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Ordering Technique for the Maximum Power Point Tracking of an Islanded Solar Photovoltaic System

Muhammad Mateen Afzal Awan [1], Aamer Bilal Asghar [2,*], Muhammad Yaqoob Javed [2] and Zsolt Conka [3,*]

1 Department of Electrical Engineering, University of Management and Technology Lahore, Sialkot 51310, Punjab, Pakistan
2 Department of Electrical and Computer Engineering, COMSATS University Islamabad, Lahore 54000, Punjab, Pakistan
3 Faculty of Electrical Engineering and Informatics, Department of Electric Power Engineering, Technical University of Kosice, 040 01 Kosice, Slovakia
* Correspondence: aamerbilal@cuilahore.edu.pk (A.B.A.); zsolt.conka@tuke.sk (Z.C.)

Abstract: The world's attention has turned towards renewable energy due to escalating energy demands, declining fossil fuel reservoirs, greenhouse gas emissions, and the unreliability of conventional energy systems. The sun is the only renewable energy source that is available every day for a specific period of time. Solar photovoltaic (PV) technology is known for its direct conversion of sunlight into electricity using the photoelectric effect. However, due to the non-linear electrical characteristics, the power output of solar PV cells is bound to a lower value and can not produce the power of which it is capable. To extract the maximum possible power, the PV cell needs to be operated at its maximum power point (MPP) uninterruptedly under numerous weather conditions. Therefore, an electronic circuit driven by a set of rules known as an algorithm is utilized. To date, the flower pollination algorithm (FPA) is one of the most renowned maximum power point tracking (MPPT) algorithms due to its effective tracking ability at the local and global positions. After an in-depth analysis of the design, strengths, weaknesses, and opportunities of the FPA algorithm, we have proposed an additional filtration and distribution process named "Random walk" along with the ordering of solutions, to improve its efficiency and tracking time. The proposed structure named "Ordered FPA" has outperformed the renowned FPA algorithm under various weather conditions at all the standard benchmarks. Simulations are performed in MATLAB/Simulink.

Keywords: maximum power point tracking; algorithms for MPPT; partial shading condition; solar photovoltaic; flower pollination algorithm

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1. Introduction

The redirection of research from conventional energy resources to renewable energy resources is due to the depletion of fossil fuels, soaring oil prices, growing energy prices, hazardous greenhouse gases emissions, and unreliability of the conventional energy generation sources [1]. However, "unreliability" and "expensive" is a matter of perspective. In areas with reliable power grids, photovoltaics are considered unreliable due to weather conditions. In areas, where an off-grid system is a must, the PV panels are more reliable and cheaper than conventional power sources. Among renewable and sustainable energy resources, the sun is the most reliable renewable energy source due to its availability all around the globe [2]. Utilization of the energy of the sun is possible through solar thermal and solar photovoltaic technologies. Solar thermal converts the heat energy from the sun into different forms of energy for attaining different purposes like heating water for domestic usage and heating oil to run sterling engines to create electricity, etc. [3]. Whereas solar photovoltaic (PV) technology directly converts sunlight into electrical energy using the photoelectric effect, which makes it the most attractive and simple energy generation technology [4,5]. Solar PV has hot research gaps to fill that include, PV cells' material efficiency, maximum power point tracking efficiency, and speed. Due to the non-linear electrical characteristics of a solar PV cell, it could not produce its maximum power until operated at its MPP [6]. To track the MPP, the electronic circuit directed by a set of rules known as an algorithm is utilized [7]. The MPPT algorithms can be categorized into the following two categories. (1) Conventional algorithms, are simple in structure and easy to implement but could not perform effectively under partial shading conditions (PSC) due to the formation of multiple peaks (multiple peaks are called local MPP, and the local MPP with the highest power is called global MPP) in the characteristic curve of a solar PV cell [8,9]. The basic tracking strategy of conventional algorithms is the calculation of power at the current operating point and then starts moving towards the MPP with multiple strategies and speed in a series of steps. This movement of operating points as a series of steps is the weakness of the conventional MPPT algorithm that forces them to imagine the first attended peak as the real MPP under PSC. Conventional MPPT algorithms include Perturb and Observe [10], Hill Climbing [11,12], Fractional Short Circuit [13], and Fractional Open Circuit [14]. The strengths of conventional algorithms are their simple structure, ease to code, and cheap implementation, whereas the drawbacks associated with conventional algorithms are steady-state oscillations, slow tracking speed, and poor performance under partial shading. Multiple improvements have been introduced so far in the conventional MPPT algorithms to overcome their weaknesses and some are as follows: The researcher in [15] has boosted the tracking speed of the P&O algorithm by initiating a reverse strategy and starting the tracking process from the open circuit side due to its closeness to the MPP. Another researcher in [16] has reduced the steady-state oscillation to zero by fixing the duty cycle after reducing it multiple times around the MPP. Further, the scientist in [17] has optimized the tracking speed of the hill climbing algorithm by using a PI controller and also reduced the steady-state oscillations.

Whereas, (2) Nature-inspired algorithms, are developed by observing the behavior of nature, insects, trees, etc. These algorithms possess the ability to track the MPP under numerous weather conditions due to the concept of randomization. The generation and distribution of solutions at the close and far positions help the nature-inspired MPPT algorithm to differentiate among the local and global MPPs under PSC. However, the weaknesses associated with nature-inspired algorithms are structural and procedural complexities, huge computations and memory requirements, being expensive and difficult to implement, and low convergence speed. The nature-inspired algorithms include Artificial Neural Network [18], Fuzzy Logic [19], Genetic Algorithm [20], Particle Swarm Optimization [21], Differential Evolution [22], Artificial Bee Colony [23], and Flower Pollination Algorithm (FPA) [24]. Several modifications have been introduced in the nature-inspired algorithm to optimize their tracking time and efficiency. A researcher in [25] has optimized the MPPT accuracy of the Particle Swarm Optimization algorithm by integrating it with the Perturb and Observe Conventional algorithm. Basically, the researcher has utilized the Particle Swarm Optimization algorithm for MPPT under PSC and further refines its accuracy by confirming the closest peaks using Perturb and Observe Conventional algorithms. Another scientist has reduced the tracking time of the FPA algorithm in [26] by introducing an efficient utilization of the concepts of local and global pollination for MPPT under PSC. After a deep literature review, we have selected the FPA algorithm based on its strengths and design to improve its performance. The FPA is the only nature-inspired algorithm that can efficiently track the MPP at the local and global positions using the mathematics of pollens [24].

The research article is ordered as follows: Section 2 describes the mathematical modeling of PV cell, Section 3 presents the conventional FPA, Section 4 is the problem formulation, Section 5 explains the proposed techniques, Section 6 presents the simulation and results, Section 7 is the discussion, Section 8 is the conclusion, and Section 9 presents references.

2. Modeling of Solar Photovoltaic Cell

The mathematical model of a PV cell is required to predict the behavior of solar PV cell/module/array under varying environmental conditions. Mathematical modeling of a PV cell is an ongoing area of research, where the researchers have developed multiple models (single diode, double diode, and triple diode). One, two, and three diode models have been designed so far but the most used model of PV cell is the single diode due to its simplicity [25]. However, the double-diode triple diode models of PV cell are more accurate compared to the single-diode model, but the difference in accuracy is quite small. The basic model of a PV cell is displayed in Figure 1.

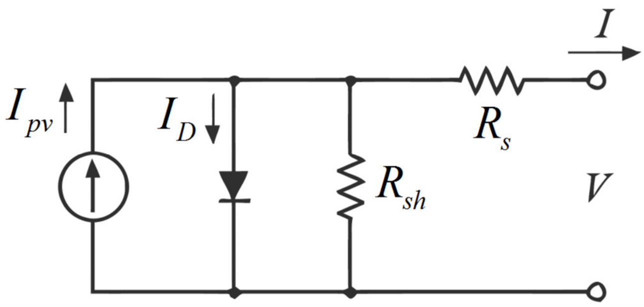


Figure 1. One Diode Model of PV cell [24].

After solving the circuit at Figure 1, the PV output current is:

$$I = I_{PV} - I_D - \frac{V + I_{RS}}{R_{Sh}} \tag{1}$$

where,

I_{PV} = current of PV cell.
I_D = diode current
R_S = resistance in series
R_{Sh} = parallel resistance

$$I_D = I_o \times \left[\exp\left({V_D}/{(\alpha \times V_T)}\right) - 1\right] \tag{2}$$

V_D = diode voltage
I_o = reverse saturation current
V_T = thermal voltage
α = diode ideality factor

3. Flower Pollination Algorithm

The FPA algorithm produces five random numbers and selects the best one as P_{best} after observing the output power against each one. Afterward, the produced pollens experience local or global pollination depending on the outcome of the comparison of a random number with probability switch "P" (P = 0.8, but can be varied) for each pollen and then sent to the converter to get a second P_{best}. Equations for the local and global pollinations are presented nn Equations (3) and (4), respectively. Where "X_i^t", "X_j^t", and "X_k^t" represent different pollens in iteration "t", and the "ε" (epsilon) denotes the local search $\varepsilon \in [0, 1]$. Whereas, "L and λ" are the levy factor and standard gamma function). Repetition of the second iteration was conducted to complete the set of 25 $P_{best.}$ P_{best} with the highest power is selected as a Global Best "G_{best}". A flowchart of the FPA algorithm is displayed in Figure 2.

