

# A bio inspired maximum power point tracking controller for PV systems under partial shading conditions

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## ABSTRACT

Maximum power point tracking (MPPT) is a technique used in extracting the maximum power from a photovoltaic panel (PV) under different weather conditions. The last decade has witnessed a wide variety of algorithm based on MPPT controllers, ranging from simple to more complex ones. Each of them has its own advantage and disadvantage. Hence, it is crucial to propose methods that are both simple and effective to track and maintain the MPPT of a PV system, even under partial shading conditions. In this study, we propose a new bio inspired method namely seagull optimization algorithm (SOA) for solving the MPPT problem in a PV system. To evaluate the proposed SOA\_MPPT performance in terms of accuracy, convergence and stability, a simulation methodology is used. First, by tuning the appropriate parameters, then, we consider the following scenarios: rapid change of solar irradiation, temperature, and three patterns to test partial shading effect. The results are compared with latest bio-inspired methods, namely, particle swarm optimization (PSO), Bat optimisation algorithm (BAT) and fire fly algorithm (FA). The obtained results confirm the effectiveness and robustness of the proposed controller compared to existing conventional and bio inspired controllers.

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## 1. INTRODUCTION

In recent years, the global energy requirements have increased significantly. Conventional energy sources, mainly fossil fuels such as coal and hydrocarbons, are gradually giving way to clean or renewable energies whose production costs are gradually decreasing. Among the so-called clean sources, solar energy appears to be an alternative energy source that can meet the needs of applications for hostile environments such as deserts, landlocked areas, satellites applications and probes, to name a few.

Indeed, the technology of solar energy conversion by photovoltaic effect has shown significant potential as an energy source. Nowadays, the photovoltaic sector has reached a stage of maturity and proven economic credibility. However, to improve the efficiency of these systems, some aspects need to be considered. In this context, the design and optimization of algorithm based maximum power point controller (MPPT) handling partial shading conditions constitute a current research issue. Initially, MPPT controllers were implemented using conventional methods (CM) such as perturb and observe (P&O) [1], [2] and incremental conductance (IncCond) [3]. These CM have the advantage of being simple, easy to implement

with low cost. They operate very well in uniform conditions of irradiation and temperature. However, these CM have major drawback when a partial shading condition occurs.

Indeed, the tracking efficiency decreases because the controller can easily fail to identify the global MPP, so thus, trapped in a local peak resulting in loss of power. Thus, none of these methods is able to handel the problem of partial shading [4], [5]. To overcome this problem, recently, new types of controllers based on the use of artificial intelligence methods (AIM) have emerged [6]–[8]. Nevertheless, despite their merits, AIMS have a major drawback related to the computation time and complexity of implementation. To alleviate this, bio inspired methods (BIM) [9] are emerging as new and more effective intelligent methods compared to the so-called traditional artificial intelligence methods such as artificial neural networks (ANN), fuzzy logic, genetic algorithm (GA).

These new methods have the ability to maximize search capacity without involving complex mathematical calculations, resulting in computational simplicity and quick response [10], [11]. In addition, they are easy to be implement due to the reduced number of required parameters. Among these methods, we can mention: particle swarm optimisation (PSO) [12], ant colony optimisation (ACO) [13], [14], firefly algorithm (FA) [15], gray wolf optimisation (GWO) [16], Cuckoo search (CS) [17], whale optimisation algorithm (WOA) [18], salp swarm optimisation (SSO) [19], artificial bee colony (ABC) [20], Bat optimisation (BA) [21], [22], teaching learning based optimisation technique (TLBO) [23].

In this paper, we propose to apply seagulls optimization algorithm (SOA) for the maximum power point tracking of photovoltaic (PV) systems subjected to partial shading. This algorithm is inspired and based on the study of the behavior of seagulls to find food sources during the migration season and on the study the behavior attack used to obtain their prey [24]. Through this paper, we demonstrate that the proposed SOA\_MPPT\_controller has an excellent tracking capability with a high accuracy and zero oscillations. It presents a very high robustness when dealing with rapid variations of weather conditions (solar irradiance and temperature) and needs no requirement of knowledge about the characteristics of the PV array. In addition, the global peak is reached under partial shading condition. Further, to prove the robustness, the accuracy and hence the superiority of the proposed SOA\_MPPT\_controller, this latter is analyzed and the results are compared with the following MPPT controllers: *PSO\_MPPT*, *BAT\_MPPT*, *FFA\_MPPT*.

## 2. PV SYSTEMS OVERVIEW

The main architecture of the PV system is depicted in Figure 1. It is mainly based on PV modules, a buck-boost converter, an MPPT controller and a resistive load. In order to simulate the PV system, we used the two diodes model elaborated by Ishaque *et al.* [25]. The model is known to have better accuracy during a low level of insolation, which allows a more accurate prediction for the performance of the PV system under a partial shading condition.

