MPPT of PV Systems under Partial Shaded Conditions using Flower Pollination Algorithm

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Abstract— **This paper reports the use of flower pollination algorithm (FPA) for maximum power point tracking (MPPT) in a partially shaded photovoltaic (PV) array. The proposed algorithm is very powerful in solving constrained and unconstrained optimization problems. The advantages of this algorithm are its fast convergence and robustness. The performance of the proposed algorithm is studied for different shading patterns in a PV array and its tracking performance is compared with that of the particle swarm optimization (PSO) algorithm. The performance of this algorithm is validated through simulation results.**

Keywords— Photovoltaic (PV) system, maximum power point tracking (MPPT), partial shading, flower pollination algorithm (FPA).

I. INTRODUCTION

The photovoltaic (PV) power generation has seen a fast growth leading to widespread use of solar energy. In order to extract the maximum available power from PV array and hence optimize its use, maximum power point tracking (MPPT) algorithms are employed. Tracking the maximum power point (MPP) under partially shaded conditions is a challenging task as there are multiple peaks in the P-V characteristics of the array. The commonly used MPPT algorithms based on the hill climbing technique fail in their performance under such conditions [1]-[3]. Many modified algorithms have been reported in the literature to track the MPP under partial shaded conditions [4]-[8]. However they are complicated and their tracking speed is low.

Recently there is a lot of focus on nature inspired algorithms due to its ability to solve large and complicated problems. These include genetic algorithm, ant and bee algorithms, swarm optimization algorithms, harmony search algorithm, firefly algorithm, bat algorithm, cuckoo search algorithm etc. [9]. Few of these algorithms have also been recently used to track the MPP under partial shaded conditions. The particle swarm optimization algorithm which is based on the social behavior of bird flocking has been extensively used in MPP tracking [10]-[13]. The bat algorithm, artificial bee colony algorithm, flashing firefly algorithm and cuckoo search algorithms have also been used as MPPT algorithm [14]-[17]. One of the recent nature inspired algorithm is flower pollination algorithm (FPA) which was proposed by Xin-She Yang in 2012 [18]. This is based on the pollination process of flowering plants.

In this paper the flower pollination algorithm has been used for MPPT application. The performance of flower pollination algorithm has been compared with the PSO algorithm for different shading patterns.

The paper is organized as follows. Section 2 describes the modeling of the PV array under partially shaded conditions. Section 3 describes the flower pollination algorithm. Section 4 discusses the application of flower pollination algorithm in MPP tracking. Section 5 discusses the simulation results and section 6 concludes the paper.

II. PV CHARACTERISTICS UNDER PARTIAL SHADING

To obtain the characteristics of a PV array under partial shading first a PV cell needs to be modeled. To do this a single diode model of a solar cell as shown in Fig. 1 has been used. The solar cell current is given by the following equation [19]-[20].

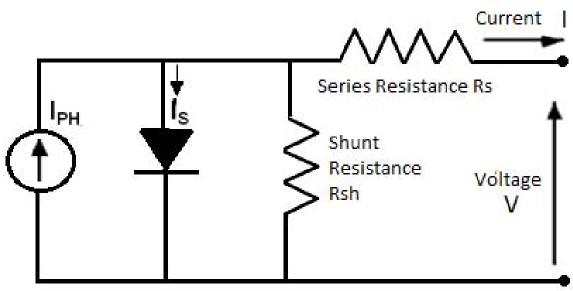

Figure 1. Single diode model of a PV cell

$$I = I_{PH} - I_S\left[e^{\left(\frac{q(V+IR_s)}{kT_C A}\right)} - 1\right] - \frac{(V+IR_S)}{R_{SH}} \qquad (1)$$

Where I_{PH} is the photo current or light generated current, I_S is the dark saturation current, q is the charge of an electron, k is the Boltzmann's constant, T_c is the temperature of the PV cell, A is the ideal factor whose value is dependent on the PV technology and R_{SH} and R_s are the series and shunt resistance

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respectively. When there are N_s cells connected in series and N_p cells connected in parallel to form an array, the solar array current is given by

$$I = N_P I_{PH} - N_P I_S [e^{\left(\frac{q\left(\frac{V}{N_S}+\frac{IR_s}{N_P}\right)}{kT_C A}\right)} - 1] - \frac{\left(\frac{N_P V}{N_S}+IR_S\right)}{R_{SH}} \qquad (2)$$

The above equation can be used to model a PV array under uniform irradiance. However when the array is partially shaded, the individual panels of the array are modeled using equation (1). The PV characteristics thus obtained are combined according to the array configuration and irradiation levels to obtain the PV characteristics of the array [21]. The PV characteristics obtained from the model for ten different shading patterns for a 3x3 array are shown in Fig. 2.

