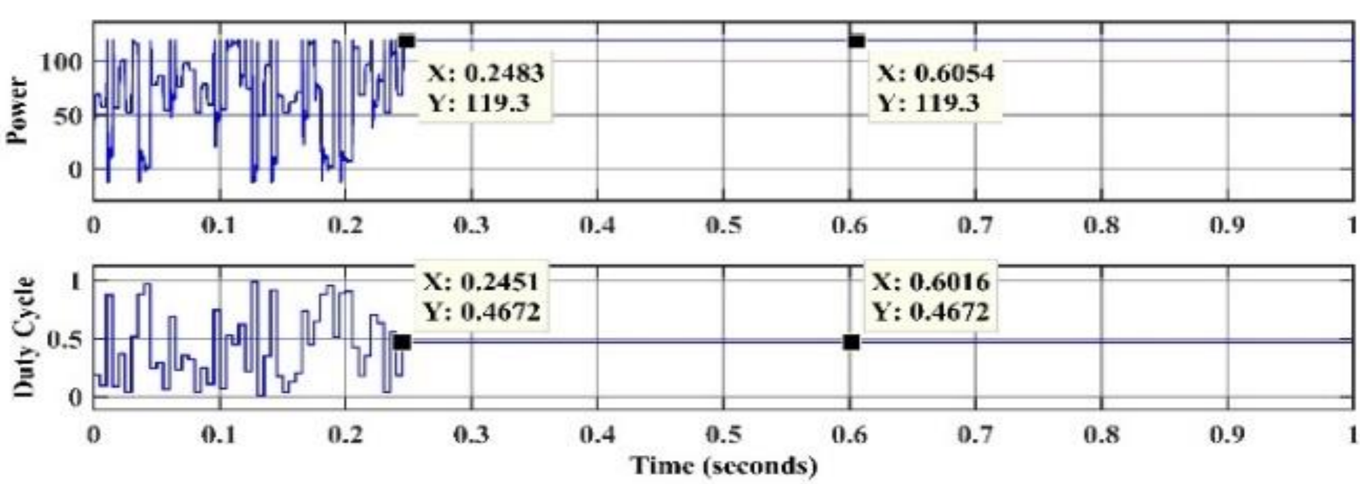


Fig. 6. I-V and P-V characteristic curves of a 4S PV array in zero shading condition



(a) FPA



(b) AFPA

Fig. 7. Performance Comparison of FPA and AFPA Algorithms for Zero Shading

3.2 Weak Partial Shading

In this case, the illumination level is not the same for all the PV modules of the 4S PV array. Multiple LMPPs appeared in the P-V curve of the 4S PV array. The characteristic curves of a PV array under weak PSC are displayed in Fig. 8.

