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A PSO_I based MPPT Technique for PV System under Dynamically Changing PSC

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Abstract:- As conventional techniques fail to track global MPP under partial shaded condition; maximum power point tracking algorithms based on optimization algorithms are an attractive alternative to track the global maximum power point under partial shaded condition. Due to several advantages particle swarm optimization algorithm is most implemented and most suitable for MPP tracking under PSC. Though in most of the cases PSO guarantees global MPP under PSC, it suffers from certain disadvantages like local maxima trapping due to random initialization of population, increased tracking time, larger exploration of search space, output power oscillations and larger settling time. To overcome the limitations of PSO, a novel improved PSO algorithm is proposed, which includes opposition based learning and worst population elimination methods. The performance of the proposed algorithm is examined on 8S and 4S2P PV configurations subjected to dynamically changing partial shaded condition irradiation patterns and results are presented. The results are compared with the conventional PSO algorithm under similar conditions. From results it is noticed that proposed algorithm has very less tracking time, less exploration of search space, do not suffer from local maxima trapping and reduces the output power oscillations. The proposed algorithm shows superior performance compared to conventional PSO algorithm.

Index Terms: Maximum power point tracking, Partial shaded condition, Photovoltaic system, Single diode model, Improved PSO algorithm.

I. INTRODUCTION

The modern day power systems are integrated with large scale photovoltaic systems to meet the growing power demand. PV systems must be operated at maximum power point at any atmospheric condition to attain maximum benefit, due to its low conversion efficiency. As the PV systems are outdoor operating systems, these are subjected to several environmental conditions like changing irradiation & temperatures, partial shaded condition etc.

Partial shading condition is one of the adverse phenomena that PV system experiences and exhibits multiple MPPs in PV characteristics [1]. In literature, authors proposed several conventional MPPT techniques like P&O, INC, HC etc.

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These techniques able to track the MPP, when the PV system characteristics exhibit single MPP [2]. But fail to track exact MPP under PSC and they trap at local maxima [3]. The inaccurate MPP tracking leads to wastage of useful power, which reduces the efficiency of PV system. Few authors developed improved and hybrid version of the conventional techniques to track global MPP under PSC, But their performance is not satisfactory under PSC [4].

The MPPT under PSC is addressed by some authors by using the artificial intelligence techniques like fuzzy, ANN. Though they give better performance than conventional techniques, these techniques are system dependent in nature and require proper training [5].

An attractive alternative for maximum power point racking of PV system under PSC are techniques based on optimization algorithms [6]. In literature, several authors proposed optimization algorithm based MPPT techniques, and they effectively addressed the PSC problem [7]. These techniques outperform the conventional and artificial intelligence techniques following certain advantages like low tracking speed, high accuracy, system independent nature etc.,

From literature it is observed that the PSO algorithm was more extensively used for MPPT of PV system under PSC due to its simple structure and its ability to solve complex non linear optimization problem [8].

In [9] authors proposed a first PSO based MPPT algorithm considering terminal voltage of modules in a PV array as decision variable. In [10] authors proposed a direct control PSO based MPPT algorithm considering duty cycle as decision variable. In [11] authors proposed an improved version of PSO based direct control MPPT technique to reduce the steady state oscillations with duty cycle as decision variable. In [12] authors proposed a PSO based MPPT technique considering duty cycle as decision variable, where the particles are initialized at fixed positions with equal distances in search space. In [13] authors proposed a deterministic PSO MPPT method by eliminating the randomness in the velocity equation considering duty cycle as decision variable. In [14] authors proposed an improved PSO based MPPT method with variable sampling time considering duty cycle as decision variable. In [15] authors developed a modified PSO based MPPT technique applying reflective impedance method to determine duty ratio positions.

Though PSO MPPT algorithm guarantees the global MPP under PSC, it has certain disadvantages like local maxima trapping due to random initialization of population, increased tracking time, larger exploration of search space, output power oscillations and larger settling time etc.,

In this work an attempt is made to overcome the disadvantages of conventional PSO. An improved PSO MPPT algorithm is proposed by incorporating opposition based learning and worst population elimination methods to conventional PSO technique to reduce the tracking time and to avoid local MPP trapping. Further to reduce the output power oscillations, the parameters of the PSO are selected based on trial and error, and fixed to constant values.