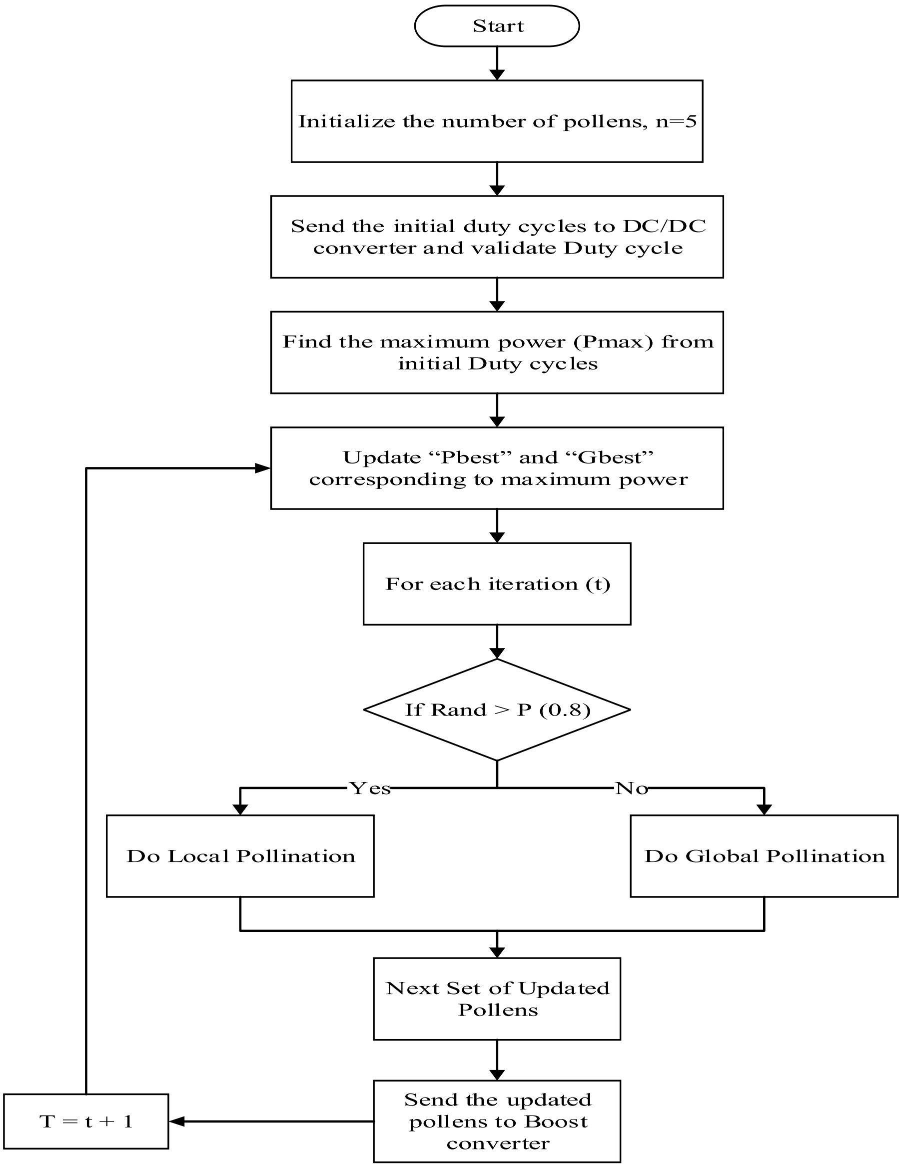


Figure 2. Flowchart of FPA Algorithm [24].

To detect the change in weather, threshold values for the change in voltage (d_V) and current (d_I), use the hit and trial method as shown in Equations (5) and (6). Where, I_{PV} and V_{PV} represent the current and voltage of the solar PV array, and k represents the iteration number.

$$X_i^{t+1} = X_i^t + \varepsilon\left(X_k^t - X_j^t\right) \tag{3}$$

$$X_i^{t+1} = X_i^t + \gamma L(\lambda)\left(G_{best} - X_j^t\right) \tag{4}$$

$$d_V = \frac{V_P(k) - V_P(k-1)}{V_P(k)} \geq 0.2 \tag{5}$$

$$d_I = \frac{I_{PV}(k) - I_{PV}(k-1)}{I_{PV}(k)} \geq 0.1 \tag{6}$$

4. Problem Formulation

Flower pollination is a renowned nature-inspired algorithm. It has produced amazing results for the MPPT of solar PV systems. The random pollens generated by the FPA create spikes and increase the settling time for each pollen. Consequently, the time interval of 0.3 s between the consecutive pollens is required to settle the power waveform in order to record the correct value for the given input. Reducing this settling time would reduce the tracking time, and further effective filtration of pollens at the close and far positions will increase the MPPT efficiency of the FPA algorithm. To achieve these targets, the additional filtration and ordering of pollens is introduced and implemented in this paper along with some structural modifications.

5. Proposed Data Arrangement Technique

In the proposed data arrangement technique, the production of the first set of random solutions will take place in the limit 0–1. However, despite processing the pollens to the DC/DC converter of the PV system, they have been passed through the local or global pollination process decided by the probability switch comparison with the random number "Rand > P" to receive the second set of solutions. The probability switch "P" will gain a random value between 0 and 1 to enhance the effectiveness of the distribution. Further, an additional filter named "Random Walk" is applied to optimize the distribution of pollens at the close and far positions using Equation (7). These pollens were then injected to repeat the process to complete the five iterations (t). At the completion of the fifth iteration (T), a solution set of 50 pollens will be received. Arrangement of the received set of 50 solutions in descending order will take place in the ordering section to reduce the settling time of the PV system. Further, the arranged set of solutions will be applied to the DC/DC converter. The solution with the maximum output would be selected as the global maximum power point (GMPP).

The random walk filter improves the distribution of pollens in the local and global areas, and the arrangement of solutions will reduce the gap between consecutive solutions which in turn reduces the large peaks and settling time. Further, the necessity of large time slots between consecutive solutions is no longer required. This is how the proposed order arrangement technique reduces tracking time, and increases the tracking speed and efficiency. The flowchart of the proposed technique is presented in Figure 3.

$$X_p^{k+1} = X_p^k + w_1 \cdot \alpha \cdot L(\lambda) \cdot \left(g^* - X_p^k\right) + \gamma \cdot \varepsilon \cdot w_2 \cdot \left(X_l^m - X_m^k\right) \tag{7}$$

where w_1 and w_2 are weights and are defined as:

$$w_1 = w_1^{max} - k \cdot \frac{w_1^{max} - w_1^{min}}{k_{max}} \tag{8}$$

$$w_2 = \frac{\min\left[F(k), F_{avg}\right]}{\max\left[F(k), F_{avg}\right]} \tag{9}$$

where, α is the scaling factor to control step size, 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.

In summary, the proposed algorithm observes the current state of the solar PV system (amperes, voltage, and power) and initiates an MPP tracking process. Afterward, it applies multiple solutions to the system and records the system's response for each solution. After observing the response of the system, the algorithm picks the best solution and applies it to the system.

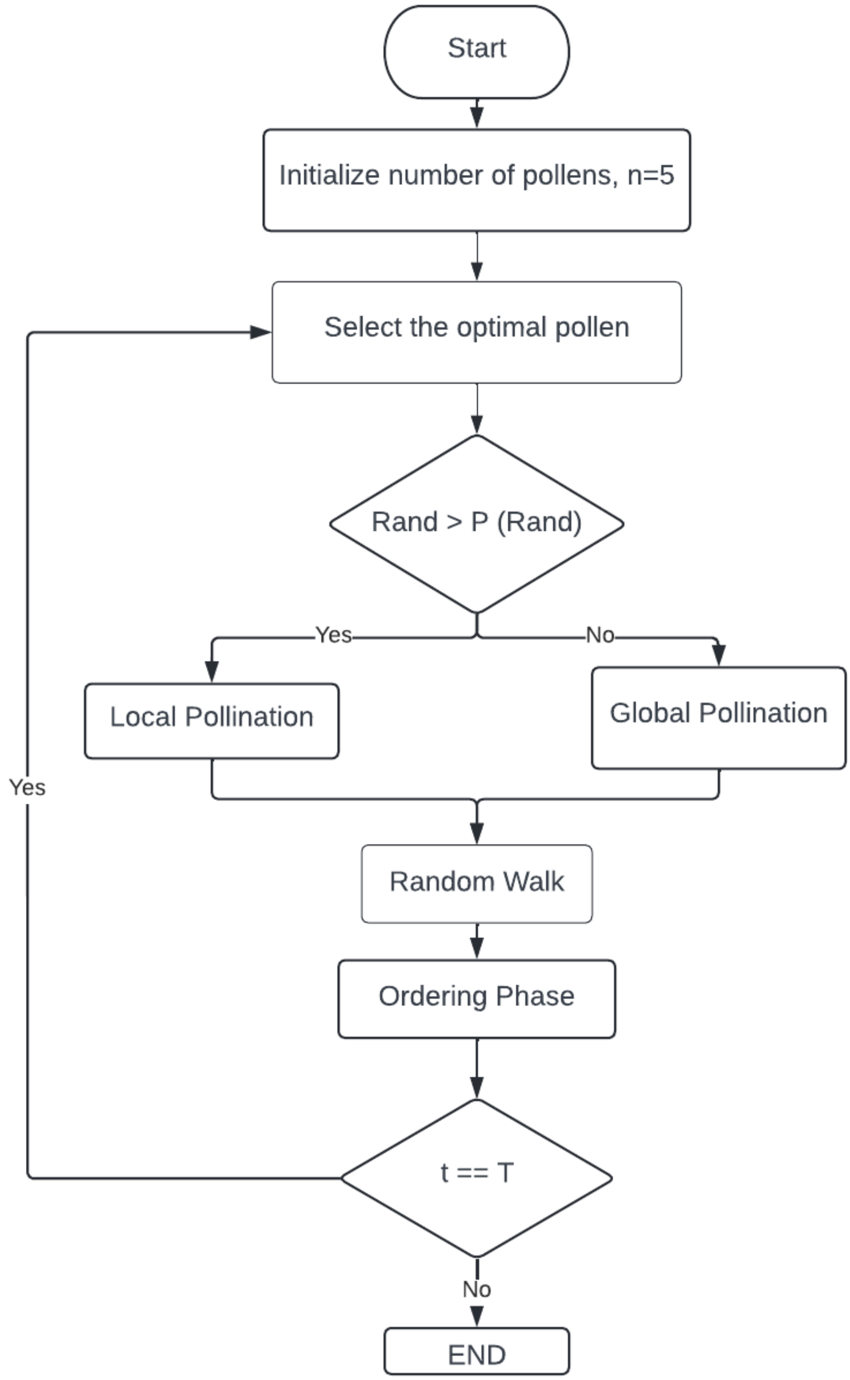


Figure 3. Flowchart of Proposed Ordered Flower Pollination Algorithm.