III. Flower Pollination Algorithm

Flower pollination algorithm is one of the recently developed metaheuristic algorithms. It is based on the pollination process in flowers which involves the transfer of pollen through pollinators such as insects and other animals. The two major forms of pollination are biotic and abiotic. Biotic pollination involves pollinators whereas abiotic pollination happens with the help of wind or water. Based on the physical proximity, pollination can be of two types: cross pollination and self pollination. Cross pollination occurs when fertilization occurs from the pollen of a different plant, while self pollination occurs from the pollen of the same flower or different flower of the same plant. Pollinators like honeybees visits flowers of same species knowing the availability of nectar in those species. Such flower constancy is helpful in maximizing the pollen transfer to the same species of flower and thus its reproduction. Based on the above characteristics of the flower pollination process, the flower pollination algorithm (FPA) is developed with the following rules and assumptions:

1. Biotic and cross-pollination happens over a long distance and hence is considered as global pollination. The movement of the pollinators is approximated using Levy flights.
2. Abiotic and self-pollination are considered as local pollination.
3. Flower constancy is taken as the reproduction possibility and is proportional to matching between the two flowers involved.
4. A switch probability $p \in [0,1]$ decides the occurrence of local and global pollination.
5. For simplicity of the algorithm it is assumed that each plant has only one flower and each flower has only one pollen gamete which is equivalent to the solution .

The two important things in the algorithm are the global pollination and the local pollination. Global pollination occurs over long distances through pollinators like insects. Based on assumption 5 and rules 1 and 3, global pollination can be written mathematically as follows

$$x_i^{t+1} = x \qquad (3)$$

Where is the solution vector at iteration t and is the best solution in the current generation. The parameter L is the step size and is drawn from Levy's distribution. Local pollination can be represented as follows

$$x_i^{t+1} \qquad (4)$$

Where and represent randomly chosen flowers of the same species from limited neighborhood and is a random number between 0 and 1. Based on the above assumptions and rules the flower pollination algorithm is formulated with the following steps:

1. An initial population of n flowers is chosen. $x=\{x_1, x_2, \ldots x_n\}$
2. A switch probability $p \in [0,1]$ is defined
3. The best solution is computed in the current population.
4. A random number r between 0 and 1 is generated.
5. If r is less than the switch probability p, a step vector L is drawn from Levy's distribution and global pollination is performed using equation (3).
6. Otherwise a uniform random number between 0 and 1 is generated, two solutions j and k are randomly selected and local pollination is performed using equation (4).
7. Steps 4 to 6 are repeated for all n flowers in the population.
8. If current iteration t is less than the maximum iteration, steps 2 to 7 are repeated for the next generation.

This algorithm can be used for maximum power point tracking and is discussed in the next section.

IV. Application of FPA for MPP Tracking

The flower pollination algorithm discussed in the last section can be used for MPP tracking in a PV array under partial shading. The initial population of n flowers is chosen as the reference voltage V as follows

$$x_i^t = \qquad (5)$$

The flower pollination algorithm is implemented in the following steps.

Step 1: Initialization: The initial population of flowers is chosen as reference voltages between 20% and 85% of the open circuit voltage V_{OC}. The parameters in the algorithm are initialized according to Table I.

Step 2: Evaluation: For each flower in the population (reference voltage), pulse is generated and given to the converter one at a time and the power is measured. The best solution is found where the power is maximum.