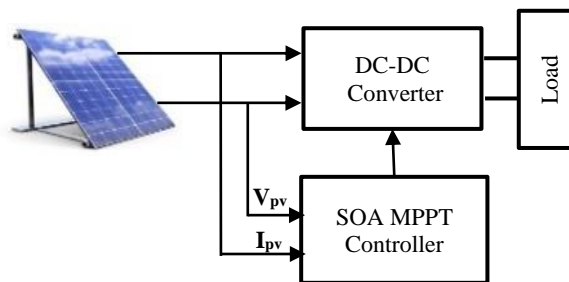


Figure 1. Standalone PV system architecture

The PV module operation depends strongly on the load characteristics to which it is connected. Under a uniform illumination, the current-voltage curve has a single point on the curve called maximum power point (i.e. MPPT), at which the array operates with maximum efficiency and provides maximum output power. Moreover, the characteristics of the PV system vary with the insolation and the temperature. Thus, MPPT controller is required to track the new modified MPP in its characteristic curves whenever an illumination variation and/or temperature variations occurs. Figure 2 illustrates the corresponding static Power-Voltage (P-V) curve for different atmospheric conditions, where Figure 2(a) shows the P-V curve of different irradiances  $G$ , Figure 2(b) shows the P-V curve under different values of temperatures  $T$ , and Figure 2(c) illustrate the effect of partial shading conditions on the PV characteristic curve.

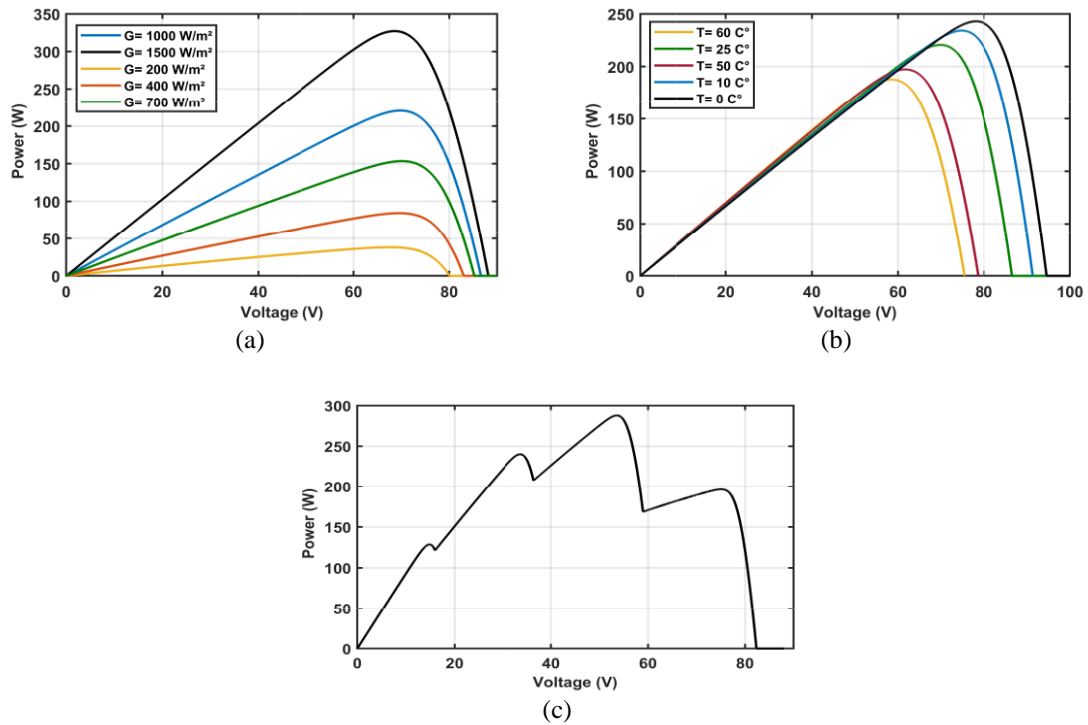


Figure 2. Power-Voltage curve under (a) different irradiation, (b) different temperature and (c) partial shading condition

### 3. SEAGULL OPTIMISATION BASED MPPT

#### 3.1. Seagull optimisation algorithm basic concepts

Seagull optimization is one of the latest bio inspired methods introduced in 2019 by Dhiman and Kumar [24]. Indeed, seagulls are very intelligent birds. Generally, they live in colony. To find and attack their prey, they use their intelligence. Thus, the most important characteristics of seagulls are their migrating and attacking behaviors.

The authors studied the biological characteristics of seagulls, adapted them to optimize and solve all engineering problems that occurs in real life. Thus, the main inspiration of the algorithm is the migration and attacking behaviors of seagulls in nature. These behaviors are mathematically modeled and implemented to highlight exploration and exploitation in a given search space. The mathematical formulation of the natural behavior of seagulls is explained in what follow.

#### 3.2. Mathematical model

##### 3.2.1. Migration (global search: exploration)

During migration, which is a seasonal activity, seagulls are known to move in groups from one area to another one for finding food. During this step, the seagull optimization algorithm mimics and reproduces the movement of seagulls. At this stage, all seagulls must meet these three principal conditions:

- Avoiding collisions: the seagulls must avoid any collision between them. So, to prevent this, an additional variable  $A$  is used to compute the new position of seagulls. The equation of  $A$  is as:

$$C_s = A * P(x) \tag{1}$$

where  $C_s$  represents the new location of the seagulls which does not collide with others,  $P_s$  is the current position of the seagull,  $x$  represents the current iteration and  $A$  represents the movement behavior of seagulls in a given search space. The equation of  $A$  is as shown in:

$$A = f_c - (x * \frac{f_c}{Maxiter}) \tag{2}$$

where  $f_c$  is introduced to control the frequency of variable  $A$  which is linearly decreased from  $f_c$  to 0 and  $Maxiter$  is the maximum number of iterations.