6. Simulation and Results

Performance analysis of the proposed technique is conducted by designing an off-grid solar PV system operating under continuously changing weather in MATLAB/Simulink. The design of a PV system is presented in Figure 4. Here, the PV array is connected to the DC–DC converter driven by the MPPT algorithm and a DC-load. The simulation of three different test cases (zero, weak, and strong partial shading) at two different standalone solar PV systems (2S and 2S2P) is conducted to validate the proposed technique at the constant and continuously changing weather conditions.

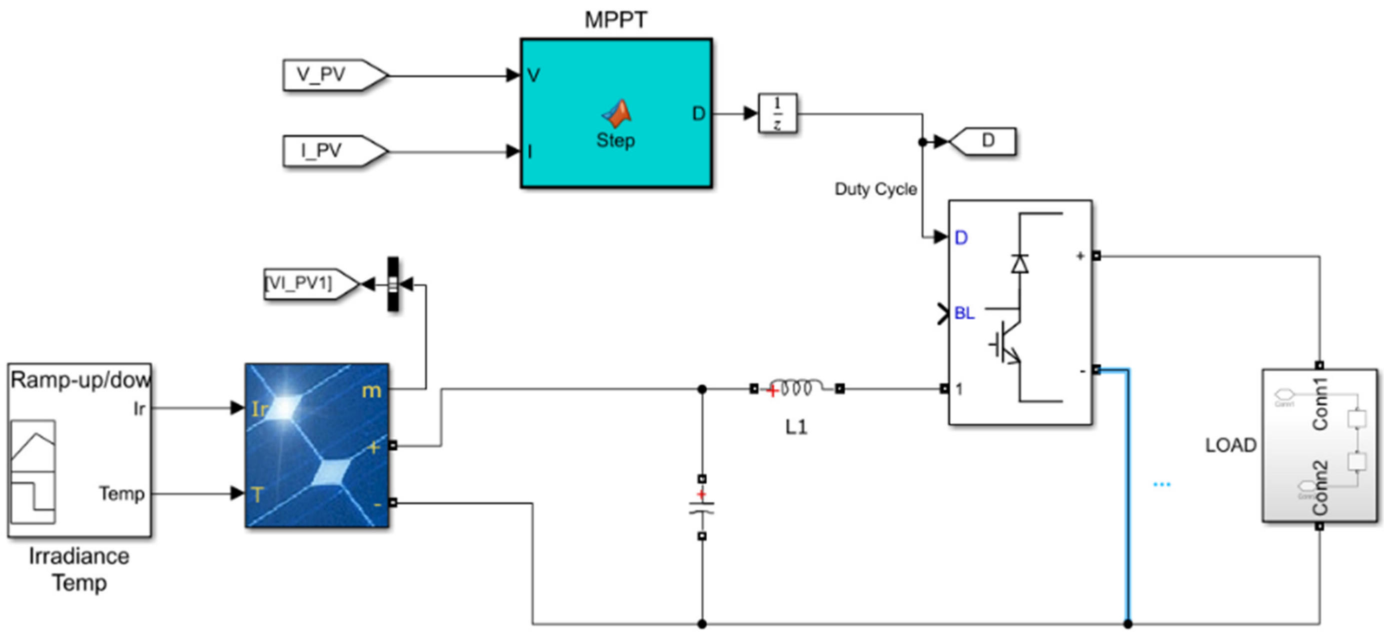


Figure 4. Photovoltaic System's Structure.

6.1. S Solar Photovoltaic System

The PV system composed of two series of connected modules (2S) would experience three test conditions of zero, weak, and strong PSC as depicted in Figure 5. Each module can produce a maximum of 30 W at its MPP with 10 V and 3 A at 1000 W/m^2 at 25 °C. The proposed algorithm will be compared with the conventional FPA at 2S PV system under constant and changing weather conditions at MPP tracking speed and efficiency.

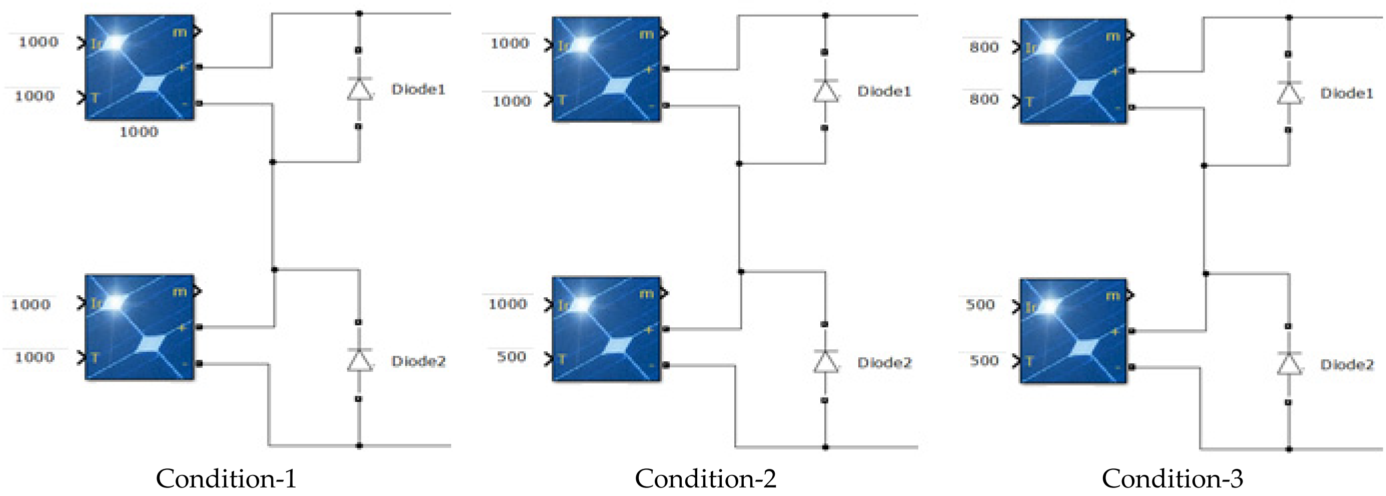


Figure 5. Weather Conditions for 2S PV System.

In the first condition, both PV modules collect 1000 W/m^2, and the characteristic curve will generate a single MPP as shown in Figure 6. Tracking a single MPP is not a big deal. Here MPP occurs at 19.99 V, 3.001 A, and 60 Ws.

Under weak PSC, one of the two modules in the 2S-PV system is partially shaded and experiences a 500 W/m^2 illumination, and the other gets 1000 W/m^2 as depicted in Figure 5. This shading disturbs the 2S-PV system and creates multiple peaks in the characteristic curve as shown in Figures 7 and 8. Detecting the real MPP also called the global MPP (GMPP) is a bit difficult compared to the zero shading. Here the GMPP occurs at 21.61 V, 1.589 A, and 34.34 Ws.

Under strong PSC, no module of the 2S-PV system receives standard illumination (1000 W/m^2) due to partial shading. Each module experiences a different illumination level. In this case, the two modules are receiving 800 W/m^2 and 500 W/m^2 as depicted in Figure 5. Strong shading disturbs the characteristic curve as shown in Figure 8. Here the GMPP occurs at 21.4 V, 1.586 A, and 33.94 Ws.

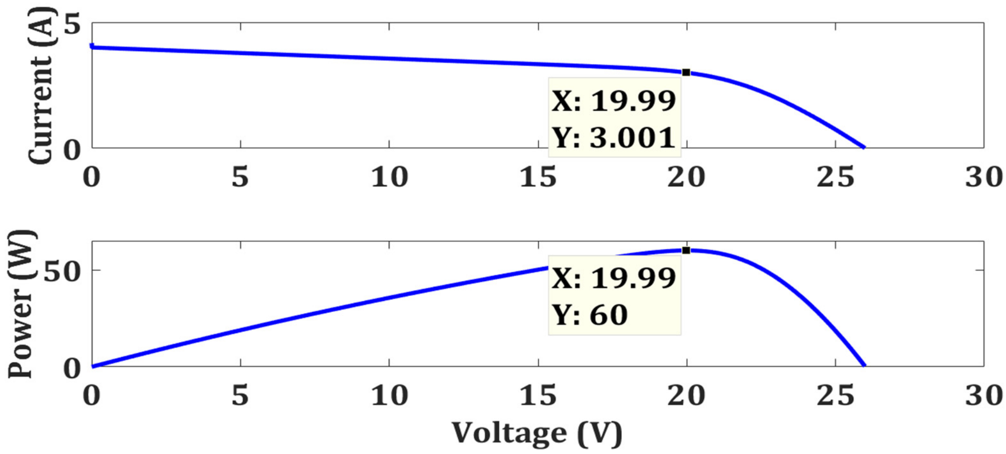


Figure 6. Characteristic curves of 2S PV System for Zero Shading.

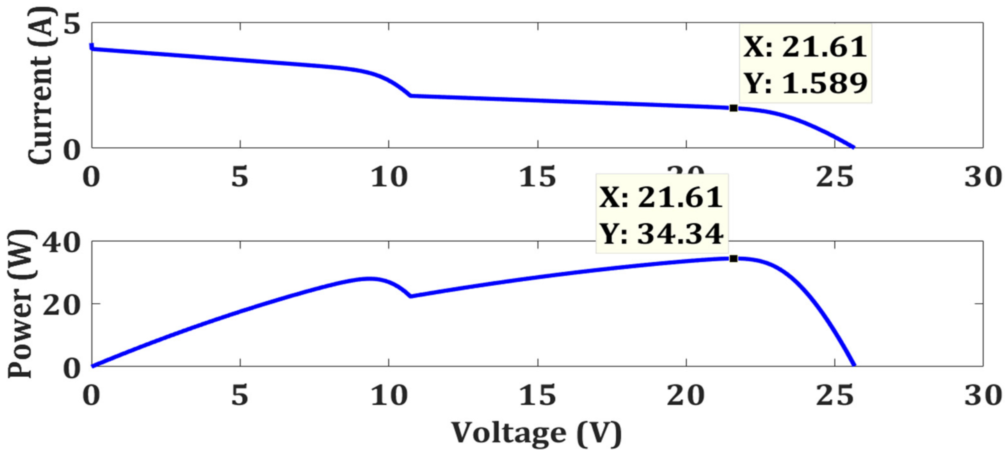


Figure 7. Characteristic curves of 2S PV System for Weak Partial Shading.

