A Novel MPPT Design for a Partially Shaded PV System Using Spotted Hyena Optimization Algorithm

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Abstract-Partial shading is a common problem in photovoltaic (PV) systems, known for its difficulty. Numerous attempts have been conducted to mitigate this problem. Some of these efforts deploy metaheuristic optimization with a view to tracking the multiple-peak P–V curve in a partial shading PV system. Hence, this paper proposes a novel metaheuristic algorithm to track the maximum power point of PV systems using the Spotted Hyena Optimization (SHO) algorithm. When evaluated, the SHO algorithm proved to be very fast, robust, and accurate in standard conditions, Partial Shading Conditions (PSCs), and irradiance variations. Also, the results reveal a remarkable improvement in the performance when we compare the SHO algorithm with the Grey Wolf Optimization (GWO) algorithm and the Perturb and Observe (P&O) algorithm.

Keywords-photovoltaic system; maximum power point tracking; partial shading condition; SHO optimization

I. INTRODUCTION

Photovoltaic solar energy is a renewable energy that is characterized by great development potential. Some of the advantages of this energy that it comes from an inexhaustible, clean source and the great safety it offers when used. Nevertheless, the two main problems that limit the use of PV systems are the high cost of installation and the low efficiency in energy conversion. We can only get up to 20% efficiency when we convert solar energy into electrical energy. Hence, the remaining of the solar energy is lost in the environment as it is not converted into useful electrical energy. As in many renewable energy systems, maintaining maximum efficiency remains a big challenge, especially when rapid changes occur in weather conditions.

Researchers have concentrated on three basic topics in order to increase the efficiency of PV systems [1]: designing solar irradiance tracking systems, implementing efficient power converters, and developing Maximum Power Point Tracking (MPPT) algorithms. The latter has the advantage that it can be deployed in both new and existing PV systems, whereas the two first can be implemented only during the design and installation of new PV systems [2]. To increase the output electrical power of a PV system, an MPPT algorithm must be adjusted to the operating point, whereas the connection of the PV system to the load is done by a DC-DC boost converter [2]. The output of MPPT algorithms can be the reference voltage, the reference current, or the duty cycle of the Pulse Width Modulation (PWM) controller, and the PV systems' operating point can be controlled and adjusted via these parameters.

Under uniform irradiance, there is a unique MPP in the power-voltage curve that changes according to temperature and irradiance variations and the MPPT algorithm is responsible to find new optimal operating points according to these changes. Part of the conventional MPPT algorithms involve the Perturb and Observe (P&O) algorithm [3], the incremental conductance algorithm, and the extremum-seeking control algorithm [4, 5]. Cloud movement, big buildings, and tree shadows may generate lower irradiance received by some elements of the PV systems. Such a condition is called a Partial Shading Condition (PSC). Under PSC, there are various MPPs in the P-V curve of the system: a cluster of Local Maximum Power Points (LMPPs) with one Global Maximum Power Point (GMPP) [6]. Under PSC, it was discovered that the conventional MPPT algorithms have low performance, especially when assuming just one MPP on the P-V curve. In reality, due to their poor global search performance, methods such as the P&O method are often trapped in LMPPs and they cannot guarantee the convergence to the GMPP [7]. Due to the limitations of the classical MPPT algorithms, several algorithms based on

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artificial intelligence and stochastic optimization, have been presented, many of which have been reviewed in [8, 9].

In this paper, the Spotted Hyena Optimization (SHO) algorithm is utilized to design a fast, robust, and precise MPPT algorithm for PV systems [10, 11]. The SHO algorithm is a new and powerful method that proved to be efficient in solving different optimization problems with many local optimum points. A PV system was simulated, and the performance of the suggested method was examined in various environmental conditions.

