Optimization of Maximum Power Point Tracking Flower Pollination Algorithm for a Standalone Solar Photovoltaic System

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ABSTRACT

Modern-day world is facing problems such as, electricity generation deficiency, mounting energy demand, GHG (Greenhouse Gas) emissions, reliability and soaring prices. To resolve these issues, sustainable and renewable energy resources like SPV (Solar Photovoltaic) would be quite helpful. In this regard, the extraction of maximum power from SPV array in PSC (Partial Shading Weather Conditions) remains a challenge. Creation of multiple power peaks in the P-V (Power-Voltage) curve of a PV array due to partial shading, makes it difficult to track GMPP (Global Maximum Power Point) out of multiple power peaks known as LMPP (Local Maximum Power Points). Conventional algorithms are not able to perform in any condition other than UWC (Uniform Weather Condition). Nature inspired SC (Soft Computing) algorithms efficiently track the GMPP in PSC. The top performing SC algorithm named, FPA (Flower Pollination Algorithm) presents an efficient solution for GMPP tracking in PSCs. In this paper, the efficiency, accuracy and tracking speed of FPA algorithm is optimized. Comparison of the proposed OFPA (Optimized Flower Pollination Algorithm) and the existing FPAs is performed for zero shading condition, weak PSC, strong PSC, and changing weather conditions. In zero shading conditions, improvement of 0.7% in efficiency and 33% in tracking speed is achieved. In weak shading conditions, improvement of 0.97% in efficiency and 32.2% in tracking speed is achieved. In strong shading conditions, improvement of 0.24% in efficiency and 30.6% in tracking speed is achieved. OFPA is also tested for changing weather conditions (entering from Case-1 to Cae-3) and it retains its outstanding performance in the changing weather conditions. Simulations are performed in MATLAB/Simulink.

Key Words: Maximum Power Point Tracking, Global Maximum Power Point, Partial Shading Condition, Solar Photovoltaic.

1. INTRODUCTION

Modern energy generation technologies created huge problems for the world such as, pollution, respiratory diseases, GHG emissions, depletion of fuel resources etc. Renewable energy is a solution to produce clean energy generation [1]. Solar Photovoltaic can directly convert sunlight into electrical energy [2-3]. Efficiency of PV directly affects the cost of PV system, its payback time, price of energy generated from PV, area requirement for PV array, and energy savings. To make PV system efficient, it is necessary to operate PV array at its MPP (Maximum Power Point) to extract maximum power. For this purpose, MPPT (Maximum Power Point Tracker) are used [4]. MPPT is an electronic device, governed by algorithm.

In UWC all the cells of PV array receive same illumination. The P-V curve of PV array has one peak

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point known as MPP. Conventional MPPT algorithms successfully track the MPP in UWC. Conventional MPPT algorithms include: P&O (Perturb and Observe) [5], InC (Incremental Conductance) [6], FSC (Fractional Short Circuit) [7] and FOC (Fractional Open Circuit) [8]. These algorithms efficiently track the MPP. The only drawback of conventional techniques in UWC is the steady state oscillations of OPP (Operating Power Point) around the MPP.

Partial shading is a condition when, all the cells or modules of PV array are receiving different illumination levels. Some area of PV array is shadowed due to any reason such as, birds dropping, buildings, trees, dust etc. In this condition the P-V curve of the PV array exhibits multiple power peaks known as LMPP (Local Maximum Power Points). The LMPP with the highest power is called GMPP. Tracking GMPP is a big challenge for trackers. Conventional algorithms fail to track GMPP in PSC [9]. Different improvements have been made but not satisfactory.

Improvements carried out in conventional MPPT algorithms like "Two Stage P&O [10]" and "Direct Search MPPT [11]" techniques. In the first stage of "Two Stage P&O technique", optimized zone is detected and in the second stage it locates the GMPP. In "Direct Search MPPT technique", the two-mode operation is conducted. Initially GMPP mode is activated and afterwards, switches to the other mode of conventional P&O method. Both improved methods are ineffective in PSC. To fill these drawbacks, researchers move towards the SC techniques.

In SC techniques, the ANN (Artificial Neural Network) [12], and the FL (Fuzzy Logic) [13], GA (Genetic Algorithm) [14], PSO (Particle Swarm Optimization) algorithm [15], DE (Differential Evolution) algorithm [16], RSM (Random Search Method) [17] and ABC (Artificial Bee Colony) algorithm [18] are the known ones. SC techniques performed better than the conventional techniques in tracking GMPP, but are complex, have high computation time and low convergence speed.