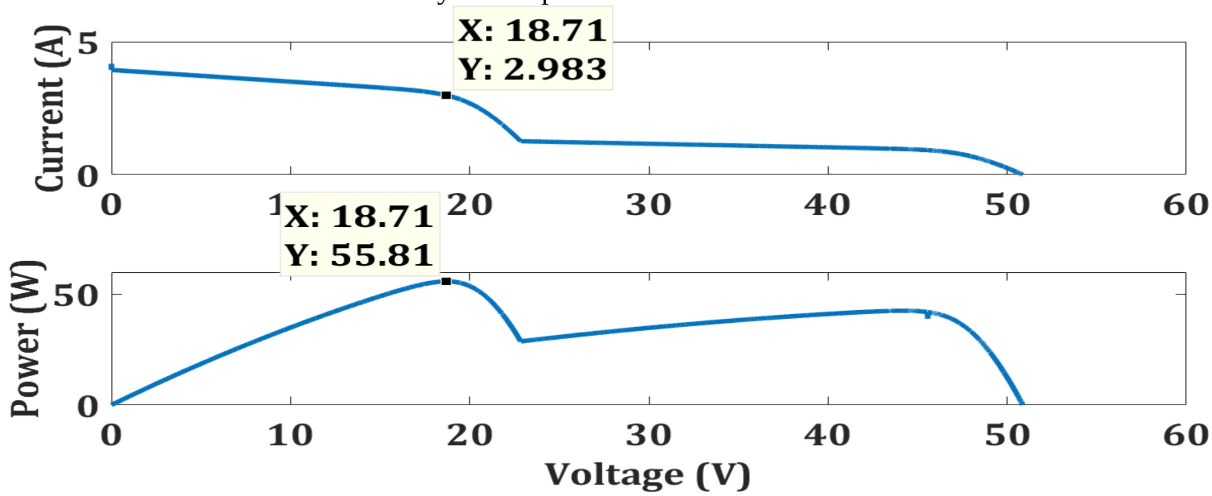
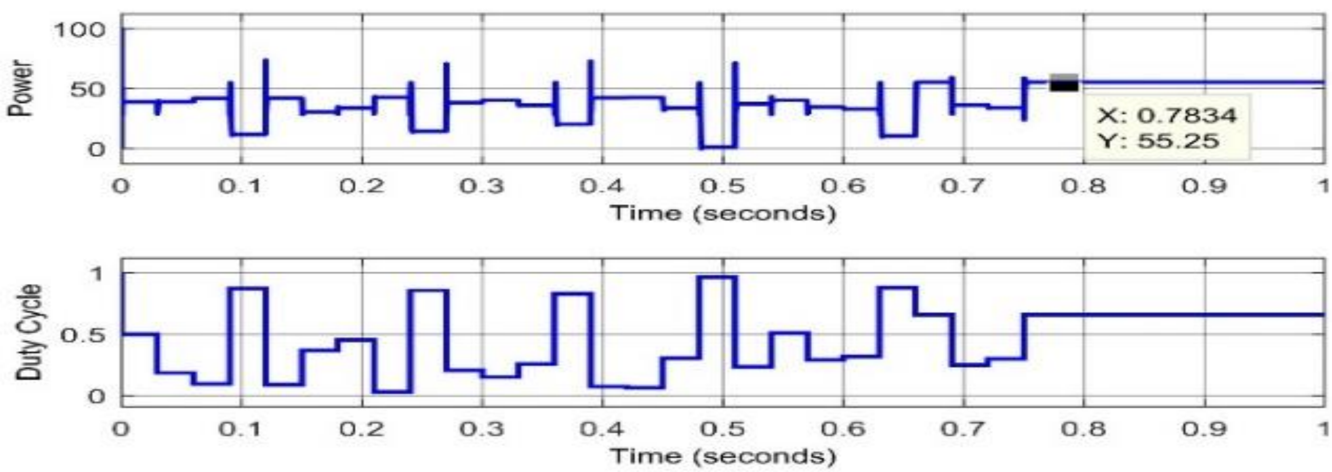
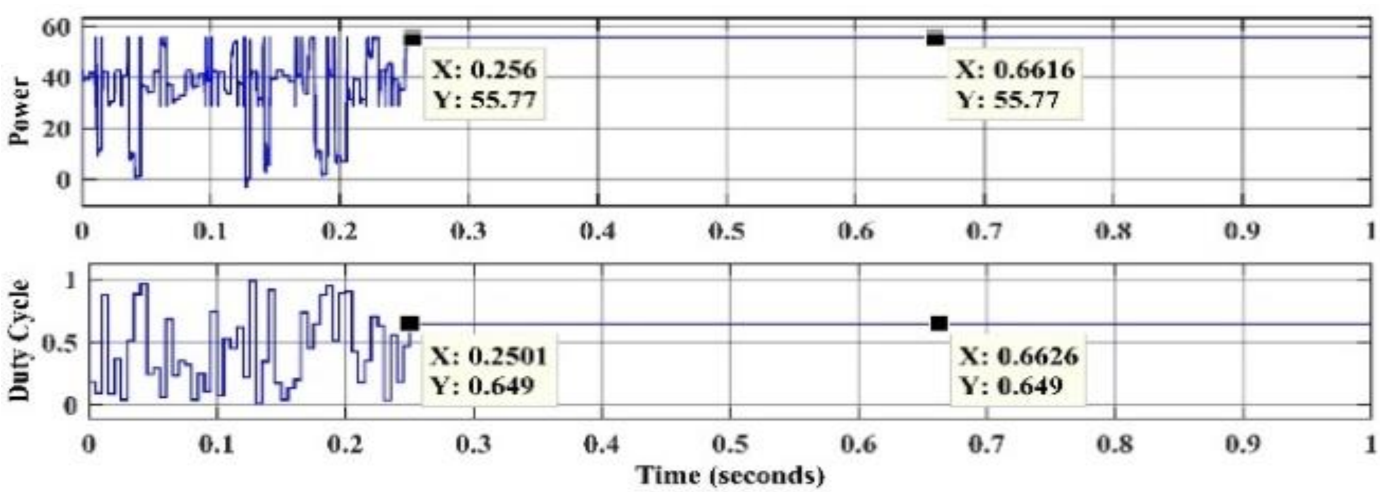


