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AN IMPROVED GRAY WOLF OPTIMIZATION-BASED HILL CLIMBING MPPT ALGORITHM TO OPERATE ENHANCEMENT OF PV SYSTEMS IN PARTIAL SHADING CONDITIONS

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ABSTRACT

The paper introduces a novel hybrid maximum power point (MPP) tracking algorithm that integrates the enhanced gray wolf optimization (IGWO) technique with the hill climbing (HC) technique. This proposal aims to efficiently extract maximum power from a photovoltaic (PV) system that is subjected to a rapid variation in solar irradiance and partial shading conditions (PSCs). The proposed algorithm is a novel optimization technique that circumvents the need for recurrent trips between the GMPP and Local Maximum Power Point (LMPP), thereby ameliorating the limitations of the conventional (HC) algorithm. Diminished tracking efficiency, steady-state oscillations, and transients characterize the latter. The newly proposed MPPT algorithm was implemented through the utilization of MATLAB/SIMULINK tools. Subsequently, a comparative analysis was conducted with the results obtained from two other MPPT algorithms: the IGWO and HC MPPT algorithms. The findings substantiate the hypothesis that the IGWO-HC MPPT algorithm exhibits superior tracking capabilities under various severe weather conditions in comparison to the IGWO and HC MPPT algorithms.

Keywords: Improved Grey Wolf Optimization (IGWO), Maximum Power Point Tracking (MPPT), Hill Climbing (HC), Partial Shading Conditions (PSCs).

1 INTRODUCTION

Presently, the world is undergoing a paradigm shift towards a renewable energy revolution. Renewable (sustainable) energy is defined as a type of energy that utilizes the natural energy present on Earth and converts it into electrical energy. Renewable energy is characterized by its sustainability, inexhaustibility, and environmental friendliness. The former attribute refers to the natural replenishment of resources, whereas the latter two pertain to the absence of pollution caused by its use [1].

The most recent studies and analyses of energy markets indicate that energy demand will undergo a period of significant growth. Alongside this, reducing reliance on fossil fuels requires further attention and consideration[2]. A substantial corpus of scientific studies has demonstrated that solar energy, which reaches Earth's surface, provides approximately 10,000 times the yearly energy reserve installed [3].The quantity of solar energy that photovoltaic (PV) systems receive determines the amount of electricity they can produce. Therefore, it is very clear that any shading applied to these systems will consequently result in a decrease in the quantity of energy generated. Under specific environmental conditions, there is only one operational point, known as MPP, characterized by a specific voltage and current value. The MPPT technique is a power regulation system that provides an appropriate duty cycle (D) to the PV power conversion system (DC-DC converter), as illustrated in Figure 1. This technique depends on the inputs of the PV module to capture maximum power production continuously. Consequently, this approach achieves maximum power and delivers stable voltage under varying weather conditions [4, 5].

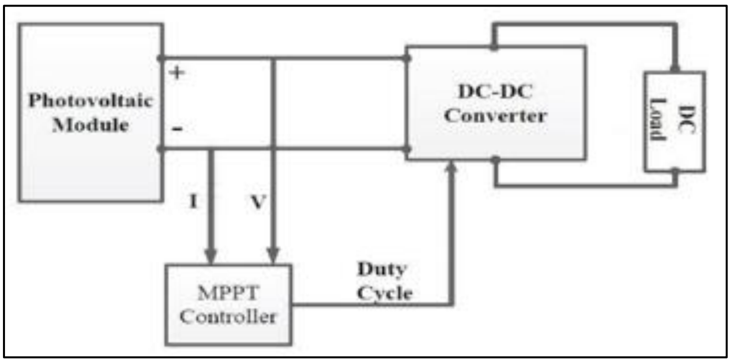

Figure 1: MPPT System with DC-DC Converter

In terms of power voltage characteristics, shading of PV modules results in complicated peaks. Because the un-shaded PV modules coupled to the shaded modules generate a lot of current, these peaks make it difficult to track the MPP. The efficiency of PV modules is decreased because of their nonlinear properties [6]. The output of photovoltaic (PV) modules in these situations is non-homogeneous and belongs to the PS category since modules do not receive an equivalent amount of irradiation. Figure 2 displays the I-V and P-V curves under conditions of partial shade and uniform irradiance levels. The non-uniformity current caused by this irregular irradiance leads to a discrepancy in the current sources, which in turn produces hot-spot effects. Bypass diodes offer a different path for larger currents in order to prevent the mismatching effect.

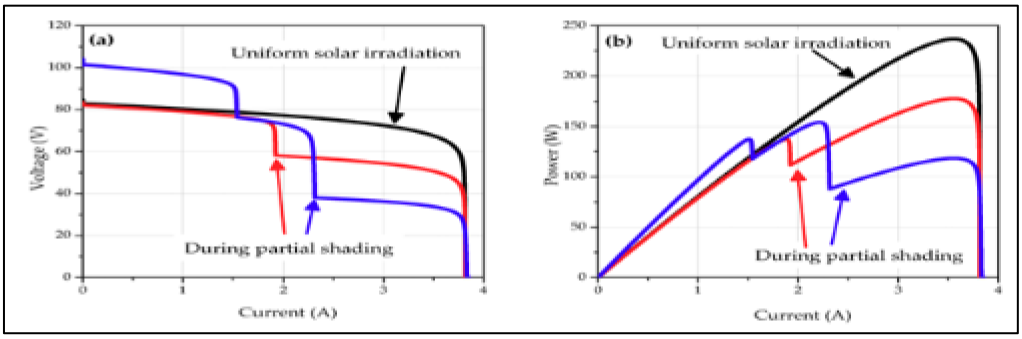

Figure 2: The I-V and P-V curves for uniform solar irradiance and PSCs.