A new SC technique named FPA [19] has been devised by the scientific community, which performs much better than all the above mentioned conventional

and soft computing techniques in UWC and PSC. [19-21].

FPA has an advantage of having less number of parameters such as switching probability and scaling factor. Switching probability has been fixed at 0.8, however, it does not ensure the fine balance between two types of searches. Such a drawback presents difficulty in GMPP tracking [22].

The rest of the paper is ordered as follows. Section-2 describes the modeling of SPV cell, section-3 explains the partial shading effects and FPA technique, section-4 presents the problem formulation, section-5 describes the proposed optimized FPA algorithm", section-6 presents the simulation and results, section-7 presents the conceptual comparison, section-8 performs the comparison, section-9 conclusion.

2. MODELING OF SOLAR PHOTOVOLTAIC CELL

One and Two diode models are the mostly used models of PV cell [23-24]. Despite of the greater accuracy of Two-diode model, mostly One-diode model is used because of its simplicity [25-26]. The One diode model of a PV cell is displayed in Fig. 1.
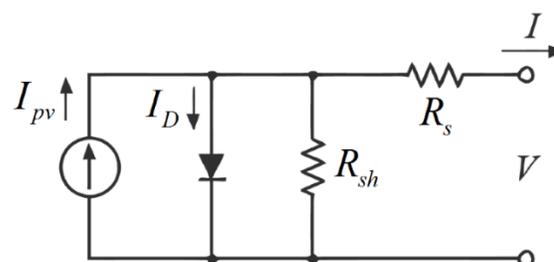
FIG 1: ONE DIODE MODEL OF PV CELL

Applying KCL at Fig. 1, the PV output current is:

$$I = I_{PV} - I_D - \left(\frac{V + IR_S}{R_{sh}}\right) \tag{1}$$

This single diode model has five parameters I_{pv}, I_D, Rs, R_{sh}, and α, where
I_{PV} = current of PV cell,
I_D = diode current, R_s is resistance in series,
R_{sh} = parallel resistance and
α = diode ideality factor.

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The diode current is calculated as

$$I_D = I_0 \times \left[\exp\left(\frac{V_D}{\alpha V_T}\right) - 1 \right] \qquad (2)$$

where V_D is Diode Voltage, I_0 is reverse saturation current. In the above equation V_T is thermal voltage which is given by

$$V_T = \frac{N_s kT}{q} \qquad (3)$$

where

k = Boltzmann Constant = 1.3805×10^{-23},
Ns = Number of series connected cells,
T is Temperature at STC (Standard Test Condition), &
q = Electron Charge = 1.9×10^{-19} C.

The PV module's current can be calculated by:

$$I = N_{pp} \times \left(I_{PV} - I_0 \left[\exp\left(\frac{V + IR_S}{\alpha V_T N_{ss}}\right) - 1 \right] - \left(\frac{V + IR_S}{R_{sh}}\right) \right) \qquad (4)$$

3. FLOWER POLLINATION ALGORITHM

3.1 Effects of Partial Shading Weather Conditions

PV cells connect in parallel-series arrangement to form PV module and PV modules are connected in series to form PV array [27-28]. Under UWC, the P-V curve of PV array has one single MPP. But PSC creates multiple MPPs in the P-V curve, out of all those LMPP there is only one GMPP. Sources of partial shading can be, trees, constructions, smokes, moving clouds, bird dropping [29-30]. Array of four modules with different shaded patterns, no shading, weak partial shading and strong partial shading is revealed in Fig.2.

Bypass diodes are used to avoid "hotspots" [31], and blocking diodes are used to stop the "reverse current" [17]. Number of peaks depends upon the strength of shading. The P-V and I-V characteristic curves of PV array for the three cases (Case-1, Case-2, and Case-3) are displayed in the next sections of the paper.
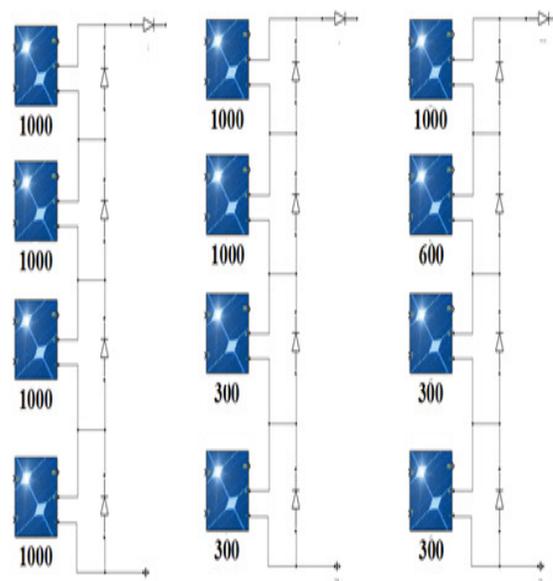
FIG. 2. ARRAY OF FOUR MODULES (4S) WITH SEPARATE TEST CASES CASE-1: NIL PARTIAL SHADING, CASE-2: WEAK PARTIAL SHADING, CASE-3: STRONG PARTIAL SHADING.