The proposed algorithm is tested on different dynamically changing PSCs of *8S* and *4S2P* PV configurations and results are compared with the convention PSO MPPT techniques.

The rest of the paper is organized as follows: Section II briefly describes the modeling of PV system under PSC, Overview and application of improved PSO (PSO$_I$) for MPPT is explained in Section III followed by results and comparison between proposed and Conventional PSO in section IV, finally conclusion is made in section V.

II. PARTIAL SHADED CONDITION MODELING OF PV SYSTEM

A. Photovoltaic module

The equivalent circuit diagram for single diode model PV cell is shown in Fig. 1. Single diode model is most used in modeling of PV system due to reduced complexity and computational efficiency over two diode model [16].

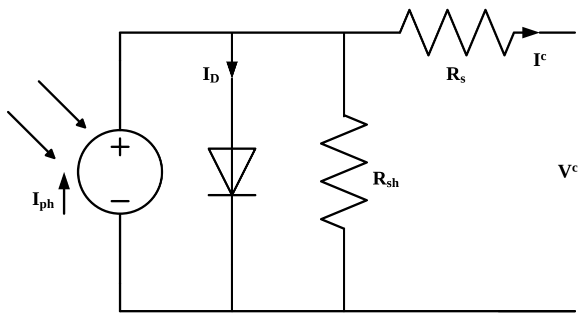


Fig. 1 Single diode model PV cell

The output current of PV cell is written as

$$I^c = I_{PV} - I_0\,[e(\frac{q(V^c + I^c R_s)}{KTA}) - 1] - (\frac{V^c + I^c R_s}{R_{sh}}) \qquad (1)$$

where I^c is PV cell output current, V^c is PV cell output voltage, I_{pv} is photo current, I_o is diode reverse saturation current, R_s and R_{sh} are series and shunt resistances, q is charge of an electron (1.6 × 10−19 C), A is diode ideality factor, K is Boltzmann's constant (1.38 × 10−23 N-m/K), T is panel operating temperature (in Kelvin).

The output current of PV module with N_s number of PV cells is given as

$$I = I_{PV} - I_0\,[e(\frac{q(V + IR_s)}{N_s KTA}) - 1] - (\frac{V + IR_s}{R_{sh}}) \qquad (2)$$

$$I_{PV} = (I_{PV\_STC} + k_i\ \Delta T)\frac{G}{G_{STC}} \qquad (3)$$

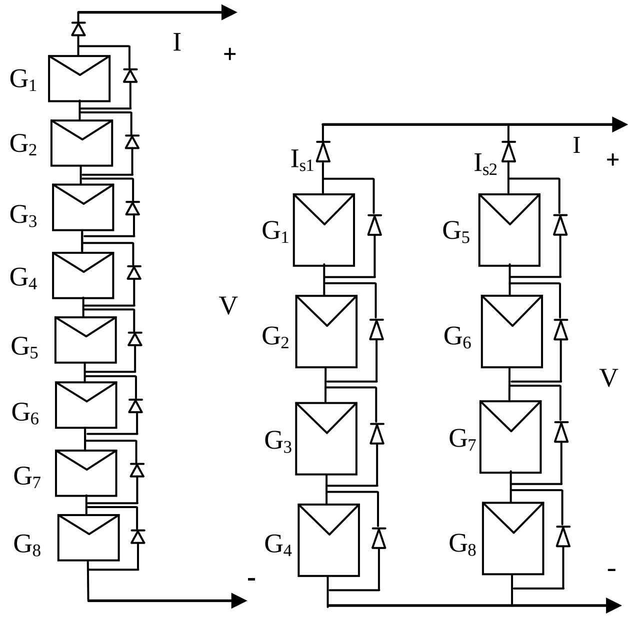
$$I_o = I_{o\_STC}\left(\frac{T_{STC}}{T}\right)^3 e\left[\frac{qE_g}{AK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \qquad (4)$$

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

where V is PV voltage, I is PV current, V_t is thermal voltage of PV module, I_{PV_STC} is photo current at standard test conditions (STC), k_i is current temperature coefficient, G is solar irradiation in kW/m2, ΔT is temperature change (ΔT=T-T_{STC}) in Kelvin, I_{0_STC} is diode reverse saturation current at STC, E_g is energy band gap (*eV*), V_{OC_STC} and I_{SC_STC} are open circuit voltage and short circuit current of PV module at STC.