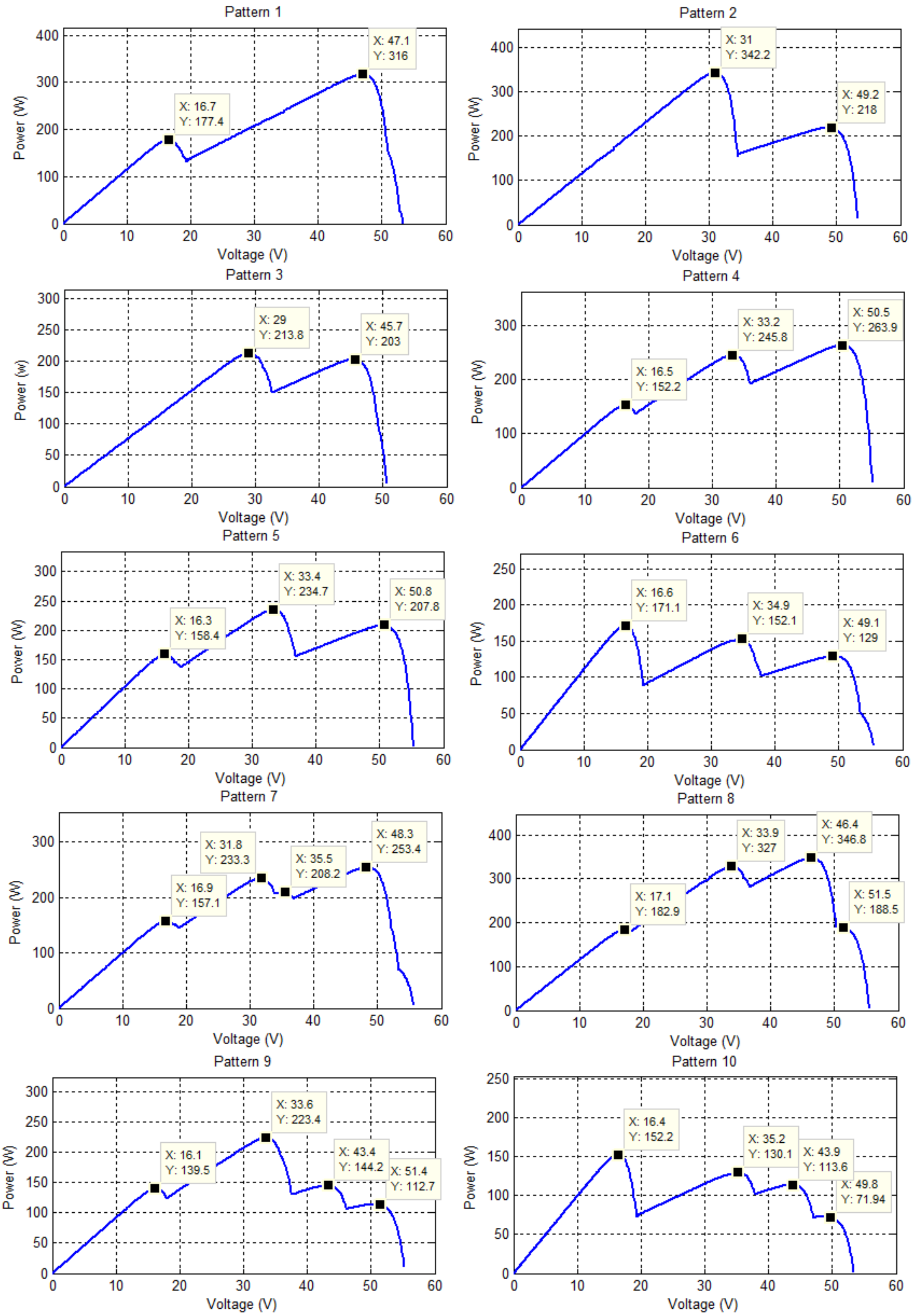

Figure 2. PV characteristics of a 3x3 PV array for ten shading patterns

Step 3: Pollination: A random number r is generated and compared with the probability p. If r < p, the next generation is computed by global pollination using equation (3). Otherwise a random number is generated and two flowers j and k are chosen randomly from the current generation to perform local pollination using equation (4) to compute the next generation. This is done for all flowers in the current generation.
Step 4: Convergence check: The algorithm is said to converge when maximum number of iterations are reached. If convergence criterion is satisfied, the best solution is output. Otherwise steps 2 and 3 are repeated for flowers in the new generation.

The simulation results using this algorithm is presented and compared with the PSO algorithm in next section.

V. Results and Discussion

A 3x3 array of solar panels connected to a DC-DC boost converter as shown in Fig. 3 was simulated in MATLAB to evaluate and compare the performance of the flower pollination algorithm with PSO algorithm for different shading patterns shown in Fig. 2. Code was written in MATLAB to implement the flower pollination algorithm and the PSO algorithm. The various parameters in the two algorithms and the values assigned to them are tabulated in Table I.

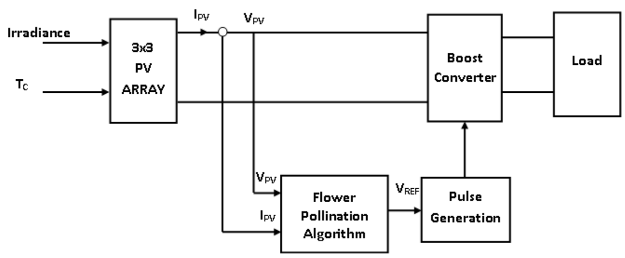

Figure 3. Block diagram for MPPT control using flower pollination algorithm

Fig. 4 (a) and (b) show the power extracted from the array, the array voltage and the array current with flower pollination algorithm and PSO algorithm respectively. Different shading patterns are applied at t=0s, 3s and 6s. As seen in Fig. 4 (a) and (b), the power extracted from the array closely matches with the maximum available power as obtained from the model. However the oscillations in the power extracted and the current is less with flower pollination algorithm.