- Going towards the best nearest neighbors: once the seagulls are sure they do not collide, then, they will move to the direction of the best neighbor position as shown in:

$$M_s = B * (P_b(x) - P_s(x)) \quad (3)$$

$$B = 2 * A^2 * r_d \quad (4)$$

where  $M_s$  indicates the direction of the best seagull location,  $B$  is a random number responsible for balancing the global and local search seagull (i.e. exploration and exploitation).

- Staying near the best search agent: lastly, when a seagull moves to the position where it does not collide with other seagulls, it moves in the direction of the best position to reach its new position as shown in:

$$D_s(x) = C_s(x) + M_s(x) \quad (5)$$

where  $D_s$  represents the best fit search seagull.

### 3.2.2. Attack (local search: exploitation)

During the migration period, gulls frequently attack migratory birds and fish over the sea when migrating from one location to another. They constantly change angle and attack speed by using their wings and weight to maintain altitude. When seagulls attack their prey, they move in a spiral in the air. The movement behavior in the x, y and z planes is described as:

$$x = r * \cos(k) \quad (6)$$

$$y = r * \sin(k) \quad (7)$$

$$z = r * k \quad (8)$$

$$r = u * e^{kv} \quad (9)$$

where  $r$  is the radius of each turn of the spiral,  $k$  is a random number in range  $[0 \leq k \leq 2\pi]$ ,  $u$  and  $v$  are constants to define the spiral shape,  $e$  is the base of the natural logarithm.

From the mentioned equations, the updated position of the seagull is expressed according to:

$$P_s(x) = (D_s * x * y * z) + P_b(x) \quad (10)$$

where  $P_s(x)$  saves the best solution and updates the position of other search seagulls.

### 3.3. Application of seagull optimisation to the MPPT problem

The performances of the SOA algorithm described in section 3.2 are used to design a new powerful MPPT controller namely *SOA\_MPPT\_Controller*. Thus, the process of migration and attack is mimicked and the objective function is used to find the operating voltage at which the maximum power i.e. MPP of the PV system is reached. In addition, the proposed *SOA\_MPPT\_Controller* allows finding the GMPP when partial shading conditions occurs, where the  $P-V$  and  $I-V$  curves have multiple peaks (global and local). The flowchart of the proposed *SOA\_MPPT\_Controller* is illustrated in Figure 3. The proposed algorithm is executed as follow:

- Step 1. Initialization: in order to start the optimization, the duty cycle of the PWM signal is chosen to be the optimization variable. Thus, it is adjusted directly by the MPPT controller. Initially, a solution vector of duty cycle with a number of  $N$  particles is defined,

$$d = d_i = (d_1, d_2, d_3, \dots, d_N) \quad (11)$$

the number of particles in the population must be chosen carefully. A greater number of particles allows a more precise tracking of the MPP even under complex patterns of partial shading but the tracking speed decreases. As the number of particles (seagulls) increases, the computation time also increases. Therefore, the size of the population must be chosen to ensure good tracking speed and accuracy. The aim of the optimization process is to maximize the power extracted from the PV system, which is defined as the objective function (P). The fitness value rating function is defined as:

$$P(d_i^k) > P(d_i^{k-1}) \tag{12}$$

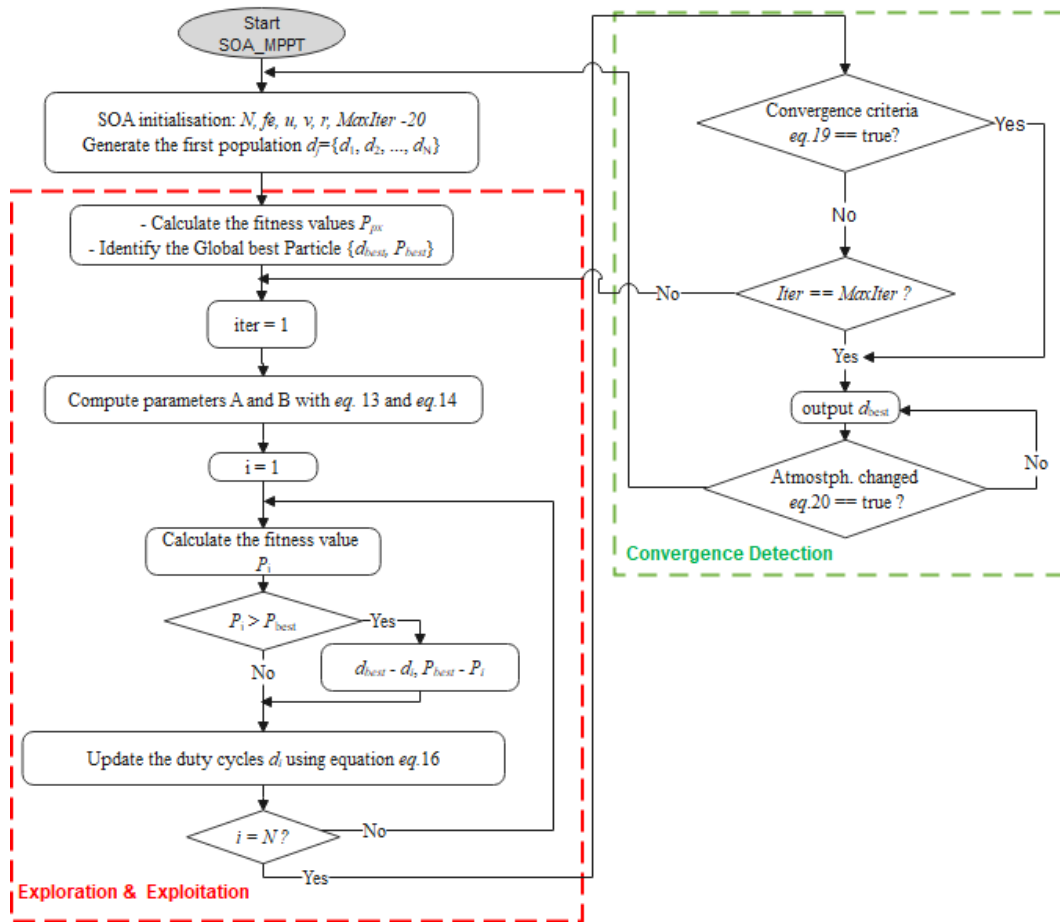


Figure 3. Flow chart of the proposed SOA\_MPPT\_controller

- Step 2. Update best global duty cycle: the best global duty cycle  $d_{best}$ , is obtained by comparing the fitness values of the actual population with the best global PV power obtained,  $P_{best}$ .
- Step 3. Update parameters: at each iteration the parameters  $A$  and  $B$  are updated using:

$$A = f_c * \exp\left(-\frac{iter}{\tau}\right) \tag{13}$$

$$B = 2 * A^2 * rd \tag{14}$$

where  $f_c$  is introduced to control the frequency of use of variable  $A$  that decreases linearly from  $f_c$  to 0 and  $k$  indicates the current iteration.

- Step 4. Update the position of each particle: after the evaluation process, the positions of each particle in the swarm are updated for each iteration.

$$D_S = A * d_i^{k-1} + B * (d_{best} - d_i^{k-1}) \tag{15}$$

$$r = u * e^{kv}, k \in [1,1.7] \tag{16}$$

$$x' = r * \cos(2 * pi * k) \tag{17}$$

$$d_i^k = (D_S * x') + d_{best} \tag{18}$$

- Step 5. Convergence criteria: the algorithm continues to calculate the new duty cycles until it meets the constraint of the convergence criteria. If the difference between each of the two different duty cycles is less than a threshold  $d$ , then the algorithm stops the process optimization and highlights  $d_{best}$ :

$$|d_i^k - d_j^k| > \Delta d \quad (19)$$

- Step 6. Monitoring the atmospheric changes: generally, in a real working environment, the MPP position is changing due to the varying weather conditions. When this scenario occurs, the proposed SOA\_MPPT\_controller must have the ability to detect the variation of the shading pattern and look for the new global MPP. Thus, the searching process is initialized if the following condition is met.

$$\frac{P_{PVnew} - P_{PVlast}}{P_{PVlast}} > \Delta P \quad (20)$$

Where  $P_{PVnew}$  and  $P_{PVlast}$  are the power values of the photovoltaic panel in two successive sampling periods and  $P$  is the power variation.

#### 4. SIMULATIONS RESULTS AND DISCUSSIONS

To verify the effectiveness of the proposed *SOA\_MPPT\_controller*, a simulation using the MATLAB and Simulink environment tools is performed. This allow first to parametrize the proposal (*evaluate and select the better parameters*), then, a comparative study in term of *convergence speed, accuracy, stability* and robustness is performed by a simulation of the bio inspired methods which contains respectively the *BAT, FA, PSO* and the proposed *SOA* MPPT controllers as illustrates in Figure 4. It is to be mentioned that the selected controllers were developed at our laboratory.

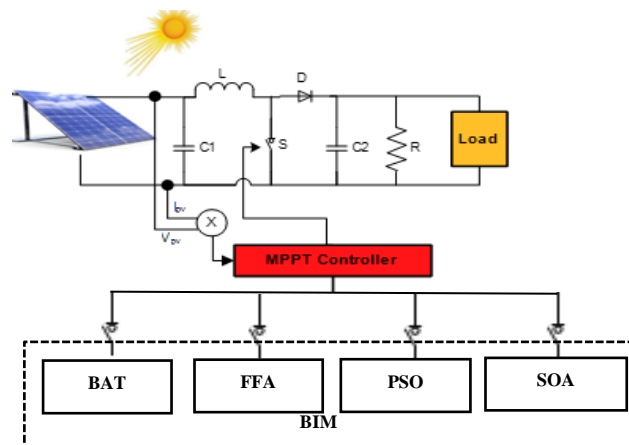


Figure 4. PV system based MPPT\_controllers under test

##### 4.1. Selection of the best seagull optimisation parameters

The performances of an MPPT controller are strongly related to their tuning parameters (*population size, coefficient constituting the algorithm and number of iterations*) which affect directly the efficiency, the accuracy and the robustness of the MPP (i.e slow convergence and blocked in a local maximum). So, the parameterization constitutes a critical step for the design and implementation of MPPT controller.

