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An improved grey wolf optimization based MPPT algorithm for photovoltaic systems under diverse partial shading conditions

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An improved grey wolf optimization based MPPT algorithm for photovoltaic systems under diverse partial shading conditions

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Abstract. The photovoltaic (PV) systems are performing a substantial role in electric power systems for generating electrical power in various uncertain circumstances. Nonetheless, the PV systems face numerous challenges for power production in the event of partial conditions. Moreover, different types of multiple peak power points (MPPP) are generated in the characteristics of the PV system under diverse partial patterns. The MPPP's having only one global maximum peak power (GMPP) and the remaining are local peak PowerPoints (LPPP), in which LPPP are interrupted to grab maximum power. Hence, improved grey wolf optimization (I-GWO) approach is developed in this work for enriching the required power generation at partial conditions. The proposed system has been designed in the MATLAB/Simulink environment. As per the simulation findings, the suggested I-GWO demonstrates great performance with regards to tracking time, accuracy, and efficiency as compared with other studied algorithms.

Keywords PV system, Partial Conditions, Power System, MPPP, GMPP, I-GWO.

1. Introduction

Due to the rapidly increased demand for electricity, recently, many researchers focus on renewable resources like solar, wind, and geothermal energy to generate electricity[1][2]. Amongst solar is one of best resources due to the cleanliness, noise-free and eco-friendly. Moreover, the cost of the system also drastically decreased due to technology updates day by day[3]. The total installed capacity of photovoltaic (PV) plants was globally 586 GW at the end of 2018, and the total target capacity is 2840GW at the end of 2030[4]. To fulfil that, some governments provide subsidies to young engineers for the installation of PV plants. Generally, the PV cell has a small power rating; it is connected in series and parallel to achieve the required power rating. The PV cell converts solar energy into electricity; however, it depends on a few parameters temperature, irradiations, tilt angle, and partial shading conditions (PSC)[5]. Amongst, PSC is one of the crucial parameters to reduce the generated electricity. The main reasons for the PSC are passing clouds, building shadows, birds waste and tree shadows[6]. Under PSC, multiple peak PowerPoint (MPPP) causes to pick the global maximum peak power (GMPP) are problematic in the characteristics of power versus voltage of PV array.

To accomplish the above difficulties, maximum power point techniques (MPPT) play a vital role in improving efficiency. The MPPT with DC-DC converters are needed to perform the required operation, as shown in Figure 1. In the past years, classical MPPT techniques are used, like perturb and observe (P&O) method[7], hill-climbing method (HC)[8], and incremental conductance method (INC), to track the GMPP under uniform conditions[9]. However, it fails to track GMPP under PSC due to oscillation around the maximum peak power (MPP)[10]. The characteristics of PV under uniform and PSC as shown in Figure 2. To overcome the fluctuation around the MPP, authors switch to soft computing methods such as ANN and fuzzy logic to track GMPP without oscillations[11]. Nevertheless, these methods require rules and proper training to perform the operations. Moreover, it is system-dependent and large complexity involved during the process.

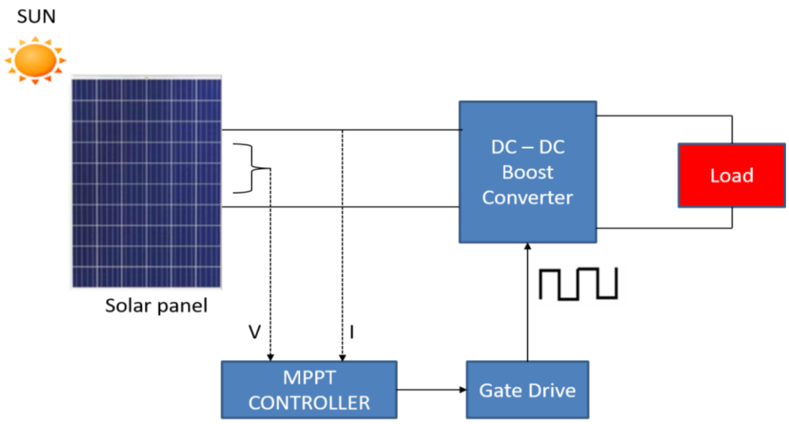


Figure 1. Block diagram for PV system.