In order to get the module voltage, (2) is modified as

$$V = \frac{N_s KTA}{q}\left[\ln\left(\frac{I_{ph} + I_o - I\left(1 + \frac{R_s}{R_{sh}}\right)}{I_o}\right)\right] - IR_s \qquad (6)$$



(a) (b)

Fig. 2 (a) 8S PV configuration (b) 4S2P PV configuration

B.Modeling of Partial Shaded Condition

A PV system under PSC is modeled using eight PV modules and these are represented in the form of eight series (*8S*) and four series two parallel (*4S2P*) PV configurations as shown in Fig. 2. The PV module parameters are given in appendix.

Output voltage of j^{th} module from (6) is obtained by comparing photo current of j^{th} module with its corresponding string current I_{si} as follows [17] :

$$V^{ij} = \begin{cases} \frac{N_s KTA}{q}\left[\ln\left(\frac{I_{pv}^{ij} + I_o - I_s^i\left(1 + \frac{R_s}{R_{sh}}\right)}{I_o}\right)\right] - I_s^i R_s, & I_{pv}^{ij} > I_s^i \\ 0, & I_{pv}^{ij} \le I_s^i \end{cases} \qquad (7)$$

where V_{ij} is voltage across j^{th} module of i^{th} string

By varying current in the string (I_s) from zero to photo

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current of module with higher irradiation, output voltage of i^{th} string of PV array is given by

$$V_s^i = \sum_{n=1}^{m} V^{ij} \tag{8}$$

where m is number of series connected modules in a string

Output current of PV array is given by

$$I = \sum_{k=1}^{s} I_i \tag{9}$$

where s is number of parallel connected strings in an array

III. PROPOSED PSO$_I$ ALGORITHM

A. Conventional PSO

PSO is swarm intelligence based algorithm proposed by Kennedy et al. [18]. It is used to solve non linear and complex optimization problems in many engineering applications. In PSO a swarm of candidate solutions (particles) are initialized randomly in search space and these particles involve in search process to find optimal solution. The positions of all particles are influenced by personal best, P_{best} and best particle in the entire population, G_{best}. PSO algorithm is mathematically represented by two equations that specify the position and velocity updates of a particle i.

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{10}$$

$$v_i^{k+1} = wv_i^k + c_1r_1\{P_{best,i} - x_i^k\} + c_2r_2\{G_{best} - x_i^k\} \tag{11}$$

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.

The movement of particles in the search process is shown in Fig. 3.

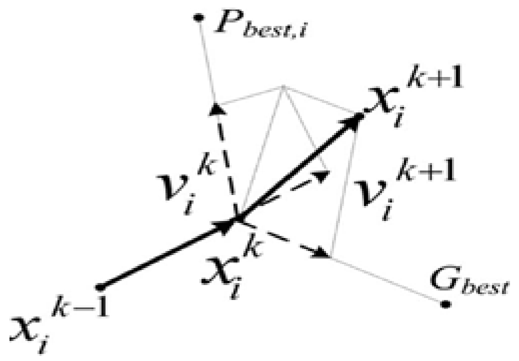


Fig.3 Movement of particles in search process

B. Improved PSO Algorithm

In conventional PSO algorithm, the population of particles is initialized randomly over the entire search space between the maximum and minimum limits of decision variable. In proposed PSO_I, half of the population of particles ($N_{p/2}$) are initialized in search space using (12) and other half of the population is distributed in opposite using (13)

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

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

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 proposed algorithm, 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 same as conventional PSO algorithm. The parameters of the proposed algorithm are given in Appendix.

IV. APPLICATION OF PROPOSED PSO$_I$ FOR MPPT

For MPPT, a boost converter is connected between load and PV array as shown in fig. 4 with a settling time of 0.1 s.

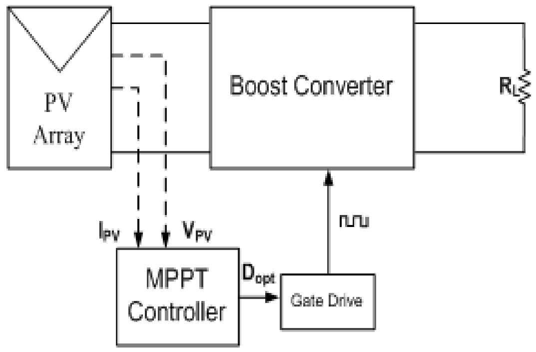


Fig.4 Block diagram of MPPT controller

MPPT is achieved by considering PV power as the objective function to be maximized and duty cycle as the decision variable.