To evaluate the influence of the SOA parameters, several tests were carried by tuning the values of parameters (*Max\_iter, Nbr\_particules, fc, u, v*) in order to select the most suitable ones, thus, reduce the processing time and improve the efficiency of the controller (i.e reach the MPP). The various tests are performed under standard conditions (1000 W/m<sup>2</sup>, 25 °C).

Table 1 resume the simulation results for the selection of the best parameters. Based on this, the best results are given in *T6*. From these, we can conclude that the choice of the selected parameters which ensures an efficiency of 99.99 to the *SOA\_MPPT\_controller* with a fast convergence time and optimum power are *Max\_iter=20, Nbr\_particules=4, fc=2, u=0.08* and *v=0.45*.

Table 1. Selection of best SOA parameters

Tests Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Max iterations	30	20	20	15	15	20	20	20	20	20
Nbr of particles	6	6	5	5	4	4	4	3	3	3
Fc	2	3	2	2	2	2	2	2	2	4
u	0.12	0.12	0.10	0.02	0.06	0.08	0.09	0.09	0.09	0.09
v	0.30	0.30	0.30	0.20	0.20	0.45	0.50	0.50	0.50	0.50
τ	5.0	4.0	3.6	2.5	3.5	3.4	3.3	3.3	5.0	2.5
P <sub>pv</sub>	130.56	130.67	130.69	130.17	127.27	130.69	130.69	128.62	130.37	127.73
Efficiency	99.90	99.98	99.99	99.60	97.37	99.99	99.99	98.41	99.75	97.73
Conv. time	4.07	3.30	1.98	0.70	1.23	1.10	1.52	1.13	1.91	0.93
Success rate (%)	100	100	100	100	78	100	100	92	98	90

4.2. Evaluation of the SO\_MPPT controller

In order to evaluate and compare the performance of the proposed *SOA\_MPPT\_controller*, different scenarios are developed. The behavioral study is based on these criteria:

- Convergence speed;
- Accuracy;
- Stability i.e. steady states oscillations;
- Robustness.

To highlight each of these criteria, we have adopted the following scenarios:

- Scenario 1: consists of observing the response time of each controller under constant conditions (25°, 1000 W/m<sup>2</sup>), thus making it possible to assess the criterion relating to the convergence of the various controllers;
- Scenario 2: consists of simulating the operation of the PV system by modifying the atmospheric conditions (irradiance and/or temperature) in order to observe the dynamic behavior of the MPPT controller, thus making it possible to study the criteria relating to *stability, oscillation, precision* and *robustness*.

4.2.1. Convergence speed

Figure 5 illustrate the evolution of the output power for the selected controllers. According to the obtained results, it can be observed that the proposed *SOA\_MPPT\_controller* converge quickly with a response time of 0.8s towards the MPP, with an average accuracy and zero oscillations at steady state compared to the other controllers. Figure 6 depicts the convergence and settle times of selected controllers.

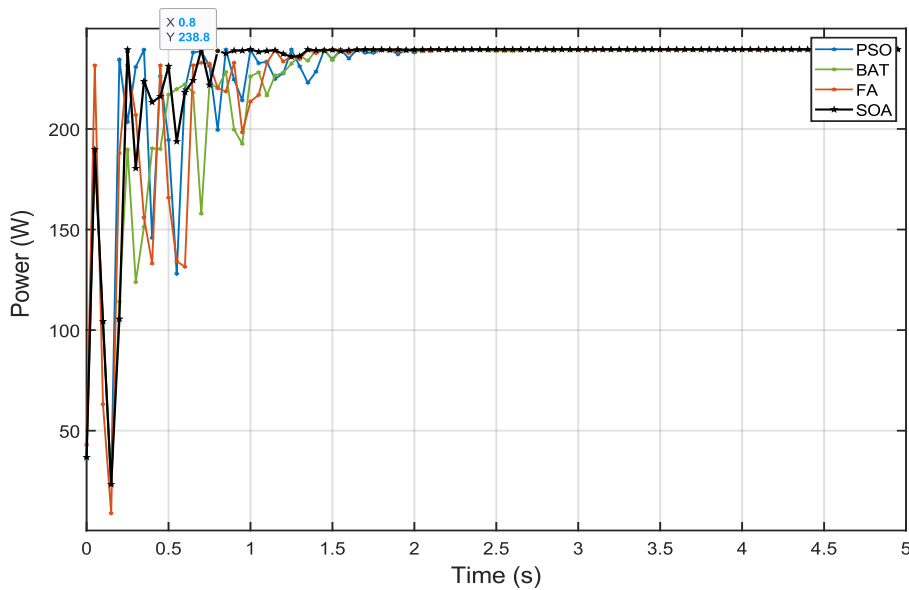


Figure 5. Comparison of convergence speed for the PSO, BAT, FA and SOA MPPT controller under STDCs