3.2 FPA Algorithm

FPA starts with the random generation of five pollens. These pollens are then send to the DC/DC converter to check amount of extracted power from the PV array against each sample. Pollen with the highest power is selected as a best pollen P_{best}. After completion of this first iteration, a random number is generated for each pollen and compared with the value of switching probability "P" (normally set at P = 0.8). If the randomly generated number is greater than the switching probability, pollen will go through the Local Pollination using Equation (7) else Global Pollination using Equation (8). The next set of new five pollens will be obtained after Local or Global pollination and then send to the DC/DC converter. After each iteration switching probability is compared with new random numbers for each pollen. The process repeats and at the end of each iteration one P_{best} is obtained. After twenty-five iterations, a set of 25 P_{best} is obtained. P_{best} with highest power is selected as a Global Best "G_{best}". Flowchart of the FPA is displayed in Fig. 3. Each step of FPA can be easily understood through Fig. 3.

The GMPP changes with the change in weather, therefore detection of change in weather is obligatory.

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This change is detected by the threshold values for the change in voltage (dV) and change in current (dI), set by the experimental trials and shown in Equations (5-6).

$$dV = \frac{V_{PV}(k) - V_{PV}(k-1)}{V_{PV}(k)} \geq 0.2 \qquad (5)$$

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

$$X_i^{t+1} = X_i^t + \xi(X_k^t - X_j^t) \qquad (7)$$

$$X_i^{t+1} = X_i^t + \gamma L(\lambda)(G_{best} - X_i^t) \qquad (8)$$
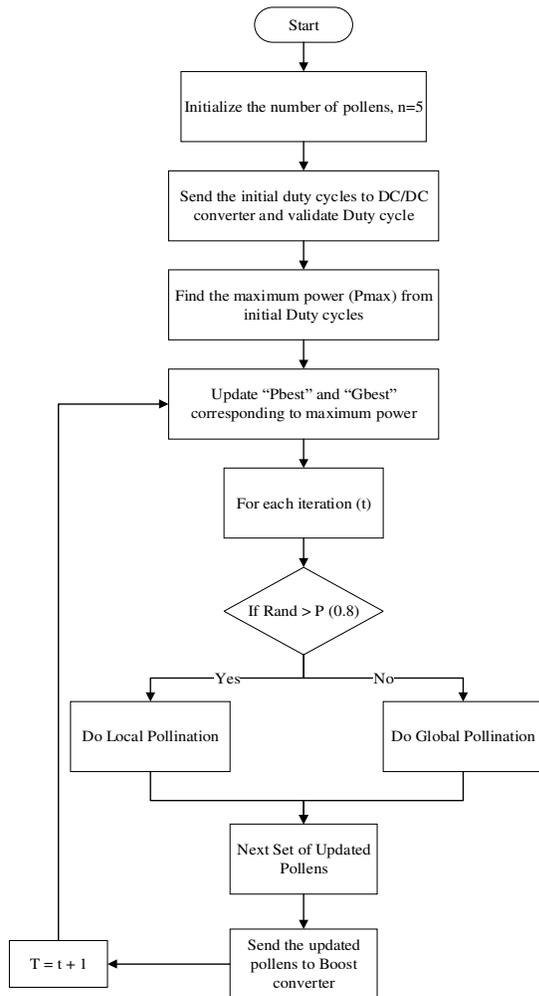
FIG. 3. FLOWCHART OF FPA ALGORITHM

$V_{pv}(k)$ is the voltage of a PV module at the tth iteration and $V_{pv}(k-1)$ is the voltage of a module at the preceding iteration. $I_{pv}(k)$ is the current of a PV module at the tth iteration and $I_{pv}(k-1)$ is the current of a PV module at the preceding iteration.

4. PROBLEM FORMULATION

FPA is an efficient technique but unfortunately not applied to PV system in an efficient manner. Problem is, that the PSC creates multiple power peaks in the P-V curve of PV array and scanning of whole array is not possible because it will take much time. Different algorithms before FPA were applied such as PSO algorithm with almost same idea of randomness but were not much successful. The only reason which make FPA superior is improvement in randomness due to local and global pollination concept and use of levy flight in global pollination process. The advantage of global pollination is that; it improves randomness by throwing the random numbers at greater distance from each other. Utilizing this advantage in a proper way is desired. It is necessary to take steps for effective use of Global Pollination such as, reducing the value of switching probability "P" to increase the chance for pollens to start Local pollinating globally after going through the Global Pollination process. Keeping this in mind we are changing the FPA algorithm to utilize it in an efficient manner.