II.   System Modeling and Description

A.   The PV System Model

The PV cell is the principal element of a PV system that directly products electrical power from sunlight. We can represent this device by a single diode model because of its simple structure. The mathematical model for the current-voltage characteristic of a PV cell is [13, 14]:

$$I_{PV} = N_{pp}\left\{I_{pvn} - I_o\left[\exp\left(\frac{V+R_sI}{N_{ss}V_t}\right) - 1\right]\right\} - \frac{V+R_sI}{R_p} \quad (1)$$

where I_{pv} is the PV current source, R_s is the series equivalent resistance, R_p is the equivalent parallel resistance, I_{pvn} is the photocurrent, I is the difference between I_{pvn} and I_D, I_D is the diode current, I_o is the saturation current, V_t is the thermal voltage, N_{ss} is the number of cells connected in series, and N_{pp} is the number of cell connected in parallel. In the present article, we used the KC200GT module (Table I) to examine the simulation [15] and a DC-DC boost converter (Table II).

TABLE I.   KC200GT MODULE CHARACTERISTICS

Parameter	Value
Model	KC200GT
Maximum power	200.143W
MPP Voltage	26.3V
MPP Current	7.61A
Open-circuit voltage	32.9V
Short-circuit current	8.21A
Kv	-0.123V/°C
Ki	0.003A/°C
Cells per module	54

TABLE II.   PARAMETERS OF THE DC-DC BOOST CONVERTER

Element	Value
Inductance	300μH
Output capacitor	100μF (μF)
Load	100Ω
Switching frequency	10kHz

Figure 1 displays the P-V characteristic of the KC200GT PV panel obtained through simulation at changing irradiation and constant temperature. We notice the effect of insolation on the efficiency of the PV module whenever the value of insolation decreases. The extracted power from the PV module also diminishes.
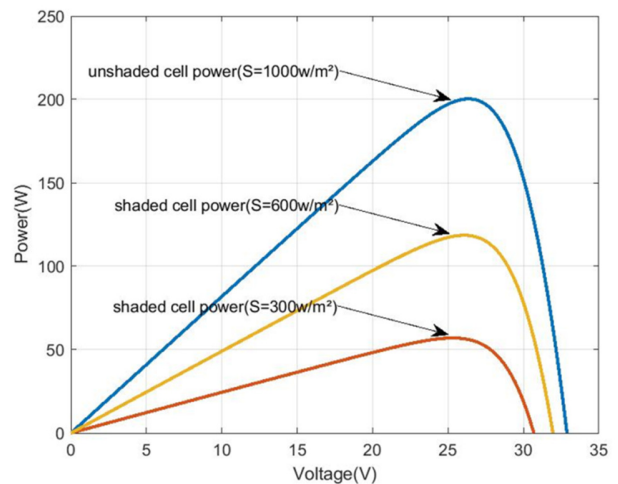

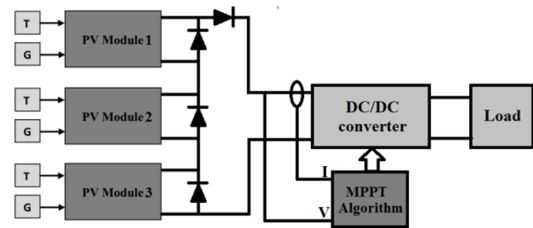Fig. 1.   P-V characteristics of the KC200GT PV module at changing irradiation and constant temperature.

Fig. 2.   The structure of the studied system.

B.   System Description

PV modules are grouped in series and in parallel in order to increase the power of the PV system according to the demand requirements. A rapid and dynamic insolation change may appear on the panels during PSCs or in cloudy days. Then, multiple peaks are viewed in the curve of P–V characteristic as shown in Figure 3 (local and global MPPs) because of the bypass diodes' existence [8]. During PSCs, the existence of the bypass diode aids to reduce the possibility of hot-spot occurrence. This makes the shaded module to behave like as if it is loading power instead of generating it.
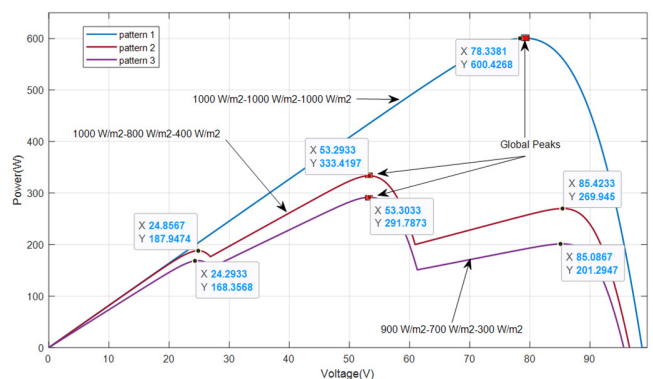

Fig. 3.   P-V characteristics for shade patterns.