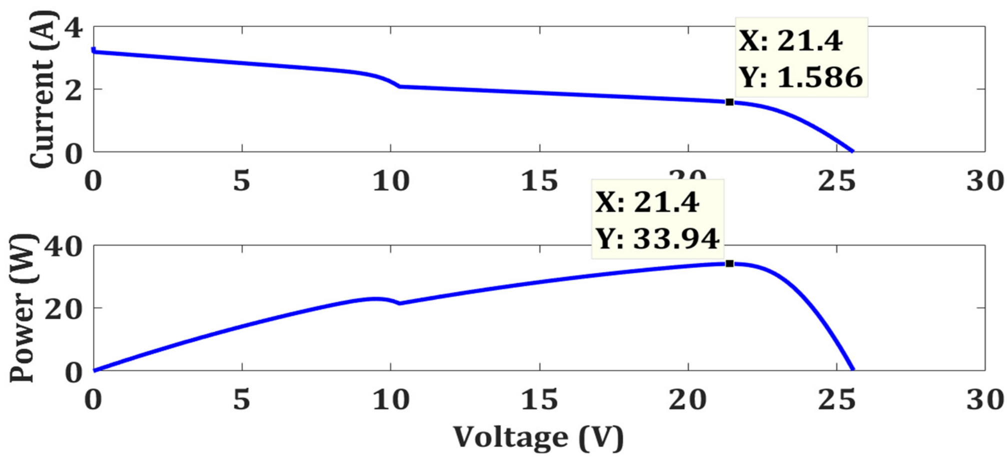


Figure 8. Characteristic curves of 2S PV System for Strong Partial Shading.

The renowned FPA and the proposed OFPA algorithms are applied to the 2S PV system experiencing three different weather conditions. The results have proved the superiority of OFPA over the FPA algorithm in MPP tracking speed.

Results presented in Figure 9 have shown that under zero shading conditions at a 2S PV system, the FPA has achieved "59.85 W" with 99.75% efficiency in 0.7537 s, whereas the proposed OFPA algorithm extracted "59.85W" with 99.75% efficiency in just 0.1103 s. The proposed algorithm has outperformed the FPA by achieving the same target with an 85.4% improvement in tracking speed.

The same mathematical formula is applied in both algorithms, but the arrangement of data has reduced the settling time which in turn decreased the tracking time. It can be clearly observed in Figure 9 that the OFPA has applied its fine decision at 0.104 s but the output became stable at 0.1103 s with the time difference of 0.0063 s, whereas the FPA need to provide a time slot of 0.03 s for each pollen to achieve a stable output.

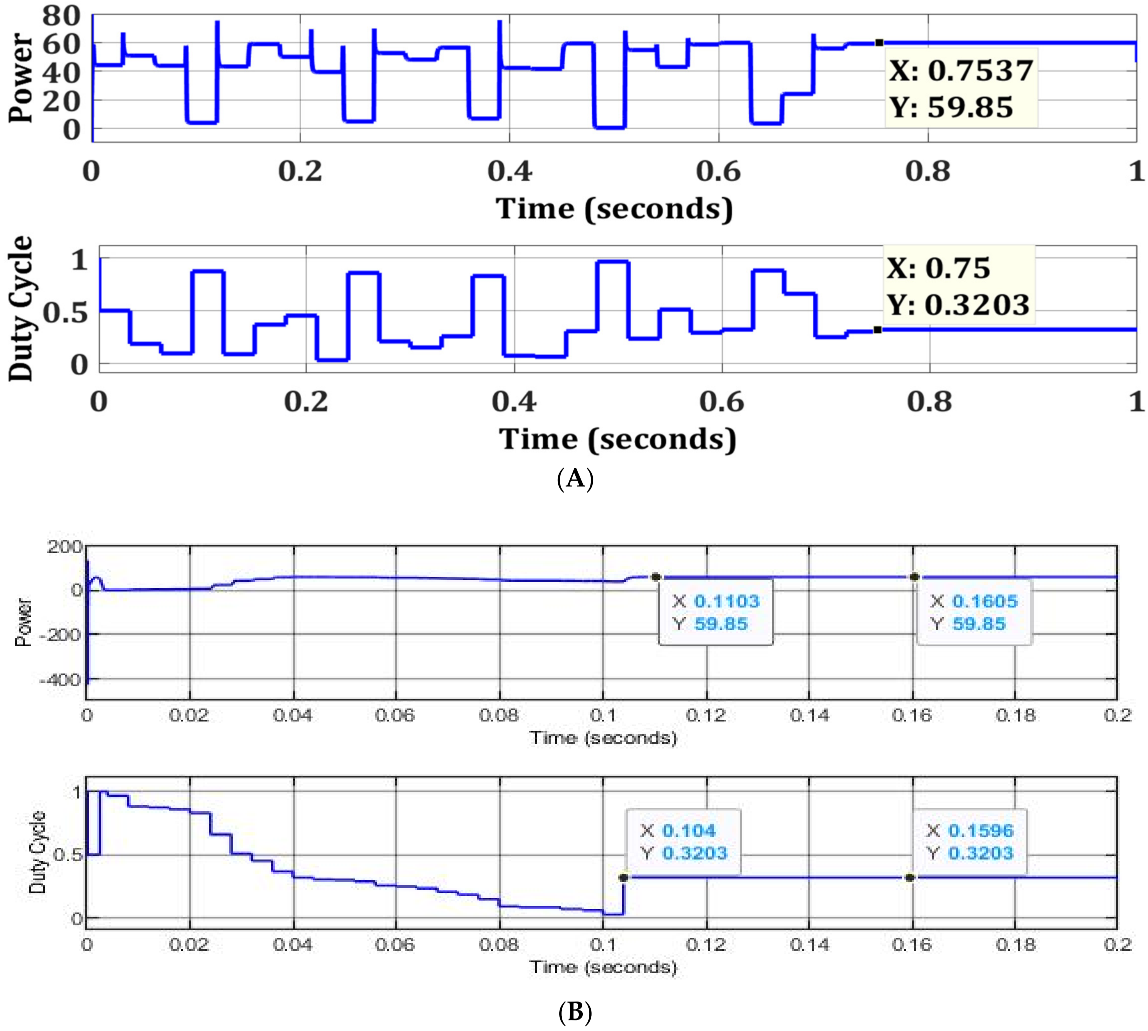
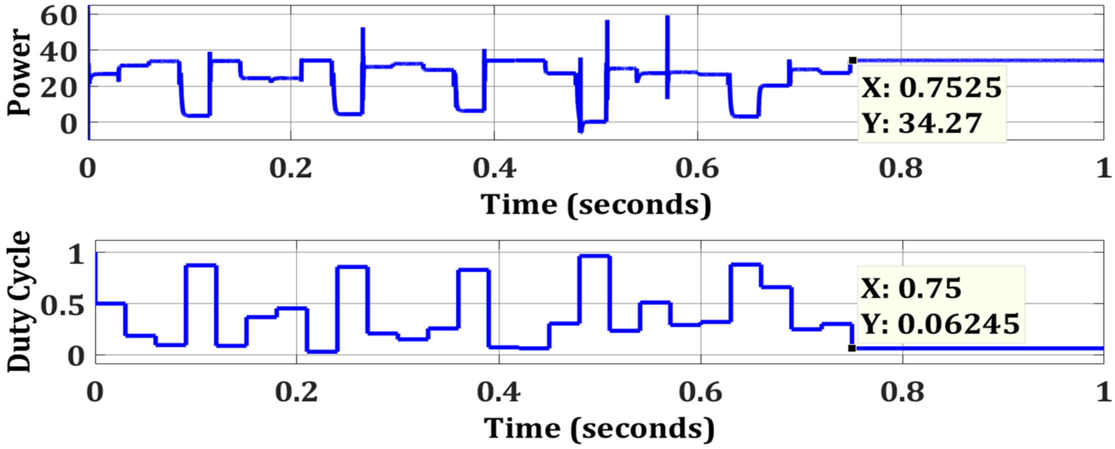


Figure 9. Simulation Results for 2S PV System for Zero Shading. (**A**) Flower Pollination Algorithm. (**B**) OFPA.

Proceeding to the case of weak PSC, both algorithms have been applied at the 2S PV system, and the extracted results depicted in Figure 10 have verified the superiority of OFPA over the FPA in tracking speed. Both the OFPA and the FPA algorithms have achieved 34.27 W, but the FPA has taken 0.7525 s, whereas the OFPA has completed the task in just 0.1055 s with an 86% improvement in tracking time.



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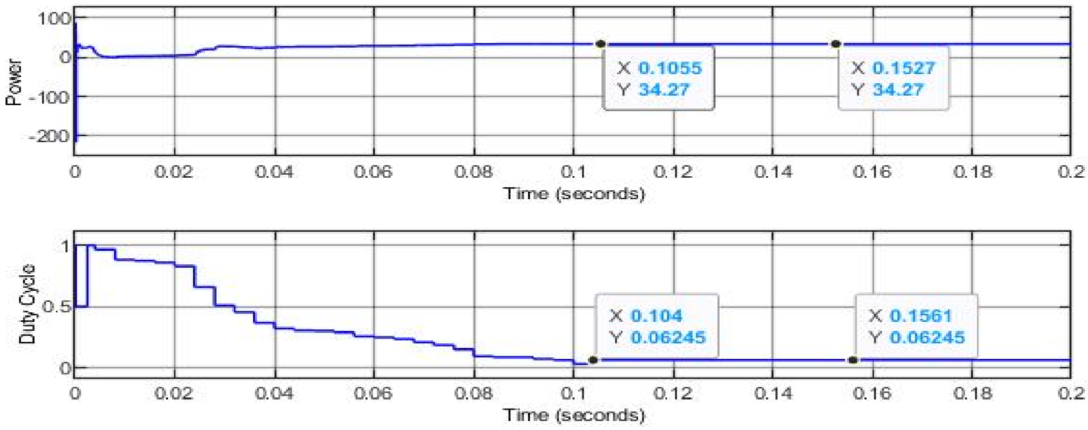

(**B**)

Figure 10. Simulation Results of 2S PV System for Weak PSC. (**A**) FPA algorithm. (**B**) OFPA algorithm.

