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An improved search ability of particle swarm optimization algorithm for tracking maximum power point under shading conditions

Introduction. *Extracting maximum possible power from solar energy is a hot topic of the day as other sources have become costly and lead to pollution.* ***Problem.*** *Dependency on sunlight for power generation makes it unfeasible to extract maximum power. Environmental conditions like shading, partial shading and weak shading are the major aspect due to which the output of photovoltaic systems is greatly affected. Partial shading is the most known issue.* ***Goal.*** *There have been many proposed techniques and algorithms to extract maximum output from solar resources by use of photovoltaic arrays but every technique has had some shortcomings that couldn't serve the complete purpose.* ***Methodology.*** *Nature inspired algorithms have proven to be good to search global maximum in a partially shaded multipeak curve which includes particle swarm optimization, artificial bee colony algorithm, and flower pollination algorithm.* ***Methods.*** *Particle swarm optimization algorithm is best among these in finding global peaks with less oscillation around maximum power point, less complexity, and easy to implement nature. Particle swarm optimization algorithm has the disadvantage of having a long computational time and converging speed, particularly under strong shading conditions.* ***Originality.*** *In this paper, an improved opposition based particle swarm optimization algorithm is proposed to track the global maximum power point of a solar photovoltaic module. Simulation studies have been carried out in MATLAB/Simulink R2018a.* ***Practical value.*** *Simulation studies have proved that opposition based particle swarm optimization algorithm is more efficient, less complex, more robust, and more flexible and has better convergence speed than particle swarm optimization algorithm, perturb and observe algorithm, hill climbing algorithm, and incremental conductance algorithm.* References 24, tables 4, figures 12.

Key words: **conventional particle swarm optimization, maximum power point, opposition based particle swarm optimization algorithm.**

Вступ. *Отримання максимально можливої потужності із сонячної енергії є надзвичайно актуальним наразі, оскільки інші джерела енергії стали коштовними та призводять до забруднення.* ***Проблема***. *Залежність від сонячного світла для вироблення електроенергії унеможливлює отримання максимальної потужності. Умови навколишнього середовища, такі як затінення, часткове затінення і слабке затінення, є основним аспектом, від якого сильно залежить потужність фотоелектричних систем. Часткове затінення – найвідоміша проблема.* ***Мета***. *Було запропоновано багато методів та алгоритмів для отримання максимальної віддачі від сонячних ресурсів за допомогою фотоелектричних батарей, але кожен метод мав деякі недоліки, які не могли служити досягненню повної мети.* ***Методологія***. *Алгоритми, натхненні природою, виявилися хорошими для пошуку глобального максимуму на частково затіненій кривій з багатьма піками, включаючи оптимізацію рою частинок, алгоритм штучної бджолиної колонії та алгоритм запилення квітів.* ***Методи***. *Алгоритм оптимізації рою частинок найкраще підходить для пошуку глобальних піків з меншими коливаннями навколо точки максимальної потужності, меншою складністю та простотою реалізації. Алгоритм оптимізації рою частинок має недолік, що полягає у тривалому часі обчислень та швидкості збіжності, особливо в умовах сильного затінення.* ***Оригінальність***. *У цій статті пропонується покращений алгоритм оптимізації рою частинок на основі протилежності для відстеження глобальної точки максимальної потужності сонячного фотоелектричного модуля. Розрахункові моделювання проводились у MATLAB/Simulink R2018a.* ***Практична цінність***. *Дослідження за допомогою моделювання довели, що алгоритм оптимізації рою частинок на основі протилежності є більш ефективним, менш складним, надійнішим і гнучкішим і має кращу швидкість збіжності, ніж алгоритм оптимізації рою частинок, алгоритм збурення та спостереження, алгоритм сходження на пагорб та алгоритм інкрементальної провідності.* Бібл. 24, табл. 4, рис. 12.

