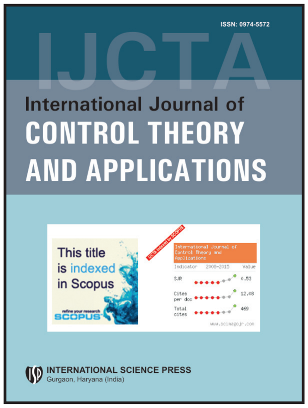

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 16 • 2017

A Forward Backward PSO Based MPPT Algorithm for PV System under Partial Shading Condition

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Abstract: Due to inaccuracy associated with traditional methods in global maximum power point tracking (MPPT) under partial shading conditions of a PV system, Meta-heuristic optimization algorithms attained as an attractive solution. One of the popular Meta-heuristic algorithm, PSO, is implemented for MPPT problem under partial shading conditions by many authors in the literature. But main drawback associated with conventional PSO method is inconsistent tracking of global MPP due to random initialization of population and it requires more computational time for tracking MPP as the population size is increased. In order to overcome this problem, an improved PSO MPPT algorithm i.e., Forward Backward PSO (FBPSO) is proposed in this paper. A detailed mathematical modeling of 8S PV array system under partial shading conditions and implementation of proposed FBPSO for MPPT is also presented in this paper. The proposed FBPSO MPPT algorithm is coded in MATLAB programming environment and simulations are carried at four different partial shading conditions and results are analyzed and presented. The results of the proposed algorithm are compared with conventional PSO and Perturb and Observe MPPT algorithms. The results show that proposed method is superior in tracking global MPP compare to other methods.

Keywords: Forward Backward PSO algorithm; Maximum power point tracking; Photovoltaic system; Partial shaded condition; Single diode model.

1. INTRODUCTION

Due to larger area, partial shaded condition (PSC) is most common phenomenon in photovoltaic (PV) system. To harvest maximum amount of solar energy, PV system should be operated at its maximum power point under uniform shading and Partial shading condition. The characteristics of the PV system exhibit single MPP under uniform shading condition, but when PV system is subjected to PSC it has multiple MPPs due to bypass diode operation across the shaded modules [1].

Traditional MPPT techniques like Perturb and Observe (P&O), Incremental Conductance (INC) and Hill Climbing (HC) fail to track global MPP under Partial shading condition of PV system [2, 3]. There are stochastic methods like ANN and Fuzzy based MPPTs that can track global MPP but these techniques require proper training and rule bases [4,5].

This makes several authors to develop MPPT techniques based on meta-heuristic optimization algorithms [6]. Out of all optimization algorithms, Particle swarm optimization (PSO) algorithm developed by Kennedy et. al.,[7] was most implemented in the field of solar PV maximum power tracking [8-15].

These PSO based algorithms differ in terms of population initialization, settling time, speed and decision variable employed. Though PSO guarantee global MPP under PSC, it has certain disadvantages like larger settling time and larger exploration of search space [16].

In general size of the population decides the accuracy and time for tracking MPP. The larger population size gives more accurate solution with larger time for tracking and the smaller population size decreases the time for tracking with a compromise in accuracy. This is very common disadvantage in all optimization algorithms. In case of MPP tracking of PV system, both accuracy and speed of tracking are having greater importance to attain highest benefit from the PV system. In order to address the above problem, In this paper a modified PSO MPPT algorithm i.e., Forward and Backward PSO MPPT algorithm is proposed. In which the initial search starts from both forward and backward direction and best initial estimates obtained are used in the further search process to reduce the tracking time.

2. MODELING OF PHOTOVOLTAIC SYSTEM

2.1. PV Module

Single diode model (SDM) of a PV module used in modeling of PV system is depicted in Figure 1[17].