In recent years some of the authors focused on metaheuristic algorithms such as particle swarm optimization (PSO)[12], artificial bee colony (ABC)[13], ant colony (ACO)[14], Bat algorithm (BAT)[15], Cuckoo Search (CS)[16], Grasshopper optimization (GHO)[17], and Grey wolf optimization (GWO)[18]. Each of these algorithms has individual properties in terms of tracking speed, accuracy and efficiency. However, PSO easily falls into LMPP instead of GMPP and low convergence during the iterative process[19]. A similar performance was performed by CS also, to improve the CS, self-adaptive parameters are used[20]. ACO is used in dynamic applications nevertheless, the theoretical analysis is too difficult and the time to convergence is uncertain. GWO algorithm performed based on four parameters such as α, β, δ, and ω for searching and hunting process in a hierarchical manner to track GMPP. However, it has limits during the process.

To avoid all the issues a novel metaheuristic algorithm is used in this paper called improved grey wolf optimization (I-GWO) and it has a quick searching process to extract the GMPP. The single diode model under PSC is presented in section 2. The proposed algorithm, results and comparison are depicted in sections 3 and section 4. Eventually, the conclusion part is presented in section 5.

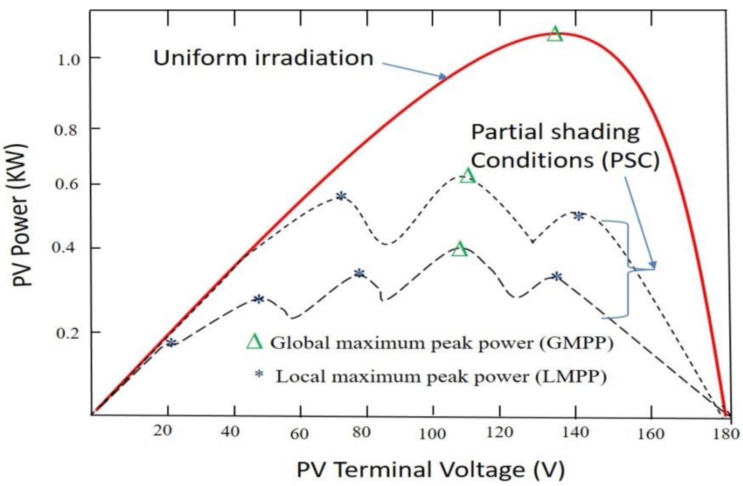


Figure 2. PV Characteristics under uniform and partial shading conditions.

2. The photovoltaic model under PSC

The diode models are classified into three types depends on the number of diodes like single diode model, two diode model, and three diode model[21][22]. Amongst single diode model is mostly preferred.

2.1 single diode model

The single diode is easy to construct and well performance as shown in Figure 3 over the other remaining two models. In the single diode model, the diode is connected in parallel to the current source and the resistors are connected in series and parallel. The basic mathematical equations are presented below[23].

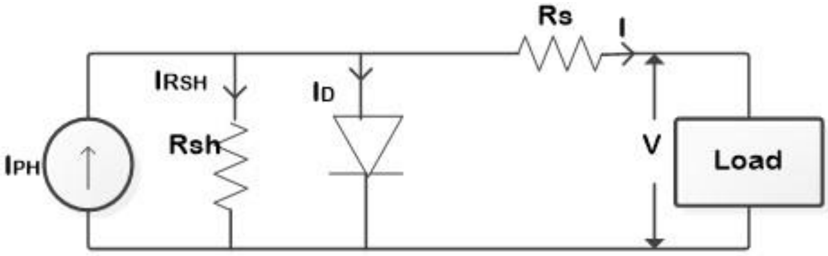


Figure 3. Single diode model connected to load.

The diode current equation

$$I_D = I_{PH} - I_0\left[\exp\left(\frac{V+IR_s}{aV_T}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \tag{1}$$

Where the photon current is I_{PH}, thermal voltage is represented by V_T and temperature is indicated by T. The series and shunt resistance are depicted by R_s and R_{SH}. The reverse saturation current is I_0.

$$I_0 = I_{0.STC}\left[\frac{T_{STC}}{T}\right]^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \tag{2}$$

Where the energy gap of the semiconductor material is E_g and the nominal current at standard test conditions is $I_{0.STC}$.

2.2 Partial shading condition modelling

In this paper, the PV modules are presented in the form of four series (4S) and two series two parallel (2S2P) as shown in Figures 4 (a) and 4(b).

suppose each PV module have the same rating of 200 W at STC and the same irradiation of 1000 W/m^2 as shown in Figure 4(a) resulting in only one peak is generated at PV characteristics whereas bypass diode act as reverse bias. When it is subjected to PSC the G_4 receives 500 W/m^2 and the remaining module receives 1000 W/m^2 whereas G_4 act as a load instead of a generator.