5. PROPOSED OPTIMIZED FPA ALGORITHM

In the proposed OFPA algorithm, the role of Global Pollination is efficiently utilized by introducing the concept of LCP (Local Cross Pollination). Initially five pollens are generated in the range of "0-1". These pollens are then send to DC/DC converter. Power against each pollen is calculated. Pollen with the highest power is selected as pollen best "P_{best}". This set of five pollens will first go through the Local Pollination using Equation (7) and then Global Pollination using Equation (8). Power is calculated for these two sets and the two more pollen bests "P_{best}" are obtained.

Now the process of LCP will start. In this LCP process, the set of pollens received after Local Pollination will now go through the Global Pollination process and the set of pollens received after Global Pollination will go through the Local Pollination process. Two more set of pollens with two pollen bests "P_{best}" will be obtained at the end of LCP process. Five set of pollens with five "P_{best}" are obtained.

Using the "Hit and Trial" method it is found that, the Switching probability "P" equal to 0.2 provide the best results. A random number is generated and compared with switching probability for each pollen. If the "RN" is greater than "P", pollen will go through the Local Pollination else will go through the Global Pollination. Five set of pollens turns to Ten sets of pollens after this step with total Ten "P_{best}".

Pollen best "P_{best}" from the Ten "P_{best}" with the highest power is selected as a Global best "G_{best}". Flowchart of the proposed OFPA is presented in Fig. 4. Complete concept of the Optimized FPA is packed in Fig. 4.
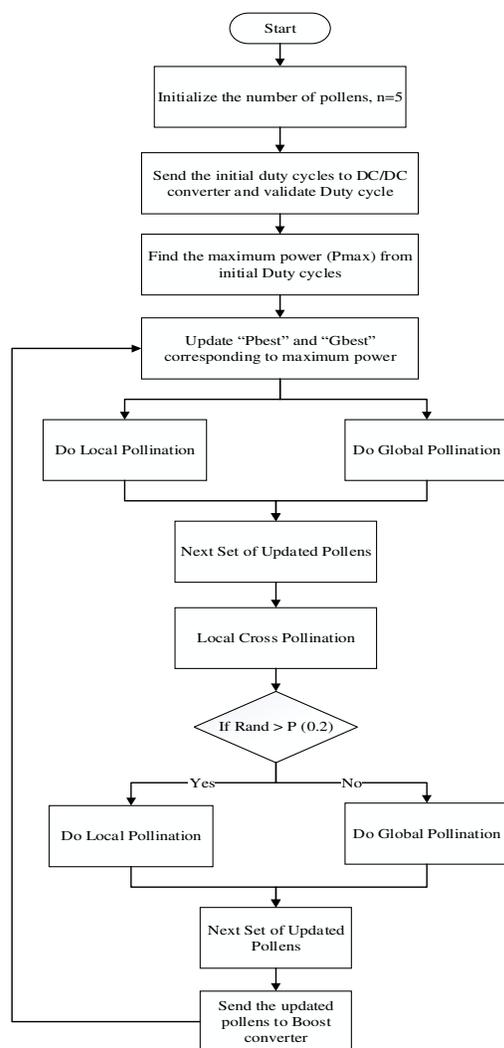
FIG. 4. FLOWCHART OF OPTIMIZED FLOWER POLLINATION ALGORITHM