Ключові слова: **традиційна оптимізація рою частинок, точка максимальної потужності, алгоритм оптимізації рою частинок на основі протилежності.**

Abbreviations

ABC	Artificial Bee Colony	OBL	Opposition Based Learning
FPA	Flower Pollination Algorithm	P&O	Perturb and Observe Algorithm
GMPP	Global Maximum Power Point	PSC	Partial Shading Conditions
IC	Incremental Conductance Algorithm	PSO	Particle Swarm Optimization
IPSO	Improved Particle Swarm Optimization	PSO-OBL	Opposition Based Particle Swarm Optimization Algorithm
MPP	Maximum Power Point	PV	Photovoltaic
MPPT	Maximum Power Point Tracking	PWM	Pulse-Width Modulation

1. Introduction. With increasing demand of renewable source of energy, solar energy is getting more and more attention because of its easy and never ending availability. But operating PV panel at MPPT is a challenging task. So accomplishing this task can make use of PV panels very effective and it will largely reduce the use of non-renewable sources which will have such a huge impact on mankind's lifestyle that it can save a huge amount of money and world resources. However high installation cost and getting lower efficiency are still the challenges that are faced nowadays by researchers [1, 2]. Solar energy plays a vital role in the development of a country. Compared to other renewable sources solar energy generation shows a significantly more dynamic development. Research studies shows that the installed capacity of solar power plants in 2016 was 315 GW [3-6]. For extracting MPPT, there are face several challenges such as temperature and irradiance affects the P-V characteristics of photovoltaic cell. For delivering maximum power to load several conventional algorithms were to tackle MPPT. For instance P&O MPPT method [7], IC MPPT method [8], modified hill climbing method [9], frictional short-circuit current approach [10], ripple correlation control method [11] and sliding mode controller [12] were used. The specialty of these algorithms is that these give good response for uniform irradiance of solar panel but under PSC these algorithms fails to track the global MPPT.

Goal. This paper present a hybrid technique used to track global max power point very efficiently by using improved particle swarm optimization algorithm. For improving search ability of PSO algorithm, PSO is hybridized with OBL [13], for getting high tracking efficiency, convergence speed and power output. PSO is an outstanding choice for problems of nature of non-linear optimization [14]. To check the robustness of this hybrid techniques, two different PV configurations of are employed.

The PV system consists of PV panels, MPPT controller, DC-DC converter and load (Fig. 1). The output of the PV panels is fed to the converter as well as to the controller. The controller uses its input to regulate the duty cycle of the converter for maximum power point operation.

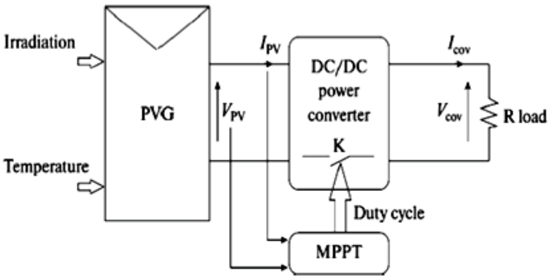


Fig. 1. Block diagram of PV system

This paper is organized as follows. In Section 2 there is description of P-V characteristics under PSC. In Section 3 methodology is describe. In Section 4 test system is presented while in Section 5 simulation results are discussed. In Section 6, comparison is discussed and paper is concluded in Section 7.

2. PV cell's modeling with single-diode equivalent circuit.

2.1. Characteristics of solar cell. Equivalent circuit of PV cell is shown in the Fig. 2 and the output in the form of current is given by:

$$I_{pv} = I_{ph} - I_0 \cdot \left[\exp\left(\frac{q \cdot \left(U_{pv} + I \cdot R_S \right)}{A \cdot K \cdot T} \right) - 1 \right] - \frac{U_{pv} - I \cdot R_S}{R_P}, \qquad (1)$$

where I_{pv} is the output current of cell; I_{ph} is the photocurrent; I_0 is the reverse saturation current; q is the charge of an electron; U_{pv} is the work voltage of a PV cell; K is the Boltzmann constant; A is the ideality factor; R_S and R_P are the series and parallel resistances; T is the cell temperature [15].

The different parameters of proposed PV module are shown in Table 1.