The bypass diode act as forwarding bias and avoid the damage of the shaded module. Due to that multiple peaks are generated in which only one GMPP remaining are LMPP of the characteristics. The blocking diodes are connected to each string to avoid the reverse current due to voltage mismatch of strings as shown in Figure 4(b).

PV array output current equation

$$I = \sum_{K=1}^{S} I_i \tag{3}$$

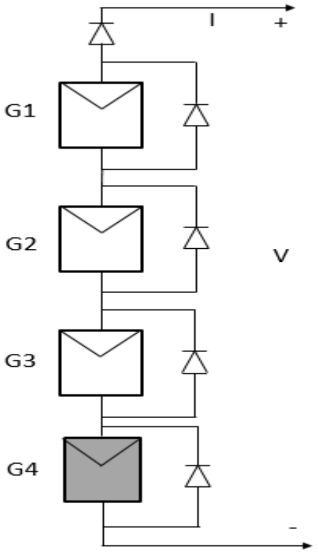


Figure 4(a). 4S PV Modules.

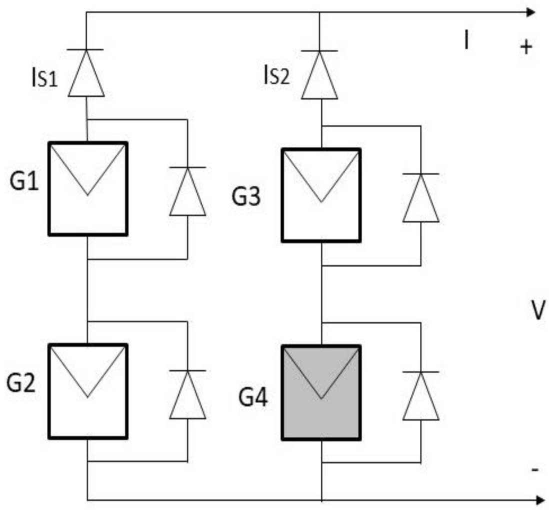


Figure 4(b). 2S2P PV Modules.

3. Improved Grey Wolf Optimization for MPPT

3.1 Grey Wolf Optimization

A new nature-inspired algorithm is called GWO and exhibits optimum solution for MPPT during the non-linear conditions. It has four groups of wolves to perform the required operation alpha (α), beta (β), delta (δ), and omega (ω) in a hierarchal manner as shown in Figure 5. In GWO, α wolves are a leader amongst the other wolves and provide an optimum solution whereas β is subordinate to α. Third wolves δ dominates the ω wolves. These wolves follow three steps during the hunting process namely: encircling, hunting, and attacking the prey[24].

Figure 5. Grey wolf optimizer.

Encircling

During this procedure, the wolves are randomly encircling between the limits and the dimensions of wolves and the position of the equations are as follows.

$$D = |C \times X_P(t) - X(t)| \quad (4)$$

$$X(t+1) = X_p\ (t) - A \times D \tag{5}$$

Where the position of grey wolves indicated X and prey position denoted by $X_{P.}$ t is the current iteration. The coefficient of vectors is represented by A and C as shown in the below equations

$$A = 2\ \times A\ \times\ r_1\ - a(t) \tag{6}$$

$$c = 2\ \times\ r_2 \tag{7}$$

Where the random vectors are r_1 and r_2 in between the limits 0 and 1. The vector elements denoted by 'a' gradually reduces from 2 to 0.

$$\mathrm{a} = 2 - (2\ \times \mathrm{t})/\mathrm{MaxIter} \tag{8}$$

Hunting
The hunting operation can be performed by α, β, and δ therefore the best position is updated. The hunting equations are as follows.

$$D_{\propto} = |C_1\ \times\ X_{\propto}\ - X(t)|,\quad D_{\beta} = |C_2 \times\ X_{\beta} - X(t)|,\quad D_{\delta} = |C_3 \times\ X_{\delta} - X(t)| \tag{9}$$

$$Xi1\ (t) = X\alpha\ (t) - Ai1 \times D\alpha\ (t)$$

$$Xi2\ (t) = X_{\beta}\ (t) - Ai2\times D_{\beta}\ (t) \tag{10}$$

$$Xi3\ (t) = X_{\delta}(t) - Ai3 \times D_{\delta}\ (t)$$

Where the coefficients $c_{1,}$ c_2 and c_3 are calculated using equation (8)

$$X\ (t+1) = \frac{X_{i1}\ (t) + X_{i2}\ (t) + X_{i3}\ \ (t)}{3} \tag{11}$$

Attacking
When prey stops moving, therefore, wolves are attacking and update the position moreover, the vector elements are decreased linearly from 2 to 0. During the process, half of the iterations are exploring and half of the iterations are exploited however, it suffers from premature convergence, lack of population diversity, unbalancing between exploration and exploitation.