6. SIMULATION AND RESULTS

Performance evaluation and comparison of OFPA with FPA is done in MATLAB/Simulink. Three different shading patterns discussed earlier in Case-1, Case-2 and Case-3, are used to verify the results. System configuration at which the algorithms are tested is, 64-bit Operating System, intel i3 Processor, and 4.00 GB RAM. Basic structure of the PV system with MPPT controller is displayed in Fig.5. PV module is connected to the DC-DC converter, which is controlled by MPPT and a DC-load is directly connected to the converter. The sample time among inputs (duty cycles) is set to 0.03-seconds for FPA as mentioned in [20].
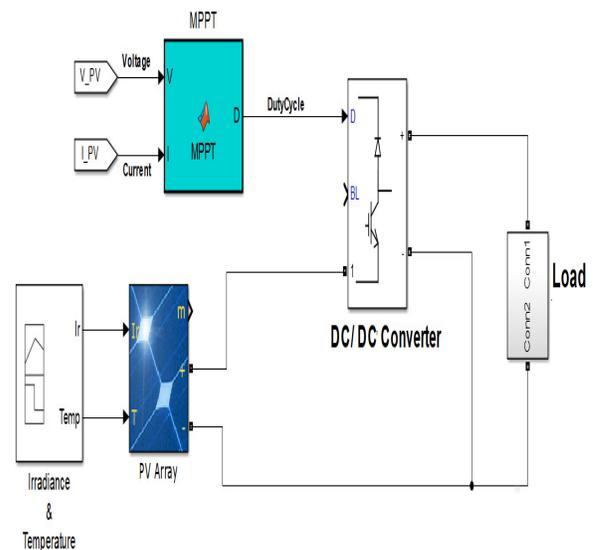
FIG. 5. PHOTOVOLTAIC SYSTEM'S STRUCTURE

6.1 Case-1: Zero Shading

In this case, where all the PV modules are receiving same illumination, there is only one peak power point in the P-V curve. Achieving MPP here, is an easy task for FPA and the OFPA. The P-V and current-voltage "I-V" characteristic curves of PV array under this zero-shading condition is displayed in Fig. 6.

The values at MPP in a P-V characteristic curve, displayed in Fig. 6 are 40-Volts, 3-Amperes and "120Watt" respectively. The OFPA technique has achieved the target of "120W" with 100% efficiency and zero oscillations and FPA is successful in

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extracting "119.2W" with the efficiency of 99.33% and without oscillations.
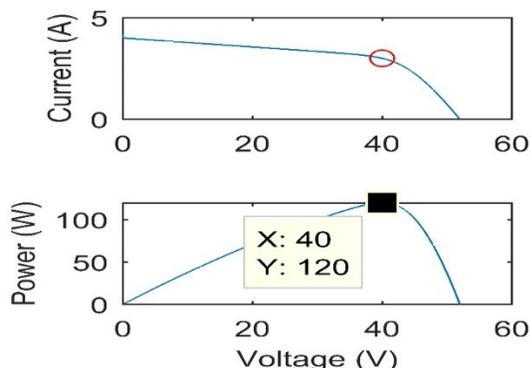
FIG. 6. GLOBAL I-V &P-V CHARACTERISTICS OF A PV ARRAY IN ZERO SHADING CONDITION

The extracted power and MPP tracking time of FPA and the OFPA are "119.2W in 0.75-seconds", and "120W in 0.247-seconds" respectively in a uniform or zero shading condition. It is evident from the results exposed in Fig. 7(a-b). that the OFPA outperforms the FPA in efficiency and accuracy. The OFPA algorithm has beaten the FPA algorithm in efficiency and tracking time in zero or uniform shading condition. The OFPA is 0.7% more efficient and 33% faster in tracking MPP than the FPA algorithm in zero or uniform shading condition.
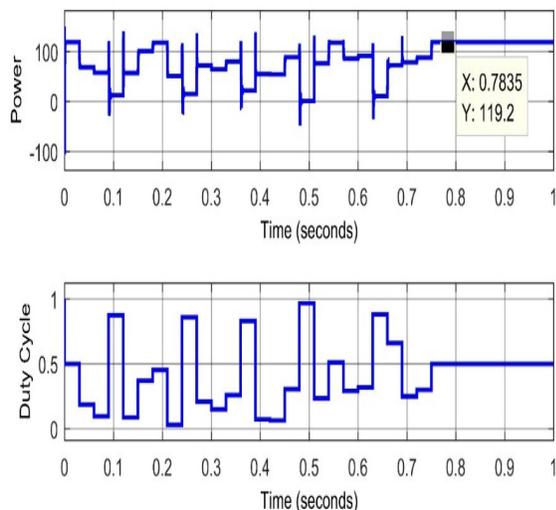
(a) FPA
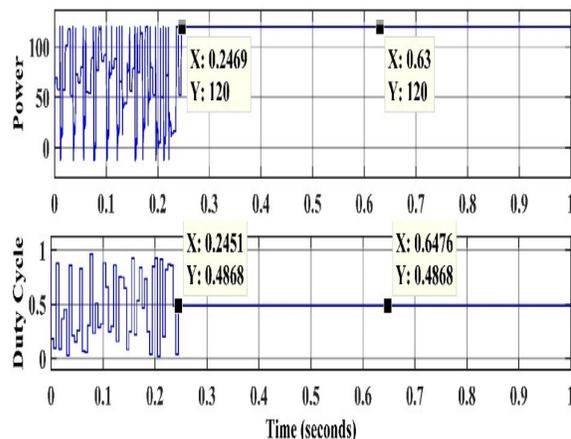
(b) OPTIMIZED FPA

FIG. 7. RESULTS OF FPA, AND OFPA ALGORITHM AT THE ZERO SHADING CONDITION.