Fig. 8. Characteristic curves of a 4S PV array in weak partial shading condition



(a) FPA



(b) AFPA

Fig. 9. Performance Comparison of FPA and AFPA in Weak Partial Shading

The MPP occurs at 18.71 V, 3 A, and '55.81 W' in Fig. 8. The AFPA has achieved '55.77 W' in 0.256 s with 99.93% efficiency, whereas the FPA has extracted '55.25 W' in 0.7834 s with an efficiency of 98.99%. The results are presented in Fig. 9. Results have shown the superiority of AFPA over the FPA in the efficiency and tracking speed.

3.3 Strong Partial Shading

In this case, the illumination pattern is worse and the number the LMPP increased compare to the weak PSC. Both FPA and AFPA are applied. The characteristic curves of a PV array under strong PSC are displayed in Fig. 10.

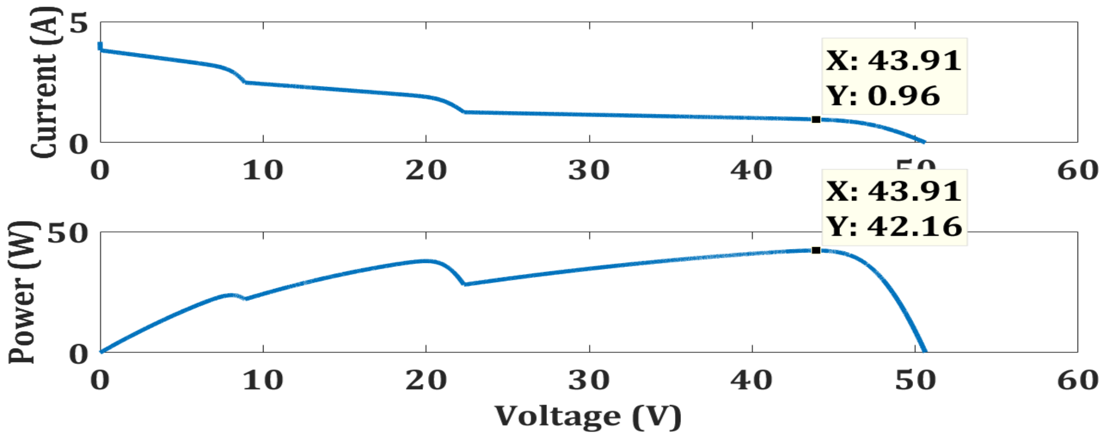
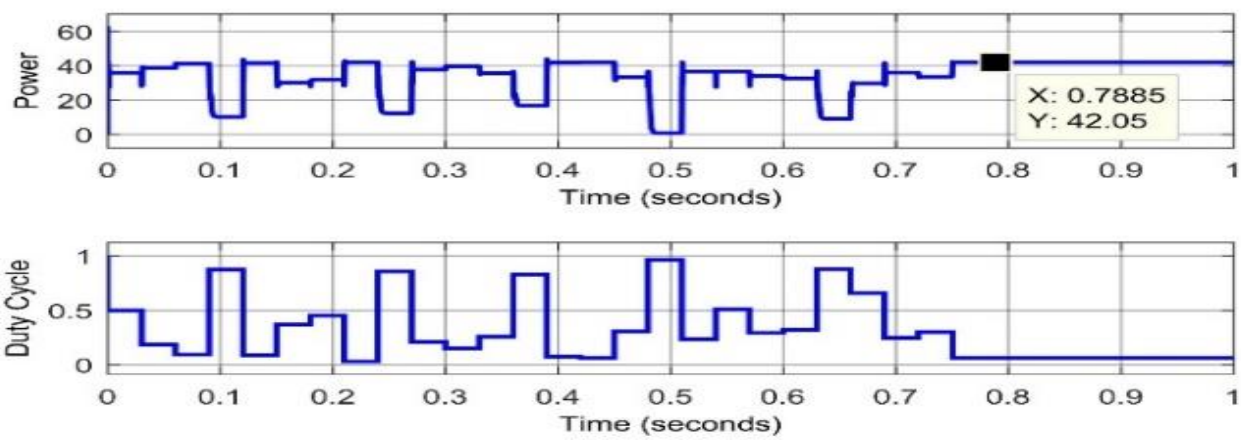
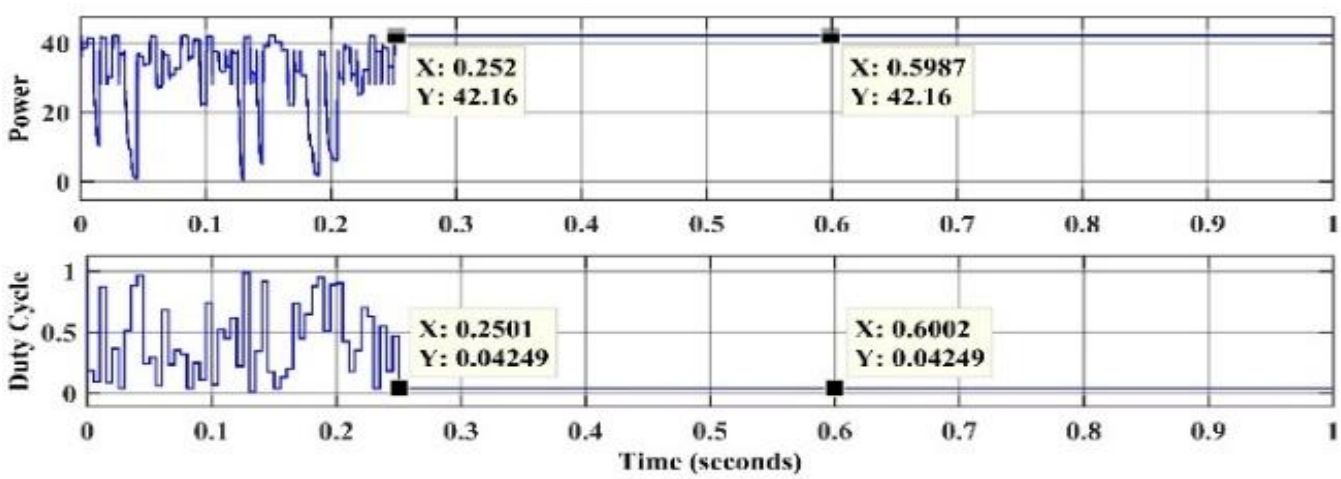