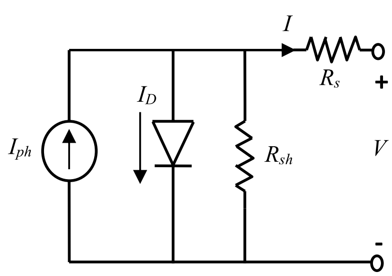

Figure 1: Single diode model of PV module

By applying KCL for Figure 1, Output current of the PV module can be deduced as:

$$\mathrm{I} = \mathrm{I_{PV}} - \mathrm{I_D} - \left(\frac{\mathrm{V} + \mathrm{IR}_s}{\mathrm{R}_{sh}}\right) \tag{1}$$

where, V is PV Output Voltage, I is PV Output Current, I_{PV} is Photo current of PV module, I_D is Current flowing through diode, R_s is Series resistance and R_{sh} is Shunt resistance.

$$\mathrm{I_{PV}} = (\mathrm{I_{PV\_STC}} + k_i \Delta \mathrm{T}) \frac{\mathrm{G}}{\mathrm{G_{STC}}} \tag{2}$$

where, I_{PV_STC} is Photo current of PV module at standard test conditions (STC), G is Surface irradiation, G_{STC} is Surface irradiation at STC, T is Panel operating temperature (in Kelvin), ΔT is Temperature difference between T and T_{STC} (in Kelvin) and k_i is Short-circuit current constant.

$$\mathrm{I_D} = \mathrm{I_0}\left[e\left(\frac{q(\mathrm{V} + \mathrm{IR}_s)}{\mathrm{N}_s\mathrm{KTA}}\right) - 1\right] \tag{3}$$

where, I_o is Diode saturation current, N_s is Number is cells in series, A is Diode ideality factor, q is Charge of an electron (1.6×10^{-19} C), K is Boltzmann's constant (1.38×10^{-23} N-m/K).

$$I_o = I_{o\_STC} \left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{AK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \tag{4}$$

$$I_{o\_STC} = I_{o\_STC} = \frac{I_{sc\_STC}}{\exp\left(\frac{qV_{oc\_STC}}{N_s AKT_{STC}}\right) - 1} \tag{5}$$

where, I_{o_STC} is Diode saturation current at STC, I_{sc_STC} is Short circuit current of PV module at STC, V_{oc_STC} is Open circuit voltage of PV module at STC.

The equation for output current of the PV module is given as:

$$I = I_{PV} - I_0\left[e\left(\frac{q(V + IR_s)}{N_s KTA}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \tag{6}$$

Here (6) is a function of two unknown variables V, I and it can be solved used Newton's iterative technique.

$$f(I, V) = I_{PV} - I - I_0\left[e\left(\frac{q(V + IR_s)}{N_s KTA}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) = 0 \tag{7}$$

2.2. Partial Shaded Condition modeling

(i) Partial Shaded Sub Module

Partial shaded sub module is formed when two groups of PV cells connected in series inside a module are subjected to different irradiance levels with only one bypass diode connected across the module. The circuitry for partial shaded sub module is depicted in Figure 2 [18].

If a sub module consisting of r number of cells in series in which s number of shaded cells receive irradiance G_1 and $(r - s)$ number of cells receive irradiance G_2. The PV parameters are calculated from (8), output current and voltage can be calculated from (9).

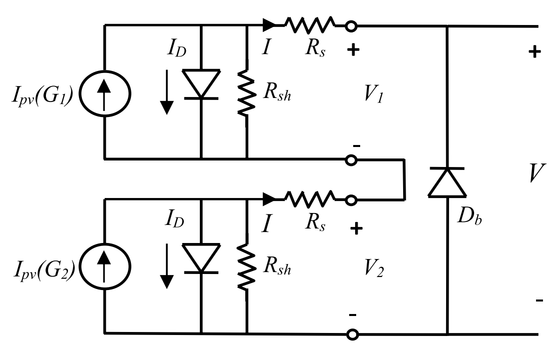

Figure 2: Partial shaded Module

$$I_{pv1} = I_{pv}(G_1), I_{pv2} = I_{pv}(G_2), N_{s1} = sN_{s1}, N_{s2} = (r - s)\, N_{s2} \tag{8}$$

where, subscripts 1 and 2 represents cells with G_1 and G_2 irradiance respectively

$$I = \min(I_1, I_2),\ V = \sum_{i=1}^{2} V(i) \tag{9}$$

(ii) Partial Shaded Array Modeling

Output power of the PV array is of more complicated form when subjected to PSC due to bypass diode operation across the shaded modules. The output current and voltage at array terminal with *n* modules can be obtained by (10) and (11).