3.2 Improved Grey Wolf Optimization
In GWO, the four parameters α, β, δ, and ω can find the optimum solution however, it easily falls into local optimum due to lack of population diversity[25]. To avoid this problem a novel new nature-inspired algorithm IGWO is considered in this paper. It has three stages to operate like initializing, movement, and selecting and updating.

Initializing stage
In this stage, N wolves are randomly distributed in between the limits [$l_{i,}$ u_j] through equation (12).

$$X_{ij} = l_j\ + rand_j[\ 0\ 1]\ \times\ (u_j -\ l_j),\ \ i\ \in [1, N],\ J \in [1,\ D] \tag{12}$$

Where the problem number of the dimensions is denoted by D and the total population is stored in a matrix with N number of rows and D number of columns. The fitness function calculated by $f(x_i(t))$.

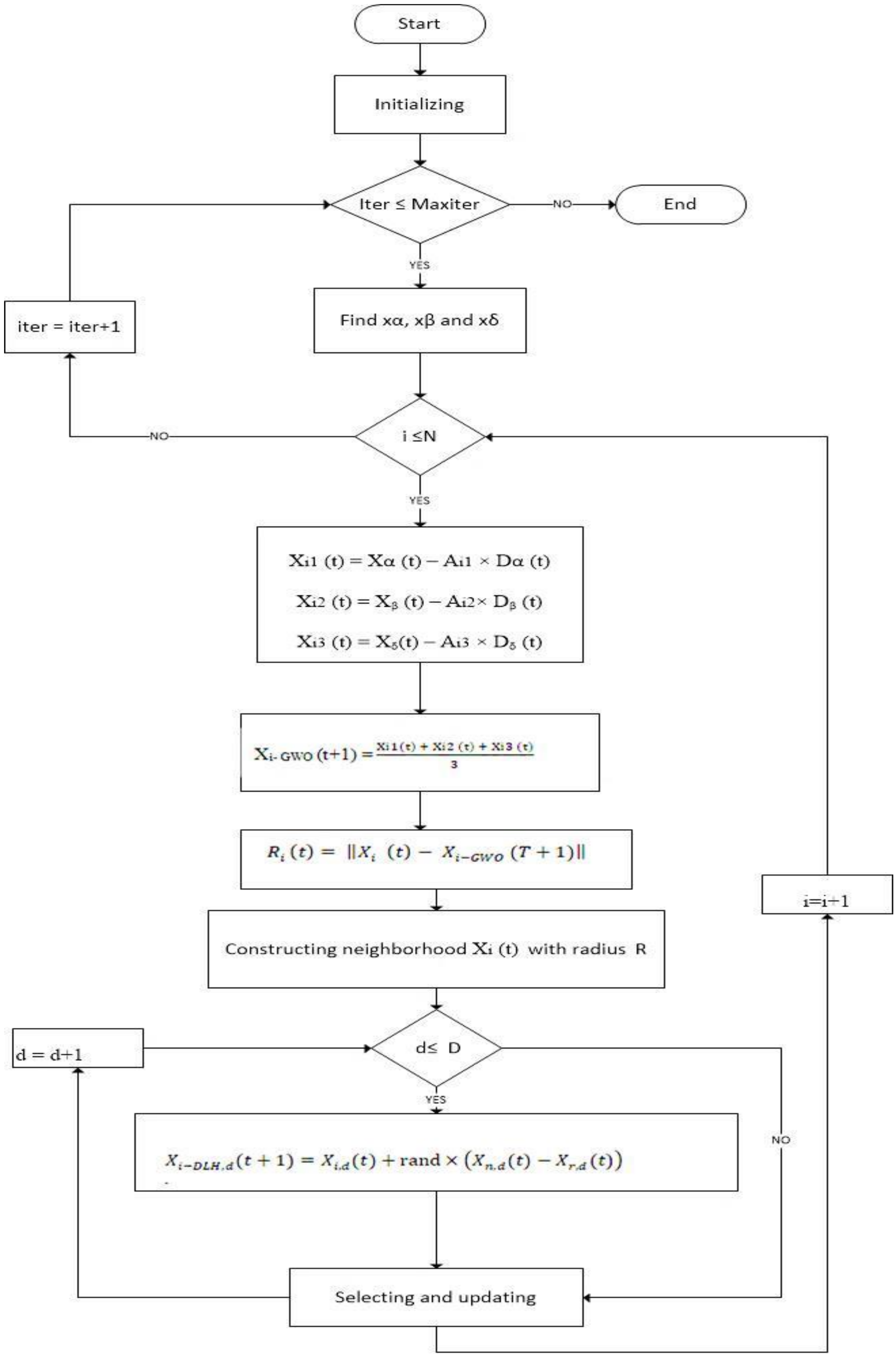


Figure 6. IGWO Flowchart.