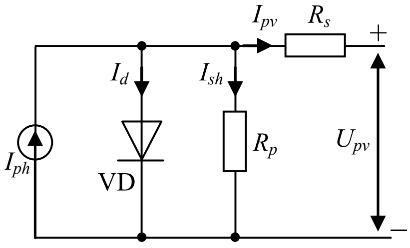


Fig. 2. Single-diode equivalent circuit of PV cell

Table 1

Parameters of Sun Earth Solar Power TPZ250MBZ PV 250 W

Parameters	Variables	Values
Maximum power	P_{MPP}	250 W
Open circuit voltage	V_{oc}	30 V
Short circuit current	I_{sc}	8.3 A
Current of $P_{\max}$	I_{MPP}	8.83 A
Voltage of $P_{\max}$	V_{MPP}	36.8 V
I_{sc} coefficient of temperature	K_I	(0.065±0.015)%/°C
V_{oc} coefficient of temperature	K_V	–(0.32±0.05)%/°C

2.2. Effect of PSC on PV characteristics. In this paper, two different PV configurations are used to check the robustness of proposed technique. The first configuration is 4S2P, which consists of 8 PV modules. Four modules are organized in one string with power of 249 W. The overall power extracted is 1992 W. Second configuration is 3S1P, which consists of 3 PV modules that are arranged in one string. The overall power extracted by second configuration is 747 W [16]. Power extracted by different pattern of PSC is shown in Table 2. The PV configuration (4S2P) proposed in this paper is shown in Fig. 3.

Table 2

Different patterns of 3S1P and 4S2P configurations

4S2P-configuration			3S1P-configuration	
Pattern 1	G11=1 kW·m^{-2}	G21=1 kW·m^{-2}	Pattern 3	G1= 1 kW·m^{-2}
	G12=1 kW·m^{-2}	G22=1 kW·m^{-2}		G2= 1 kW·m^{-2}
	G13=1 kW·m^{-2}	G23=1 kW·m^{-2}		G3= 1 kW·m^{-2}
	G14=1 kW·m^{-2}	G24=1 kW·m^{-2}		
Pattern 2	G11=1 kW·m^{-2}	G21=1 kW·m^{-2}	Pattern 4	G1= 1 kW·m^{-2}
	G12=900 W·m^{-2}	G22=800 W·m^{-2}		G2= 900 W·m^{-2}
	G13=600 W·m^{-2}	G23=700 W·m^{-2}		G3= 900 W·m^{-2}
	G14=500 W·m^{-2}	G24=1 kW·m^{-2}		

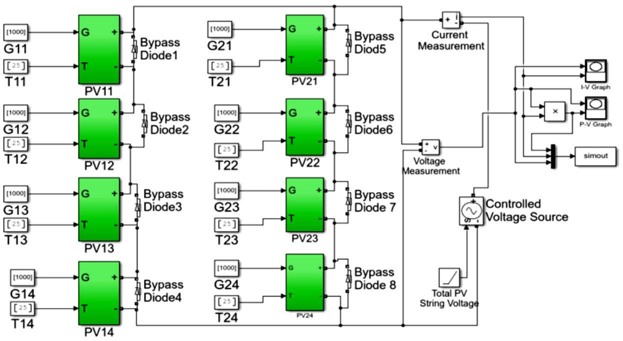


Fig. 3. Proposed PV configuration (4S2P)

3. Methodology.

3.1. PSO algorithm. PSO is an outstanding choice for problems of nature of non-linear optimization. PSO method is inspired by the behavior of swarms, insects and flocks [17]. In the previous decade, PSO is mostly the utmost favored optimization method for MPPT applications. In PSO, the initial particles (duty cycles) are chosen randomly in domain of the bounding limits. These particles are spread in whole search domain. The best among them in each iteration is known to be $P_{\_best}$ and the finest in all repetitions is recognized as $G_{\_best}$. Further, position and velocity of the particles/units are modified in each repetition and the procedure keeps continuing till it reaches the best position. The motion of PSO particles in arbitrary search domain space are demonstrated in Fig. 4. The velocity and position updates are provided in:

$$X_i^{t+1} = X_i^t + V_i^{t+1}; \tag{2}$$

$$V_i^{t+1} = W \cdot V_i^t + 1 + C_1 \cdot r_1 \cdot \left(P_{besti}^{t+1} - X_i^t\right) + C_2 \cdot r_2 \cdot \left(G_{besti}^{t+1} - X_i^t\right), \tag{3}$$

where W is the inertial weight; X is the position; V is the velocity; C_1 and C_2 are the inertia constants; t is the iteration count.