Considering the strong PSC, both algorithms were applied at the 2S PV system. The result presented in Figure 11 shows that both algorithms achieved 33.9 W with 99.88% efficiency, but the proposed OFPA has outperformed the FPA in tracking speed by achieving the same target in 0.1052 s, that is an 86% improvement in tracking time and speed.

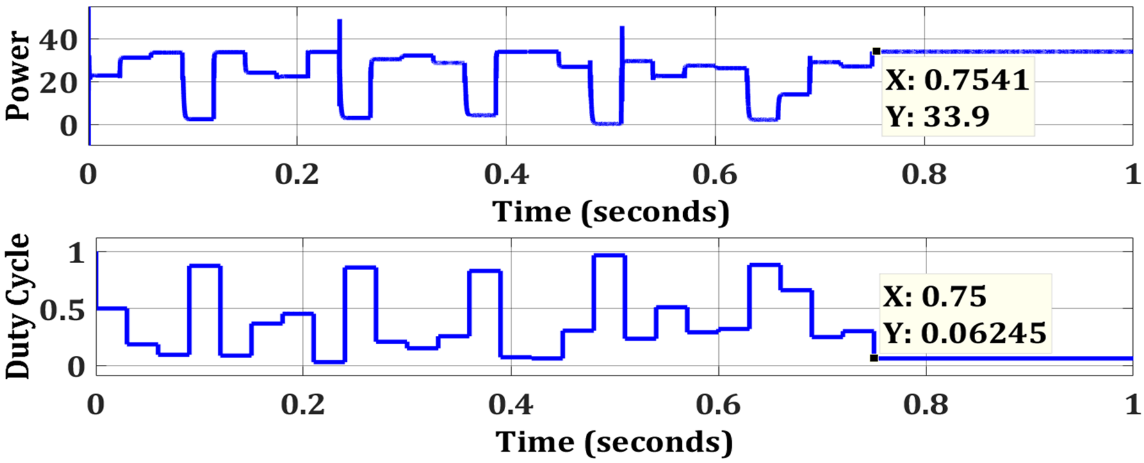

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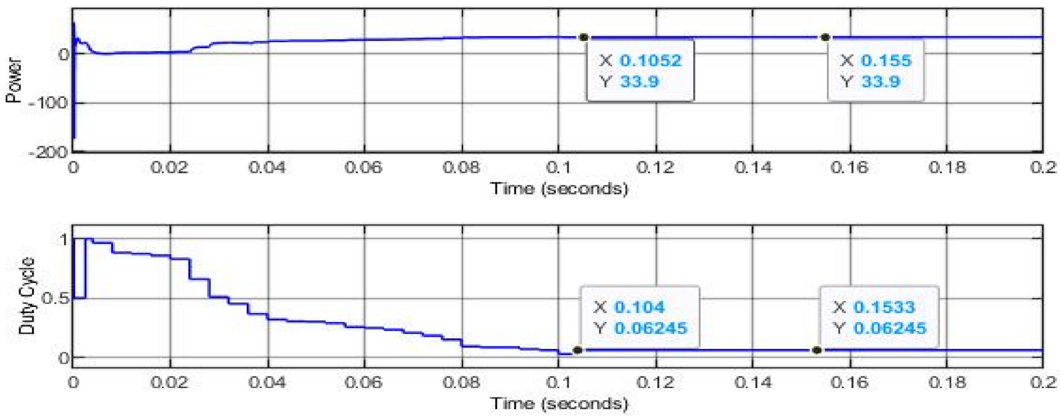
Figure 11. *Cont.*



(**B**)

Figure 11. Simulation Results for 2S Configuration under Strong PSC. (**A**) FPA algorithm. (**B**) OFPA algorithm.

The performance analysis of both FPA and the proposed OFPA algorithms for the 2S PV system under different weather conditions is summarized in Table 1. Huge improvement in tracking speed is observed due to the optimization made in the conventional FPA algorithm.

Table 1. Performance Comparison for 2S PV System.

Partial Shading	MPPT Algorithms	Power Output (W)	Rated Power (W)	Efficiency (%)	Tracking Speed (s)	Improvement in Tracking Speed (%)
Zero Shading	FPA	59.85	60	99.75	0.7537	**85.4**
	OFPA	59.85		99.75	0.1103	
Weak Partial Shading	FPA	34.27	34.34	99.8	0.7525	**86**
	OFPA	34.27		99.8	0.1055	
Strong Partial Shading	FPA	33.9	33.94	99.88	0.7541	**86**
	OFPA	33.9		99.88	0.1052	

Further, the analysis of the OFPA algorithm under continuously changing scenarios is conducted by applying the zero, weak, and strong shadings one after another with a time span of 0.5 s, and the results presented in Figure 12 prove its reliability under numerous weather conditions. The proposed OFPA algorithm has retained its performance in terms of efficiency and tracking speed under continuously changing weather.

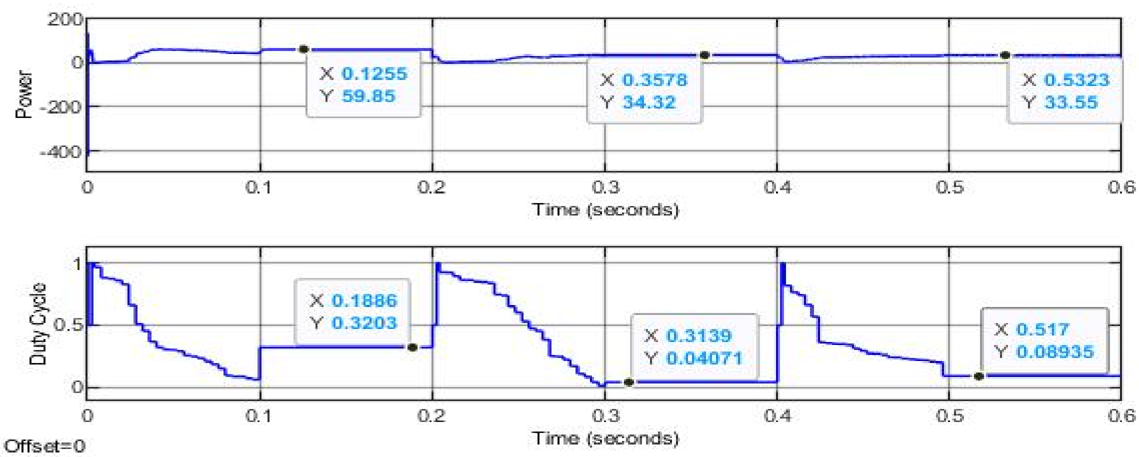


Figure 12. Performance of OFPA Algorithm under Changing Weather Conditions for 2S PV system.

6.2. S2P Solar Photovoltaic System

The performance evaluation of FPA and OFPA algorithms is conducted under multiple conditions at the 2S2P PV system presented in Figure 13. This system is composed of two parallel strings, each contained two series connected modules. The 2S2P experiences the same shading patterns that were previously experienced by the 2S PV system.

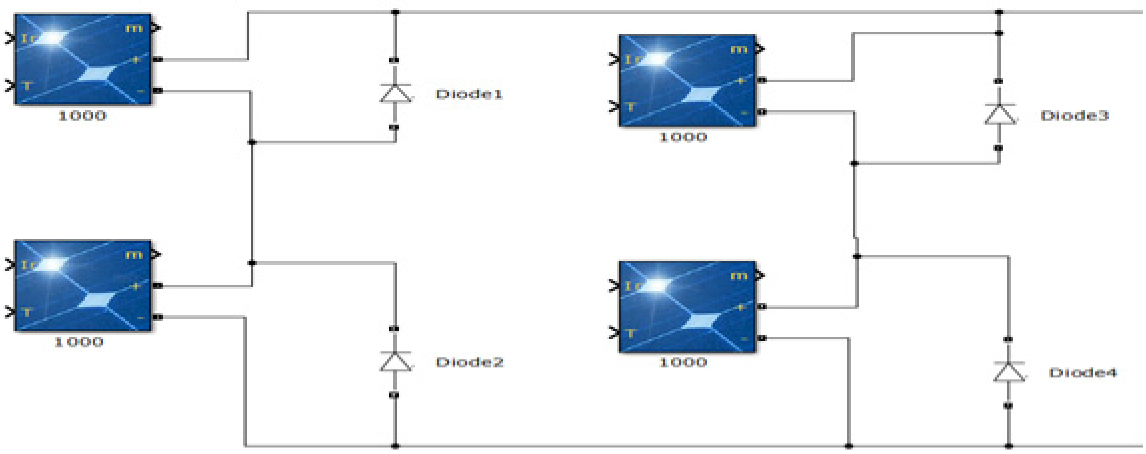


Figure 13. S2P PV System.

The characteristic curves and the comparison of a 2S2P PV system for OFPA and FPA algorithms under zero, weak, and strong PSC are represented in Figures 14–16, respectively. Under zero shading, the MPP occurs at 120 W. Under weak PSC, it reduces to 68.67 W and the characteristic curve of the 2S2P PV system is disturbed. Under strong PSC, the MPP moves to 67.88 W, and this is the worst case.