Movement stage
Individual hunting's are added to group hunting to improve the behavior of the wolves hunting process is called dimension learning-based hunting (DLH). In DLH, the behavior of individual hunting learns by neighbor wolves for the updated position $x_i(t)$.
During this new learning, the updated position $x_i(t)$ is indicated by $x_{i\text{-}DLH}(t+1)$. For this individual hunting radius $R_i(t)$ is calculated using Euclidean distance as shown below. Moreover, it reduces premature convergence and balances the exploration and exploitation process[25].

$$R_i\,(t) = \|X_i\ \ (t) - X_{i-GWO}\,(T+1)\| \quad (13)$$

$$X_{i-DLH,d}(t+1) = X_{i,d}(t) + \text{rand} \times \left(X_{n,d}(t) - X_{r,d}(t)\right) \quad (14)$$

Selecting and updating stage
In this stage the best one is selected by comparing the fitness of these two $X_{i\text{- }GWO}$ (t+1) and $X_{i\text{-}DLH}$(t+1) as shown below equation.

$$X_i\,(t+1) = \begin{cases} X_{i-GWO}\,(t+1) & if\ f(X_{i-GWO}) < f(X_{i-DLH}) \\ X_{i-DLH}\,(t+1) & otherwise \end{cases} \quad (15)$$

Eventually, the iteration value is increased by one for all individual values and the searching is continued until the predetermined value is reached. The total procedure can be described by the flow chart of I-GWO as shown in Figure 6.

4. Simulation results and comparisons

The proposed I-GWO is used to perform the simulation results on different combinations, like 4S PV modules and 2S2P PV modules with three different patterns for each module combination as shown below.

Three patterns for 4S modules
Pattern 1:- G1G2 =1000, G3G4 =600.
Pattern 2:- G1G2 =1000, G3G4 =400.
Pattern 3:- G1= 1000, G2 =600, G3 =400, G4 =200.

Another three patterns for 2S2P modules
Pattern 4:- G1= 1000, G2= 600, G3= 1000, G4= 600.
Pattern 5:- G1= 1000, G2= 400, G3= 1000, G4= 400.
Pattern 6:- G1= 1000, G2= 600, G3= 1000, G4= 400.

4.1 4S PV modules

The electrical characteristics of 4S PV modules with three cases as shown in Figure 7. It has multiple peaks due to bypass diode subjected to different irradiation conditions with different local peak PowerPoint (LPPP) amongst one is global maximum peak power (GMPP). To find the GMPP here I-GWO optimization method is used and compare with other algorithms GWO and PSO.