Equation (4) represents fitness function:

$$P\left(D_i^k\right) > P\left(D_i^{k-1}\right). \tag{4}$$

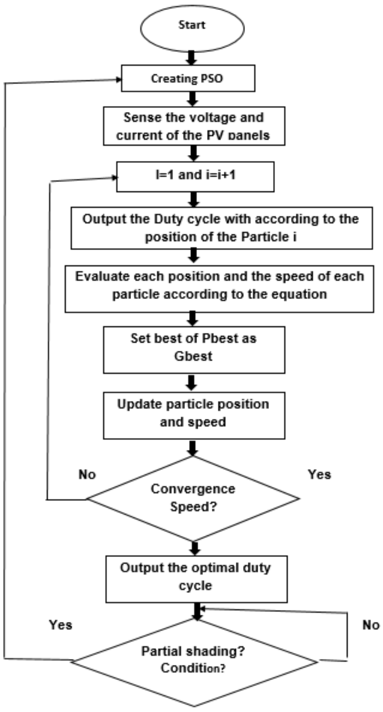


Fig. 4. Flowchart of the PSO algorithm

3.2. Opposition Based Learning (OBL). In 2005 Tizhoosh proposed the OBL technique [18] in the field of machine learning. He found that it is easier to find global maxima through opposite solution rather than random solutions and it is 50 % highly probable than original random solutions. OBL produces opposite solutions of original random solutions in each iteration and finds the fitness value of every solution and it is opposite. The one with the lower fitness is retained and other is discarded. The best among current solution space is selected and its opposite is sent to next iteration. This opposition based technique can increase the random search ability of random search methods. It has been used in PSO [19] and differential evolution algorithm [20] to improve their random search domain. The opposite point is defined as follow. Let $q(x_1, x_2, \ldots, x_n)$ is a point in an n-dimensional space, $x_1, x_2, \ldots, x_n \in R$, $x_i \in [a_i, b_i]$. The opposite point $q^*(x_1^*, x_2^* \ldots x_n^*)$ of q is defined as

$$x_i^* = a_i + b_i - x_{ii} = 1 \ldots n. \tag{5}$$

The opposition based optimization is defined as follow. Let $q(x_1, x_2 \ldots, x_n)$ is a point in n-dimensional space and $q^*(x_1^*, x_2^* \ldots x_n^*)$ is its opposite. For objective fitness function $f(q)$, if $f(q^*) < f(q) q^*$ is kept otherwise q is kept unchanged.

3.3. PSO with OBL. PSO algorithm was presented by Eberhart R. and Kennedy J. in 1995 [21] and is based on the behavior of folk of birds. The present state of a particles that are in continues movement in the possible solution space is described by two variables, the position x_j and the velocity of movement v_j. The state of each particle in n-dimensional solution space, is determined by the position vector $X_j = [x_{j1}, x_{j2}, \ldots, x_{jN}]$ and velocity vector $V_j = [v_{j1}, v_{j2}, \ldots, v_{jN}]$. At the start, the particles are dispersed randomly over the whole possible solution space. Its implementation in PSO is depicted in Fig. 5.

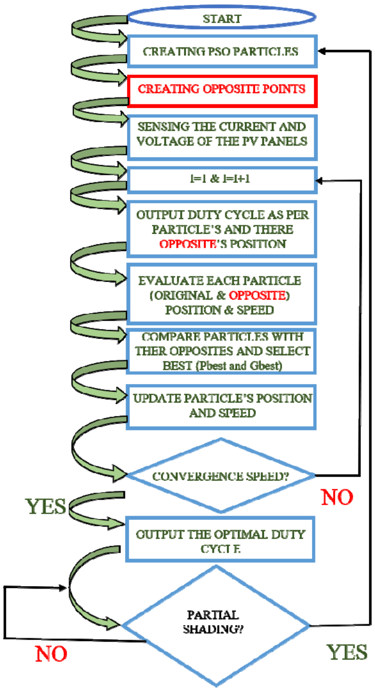


Fig. 5. Particle swarm optimization hybridized with opposition based learning

4. Test systems. Simulation studies for different cases of the PSO and PSO-OBL techniques have been carried out in MATLAB/Simulink R2018a. The system proposed for simulations is shown in Fig. 6. PV module is used followed by a DC-DC buck converter and load. MPPT block is consisting of an MPPT controller and PWM generator. Current and voltage from PV module are presented as input to MPPT controller which produces duty cycles accordingly to run DC-DC converter.