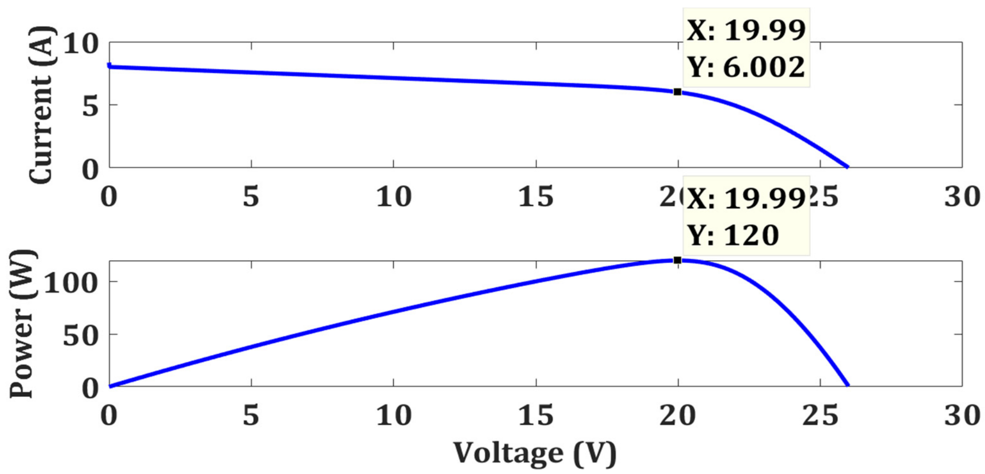


Figure 14. Characteristic Curve of 2S2P PV System for Zero PSC.

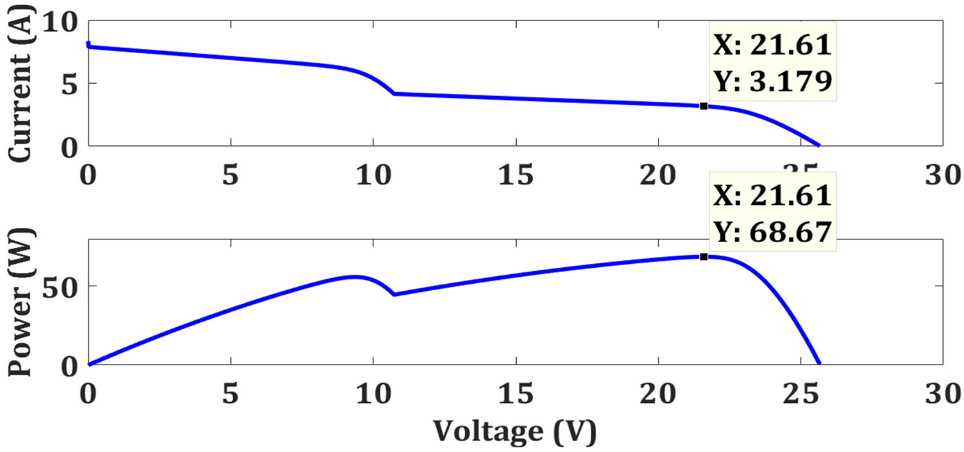


Figure 15. Characteristic Curve of 2S2P PV System for Weak PSC.

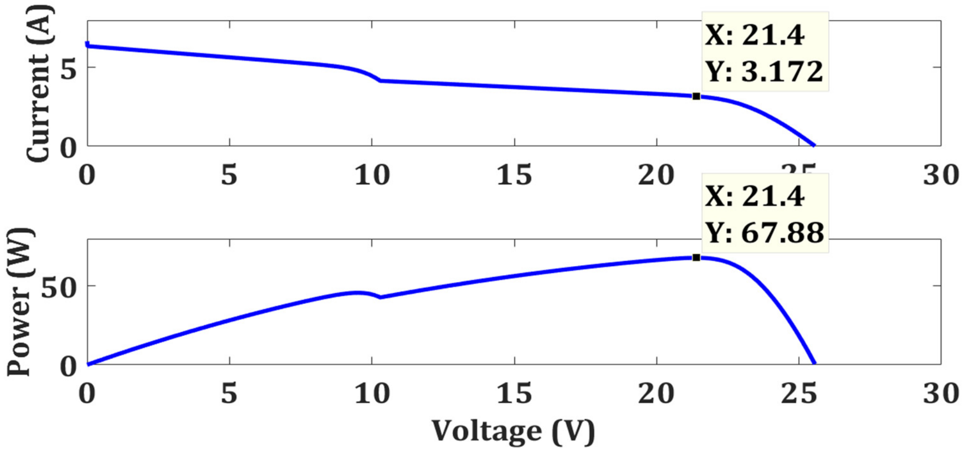
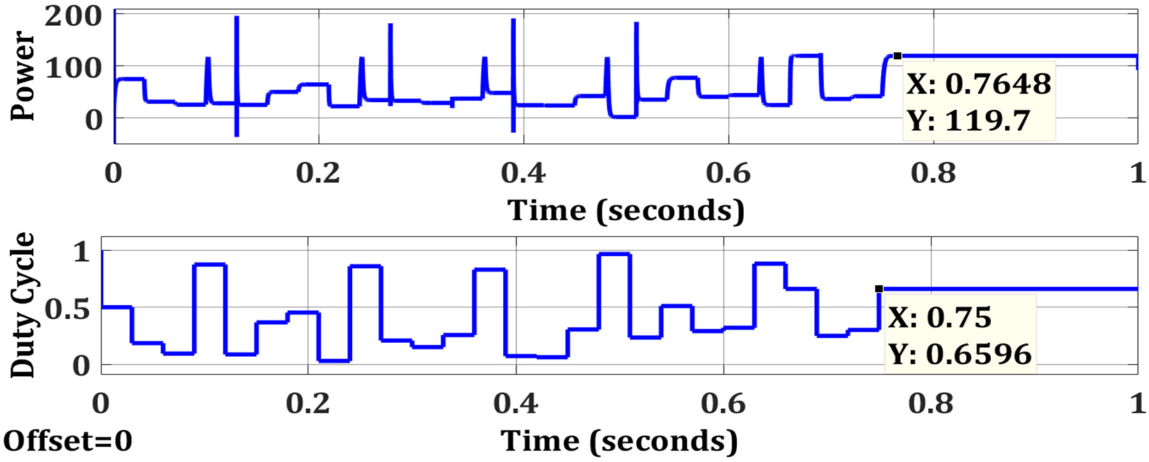


Figure 16. Characteristic Curve of 2S2P PV System for Strong PSC.

The struggle of FPA and the proposed OFPA algorithms under zero shading for the 2S2P PV system is presented in Figure 17. The FPA has extracted 119.7 W in 0.7648 s and attained an efficiency of 99.75%. Whereas, the proposed OFPA algorithm has extracted 120 W with 100% efficiency in just 0.1071 s. The achievement of 0.25% in efficiency and 86% in tracking speed is achieved by the proposed OFPA algorithm compared to the FPA algorithm. A little variation in the output could be expected due to the changes introduced in the structure of conventional FPA.

The achievement in tracking speed/tracking time is excellent; however, the improvement in efficiency is small. The main motive of the proposed OFPA is to collect, apply, and arrange the output data of FPA in an effective manner to reduce the tracking time.



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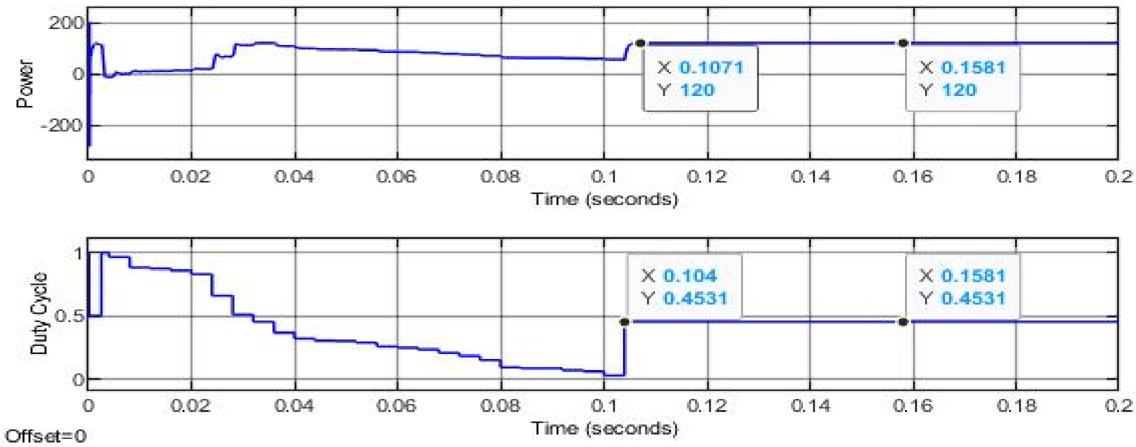


(**B**)

Figure 17. Simulation Results for 2S2P Configuration under Zero PSC. (**A**) FPA algorithm for Zero Shading. (**B**) OFPA algorithm for Zero Shading.

The power output extracted by the OFPA and FPA from the 2S2P PV system under weak PSC is 68.16 W with 99.26% efficiency in 0.113 and 0.7584 s, respectively, as presented in the Figure 18. The improvement in tracking speed achieved by the OFPA comparing to the FPA for 2S2P PV system under weak PSC is 85.10%.