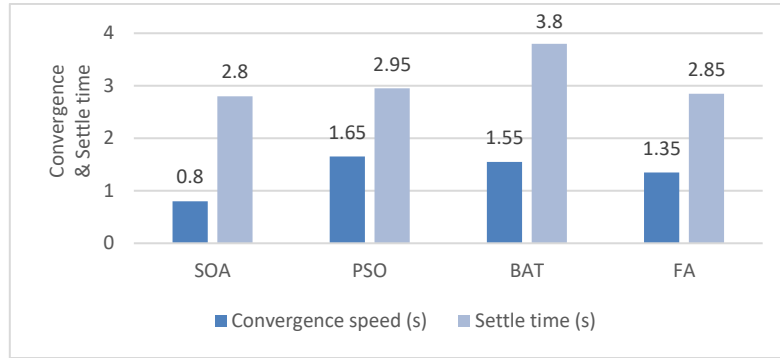


Figure 6. Speed convergence and settling time of the PSO, BAT, FA and SOA MPPT controller

**4.2.2. Accuracy, stability and robustness**

The efficiency of an MPPT controller is evaluate in terms of its ability to follow maximum power but also in terms of its robustness, accuracy and stability against oscillations. To estimate the performance of the proposed MPPT controller, a PV system fit out a set of different controllers is used and subject to three senarios.

- Rapid variation of the irradiance
- Rapid decrease of the temperature
- Handling the partial shading

In the first senarios, a rapid increase of the irradiance from 600 to 1000 W/m<sup>2</sup> is set at time t=5s. Then a decrease in the irradiance occurs at time t=10s from 1000 to 400 W/m<sup>2</sup> as depicted in Figure 7. The temperature is maintained at 25 °C for the duration of the test.

The second scenario as shown in Figure 8, adopt a rapid decrease of temperature. In the first 5s the system is subjected to a higher temperature of 45 °C then decreases to 25 °C at t=5s, and to a lower temperature of 10 °C at t=10s. In the last scenario, the system was subjected to three partial shading patterns as depicted in Figure 9 at every 5s intervals. The corresponding simulation’s results are illustrated in Figure 10.

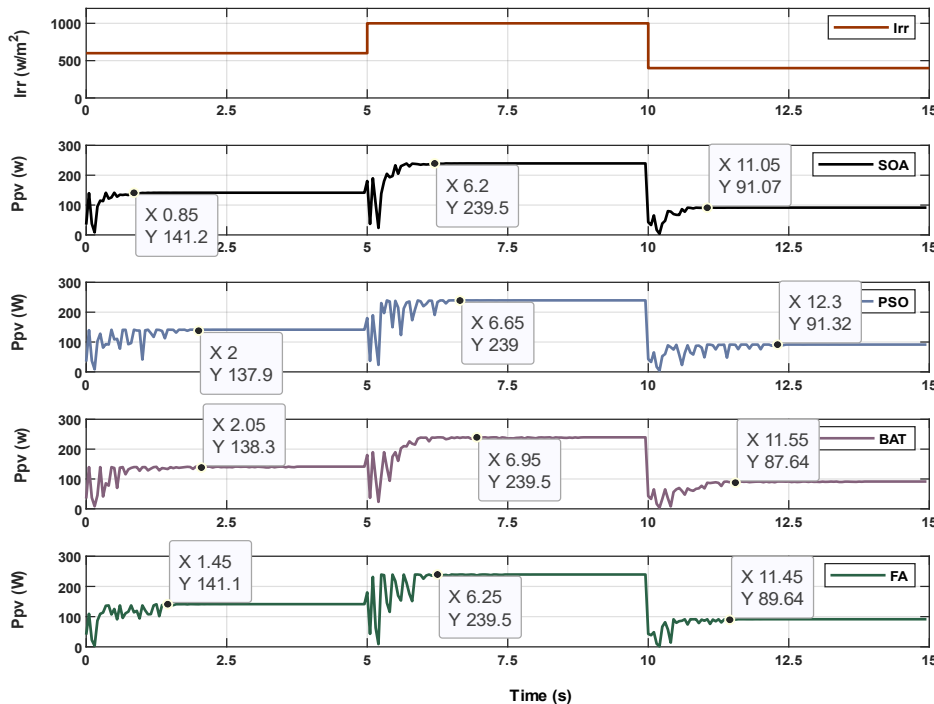


Figure 7. Power evolution of the simulated MPPT controllers for rapid variation of the irradiance



**4.3. Discussion**

As *SOA* is a stochastic method, it is subject to 100 trails of test under 4 scenarios: STC, and three partial shading condition PSC1, PSC2, and PSC3. Based on the obtained simulation results, a quantitative comparison in terms of tracking power, convergence time, static efficiency, and number of successful tracking is done between PSO, BAT and FA. Table 2 depicts the results.