6.2 Case-2: Weak Partial Shading

In case-2, weak partial shading is introduced. This creates two power peaks in the P-V curve of PV array. The P-V and I-V characteristic curves of a PV array for this case is displayed in Fig. 8.
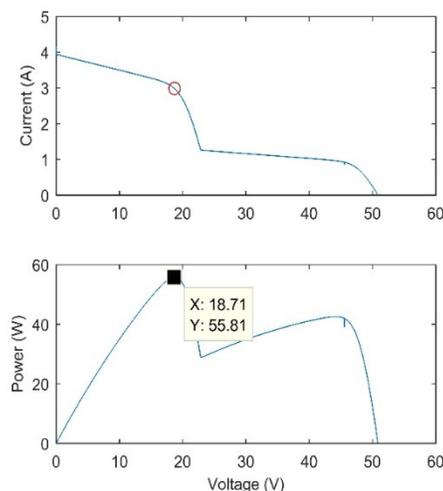
FIG. 8. GLOBAL I-V &P-V CHARACTERISTICS OF PV ARRAY IN WEAK PARTIAL SHADING CONDITION

The values of the three variables voltage (V), current (I) and power (P) at MPP in a P-V characteristic curve is displayed in Fig. 8 are 18.71-Volts, 2.983-Amperes and 55.81Watt respectively.

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The extracted power and tracking time of FPA and OFPA algorithms are "55.25W in 0.78-seconds", and "55.78W in 0.251-seconds" respectively, in weak partial shading condition. It is evident from the results revealed in Fig. 9(a-b) that, in weak partial shading condition the OFP out performs the FPA in efficiency and accuracy. The OFPA algorithm has beaten the FPA algorithm in efficiency and tracking time in weak shading condition. The OFPA is 0.97% more efficient and 32.2% faster in tracking GMPP than the FPA algorithm in zero or uniform shading condition.
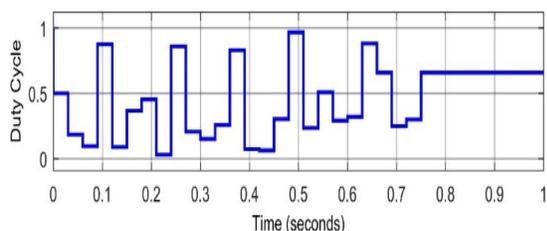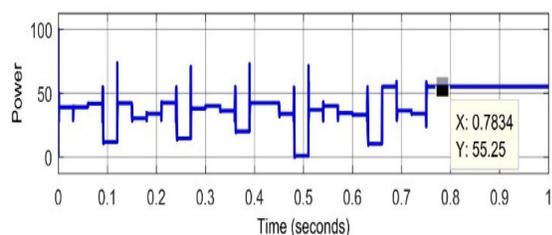
(A) FPA
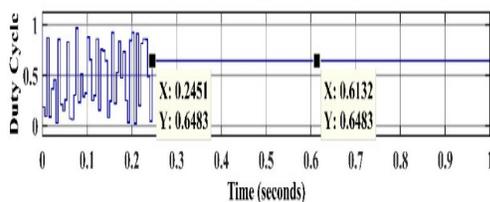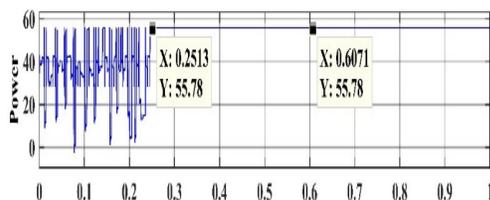
(B) OPTIMIZED FPA(TRACKING TIME AND POWER)
FIG. 9. RESULTS OF FPA AND PROPOSEDOPTIMIZED FPA ALGORITHM AT WEAK SHADING CONDITION.