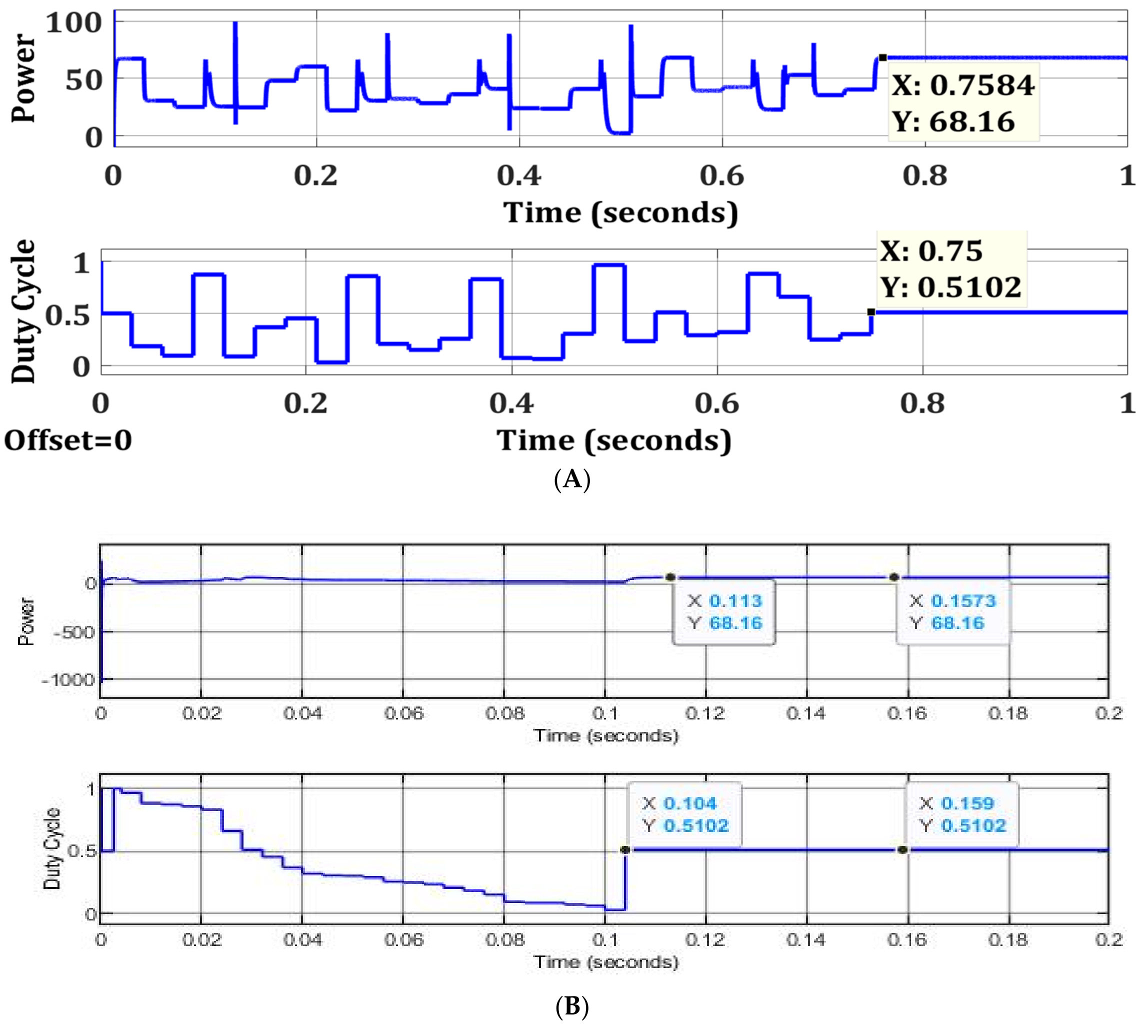
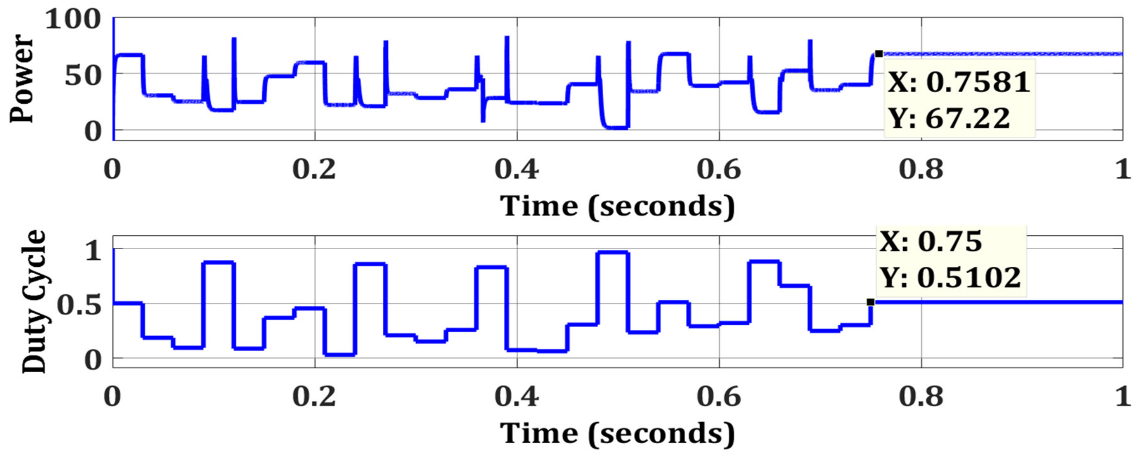


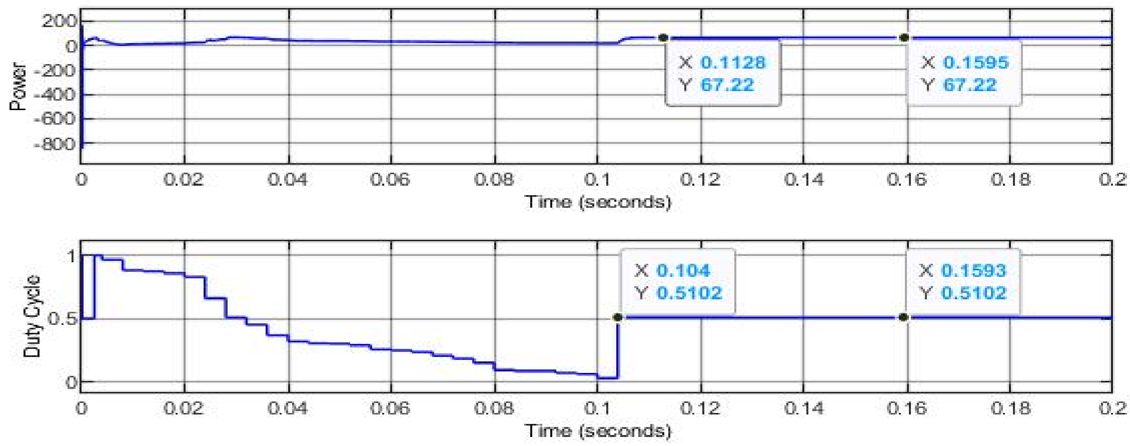
Figure 18. Simulation Results for 2S2P Configuration under Weak PSC. (**A**) FPA algorithm. (**B**) OFPA Algorithm.

Under strong PSC, the power output extracted by both the OFPA and FPA from the 2S2P PV system is 67.22 W with 99.02% efficiency in 0.1128 s and 0.7528 s, respectively, as presented in Figure 19. The improvement in tracking speed achieved by the OFPA compared to the FPA for 2S2P PV system under strong PSC is 85.02%.



(**A**)

Figure 19. *Cont.*



(**B**)

Figure 19. Simulation Results for 2S2P Configuration under Strong PSC. (**A**) FPA algorithm. (**B**) OFPA algorithm.

The performance analysis of both FPA and the proposed OFPA algorithms for the 2S2P PV system under defined weather conditions is abridged in Table 2. A huge improvement in tracking speed is observed due to the optimization made in the conventional FPA algorithm.

Table 2. Performance Comparison for 2S2P PV System.

Partial Shading	Algorithms	Power Output (W)	Rated Power (W)	Efficiency (%)	Tracking Speed (s)	Improvement in Tracking Speed (%)
Zero Shading	FPA	119.7	120	99.75	0.7648	**86**
	OFPA	120		100	0.1071	
Weak Partial Shading	FPA	68.16	68.67	99.26	0.7584	**85.10**
	OFPA	68.16		99.26	0.113	
Strong Partial Shading	FPA	67.22	67.88	99.02	0.7581	**85.02**
	OFPA	67.22		99.02	0.1128	

The final test of OFPA for changing weather conditions is conducted for the 2S2P PV system, and the results presented in Figure 20 show that the OFPA algorithm has retained its performance under all weather conditions.

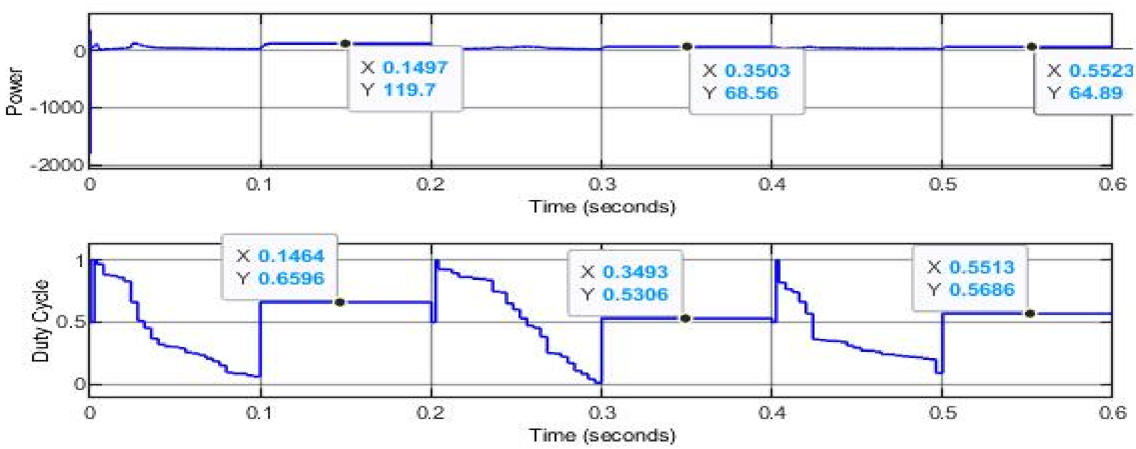


Figure 20. Performance of OFPA Algorithm under Changing Weather Conditions for 2S2P PV system.

7. Discussion

After long simulation results and discussion, we need to summarize the gain or contribution we have made in the field of MPPT algorithms. In Table 3, a comparison of the proposed OFPA algorithm is presented with the well-known MPPT algorithms at all the standard benchmarks.

Table 3. Performance Assessment of OFPA against Leading MPPT Algorithms.