$$I = \begin{cases} I_{PV}(G_n) - I_0\left[e^{\frac{q(V_{mn}+IR_s)}{N_s AKT}} - 1\right] - \left(\dfrac{V_{mn}+IR_s}{R_{sh}}\right), & I > I_{PV_{n-1}} \\ I_{PV}(G_{n-1}) - I_0\left[e^{\frac{q(V_{mn-1}+IR_s)}{N_s AKT}} - 1\right] - \left(\dfrac{V_{mn-1}+IR_s}{R_{sh}}\right), & I_{PV_{n-2}} < I < I_{PV_{n-1}} \\ I_{PV}(G_1) - I_0\left[e^{\frac{q(V_1+IR_s)}{N_s AKT}} - 1\right] - \left(\dfrac{V_1+IR_s}{R_{sh}}\right), & I < I_{PV_1} \end{cases} \tag{10}$$

$$V = \begin{cases} V_{mn} & I > I_{PV_{n-1}} \\ V_{mn} + V_{mn-1}, & I_{PV_{n-2}} < I < I_{PV_{n-1}} \\ V_{mn} + V_{mn-1} + \ldots + V_1, & I < I_{PV_1} \end{cases} \tag{11}$$

3. PROPOSED FBPSO ALGORITHM

3.1. Overview of FBPSO Algorithm

In conventional PSO algorithm, the population of particles is initialized randomly over the entire search space between the maximum and minimum limits. In FBPSO, half of the population of particles is initialized in one half of the search space using (12) and other half of the population is distributed in the second half using (13):

$$\text{PopF} = a + (b - a)\ \text{rand} \tag{12}$$

$$\text{PopB} = a + b - \text{PosF} \tag{13}$$

where, a and b are the maximum and minimum limits of decision variable, PopF and PopB are the forward and backward initialization of population.

In FBPSO, reduced population of particles is involved in the search process. The best particles are obtained by comparing the fitness values of successive forward and backward particles. The particles thus obtained are involved in the search process.

The position and velocity updating of particle *i* can be modeled as:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{14}$$

$$v_i^{k+1} = wv_i^k + c_1 r_1 \{P_{\text{best},i} - x_i^k\} + c_2 r_2 \{G_{\text{best}} - x_i^k\} \tag{15}$$

where, k is the current iteration, w is inertia weight, c_1 and c_2 are learning parameters (cognition and social parameters), r_1, r_2 are random numbers, $P_{best,\,i}$ is personal best position of particle i, G_{best} is best position of the particle in entire population.

Here w is updated over the course of iterations using (16) [19].

$$w = w_{max} - (w_{max} - w_{min})\left(\frac{k}{k_{max}}\right) \tag{16}$$

3.2. Application of FBPSO for MPPT

For MPPT, an indirect control considering objective function to be maximized as PV output power and voltage as decision variable is employed.

The objective function for MPPT is modeled as:

Maximize: $P(V_i)$ (17)

Subjected: $0.1\ V_{oc,\,A} \le V_i \le 0.9\ V_{oc,\,A}$ (18)

where, V_i is the voltage particle and $V_{oc,\,A}$ is Open circuit voltage of PV array. Here in FBPSO, initialization of population of voltage vector for uniform shading condition with one MPP and for PSC with two MPP on power-voltage characteristic is depicted in Figure 3.

Here population size is taken same as the number of modules in series in an array. The detailed methodology for tracking MPP using FBPSO are depicted in Figure 4. The parameters of the proposed algorithm are given in Table 1.