The objective function for MPPT is modeled as

Maximize: $P(D_i)$ (14)

Subjected: $0.1 \le D_i \le 0.9$ (15)

Initialization of duty ratios on power vs. duty ratio characteristic under PSC with two MPP is shown in Fig. 5.

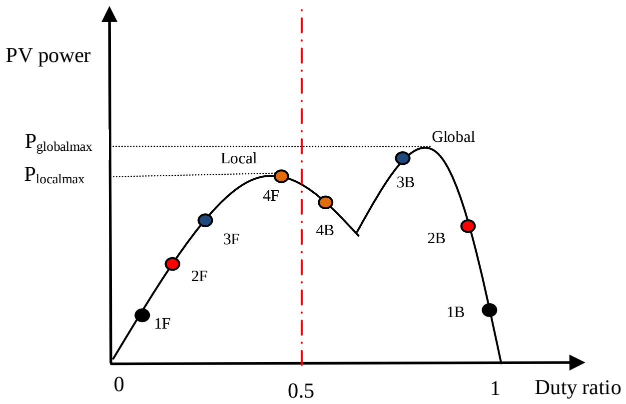


Fig.5 Population initialization in proposed PSO

Here population of duty ratios is considered same as the number of modules in an array. The algorithm reinitializes the search process for any change in the irradiation pattern by sensing change in output power of the PV array using (16)