Fig. 10. Characteristic curves of a 4S PV array in strong partial shading condition



(a) FPA



b) AFPA

Fig. 11. Performance Comparison of FPA and AFPA in Strong Partial Shading

The MPP occurs at 43.91-Volts, 0.96-Amperes, and '42.16 W' in Fig. 10. The AFPA algorithm has obtained '42.16 W' in 0.252 s with 100% efficiency, whereas the FPA has extracted '42.05 W' in 0.7885 s with an efficiency of 99.74%. The results are presented in Fig. 11. Results have shown the superiority of AFPA over the FPA in the efficiency and tracking speed.

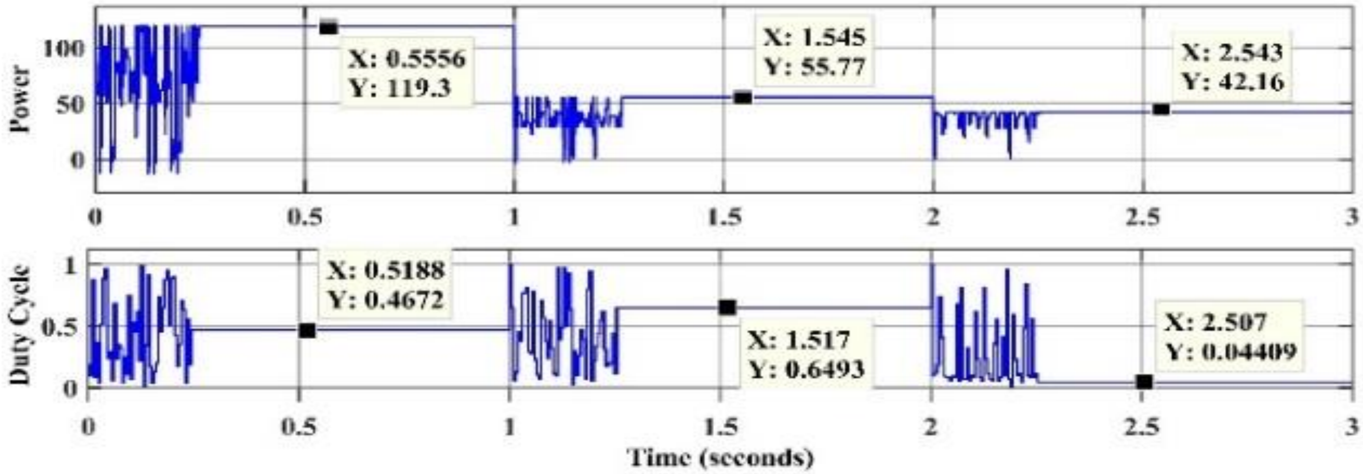


Fig. 12. Performance of AFPA under continuous changing weather

Continuous changing weather condition is applied to the test system of the 4S PV array and the performance of FPA and AFPA is observed. The result is displayed in Fig. 12. The proposed AFPA has retained its performance under continuous changing weather conditions. Additionally, the AFPA has successfully detected the change in weather conditions. Performance comparison of FPA and AFPA for the 4S PV system under zero, weak, and strong PSC are summarized in Table-1. The AFPA has outperformed the FPA inefficiency and tracking speed under various weather conditions. Moreover, an excellent improvement of almost 32% is achieved in tracking speed.

Table 1

Performance Comparison of AFPA and FPA Algorithms

Case	Algorithms	Power (W)	Rated Power (W)	Efficiency (%)	Enhancement in Efficiency (%)	Tracking Speed (sec)	Improvement in Tracking Speed
1	FPA	119.2	120	99.33	0.09	0.7835	0.5352 s (31.70%)
	AFPA	119.3		99.42		0.2483	
2	FPA	55.25	55.81	99.00	0.93	0.7834	0.5274 s (32.68%)
	AFPA	55.77		99.93		0.256	
3	FPA	42.05	42.16	99.74	0.26	0.7885	0.5365 s (32.00%)
	AFPA	42.16		100		0.252	

4. Energy Conservation and Price

Average peak hours of the city Multan of Pakistan have been taken for analysis from [15]. Energy generated by each algorithm per year is calculated using peak hours and mentioned in column 5 of Table 2. Surplus energy generated by AFPA compared to the FPA is mentioned as 'Energy Conservation using AFPA' in column 6 of Table 2. The price per unit of energy (unit = KWh = 18.65 PKR) is the current rate of Govt. of Pakistan. Calculating the price of conserved energy (mentioned in column 6), it is found that the AFPA could save millions of Rupees compared to the FPA algorithm, especially under weak partial shading conditions The efficiencies achieved by the FPA and AFPA algorithms under zero, weak, and strong PSCs for the 120W PV system are assumed the same for a PV system of 120 MW. Results summarized in Table 2 have shown that the proposed AFPA has outperformed the FPA in energy conservation, per unit energy price, and the payback time.

Table 2

Energy Conservation and Price Analysis for FPA and AFPA Algorithms

Case	Algorithms	Power (MW)	Avg. Peak Hours / Day [15]	Generation / Year (MWh)	Energy Conservation using AFPA (MWh)	Price / Unit (Rs.)	Saving (Million Rs.)
1	FPA	119.2	5.430	236248.440	198.195	18.65	3.696336
	AFPA	119.3		236446.635			
2	FPA	55.25		109502.7375	1030.614		19.220951
	AFPA	55.77		110533.3515			
3	FPA	42.05		83340.9975	218.0145		4.065970
	AFPA	42.16		83559.012			

5. Conclusion

In this research paper, a modified FPA have been proposed. The proposed AFPA has improved the distribution strategy for pollens at local and global positions. It marks the local and global positions initially, then performs a local search at global positions and global search at local positions to increase the probability of achieving GMPP with high efficiency and in less time comparing to the FPA. Further an additional filtration of the processed solutions is carried out through random walk. The proposed AFPA has proved its superiority over the FPA under zero, weak, and strong PSCs. Moreover, the AFPA is proved favorite when compared with the FPA for energy conservation, per unit energy price, and payback time.

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