Sr. No.	Algorithms / Parameters	P&O [27,28]	Fuzzy [29]	PSO [30]	FPA [24]	Ordered FPA
1	**Steady State Oscillations**	High	Low	Zero	Zero	Zero
2	**Tracking Speed**	Low	Adequate	Adequate	Fast	FASTEST
3	**Procedural Complications**	Less	High	Reasonable	Reasonable	Nil
4	**Memorizing Necessity**	Few	Large	Few	Few	FEW
5	**Computational Complications**	Zero	High	Average	Average	No
6	**Implementation**	Cheap	Costly	Costly	Costly	Costly
7	**Performance in PSC**	N/A	Good	Good	Good	EXCELLENT
8	**Module Dependent**	Yes	Yes	No	No	No
9	**Efficiency**	Fail	Low under PSC	Effective	Effective	Exciting
10	**Structure**	Simple	Complex	Complex	Complex	Simple

The parameters in Table 3 explain the strength, weaknesses, and performance of algorithms. Toggling of operating power point around the MPP creates steady-state oscillations, but this mostly occurs in conventional MPPT algorithms. Tracking speed defines the tracking time of MPP or GMPP. Procedural complications depend upon the number of steps and processes taken by the algorithm. Memory is mostly required by the artificial-intelligence-based algorithm that requires huge data training. The computational complications depend on the number of mathematical computations and on the number of variables computed in the equations. Implementation includes the implementation cost. Performance in PSC explains the MPPT ability of any algorithm under numerous weather conditions. Module dependency expresses the dependence of MPPT algorithm tracking time upon the size of PV system. Efficiency describes the accuracy of results. The structure informs about the flow of tracking procedures.

8. Conclusions

After a deep literature review of conventional, nature-inspired, and soft computing MPPT algorithms, it was found that the only category of MPPT algorithm that can perform efficiently under numerous weather conditions is the nature-inspired MPPT algorithm. These nature-inspired algorithms have a complex structure and produce random output based on different mathematical calculations. The complex structure and huge computations do not allow nature-inspired algorithms to converge quickly and avoid spikes. It is found in this research that the randomness in calculating the optimal GMPP is a good approach but delivering those randomly generated figures increases the tracking time, reducing the tracking speed and efficiency as well. Therefore, the structure of one of the most renowned nature-inspired algorithms, FPA, has been implemented and compared with the modified version of FPA that does not use random features as the output. Results have shown remarkable achievement by the proposed ordered flower pollination algorithm in MPPT tracking time compared to the conventional flower pollination algorithm. An improvement of around 85% in MPPT tracking time has been achieved by the proposed ordered flower pollination algorithm under numerous weather conditions. Further achievements (reduction in tracking time and increase in the efficiency) of the proposed ordered flower pollination algorithm are that the solar PV system can produce more power in less time, which would have a positive impact on the energy production cost and the payback period of the solar PV system.

9. Future Work

The detailed economical view of the OFPA in terms of the payback period would be interesting research. Moreover, the performance of OFPA can be compared with the recently developed GMPPT algorithm to further validate the performance.

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References

1. Awan, M.M.A.; Javed, M.Y.; Asghar, A.B.; Ejsmont, K. Economic integration of renewable and conventional power sources—A case study. *Energies* **2022**, *15*, 2141. [CrossRef]
2. Ellabban, O.; Abu-Rub, H.; Blaabjerg, F. Renewable energy resources: Current status, future prospects and their enabling technology. *Renew. Sustain. Energy Rev.* **2014**, *39*, 748–764. [CrossRef]
3. Huide, F.; Xuxin, Z.; Lei, M.; Tao, Z.; Qixing, W.; Hongyuan, S. A comparative study on three types of solar utilization technologies for buildings: Photovoltaic, solar thermal and hybrid photovoltaic/thermal systems. *Energy Convers. Manag.* **2017**, *140*, 1–13. [CrossRef]
4. Afzal Awan, M.M.; Mahmood, T. A novel ten check maximum power point tracking algorithm for a standalone solar photovoltaic system. *Electronics* **2018**, *7*, 327. [CrossRef]
5. Awan, M.M.A.; Mahmood, T. Modified flower pollination algorithm for an off-grid solar photovoltaic system. *Mehran Univ. Res. J. Eng. Technol.* **2022**, *41*, 95–105. [CrossRef]
6. Başoğlu, M.E. A fast GMPPT algorithm based on PV characteristic for partial shading conditions. *Electronics* **2019**, *8*, 1142. [CrossRef]
7. Feroz Mirza, A.; Mansoor, M.; Ling, Q.; Khan, M.I.; Aldossary, O.M. Advanced variable step size incremental conductance MPPT for a standalone PV system utilizing a GA-tuned PID controller. *Energies* **2020**, *13*, 4153. [CrossRef]
8. Awan, M.M.A.; Javed, M.Y.; Asghar, A.B.; Ejsmont, K. Performance optimization of a ten check MPPT algorithm for an off-grid solar photovoltaic system. *Energies* **2022**, *15*, 2104. [CrossRef]
9. Awan, M.M.A. A Technical Review of MPPT Algorithms for Solar Photovoltaic System: SWOT Analysis of MPPT Algorithms. *Sir Syed Univ. Res. J. Eng. Technol.* **2022**, *12*, 98–106. [CrossRef]
10. Elgendy, M.A.; Zahawi, B.; Atkinson, D.J. Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications. *IEEE Trans. Sustain. Energy* **2011**, *3*, 21–33. [CrossRef]
11. Jately, V.; Azzopardi, B.; Joshi, J.; Sharma, A.; Arora, S. Experimental Analysis of hill-climbing MPPT algorithms under low irradiance levels. *Renew. Sustain. Energy Rev.* **2021**, *150*, 111467. [CrossRef]
12. Jately, V.; Arora, S. Performance investigation of Hill-Climbing MPPT techniques for PV systems under rapidly changing environment. In *Intelligent Communication, Control and Devices, Proceedings of ICICCD 2017*; Springer: Singapore, 2018; pp. 1145–1157.
13. Jately, V.; Bhattacharya, S.; Azzopardi, B.; Montgareuil, A.; Joshi, J.; Arora, S. Voltage and current reference based MPPT under rapidly changing irradiance and load resistance. *IEEE Trans. Energy Convers.* **2021**, *36*, 2297–2309. [CrossRef]
14. Debnath, A.; Olowu, T.O.; Parvez, I.; Dastgir, M.G.; Sarwat, A. A novel module independent straight line-based fast maximum power point tracking algorithm for photovoltaic systems. *Energies* **2020**, *13*, 3233. [CrossRef]

15. Awan, M.M.A. Strategic Perturb and Observe Algorithm for Partial Shading Conditions: SP&O Algorithm for PSC. *Sir Syed Univ. Res. J. Eng. Technol.* **2022**, *12*, 26–32.
16. Awan, M.M.A.; Awan, F.G. Improvement of maximum power point tracking perturb and observe algorithm for a standalone solar photovoltaic system. *Mehran Univ. Res. J. Eng. Technol.* **2017**, *36*, 501–510. [CrossRef]
17. Jately, V.; Arora, S. November. An efficient hill-climbing technique for peak power tracking of photovoltaic systems. In Proceedings of the 2016 IEEE 7th Power India International Conference (PIICON), Bikaner, India, 25–27 November 2016; pp. 1–5.
18. Tiwari, R.; Krishnamurthy, K.; Neelakandan, R.B.; Padmanaban, S.; Wheeler, P.W. Neural network based maximum power point tracking control with quadratic boost converter for PMSG—Wind energy conversion system. *Electronics* **2018**, *7*, 20. [CrossRef]
19. Wang, Y.; Yang, Y.; Fang, G.; Zhang, B.; Wen, H.; Tang, H.; Fu, L.; Chen, X. An advanced maximum power point tracking method for photovoltaic systems by using variable universe fuzzy logic control considering temperature variability. *Electronics* **2018**, *7*, 355. [CrossRef]
20. Settles, M.; Soule, T. June. Breeding swarms: A GA/PSO hybrid. In Proceedings of the 7th Annual Conference on Genetic and Evolutionary Computation, Prague, Czech Republic, 25–27 August 2005; pp. 161–168.
21. Sharma, A.; Sharma, A.; Jately, V.; Averbukh, M.; Rajput, S.; Azzopardi, B. A novel TSA-PSO based hybrid algorithm for GMPP tracking under partial shading conditions. *Energies* **2022**, *15*, 3164. [CrossRef]
22. Zhang, P.; Sui, H. Maximum power point tracking technology of photovoltaic array under partial shading based on adaptive improved differential evolution algorithm. *Energies* **2020**, *13*, 1254. [CrossRef]
23. Pilakkat, D.; Kanthalakshmi, S. Single phase PV system operating under Partially Shaded Conditions with ABC-PO as MPPT algorithm for grid connected applications. *Energy Rep.* **2020**, *6*, 1910–1921. [CrossRef]
24. Awan, M.M.A.; Mahmood, T. Optimization of maximum power point tracking flower pollination algorithm for a standalone solar photovoltaic system. *Mehran Univ. Res. J. Eng. Technol.* **2020**, *39*, 267–278. [CrossRef]
25. Figueiredo, S.; e Silva, R.N.A.L. Hybrid MPPT technique PSO-P&O applied to photovoltaic systems under uniform and partial shading conditions. *IEEE Lat. Am. Trans.* **2021**, *19*, 1610–1617.
26. Awan, M.M.A.; Awan, M.J. Adapted flower pollination algorithm for a standalone solar photovoltaic system. *Mehran Univ. Res. J. Eng. Technol.* **2022**, *41*, 118–127. [CrossRef]
27. Mousa, H.H.; Youssef, A.R.; Mohamed, E.E. Variable step size P&O MPPT algorithm for optimal power extraction of multi-phase PMSG based wind generation system. *Int. J. Electr. Power Energy Syst.* **2019**, *108*, 218–231.
28. Balaji, V.; Fathima, A.P. Enhancing the maximum power extraction in partially shaded PV arrays using hybrid salp swarm perturb and observe algorithm. *Int. J. Renew. Energy Res. (IJRER)* **2020**, *10*, 898–911.
29. Zhang, S.; Wang, T.; Li, C.; Zhang, J.; Wang, Y. June. Maximum power point tracking control of solar power generation systems based on type-2 fuzzy logic. In Proceedings of the 2016 12th World Congress on Intelligent Control and Automation (WCICA), Guilin, China, 12–15 June 2016; pp. 770–774.
30. Miyatake, M.; Veerachary, M.; Toriumi, F.; Fujii, N.; Ko, H. Maximum power point tracking of multiple photovoltaic arrays: A PSO approach. *IEEE Trans. Aerosp. Electron. Syst.* **2011**, *47*, 367–380. [CrossRef]