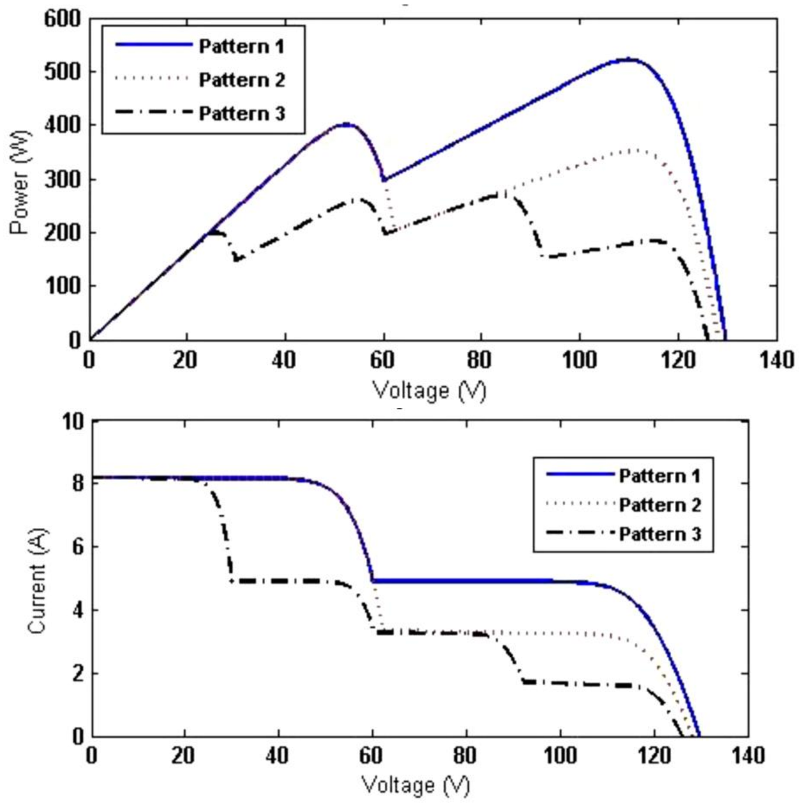


Figure 7. Electrical characteristics of 4S modules with three patterns 1, 2 and 3.

The simulation results indicate the performance of three patterns with every 30s duration for the characteristics of Figure 7. The proposed algorithm I- GWO with time period is 0- 30s for pattern 1, pattern 2 time period is 30 - 60s, and pattern 3 time period is 60 – 90s. In this paper the results are taken for power, voltage and current with respect to time as shown in Figure 8, Figure 9 and Figure 10. The performance analysis of three algorithms like I- GWO, GWO and PSO is shown in Table 1.

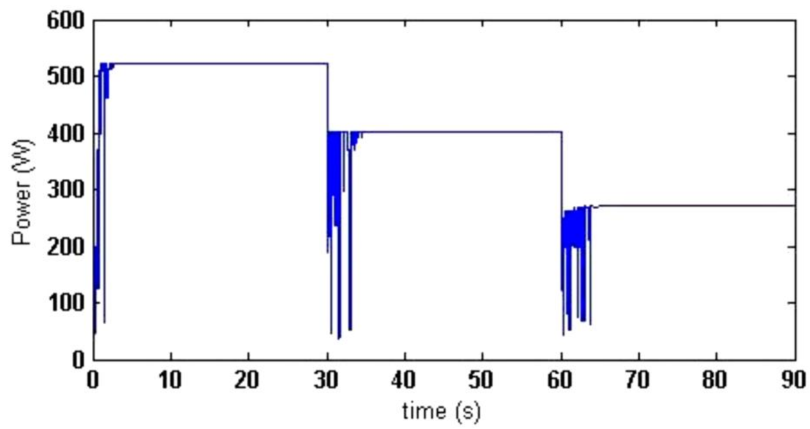


Figure 8. MPPT curve for power.

Table 1. Performance of suggested three algorithms under diverse parameters.

Type of module	Pattern number	Algorithm	Power (W)	Voltage (V)	Current (A)	Duty ratio	Tracking time (sec)	Maximum power from P-V curve	Efficien-cy (%)
4S	1	I- GWO	533.22	118.49	4.50	0.5192	3.4	533.22	99.99
		GWO	533.22	118.49	4.50	0.5183	8.2		99.99
		PSO	533.22	118.49	4.50	0.5191	11.7		99.99
	2	I- GWO	402.06	55.45	7.25	0.7261	4.9	402.06	99.99
		GWO	402.06	55.45	7.25	0.7254	8.4		99.99
		PSO	402.06	55.45	7.25	0.7254	12.3		99.99
	3	I- GWO	268.09	76.59	3.50	0.4523	5.8	268.09	99.99
		GWO	268.09	76.59	3.50	0.4521	9.2		99.99
		PSO	268.09	76.59	3.50	0.4518	12.1		99.99
2S2P	4	I –GW0	510.33	55.11	9.26	0.7345	4.2	510.24	99.99
		GWO	510.32	55.17	9.25	0.7354	8.4		99.99
		PSO	508.23	54.53	9.32	0.7426	13.6		99.96
	5	I – GWO	401.18	26.34	15.23	0.8492	3.5	401.28	99.97
		GWO	401.12	26.51	15.13	0.8486	7.4		99.98
		PSO	360.18	56.99	6.32	0.6234	10.6		88.64
	6	I – GWO	437.65	56.26	7.76	0.7254	3.7	437.78	99.98
		GWO	437.62	56.54	7.74	0.7243	7.6		99.98
		PSO	437.62	56.54	7.74	0.7242	11.6		99.98

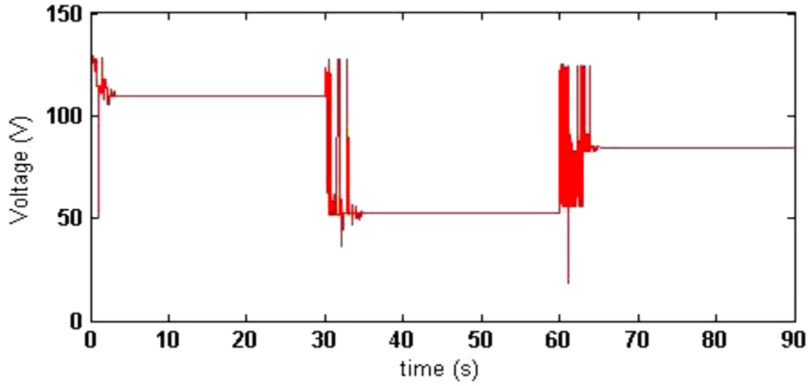


Figure 9. MPPT curve for voltage.