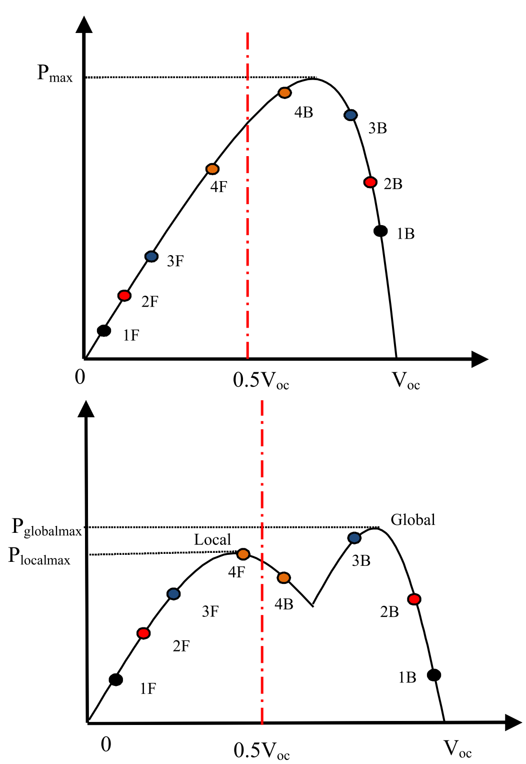

Figure 3: Population initialization in FBPSO

Table 1
Parameters of Proposed FBPSO method

Parameter	*Proposed FBPSO*
Initial Population (Voltage)	Between 10% to 90% of V_{oc}
N_p	8
c_1	2
c_2	2
w_{min}	0.1
w_{max}	1.0
Max number of iterations (k_{max})	100
Termination criterion	Max number of iterations

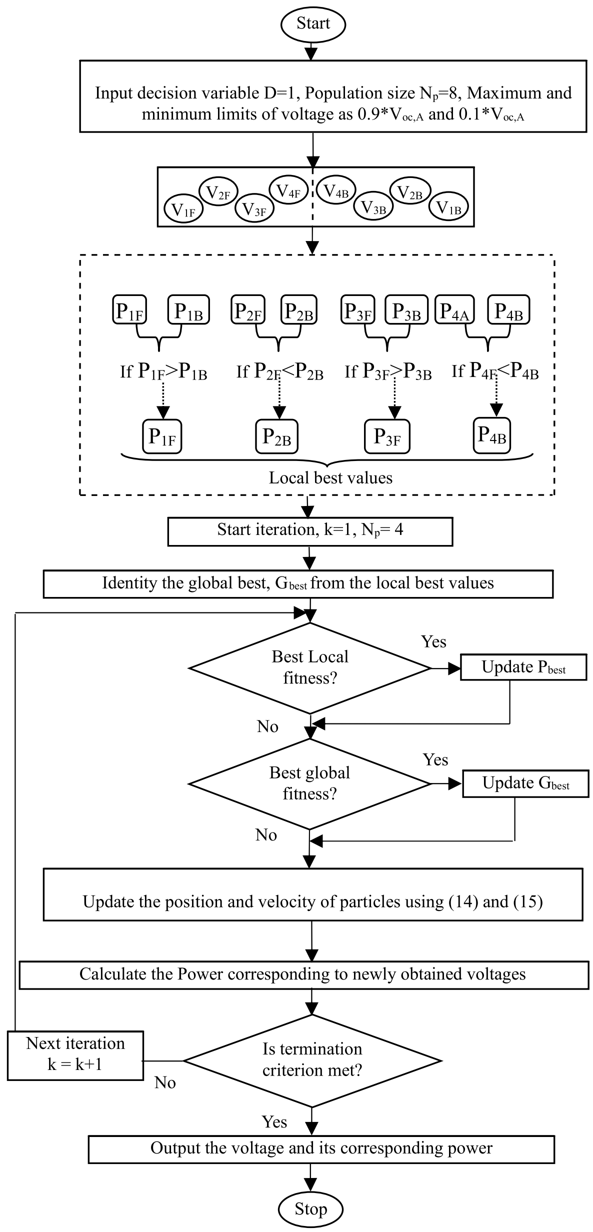

Figure 4: Flowchart for FBPSO MPPT

4. RESULTS AND COMPARISON

In order to analyze the performance of proposed MPPT algorithm, simulations are performed on 8S PV array configuration for different shading patterns. The specifications of the PV module used in modeling the PV system are given in appendix.

The shading patterns in watt/m^2 of 8S PV configuration are

1. $G_1, \ldots, G_8 = 1000$
2. $G_1, \ldots, G_4 = 1000, G_5, \ldots, G_8 = 600$
3. $G_1, G_2 = 1000, G_3, G_4 = 800, G_5, G_6 = 600, G_7, G_8 = 200$
4. $G_1 = 1000, G_2 = 900, G_3 = 800, G_4 = 700, G_5 = 600, G_6 = 500, G_7 = 400, G_8 = 300$

The Power-Voltage (P-V) characteristics of the PV array subjected to these four shading patterns are depicted in Figure 5. For uniform shading pattern (pattern 1), PV curve exhibits only one MPP. While in case of other patterns the PV curve exhibit multiple MPPs due to bypass diode operation across shaded modules. This makes the MPP tracking more complex for traditional MPP techniques.