$$\frac{P^{new} - P^{old}}{P^{new}} \geq 0.1 \tag{16}$$

The detailed methodology for MPPT using proposed PSO$_I$ is given in Fig.6

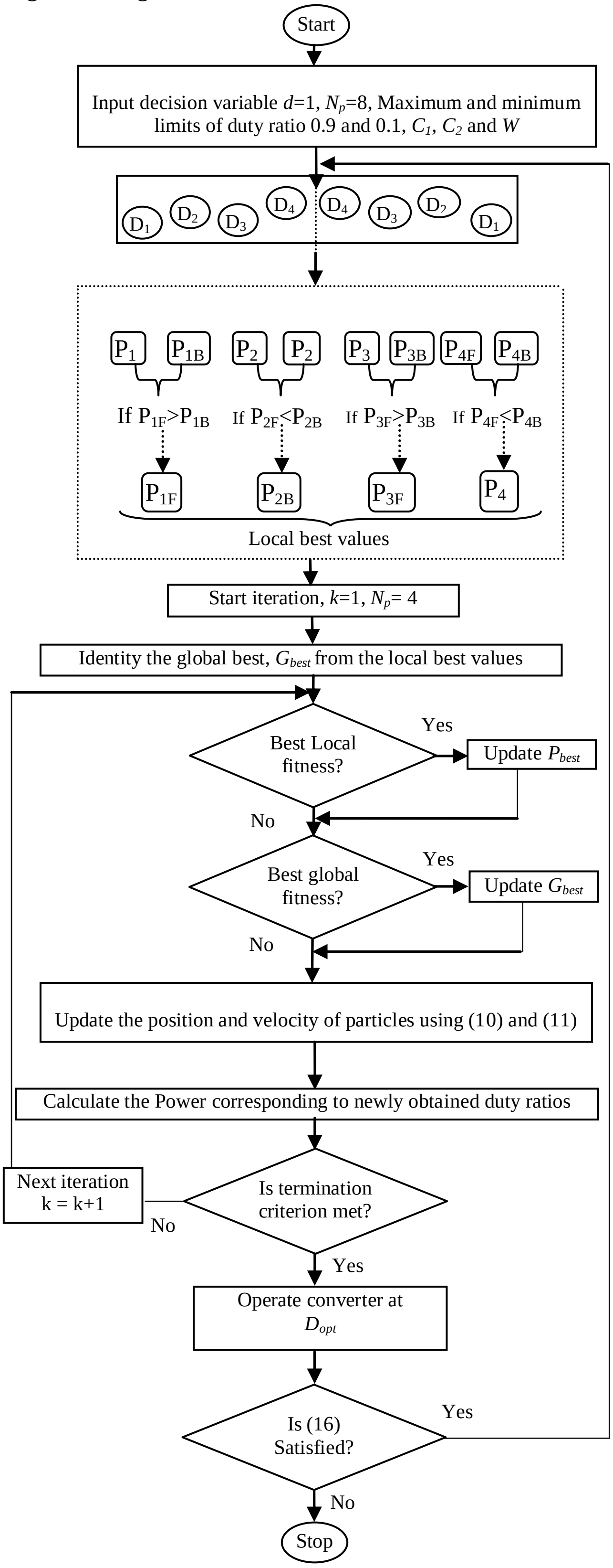


Fig.6 Flowchart for PSO$_I$ MPPT

V. RESULT ANALYSIS

A. Characteristics of PV array under PSC

In this work, PV array configurations consisting of eight series (*8S*) and four series two parallel (*4S2P*) are modeled under PSC. Each of these PV configurations are subjected to two different irradiation patterns as given below

The irradiation patterns in Watt/m^2 of *8S* configuration are

i) G_1,G_2=1000 W/m^2, G_3,G_4=600 W/m^2, G_5,G_6=400 W/m^2, G_7,G_8=200 W/m^2

ii) G_1=1000 W/m^2, G_2=900 W/m^2, G_3=800 W/m^2, G_4=600 W/m^2, G_5=500 W/m^2, G_6=400 W/m^2, G_7=300 W/m^2, G_8=200 W/m^2

The irradiation patterns in Watt/m^2 of *4S2P* configuration are

iii) G_1=1000 W/m^2, G_2=600 W/m^2, G_3=400 W/m^2, G_4=200 W/m^2, G_5=1000 W/m^2, G_6=600 W/m^2, G_7=400 W/m^2, G_8=200 W/m^2

iv) G_1=1000 W/m^2, G_2=600 W/m^2, G_3=400 W/m^2, G_4=200 W/m^2, G_5=1000 W/m^2, G_6=800 W/m^2, G_7=600 W/m^2, G_8=400 W/m^2

The characteristics of PV array for different shading patterns of 8S and 4S2P are shown in fig.7 and fig.8.

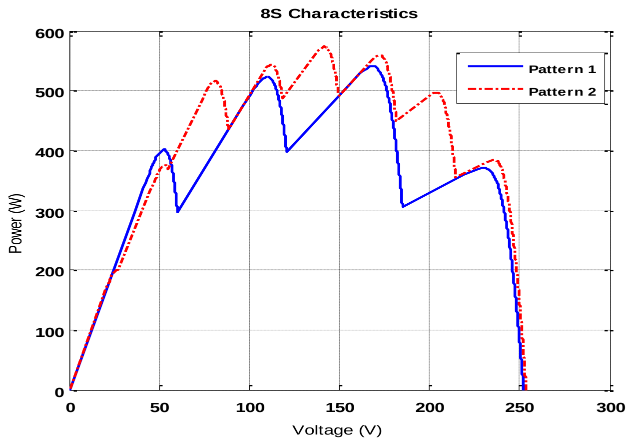


Fig.7 Power-Voltage characteristics of *8S* PV configuration for different shading patterns.

From Fig 7, it is observed that the characteristics of *8S* PV array exhibit multiple maxima under PSC with four peaks for pattern 1 and eight peaks for pattern 2. From fig 8, it is observed that the characteristics of *4S2P* PV array exhibit multiple maxima under PSC. The MPP tracking under PSC is more complex due to high non-linear characteristics and can be achieved by using the proposed MPPT algorithm.