Table II shows a comparison between the performances of the two algorithms for the ten shading patterns in Fig. 2. The reference voltage and maximum power as obtained from the model is also given in the table. For both the algorithms the table gives the panel operating voltage and the power extracted for that shading pattern. It is observed that the flower pollination algorithm is capable of detecting the global peak irrespective of its position in the PV curve.

TABLE I
PARAMETERS FOR FLOWER POLLINATION AND PSO ALGORITHM

Parameters	Flower Pollination Algorithm		PSO Algorithm	
1	n	6	n	6
2	pa	0.8	C_1	2
3	l	1.5	C_2	1
4	s	0.8	w	0.4

VI. Conclusion

A solar array model has been developed using the basic equations to study the effect of variations in irradiations and cell temperature. To study the effects of partial shading a generalised model of a solar array under partial shading has been developed using MATLAB Simulink. The developed model is verified for various shading patterns.A 3x3 PV array and a boost converter has been modeled and simulated in MATLAB/Simulink. The performance of the flower pollination algorithm has been evaluated and compared for ten different shading patterns. It is found that the flower pollination algorithm, like the PSO algorithm is capable of extracting the maximum available power from the array during partial shading conditions. Further, the results also show that the flower pollination algorithm converges faster.

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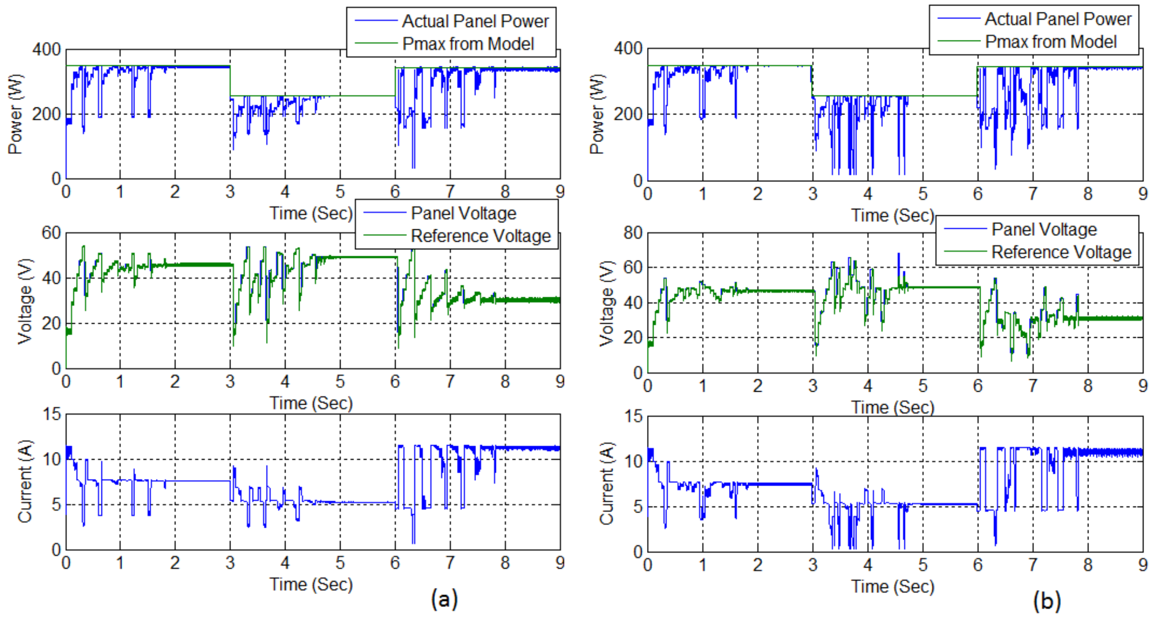

Figure 4. Power extracted from PV array, array voltage and array current using (a) flower pollination algorithm and PSO algorithm

TABLE II
COMPARISON OF PANEL VOLTAGE AND POWER EXTRACTED WITH FLOWER POLLINATION AND PSO ALGORITHM

Shading Pattern No.		1	2	3	4	5	6	7	8	9	10
As obtained from the model	MPP Voltage (V)	47.1	31	29	50.5	33.4	16.6	48.3	46.4	33.6	16.4
	MPP Power (W)	316	342.2	213.8	263.9	234.7	171.1	253.4	346.8	223.4	152.2
Flower Pollination Algorithm	Panel Voltage (V)	46.68	31.18	28.49	50.50	33.75	17.14	48.92	45.93	33.38	15.83
	Power Extracted (W)	315.6	342.1	213.4	263.8	234.5	170.8	253.3	346.4	223.3	151.9
PSO Algorithm	Panel Voltage (V)	47.05	31.15	28.65	50.34	33.24	16.2	48.66	46.6	33.6	16.39
	Power Extracted (W)	315.9	339.7	212.7	263.8	234.2	169	253.3	346.9	223.2	150.1

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