More importantly, the GMPP is changing, mainly depending on the shade pattern (Figure 3). Therefore, under

partial shading, GMPP tracking is important in order to improve the power generation efficiency. As shown in Figure 2, in our operating scenario of the PV system, an array of 3 KC200GT PV modules in series is simulated in Matlab/Simulink. We remark the immense effect of insolation on the extracted power of the three modules (Figure 3). The first case (pattern 1) shows that the insolation applied on the three modules was the same ($1000W/m^2$) and the outcome of the global power was estimated as 600.42W. In the two other cases, the insolation changed (pattern 2: 1000/800/400, pattern 3: 900/700/300) and new LMPPs and GMPP occurred for each case. The power of GMPP was estimated as 333.4W and 291.7W respectively. In all these patterns, the temperature did not change.

III. A REVIEW OF P&O AND GWO ALGORITHMS

A. P&O Algorithm

The MPPT that can be generated from a PV system is maintained due to the use of the P&O MPPT algorithm [16]. This method is considered as the most useful technique due to its simple simulation and easy implementation [4]. Firstly, the P&O algorithm senses the voltage and current, and after it calculates the power. Based on the change of the power, this algorithm generates a variation in the DC–DC converter's duty cycle as presented in (2):

$$\begin{cases} D_{new} = D_{old} + \Delta D \ (if P > P_{old}) \\ D_{new} = D_{old} - \Delta D \ (if P < P_{old}) \end{cases} \quad (2)$$

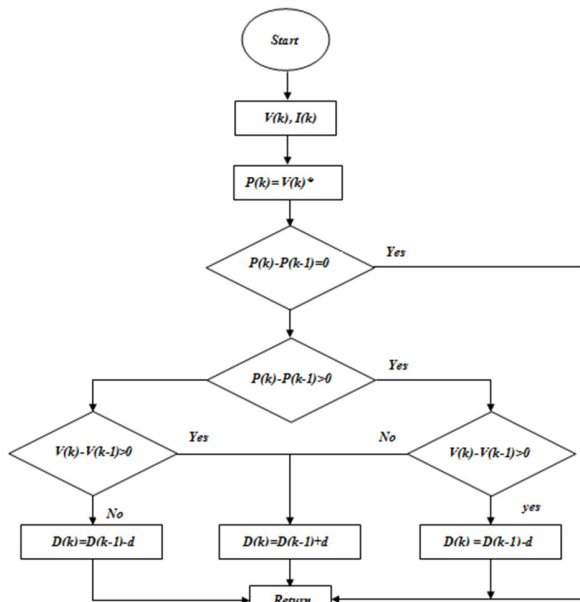The flowchart of P&O is presented in Figure 4 [4].

Fig. 4.   Flowchart of the P&O algorithm.

B. GWO Algorithm

In 2014, Mirjalili formulated the social hierarchy and the hunting behavior of the grey wolf packs as an optimizer to deal with many optimization problems [17, 18]. A pack of grey