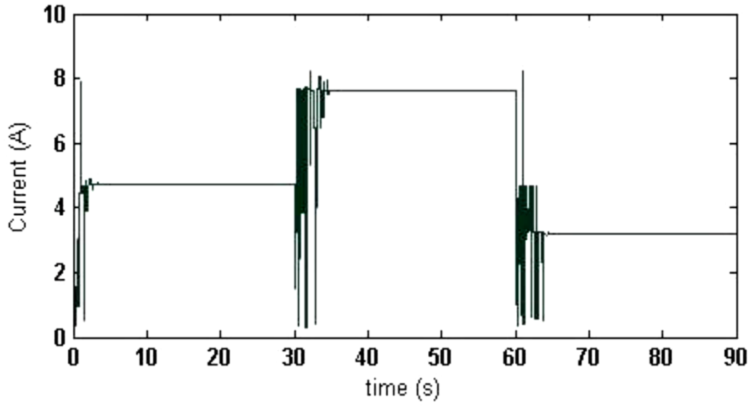
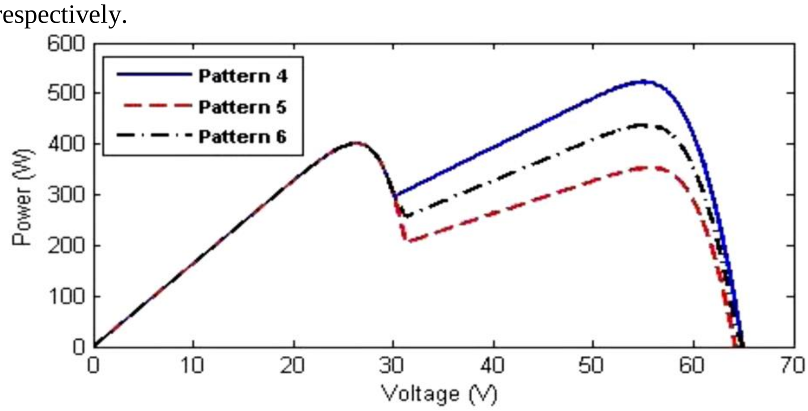


Figure 10. MPPT curve for current.

The MPPT by I-GWO for three patterns are 533.22 W, 402.06W and 268.09W with tracking times 3.4 s, 4.9 s and 5.8 s.

4.2 2S2P PV modules

The electrical characteristics of 2S2P PV modules with three different patterns 4, 5 and 6 as shown in Figure 11, and every pattern has one LMPP and one GMPP. In those two points, the proposed I-GWO finds GMPP for every pattern with every 30sec duration. The simulation results for power, voltage and current as shown in Figure 12, Figure 13 and Figure14. The MPPT tracked by pattern 4 is 510.33W with 4.2s tracking time; pattern 5 and pattern 6 are 401.18W, 437.65W with tracking time 3.5s and 3.7s respectively.



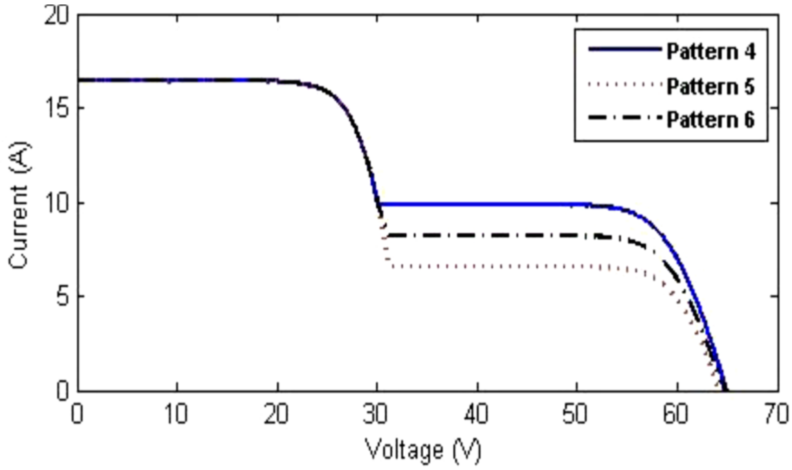


Figure 11. Electrical characteristics of 2S2P modules with three patterns 4, 5and 6.