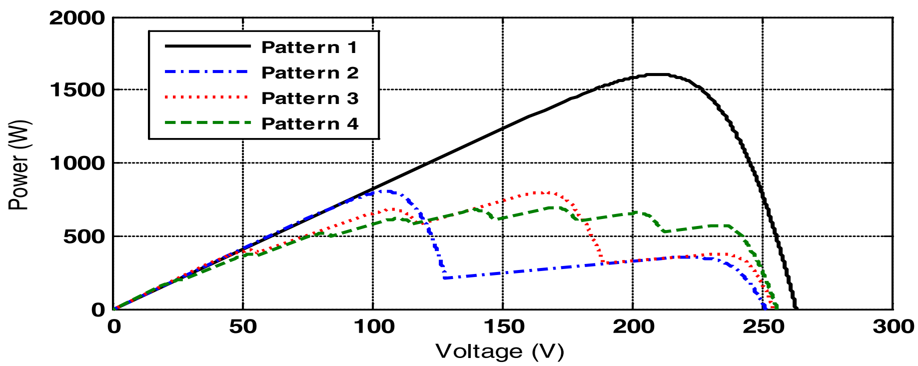

Figure 5: Power-Voltage characteristics of 8S PV configuration for different shading patterns

The tracking curves of FBPSO MPPT of 8S PV configuration for pattern 1 are depicted in Figure 6. It is noticed maximum power tracked by proposed algorithm is 1604.9 W with a tracking time of 2.9 s.

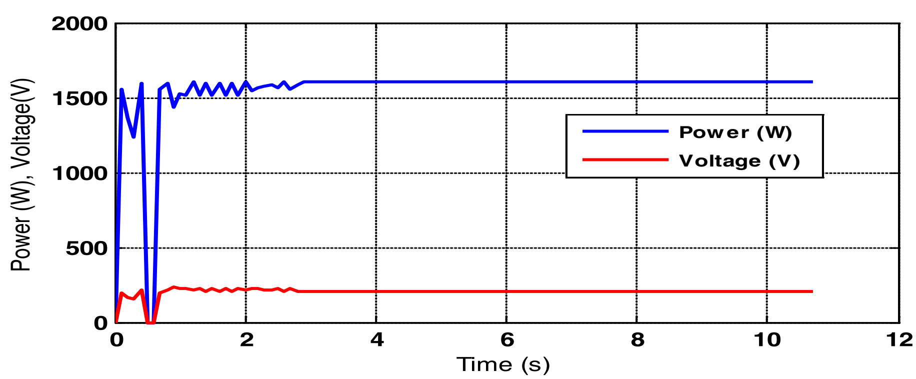

Figure 6: Tracking curves of 8S PV configuration for pattern 1

The tracking curves for pattern 2 are shown in Figure 7. It is observed that the proposed algorithm tracks global MPP of 1045.5 W with tracking time 3.3 s.

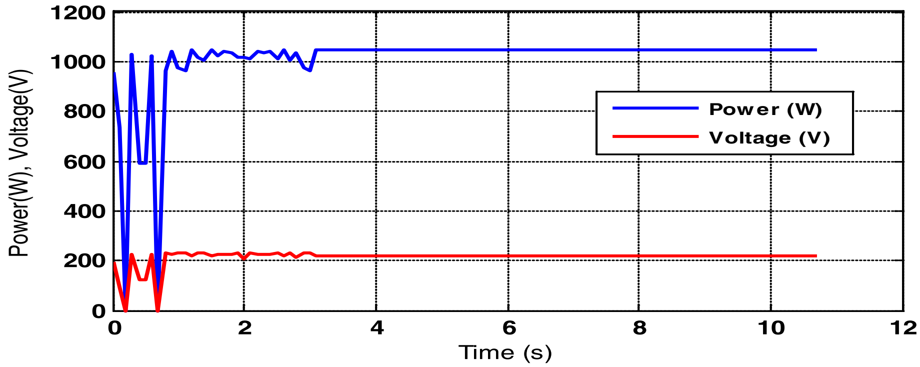

Figure 7: Tracking curves of 8S PV configuration for pattern 2

Similarly the tracking curves for pattern 3 and 4 are given in Figure 8 and Figure 9. It is clear that the proposed algorithm tracks the global MPP of 800.28 W and 691.26 W with tracking times 3.92 s and 3.81 s for pattern 3 and pattern 4 respectively.