wolfs is composed of an alpha (α), a beta (β), and a delta (δ) wolf, while the rest of the pack are omega wolves. α, β, and δ are the dominating wolves. They are responsible for decision making and discipline in the pack. During the hunt, the omega wolves update their locations and surround the area determined by α, β, and δ. The hunt will continue until the prey stops moving, and finally the hunt will end by attacking the prey. The mathematical model of the aforementioned behaviors is detailed in [17, 18]. GWO-based MPPT design for PV system has been presented in [18, 19]. The duty cycle has been considered as a grey wolf that tries to find the optimum solution related to the MPP. The flow chart of the GWO-based algorithm is presented in Figure 5 [18].
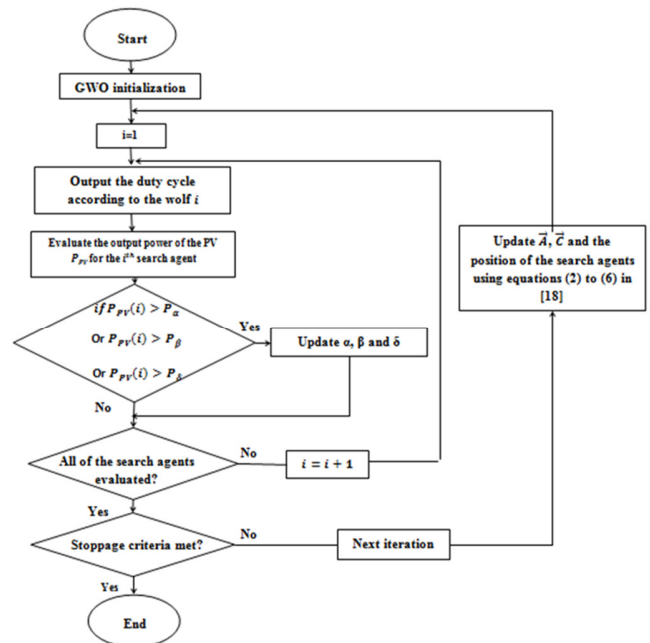

Fig. 5.   Flowchart of the GWO algorithm.

IV. THE SHO ALGORITHM

A. Spotted Hyena Optimizer (SHO)

The SHO was first presented in 2017 [11]. This bio-inspired optimization technique imitates the social hierarchy and the group hunting behavior of the spotted hyenas in the purpose of solving various optimization problems. For more details see [11, 12, 20]. The pack of spotted hyenas can contain more than 100 members working together in an organized way. It is a hunting technique that can be divided into 4 main behaviors which are:

- Searching for prey

- Encircling prey

- Hunting

- Attacking prey

B. Application of SHO for MPPT

Figure 6 represents the diagram of the SHO algorithm. Our optimization problem is the maximization of PV output power. The duty cycle (D) of the PWM signal (which controls the switch of the boost converter) is defined as a hyena [12]. The SHO algorithm, which is used for the first time in this field in the current paper, is proved to be applicable when racking the GMPP in the case of partial shading fault in PV systems.
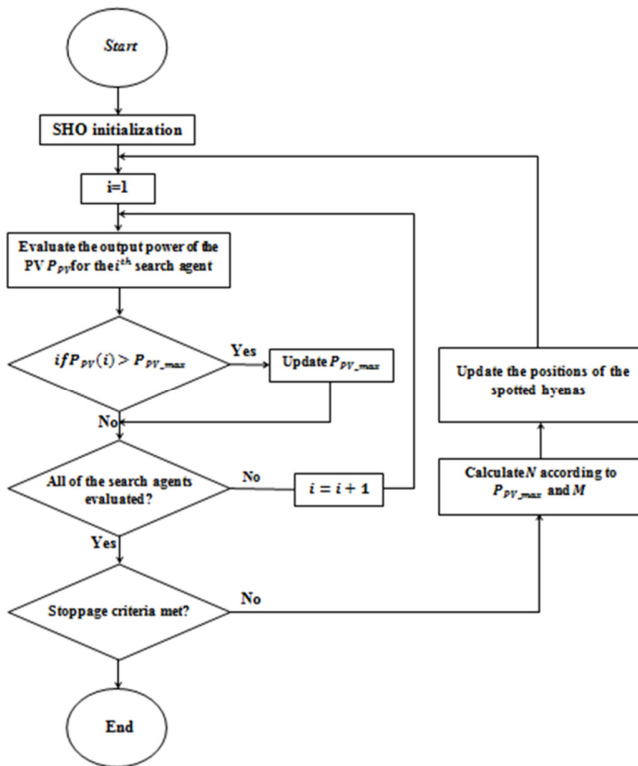

Fig. 6.   Flowchart of the SHO algorithm.