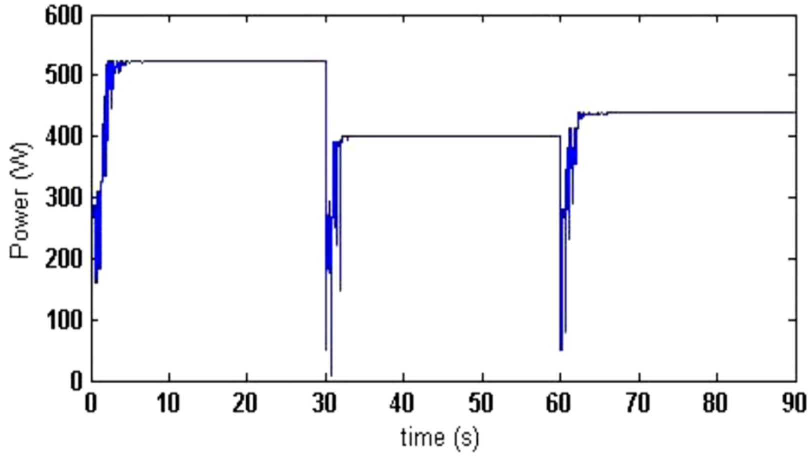


Figure 12. MPPT curve for power.

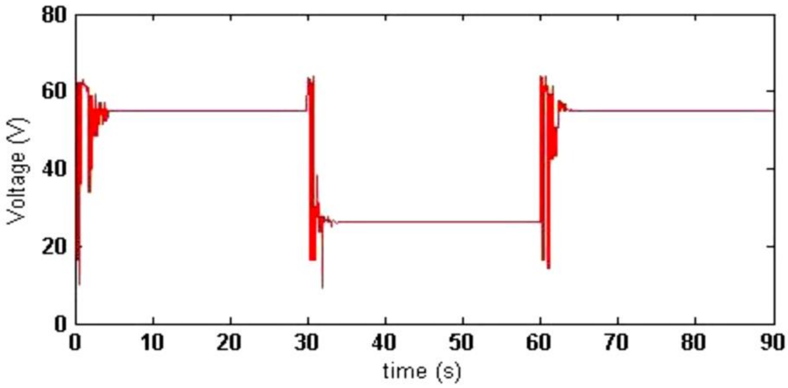


Figure 13. MPPT curve for voltage.

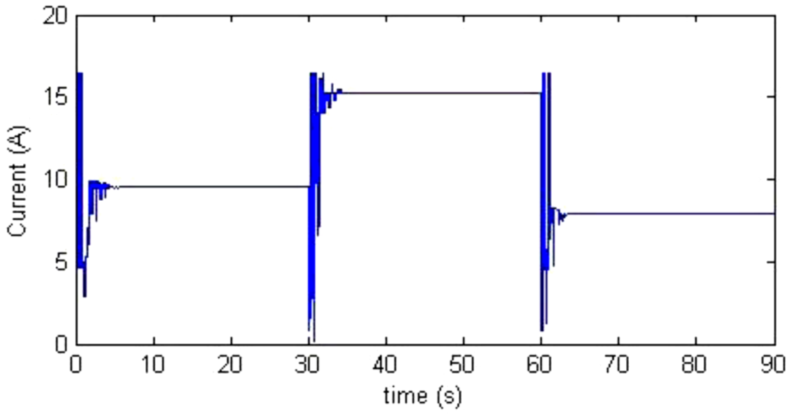


Figure 14. MPPT curve for current.

4.3 Comparisons
The proposed I-GWO algorithm is compared with the other two algorithms GWO and PSO in terms of power, voltage, current, duty ratio, tracking time, maximum power and efficiency as shown in Table 1.

5. Conclusion
In this study, the I-GWO is proposed to improve the required power generation in the event of three different partial patterns for the PV systems. The suggested system has been developed in the MATLAB/Simulink software. The simulation results disclose that the proposed I-GWO method ensures better enrichment with respect to settling time and accuracy as compared with other existed algorithms. Besides, the efficiency of the PV system with suggested I-GWO is high as contrasted to studied algorithms. Further research might explore with the combination of I-GWO and other novel optimization methods for solving the difficulties in the PV system under various partial patterns for acquiring the maximum power.

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