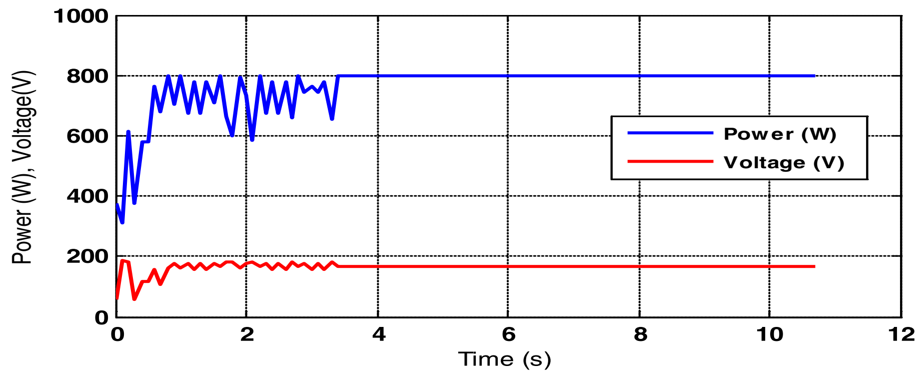

Figure 8: Tracking curves of 8S PV configuration for pattern 3

The performance comparison between proposed FBPSO, Conventional PSO and P&O algorithms in tracking exact MPP for different shading patterns are represented in Table 2. Here tracking efficiency is presented as ratio of the maximum power extracted by algorithm to maximum power from the PV curve. From Table 2, it is clear that proposed FBPSO has slightly higher efficiency than Conventional PSO algorithm and superior tracking efficiency over P&O algorithm for all shading patterns. Both FBPSO and Conventional PSO track the global MPP, but FBPSO has less tracking time than Conventional PSO due to less population involved in search process. While P&O algorithm converges in less time but fails to guarantee global MPP and it traps at the local MPP except for uniform shading pattern 1.

Table 2
Performance Comparison of Proposed FBPSO, Conventional PSO and P&O MPPT Methods

PV configuration	*Shading pattern*	*Tracking method*	*PV power (W)*	*PV voltage (V)*	*Tracking time (s)*	*Tracking speed (steps)*	*Maximum power from P-V curve (W)*	*Tracking efficiency (%)*
8S		FBPSO	1604.9	209.78	2.9	29		99.99
	1	CPSO	1604.9	209.78	5.5	55	1604.9	99.99
		P&O	1604.5	209.5	1.9	19		99.97
		FBPSO	1045.5	219.84	3.3	33		99.99
	2	CPSO	1044.6	220.14	5.8	58	1045.7	99.89
		P&O	802.5	105	1.6	16		76.74

PV configuration	*Shading pattern*	*Tracking method*	*PV power (W)*	*PV voltage (V)*	*Tracking time (s)*	*Tracking speed (steps)*	*Maximum power from P-V curve (W)*	*Tracking efficiency (%)*
		FBPSO	800.28	166.34	3.6	36		99.99
	3	CPSO	792.67	168.18	5.9	59	800.28	99.04
		P&O	401.5	52.5	1.1	11		50.16
		FBPSO	691.26	170.56	3.9	39		99.99
	4	CPSO	677.55	139.71	7.2	72	691.28	98.01
		P&O	374.5	53	0.9	9		54.17