- Test 1: Standard Test conditions. For this test, the PV system is subject to a uniform irradiance  $1000\text{W/m}^2$  and a fixed Temperature  $25^\circ\text{C}$ . It can be observed that all the selected controllers converge to the MPP. The *SOA* MPPT controller has demonstrated its high searching dynamic, and it has achieved the fastest convergence speed of 1.301s in comparison to other algorithms.
- Test 2: PSC1. The PV system is subject to PSC1, where, as depicted in Figure 10, the GMPP is located in the right side. *SOA* has achieved the highest efficiency among other methods, with a result of 99.88% followed by PSO, BAT, then FA. The number of local maximum stagnation was almost zero for *SOA*, 2 GMPP fails for PSO, 7 fails for BAT and 16 fails for FA. *SOA* has the fastest convergence speed of 1.219s.
- Test 3: PSC2. For this scenario, as illustrated in Figure 10, the GMPP is located on the middle. All controllers have very high efficiency of 99.99%. However, compared to other controllers, *SOA* converged rapidly with 1.247s followed by 1.519s, 1.57s and 1.69s for FA, BAT, PSO respectively.
- Test 4: PSC3. For this scenario, the GMPP is located in the left side. The GMPP is tracked successfully with an efficiency of 99.99% and zero fails for *SOA*, PSO and BAT compared to FA that has six time fails and a low efficiency of 98.50%.

Based on the obtained and analysed results, a qualitative comparison of the selected controllers is depicted in Table 3.

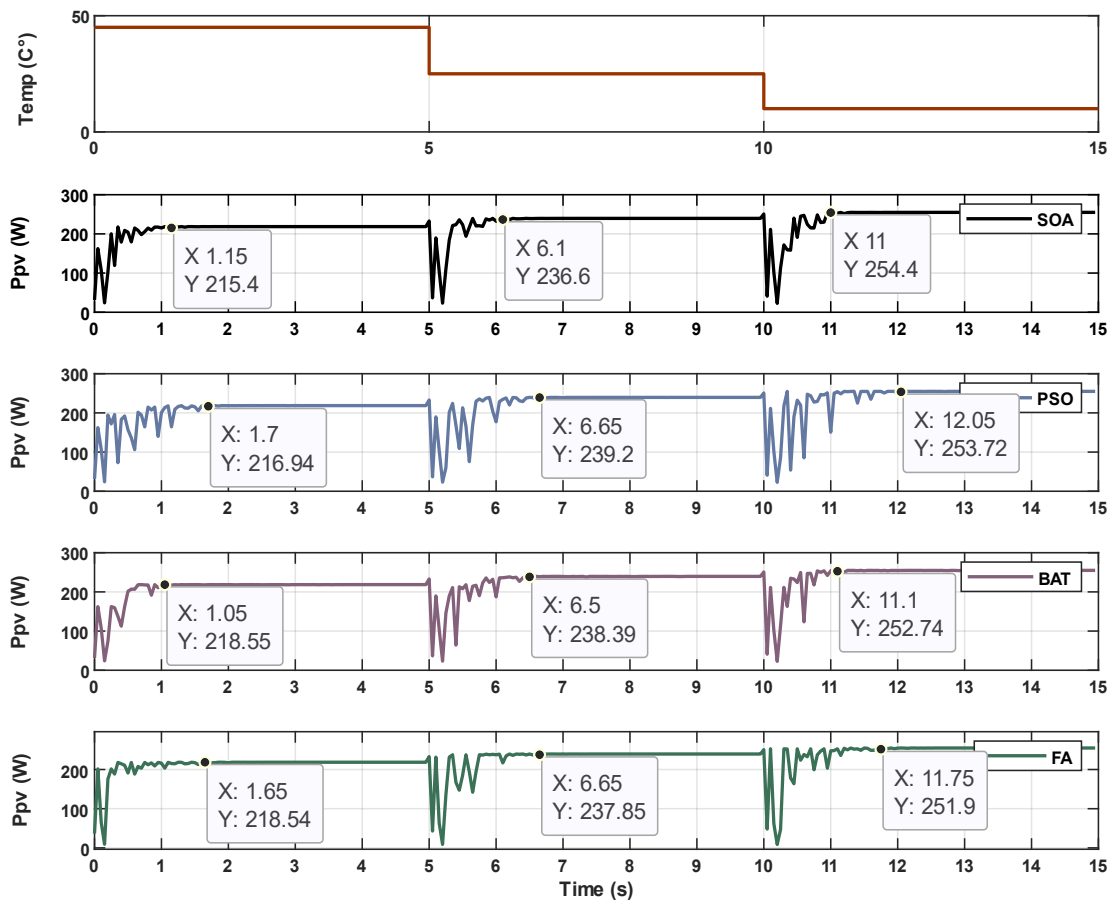


Figure 8. Power evolution of simulated MPPT controllers for rapid decrease of the temperature