V.   SIMULATION AND ANALYSIS

To examine the performance of the proposed SHO MPPT algorithm, we compared its performance with the P&O and GWO algorithms'. The structure of the PV system under study (Figure 2), has been simulated in MATLAB/Simulink. The KC200GT PV model module was used in the simulations.

A. Performance Under Standard Conditions

In this situation, the proposed method's performance is evaluated throughout the PV system simulations under standard conditions. The levels of irradiance of the 3 PV modules are set as 1000W/m^2. The modules' temperature is 25°C as shown in Figure 3 (pattern 1). Figures 7-9 show PV output's power, voltage, and current of the 3 algorithms. P&O, GWO, and SHO took approximately 0.53s, 0.58s, and 0.50s respectively, to arrive at the MPP. We note that the time response of SHO is better than that of P&O and GWO. Moreover, the steady-state output power of the SHO algorithm is about 600.41W which is closer to the PV's maximum power, i.e. 200.143×3=600.43W when compared to the other methods.
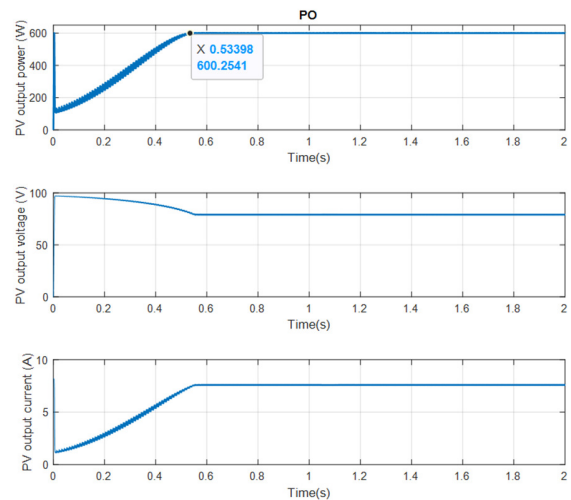

Fig. 7.   Performance of P&O algorithm under standard conditions.
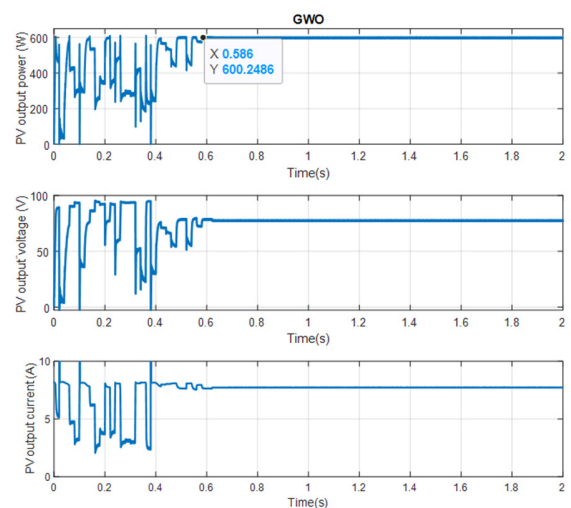

Fig. 8.   Performance of GWO algorithm under standard conditions.
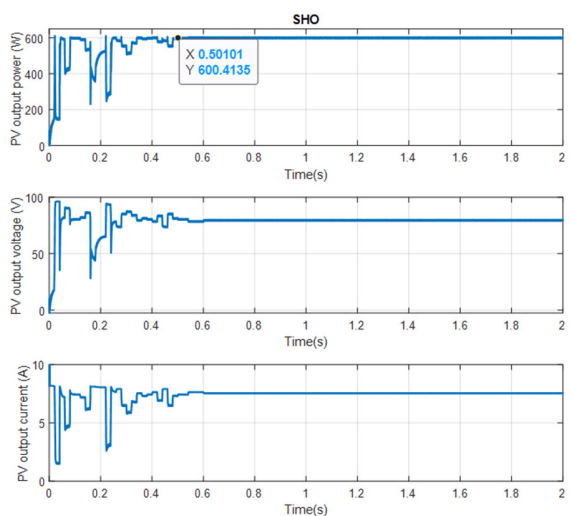

Fig. 9.   Performance of SHO algorithm under standard conditions.