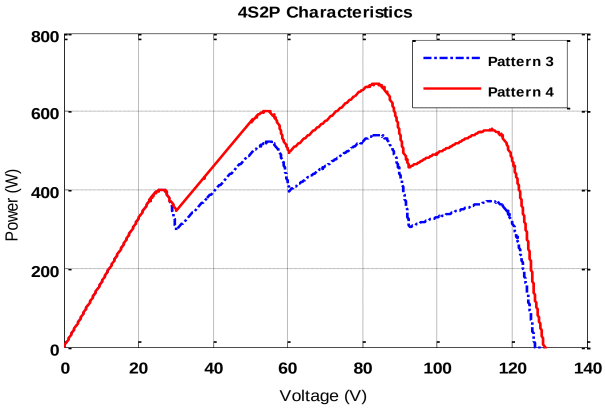
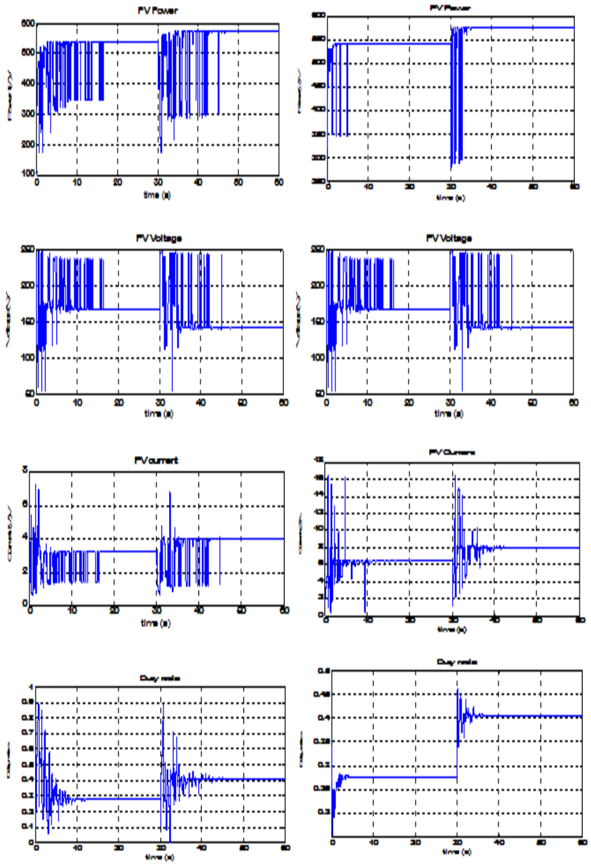


Fig.8 Power-Voltage characteristics of 4S2P PV configuration for different shading patterns

B. MPP tracking of 8S PV configuration

To analyze the performance, simulations are performed for proposed and conventional PSO on *8S* PV array configurations for dynamically changing irradiation patterns. The *8S* PV configuration is subjected to dynamically changing patterns each for 30 s. Here pattern 1 exits from 0-30s and pattern 2 from 30-60 s. The tracking curves of conventional PSO and proposed PSO_I algorithm are shown in Fig.9.

From fig 9, it is observed that the proposed algorithm tracks the global MPP of 540.24 W and 573.28 W with a tracking time of 5.1 s for pattern 1 and 4.8 s for pattern 2. The conventional PSO algorithm guarantees the global MPP for most of the simulations with tracking time of 16.5 s for pattern 1 and 15.2 s for pattern 2.



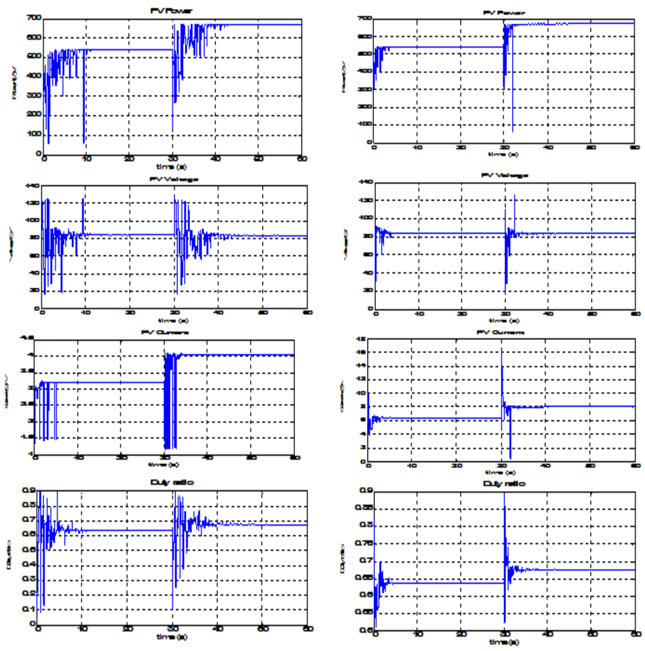
(a) PSO **(b) PSO_I**

Fig.9 Tracking curves of 8S PV configuration

C. MPP tracking of 4S2P PV configuration

To analyze the performance of proposed algorithm for series-parallel array, simulations are performed on *4S2P* configurations for proposed and conventional PSO for dynamically changing irradiation patterns. The *4S2P* configuration is subjected dynamic changing irradiation patterns; pattern 3 exists from 0-30 s and pattern 4 from 30-60 s.