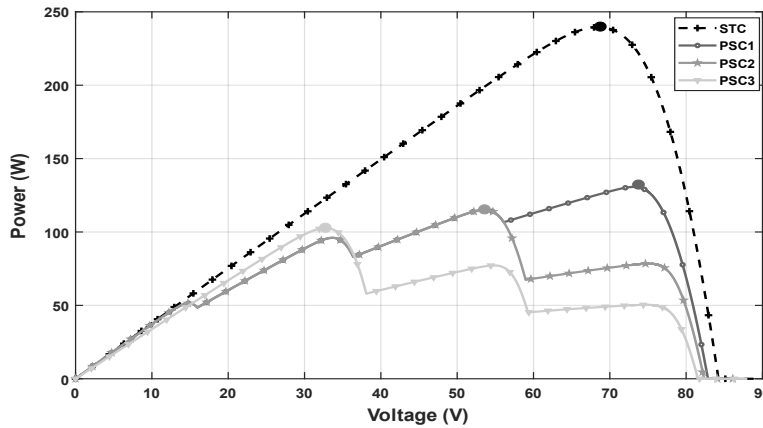


Figure 9. Power\_Voltage characteristic curves for 3 different patterns

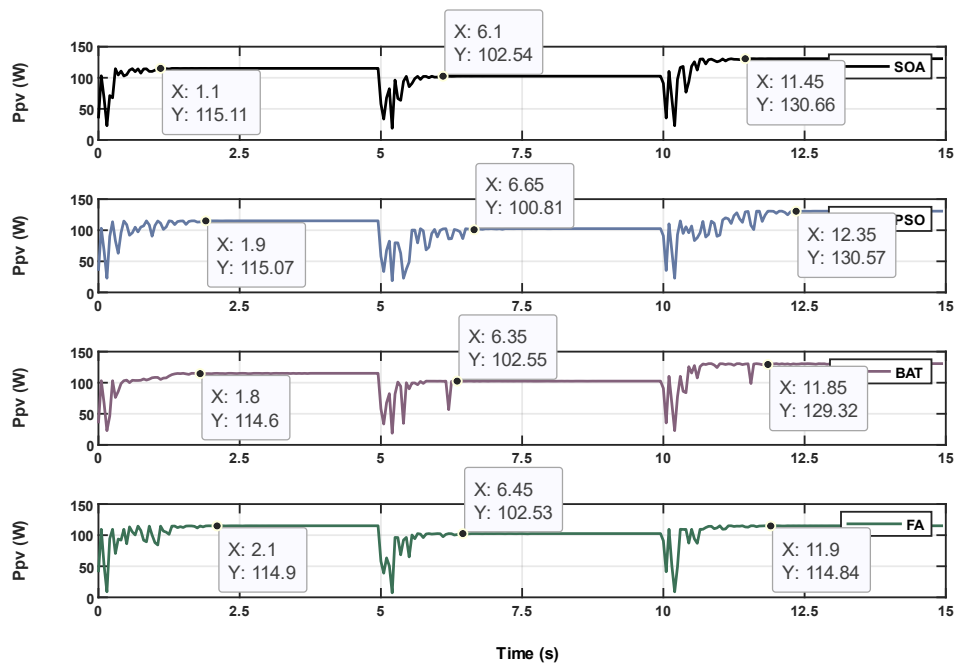


Figure 10. Power evolution of the simulated MPPT controllers

Table 2. Comparison of test results

Parameter	MPPT controller	PV_Power. available(W)	Avr. Ppv tracked (w)	Avr. efficiency (%)	Avr. speed (s)	Success rate (%)
Test 1 STC	SOA	239.548	239.548	99.99	1.301	100
	PSO		239.547	99.99	1.740	100
	BAT		239.547	99.99	1.845	100
	FA		239.547	99.99	1.543	100
Test 2 SC1	SOA	130.699	130.540	99.88	1.219	99
	PSO		130.387	99.76	1.669	98
	BAT		129.606	99.16	1.545	93
	FA		128.192	98.08	1.520	84
Test 3 PSC2	SOA	115.118	115.118	99.99	1.247	100
	PSO		115.118	99.99	1.693	100
	BAT		115.117	99.99	1.575	100
	FA		115.117	99.99	1.519	100
Test 4 PSC3	SOA	102.563	102.563	99.99	1.362	100
	PSO		102.563	99.99	1.727	100
	BAT		102.563	99.99	1.558	100
	FA		101.023	98.50	1.515	94

Table 3. Qualitative comparison of SOA performances with other MPPT algorithms

Criteria	SOA	PSO	BAT	FA
Convergence speed	Fast	Slow	Medium	Medium
Possibility of wrong convergence to LMPP	Zero	Almost Zero	Almost Zero	Medium
Efficiency	Very High	Very High	High	Medium
Steady state oscillation	Zero	Zero	Zero	Zero
Tuning parameters	4	4	3	3
Complexity	Easy	Easy	Medium	Medium

## 5. CONCLUSION

In this work, we have presented a novel bio inspired algorithm namely seagull optimization to design an MPPT controller. The proposed SOA\_MPPT\_controller has been assessed with the PSO, BAT and FA controllers in term of accuracy, convergence, stability and robustness regarding the variation of weather conditions and PS effects. The simulation was done for four distinct scenarios, where a rapid variation of temperature, irradiance and partial shading effect are carefully studied. The simulation results show that the proposed SOA\_MPPT\_controller provides better performances regarding the accuracy, the convergence speed, the stability with zero oscillations and a high robustness tracking the global maximum power point GMPP under partial shading and dynamic weather conditions than the selected controllers. The SOA\_MPPT\_controller extract maximum power generated from the photovoltaic system with an average of 99.95% of efficiency compared to the selected controllers with 99.91% for PSO, 99.71% pour BAT and 98.85% for FA.




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