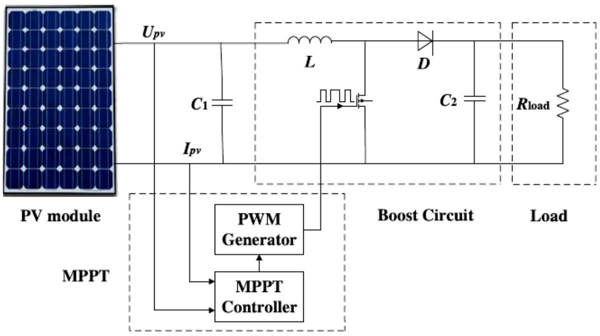


Fig. 6. Proposed system for PV using PSO algorithm

In Fig. 7 PV array configuration of 3S1P is shown, in which a single rail of three series connected modules in used to check partial shading effect.

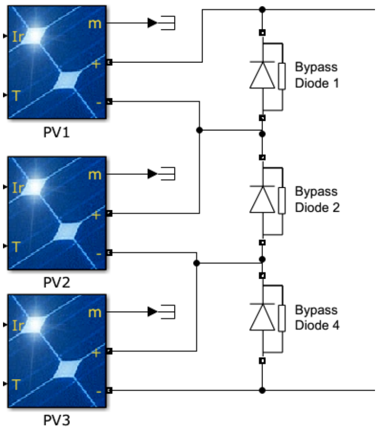


Fig. 7. 3S1P configuration of PV panel array

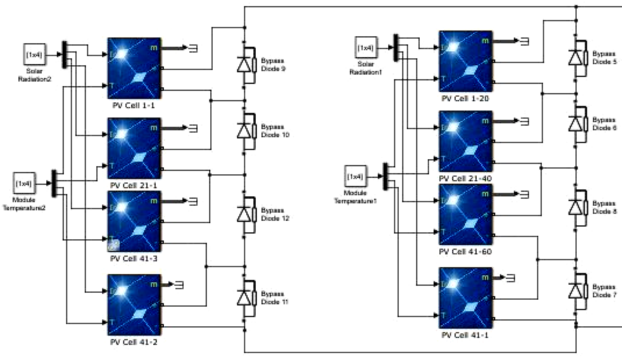


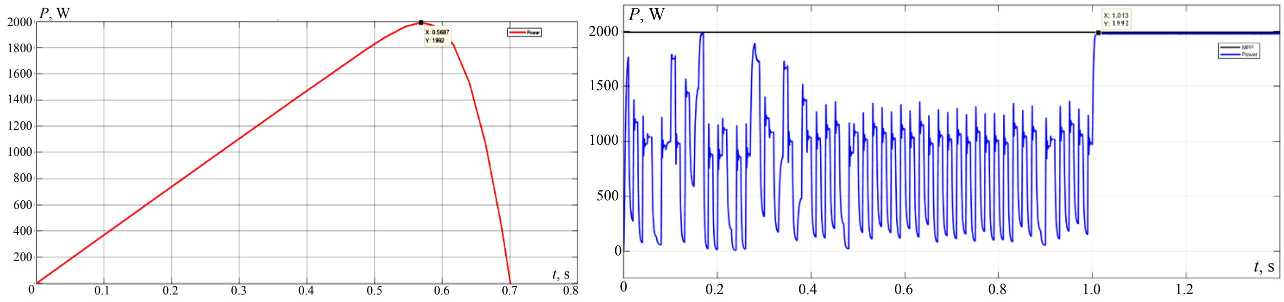
Fig. 8. 4S2P configuration of PV panel array

Different cases of partial shading considered for 3S1P are shown in Table 2. Three different modules are given separate values of irradiance and their output P-D curve is generated which generates a 3-peaks curve corresponding to values of irradiance being given as an input. Similarly, 4S2P is shown in Fig. 8 and its different cases for partial shading are shown in Table 2.

5. Simulation results.

5.1. Simulation results of PSO and PSO-OBL for 4S2P configuration. Figures 9, 10 show simulation results of 4S2P configuration for PSO-OBL in different cases of partial shading as shown in Table 2. The number of iterations used for PSO is 25 while number of iterations used for PSO-OBL is 100 which helps creating opposite candidate solutions and effectively tracks GMPP.