Thus, we can conclude that the SHO algorithm is more efficient than the formerly mentioned algorithms.

B. Performance Under PSCs

In this test, the PV modules have 3 irradiance values, set as follows: 900, 700, and 300W/m². Their temperature is at 25°C as shown in Figure 3 (pattern 3). We observe the existence of a GMPP at 291.78W and two LMPPs at 168.35W and 201.29W. Figures 10-12 show the PV output power, PV output voltage, and PV output current of the three algorithms. In this state of shading condition, both SHO and GWO algorithms are able to find the GMPP. The SHO algorithm came to 291.7W while GWO reached 291.06W. Hence, it is affirmed that for reaching the GMPP (291.78W), the SHO proved to be more valid than the GWO. It should be noted that the P&O algorithm converges to an LMPP (201.22W). This result shows that power losses due to wrong tracking of the GMPP are significant. To arrive at the GMPP, GWO takes 0.6s and SHO 0.5s. As a result, the SHO algorithm proved to be more effective than the GWO algorithm.
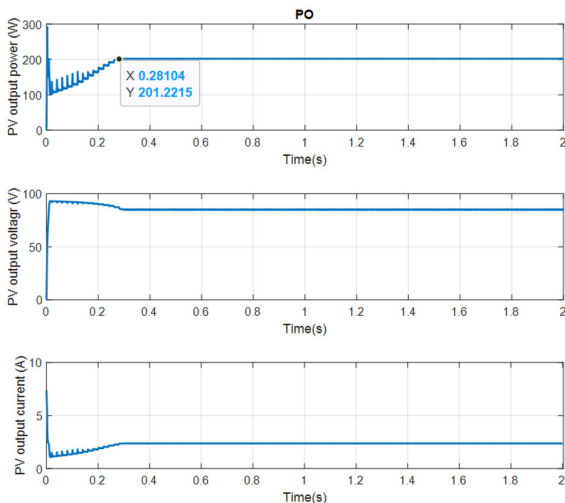

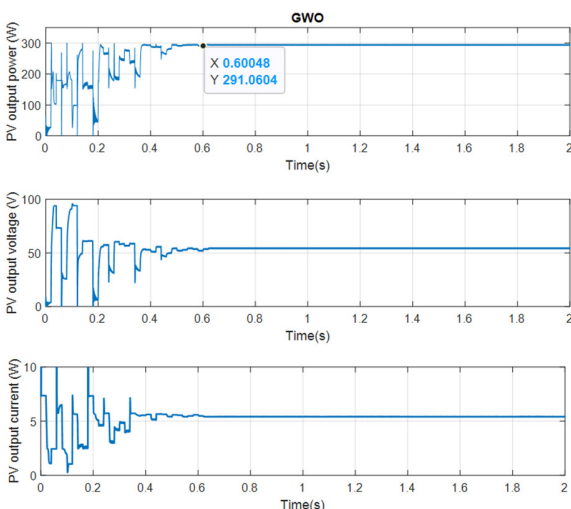Fig. 10.   P&O algorithm under PSC.
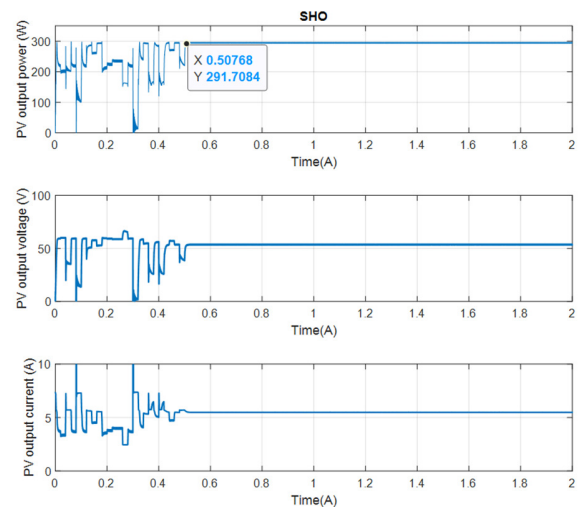

Fig. 11.   GWO algorithm under PSC.