6.3   Case-3: Strong Shading

In case-3, Strong partial shading is applied to PV array. This creates three power peaks in the P-V curve. The P-V and I-V characteristic curves of a PV array

under this strong SC is displayed in Fig. 10. It is very difficult to track the GMPP in this condition.
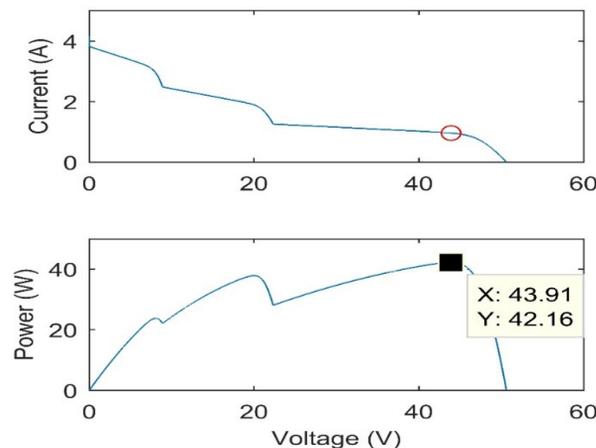
FIG. 10. GLOBAL I-V &P-V CHARACTERISTICS OF PV ARRAY IN STRONG PARTIAL SHADING CONDITION

The values of the three variables voltage (V), current (I) and power (P) at GMPP in a P-V characteristic curve displayed in Fig. 10 are 43.91-Volts, 0.96-Amperes and 42.16-Watt respectively.

The extracted power and tracking time of FPA and OFPA are "42.05W in 0.79-seconds", and "42.15W in 0.242-seconds" respectively, in strong partial shading condition. It is evident from the results presented in Fig.11(a-b) that the OFPA out performs the FPA in efficiency and accuracy in strong partial shading condition. The OFPA algorithm has beaten the FPA algorithm in efficiency and tracking time in strong shading condition. The OFPA is 0.24% more efficient and 30.6% faster in tracking GMPP than the FPA algorithm in zero or uniform shading condition.

A) FPA

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FIG. 11: RESULTS OF FPA AND PR
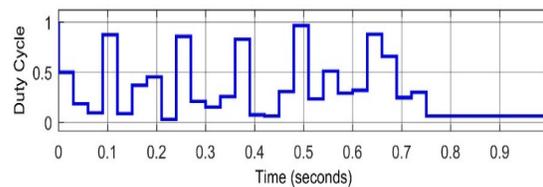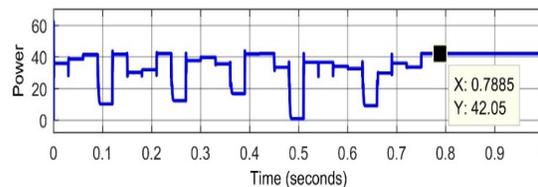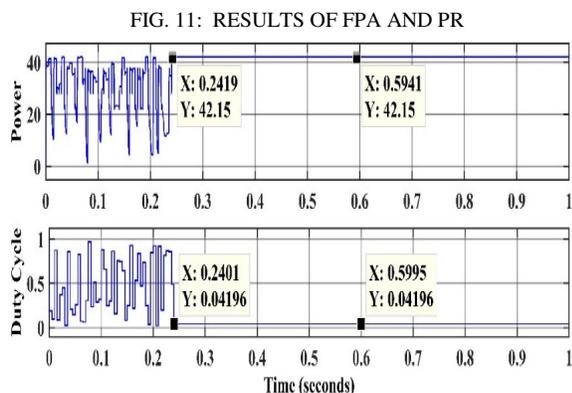
E) OPTIMIZED FPA (TRACKING POWER CONFIRMATION)
FIG. 11. RESULTS OF FPA AND PROPOSEDOPTIMIZED FPA ALGORITHM AT STRONG SHADING CONDITION.

7.   CONCEPTUAL VIEW OF FPA AND THE OFPA ALGORITHM

Conceptually the FPA and the OFPA can be compared at the following benchmarks, presented in the Table 1.

TABLE 2. CONCEPTUAL COMPARISON OF FPA AND OFPA ALGORITHMS

Benchmarks	FPA	Optimized FPA
No. of Pollens Generated	125	50
Switching Probability	0.8	0.2
No. of Pollens pass through Global Pollination	Less than Local	Confirm = 10 Less than Local (For last 25 pollens)
No. of Pollens pass through Local Pollination	More than Global	Confirm = 10 More than Global (For last 25 pollens)

It can be clearly seen in Table. 1, that the FPA is not utilizing the Local and Global Pollination in an efficient manner by providing a huge space (80%) to Local pollination only, by using P=0.8. Most of the pollens pass through Local Pollination in FPA and there is no balance between Local and Global Pollination. In the OFPA, Local and Global Pollination are balanced by passing minimum TEN pollens from each Pollination process. OFPA provide a chance to Local Pollination to search at Global positions for the remaining Twenty-Five pollens by setting P=0.2.