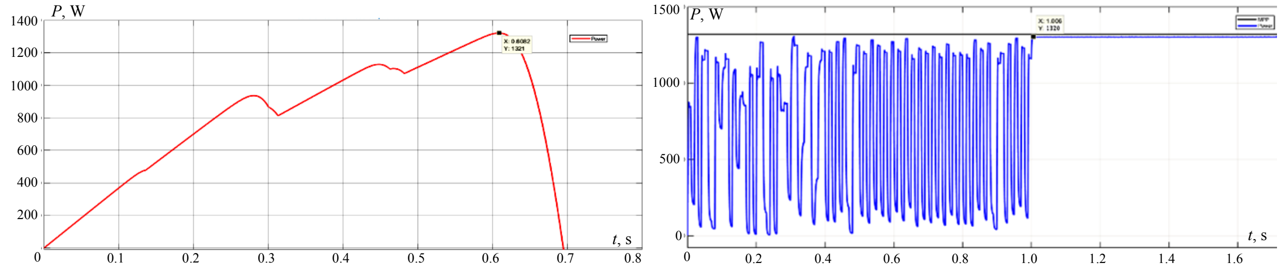
5.1.1. Results of pattern no. 1. In pattern no. 1 the rated power is 1992 W and the power extracted from simulation is also 1992 W. The calculated results show that tracking efficiency will be 100 % and the convergence speed will be 1.021. The P-V curve of rated power and extracted power is shown in Fig. 9.



a *b*

Fig. 9. 4S2P pattern no. 1: *a* – characteristic curve; *b* – P-V curve using PSO-OBL

5.1.2. Results of pattern no. 2. In pattern no. 2 the rated power is 1321 W and the power extracted from simulation is 1320 W. The calculated results show that tracking efficiency will be 99.81 % and the convergence speed will be 1.008. The P-V curve of rated power and extracted power is shown in Fig. 10.



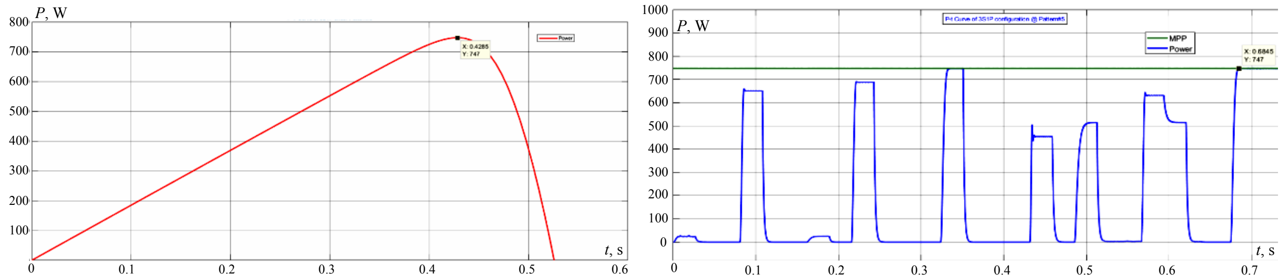
a *b*

Fig. 10. 4S2P pattern no. 2: *a* – characteristic curve; *b* – P-V curve using PSO-OBL

5.2. Simulation results of PSO for 3S1P configuration. The parent technique (PSO) implementation for 3s1p has shown promising results as agreeing with work [22]. The characteristic curves for different patterns of 3S1P and corresponding P-V curves using PSO are shown in Fig. 11, 12.