The tracking curves of conventional PSO and proposed PSO_I algorithm are shown in fig.10. From fig, it is observed that the global MPP of 541. 5 W and 670.35 W are tracked with a tracking time 3.6 s, 4.2 s by proposed PSO_I algorithm and 11.2 s, 13.2 s by conventional PSO for pattern 3 and pattern 4 respectively.



(a) PSO **(b) PSO_I**

Fig.10 Tracking curves of 4S2P PV configuration

D. Comparison of PSO and PSO_I

The comparative analysis in terms of tracking speed and accuracy between conventional PSO and proposed PSO_I MPPT algorithms are done and results are presented in the Table 1. From table it is noticed that the proposed algorithm tracks the global MPP with very less tracking time than conventional PSO algorithm. Due to stochastic nature of the optimization algorithms and for statistical performance analysis, 100 trail runs are performed on both the algorithms and the results are presented in the table 2.

From table 2, it can be observed that the proposed algorithm tracks the global MPP for all the trail runs performed and it has low standard deviation. The conventional PSO MPPT algorithm suffers from local MPP trapping for some trail runs and therefore it has high standard deviation.

Table 1
Comparative analysis of PSO_I and PSO MPPT algorithms

PV Configuration	Shading Pattern	Tracking algorithm	Power (W)	Voltage (V)	Current (A)	Duty ratio (d_{opt})	Tracking time (sec)	Maximum Power from P-V curve	Efficiency (%)
8S	1	PSO_I	540.24	168.3	3.21	0.275	5.1	540.2409	99.99
		PSO	540.24	168.3	3.21	0.275	16.5		99.99
	2	PSO_I	573.283	141.9	4.04	0.407	4.8	573.2836	99.99
		PSO	573.283	141.9	4.04	0.407	15.2		99.99
4S2P	3	PSO_I	541.05	84.27	6.42	0.637	3.6	541.0134	99.99
		PSO	541.05	84.27	6.42	0.637	11.2		99.99
	4	PSO_I	670.35	83.69	8.01	0.676	4.2	670.3569	99.99
		PSO	670.35	83.69	8.01	0.676	13.2		99.99

Table 2
Statistical comparative analysis of PSO_I and PSO MPPT algorithms

PV Configuration	Shading Pattern	Tracking algorithm	Maximum Value (W)	Minimum Value (W)	Mean Value (W)	Standard Deviation (W)	Average tracking time (sec)
8S	1	PSO_I	540.2409	522.6331	533.1978	8.6694	5.1
		PSO	540.2409	522.6331	536.5403	7.2064	16.5
	2	PSO_I	573.2836	559.1386	571.8691	4.2649	4.8
		PSO	573.2836	496.7884	566.4857	13.3180	15.2
4S2P	3	PSO_I	541.0134	523.1240	540.8334	1.7888	3.6
		PSO	541.0134	523.0782	537.2515	7.3229	11.2
	4	PSO_I	670.3569	670.1512	670.3548	0.0206	4.2
		PSO	670.3569	554.2284	659.8774	28.0240	13.2

VI. CONCLUSION

An accurate analytical modeling of PV system considering the effect of shunt resistance under PSC is presented in this paper. The electrical characteristics of 8S and 4S2P PV configurations each subjected to two different irradiation patterns are presented. A new improved PSO MPPT algorithm is developed to overcome the disadvantages of conventional PSO algorithm by introducing opposition based learning and worst population elimination methods. The proposed algorithm tracks the global MPP with very less tracking time using the best initial population and also reduces larger exploration of search space. The conventional PSO algorithm suffers from local MPP trapping leads to high standard deviation, the proposed algorithm has very low standard deviation and it overcomes the limitation of local MPP trapping. The proposed algorithm improves the overall system performance and it is superior to conventional PSO algorithm in terms of tracking speed, local MPP trapping and it also reduces steady state oscillations of output power due to fixed parameters.

Appendix

Table A
Parameters of Kyocera KC-200GT module

Parameter	PSO	PSO_I
N_p	8	8
c_1	1.2	1.2
c_2	1.6	1.6
w	0.4	0.4
Maximum number of iterations, k_{max}	100	100
Termination criteria	k_{max}	k_{max}

Table B
Parameters of PSO and PSO_I MPPT algorithms

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 x 10^{-1} V/ºC

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