8.   COMPARISON

The results of FPA and OFPA for zero, partial weak and partial strong shadings are summarized in the Table 2. The Table 2. has summarized the performance evaluation of FPA and OFPA algorithms. It presents the comparison in terms of efficiency and tracking time for the three cases of partial shadings. The OFPA algorithm has proved it priority over FPA algorithm in efficiency and tracking time in three cases. Comparison results have proved OFPA algorithm a better choice for GMPP and MPP tracking under shading and non-shading conditions respectively.

8.1   Analysis of OFPA Algorithm for Partial Shading

The performance of OFPA has been checked for nil, weak and strong PSC separately. Performance test of OFPA undergoing case-1 to case-2 and then case-3 together is also performed. Rise and fall in illumination due to different actions like clouds, birds fallen leaf etc. is considered and simulated. Results are presented in Fig. 12.

TABLE 2. COMPARISON BETWEEN OFPA, AND FPA ALGORITHMS

Shading Patterns	Algorithms	P_MPP (w)	Rated Power (W)	Efficiency (%)	Tracking Time (Sec)	Efficiency Improvement by OFPA	Improvement in Tracking Time by OFPA
Case-1	OFPA	120	120	100	0.247	0.7%	33%
	FPA	119.2		99.3	0.75		
Case-2	OFPA	55.78	55.81	99.95	0.251	0.97%	32.2%
	FPA	55.25		98.99	0.78		
Case-3	OFPA	42.15	42.16	99.98	0.242	0.24%	30.6%
	FPA	42.05		99.74	0.79		

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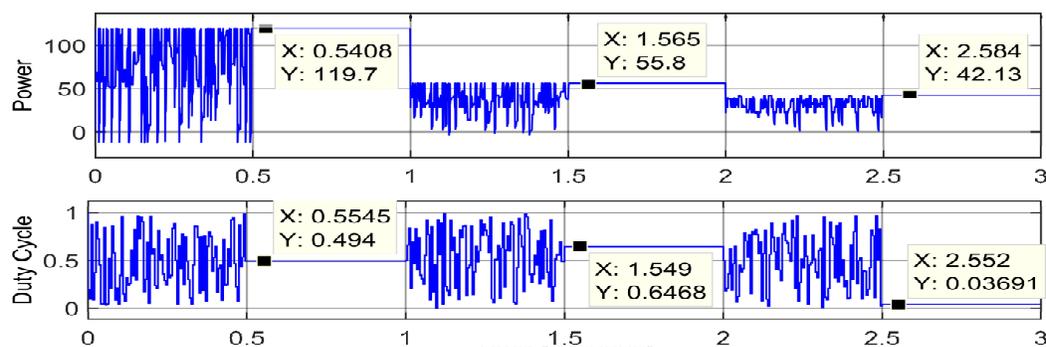
FIG. 12. COMBINE ANALYSIS OF CASE-1, CASE-2 AND CASE-3

Success story of OFPA can be clearly in Fig. 12. It starts with zero partial shading (Case-1), after 1-sec the PV array undergoes weak partial shading (Case-2), and after 2-sec the PV array experience strong partial shading condition (Case-3). In all three cases OFPA retains its performance in terms of GMPP tracking accuracy and efficiency. It proves that it can easily handle the change in weather conditions. It detects the change in weather (illumination or temperature) by observing the change in power output of PV array. It does not need any illumination or temperature sensors which also reduces the cost of PV system. Entering from zero shading to weak and from weak to strong partial shading could not affects the accuracy, efficiency and speed of OFPA algorithm in tracking GMPP. Performance analysis of OFPA undergoing three cases is summarized in Table 3.

TABLE 3.PERFORMANCE ANALYSIS OF OPTIMIZED FPAALGORITHM UNDERGOING THREE CASES

Cases	P_{MPP} (W)	Rated Power (W)	Efficiency (%)
1	119.7	120	99.75
2	55.8	55.81	99.98
3	42.13	42.16	99.93

9. CONCLUSION

An optimized FPA algorithm is Proposed for GMPP tracking in PSC. Various cases of zero shading, uniform shading, weak partial shading and strong partial shading are simulated and compared. The results have proved that, the optimized FPA algorithm performs better than the FPA algorithm in all shading and non-shading weather conditions. In the proposed "Optimized Flower Pollination" (OFPA) algorithm, the role of Global Pollination is efficiently utilized by introducing the concept of Local Cross Pollination (LCP). Additionally, the switching probability is set to "0.2" to optimize the role of local pollination process in tracking GMPP, to get efficient results. Optimized FPA is more efficient and accurate than the FPA algorithm. The optimized FPA algorithm successfully, efficiently and accurately achieved GMPP in record time in all weather conditions (zero shading, uniform shading, weak partial shading and strong partial shading).

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