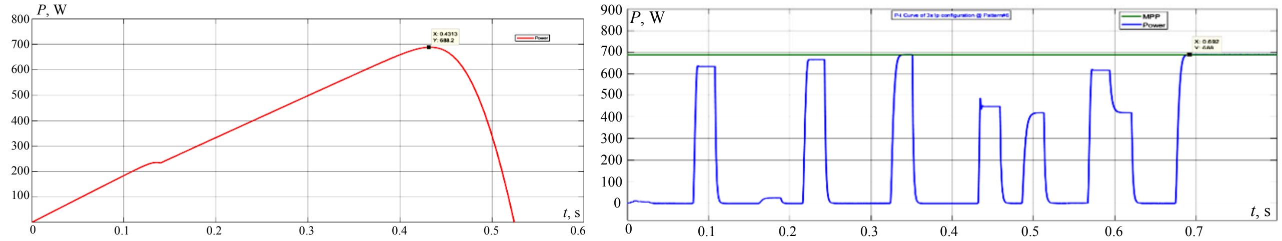
5.2.1. Results of pattern no. 3. In pattern no. 3 the rated power is 747 W and the power extracted from simulation is also 747 W. The calculated results show that tracking efficiency will be 100 % and the convergence speed will be 1.01. The P-V curve of rated power and extracted power is shown in Fig. 11.

5.2.2. Results of pattern no. 4. In pattern no. 4 the rated power is 688.2 W and the power extracted from simulation is 688 W. The calculated results show that tracking efficiency will be 100 % and the convergence speed will be 1.015. The P-V curve of rated power and extracted power are shown in Fig. 12.



a *b*

Fig. 11. 3S1P pattern no. 3: *a* – characteristic curve; *b* – P-V curve using PSO



a *b*

Fig. 12. 3S1P pattern no. 4: *a* – characteristic curve; *b* – P-V curve using PSO

6. Comparison among PSO and PSO-OBL. After performing simulation studies of PSO and PSO-OBL, one can see the clear improved efficiency and effective tracking of GMPP in less *t*/*n* ratio (where *t*/*n* is the maximum amount of time (or, more specifically, steps) that a function takes to run). This proves that PSO-OBL is better in all conditions as compared to PSO because PSO doesn't perform as well as PSO-OBL and especially when it comes to strong shading PSO-OBL totally outperforms PSO and proves itself to be best to use as MPPT algorithm in all environmental conditions. Tables 3, 4 provide the comparison of both the techniques.

Table 3

Comparison of both techniques

Configuration	Case	Algorithm	*t*/*n*	Power	Rated power	Convergence speed	Oscillations at GMPP	Efficiency	BEST algorithm
4S2P	Pattern 1	PSO	0.027	1992	1992	0.6826	0	100	PSO-OBL
		PSO-OBL	0.010	1992		1.021	0	100	
	Pattern 2	PSO	0.027	1317.5	1321	0.6769	0	99.73	PSO-OBL
		PSO-OBL	0.010	1320		1.008	0	99.81	
3S1P	Pattern 3	PSO	0.027	743.1	747	0.6917	0	99.72	PSO-OBL
		PSO-OBL	0.010	747		1.01	0	100	
	Pattern 4	PSO	0.027	688	688.2	0.6811	0	99.97	PSO-OBL
		PSO-OBL	0.010	688		1.015	0	99.97	

Table 4

Comparison of parameters of P&O, IC, PSO and PSO-OBL

Algorithm	Steady state oscillations	Falling to local maximums	Complexity
P&O	✓	✓	✓
IC	✓	✓	✓
PSO	×	×	Less complex
PSO-OBL	×	×	Less complex

7. Conclusions. Environmental conditions limit the functionality of photovoltaic module. A lot of methods have been proposed in literature to address this problem but it never achieved goal due to number of reasons. Partial shading is most known issue. Nature inspired algorithms have proven them to be good to search global maximum in a partially shaded multipeak curve which includes particle swarm optimization, artificial bee colony, flower pollination algorithm etc. Particle swarm optimization is best among these in finding global peak with less oscillation around maximum power point, less complexity and easy to implement nature. Particle swarm optimization has disadvantage of having long computational time and converging speed particularly under strong shading conditions. In this paper, hybrid technique is used to track global max power point very efficiently by using improved particle swarm optimization algorithm. This technique is effective in all shading conditions. Simulation results shows that opposition based particle swarm optimization algorithm is less complex, more efficient, robust, flexible and have better convergence speed than particle swarm optimization and other techniques. Since shading is an unpredictable process so to predict the accuracy and to expect a 100 % output is still an uncertain thing. The increasing demand of energy and ever increasing advancement in technology is making more and more space to bring improvement to maximum power point tracking as well as the improve the transient response of the system [23, 24]. So power extraction with more accuracy in less amount of time is still a scope.

Conflict of interest. The authors declare that they have no conflicts of interest.

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