Fig. 12.   SHO algorithm under PSC.

C. Performance Under Fast Changing Solar Irradiance

In this condition, all 3 modules of the simulated array are used under standard conditions (T=25°C, G=1000W/m²). At 1s, we applied a step variation to the solar irradiance (the irradiances of the second and third modules are decreased to 800 and 400W/m² (see Figure 3, pattern 2) respectively, while the irradiance of the first module remains as before to test and examine the performance and precision of the SHO in comparison with the GWO algorithm, when solar irradiance changes rapidly. In this case, at 1s we got a new curve that involves a GMPP at 333.41W and two LMPPs (187.94W and 269.94W). In Figures 13, 14, the trajectories of the solar array for GWO and SHO algorithms are displayed.
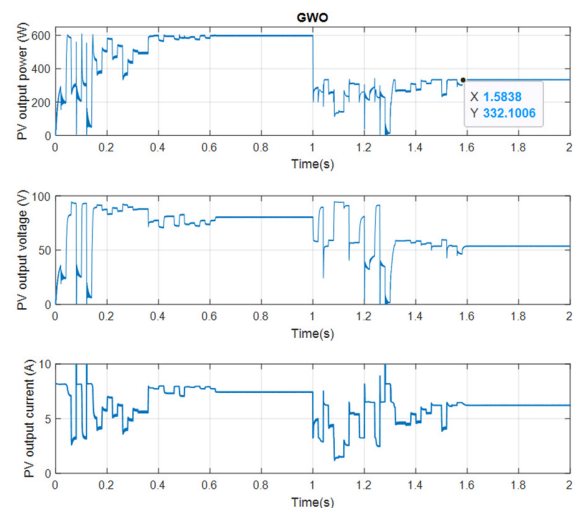

Fig. 13.   GWO tracking trajectories under rapid solar irradiance change.

As can be seen in Figures 13 and 14, after applying a step change of the solar irradiance, the presented SHO algorithm has absolutely detected the GMPP (333.24W) and converged with a proper speed, while GWO reached it satisfactorily (332.1W). The time of convergence has increased by about 0.48s after a fast change of solar insolation. When observing

the obtained simulations results, it can be noted that the GMPP tracking can be reached with more accuracy with the proposed SHO algorithm than with other literature results [6-8].
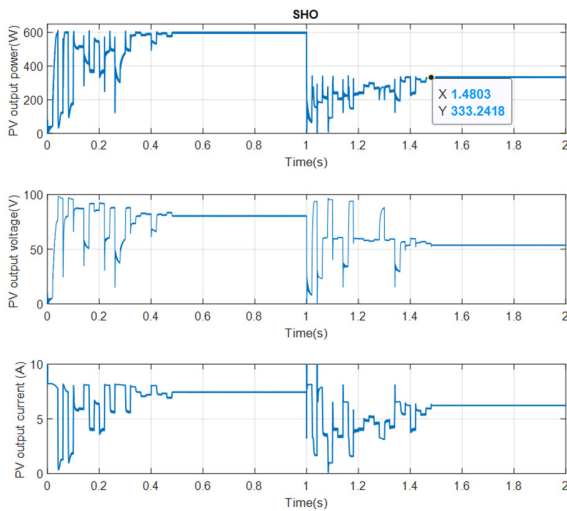

Fig. 14.   SHO tracking trajectories under rapid solar irradiance change.

VI.   CONCLUSION

With the aim of designing an MPP tracker for PV systems, SHO has been presented in this research paper and it is proposed for working under PSCs. The performance of the SHO algorithm was tested and compared with GWO and P&O algorithms. According to the test results, it was concluded that SHO proved to be efficient in tracking the GMPP with high fidelity, mainly under PSCs. The proposed algorithm exhibits fast, robust, and accurate performance. As a final result, this work confirmed that this optimization exhibited superior performance when compared with the two other tested methods, especially in terms of tracking ability.

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