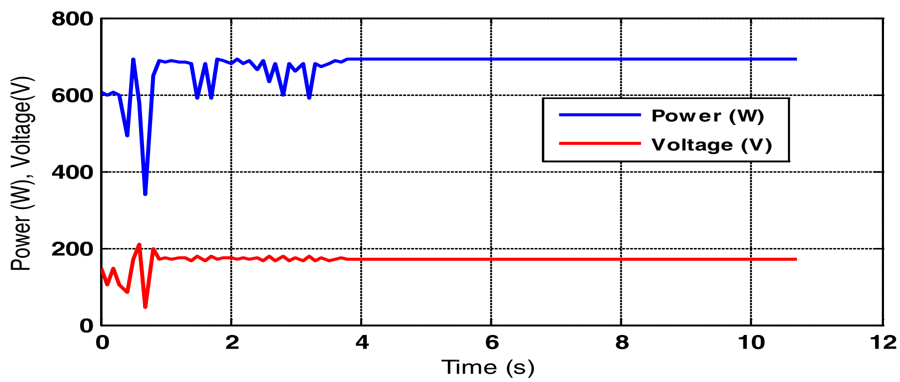

Figure 9: Tracking curves of 8S PV configuration for pattern 4

The bar chart comparative analysis between the three algorithms for all shading patterns in terms of maximum power extraction and speed of tracking are represented in Figure 10 and Figure 11.

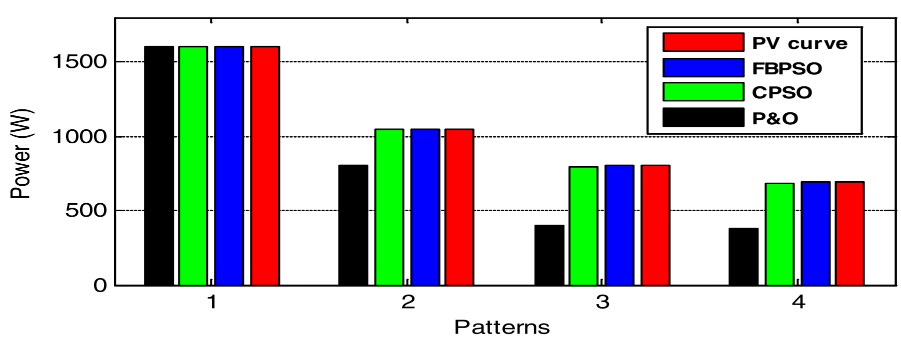

Figure 10: Maximum power extracted by FBPSO, Conventional PSO and P&O MPPT algorithms

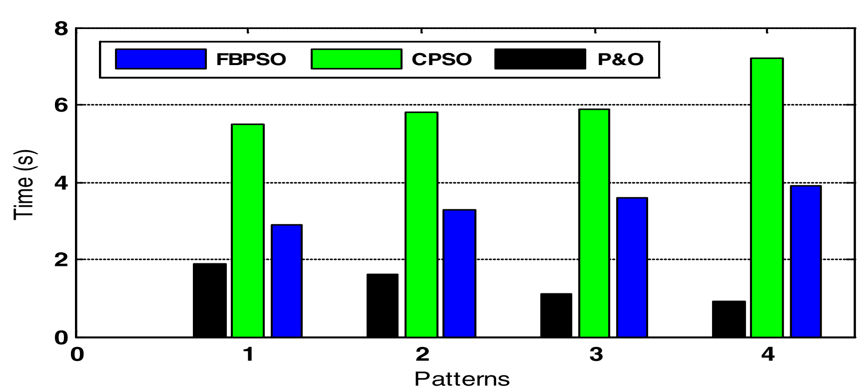

Figure 11: Tracking Time of FBPSO, Conventional PSO and P&O MPPT algorithms

5. CONCLUSION

The Power-Voltage characteristics for different shading patterns of 8S PV configuration indicate the complexity of tracking of global MPP under PSC due to high nonlinearity. The tracking curves for different patterns indicate the efficacy of proposed algorithm in tracking exact MPP under both uniform and partial shaded condition. The proposed algorithms track the exact MPP with more accuracy than Conventional PSO and P&O due to best particle involvement in the search process and less population involvements makes search process faster. These features makes the proposed algorithm adaptable for MPP tracking of PV system subjected to PSC in less time without compromising the accuracy. The analytical performance clearly evince the supremacy of proposed algorithm over Conventional PSO and P&O MPPT algorithms.

Appendix

Specifications of PV module at Standard Test Conditions

Maximum power (P_{mp})	200 W
Open circuit voltage (V_{oc})	32.9 V
Short circuit current (I_{sc})	8.21 A
Maximum power Voltage (V_{mp})	26.3 V
Maximum power current (I_{mp})	7.61 A
Voltage temperature coefficient (k_v)	-1.23×10^{-1} V/ºC
Current temperature coefficient (k_i)	3.18×10^{-3} A/ºC

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