2 LITERATURE REVIEW

Numerous MPPT strategies, which include the following, have been developed: the fractional open circuit voltage [7], the fractional short circuit current [8], the perturb and observe [9], the incremental conductance [10], modified incremental conductance [11], and hill climbing [12]. These approaches, as substantiated by extant research, have been proposed to optimize the performance of PV systems. These methods offer a straightforward and reliable way to monitor MPP, but the absence of shade limits their effectiveness. These algorithms have significant shortcomings in the face of rapidly shifting environmental and climatic variables. Their main flaw is that they experience constant oscillations and become disoriented when temperature and environmental conditions change. Additionally, it is possible that these techniques will not differentiate between local (LM) and global maxima (GM).

To address these issues, a meta-heuristic strategy—that is, soft computing techniques known as bio-inspired algorithms has been used, like particle swarm optimization (PSO) [13], Ant colony optimization (ACO) [14], Grey wolf optimization (GWO) [15], Slap Swarm Optimization (SSO) [16], Grasshopper Optimization (GHO) [17], butterfly algorithm [18], Cat Swarm Optimization (CSO) [19], Artificial Bee Colony Algorithm (ABC) [20], Cuckoo Search (CS) [21] and Bat Algorithm (BA) [22] are quite successful in maximizing power. The efficacy of these algorithms is contingent upon various factors, including the number of iterations, population size, and computation time, etc.

In the present study, a new IGWO-HC MPPT method is proposed. Firstly, the MPP is tracked using the IGWO algorithm, with the HC algorithm applied at the final stage. This approach has been demonstrated to achieve faster GMPP convergence. The response speed, system stability, and adaptability to external changes are all critical factors in the system's functionality. In the strategy that is currently under consideration, a non-linear tangent trigonometric function is to be integrated into the IGWO algorithm as a convergence factor. Finally, this method will be simulated under PSCs and, at the end, compared to that of conventional HC and IGWO algorithms. The subsequent sections of the document delineate its organizational structure as such. Section III explains the proposed MPPT approach, while Section IV will review the simulation outcomes and a discourse of the proposed algorithm in comparison to other MPPT algorithms (HC and IGWO). The final section of the paper offers a conclusion.

3 THE SUGGESTED ALGORITHM

3.1 The description of GWO

In 2014, Mirjalili et al. presented the GWO algorithm, which was based on grey wolf social hierarchy and hunting technique [23]. The gray wolf population hierarchy can be classified the wolves into four main groups: delta (δ), omega (w), beta (β), and alpha (α). The fittest solution is the α in the real-world implementation of the GWO method. Beta β and δ, respectively, are chosen. It is believed that the remaining potential solutions are w. The following formulas are suggested in order to update the gray wolves' location [24]:

$$\vec{D} = \left| \vec{C} \cdot \vec{X}_p(t) - \vec{X}(t) \right| \tag{1}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \cdot \vec{D} \tag{2}$$

where t is the current iteration $\vec{X}_p$, $\vec{X}$ *is* the position of the prey wolf, $\vec{A}$, $\vec{C}$ and $\vec{D}$ are coefficient vectors. The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows [23]:

$$\vec{A} = 2\vec{\alpha} \cdot \vec{r}_1 - \vec{\alpha} \tag{3}$$

$$\vec{C} = 2 \cdot \vec{r}_2 \tag{4}$$

where r_1, r_2 are random vectors in [0, 1] and a decrease linearly from 2 to 0.

The hunting is typically guided by the α, though the β and δ may also partake in the activity on occasion. The three wolves are pursued by a pack of wolves *w*. The formula for updating the position is as follows:

$$\vec{D}_\alpha = \left| \vec{C}_1 \cdot \vec{X}_\alpha(t) - \vec{X}(t) \right|, \ \vec{D}_\beta = \left| \vec{C}_2 \cdot \vec{X}_\beta(t) - \vec{X}(t) \right|, \ \vec{D}_\delta = \left| \vec{C}_3 \cdot \vec{X}_\delta(t) - \vec{X}(t) \right| \tag{5}$$

$$\vec{X}_1 = \vec{X}_\alpha(t) - \vec{A}_1 \cdot \vec{D}_\alpha, \ \vec{X}_2 = \vec{X}_\beta(t) - \vec{A}_2 \cdot \vec{D}_\beta, \ \vec{X}_3 = \vec{X}_\delta(t) - \vec{A}_3 \cdot \vec{D}_\delta \tag{6}$$

$$\overrightarrow{X}(t+1)=\frac{\overrightarrow{X}_1+\overrightarrow{X}_2+\overrightarrow{X}_3}{3} \qquad (7)$$

3.2 Improve GWO algorithm (IGWO)

As the number of iterations increases, the convergence factors a for the GWO algorithm drops linearly from 2 to 0. However, the algorithm's convergence mechanism is not linearly convergent. This study uses a nonlinear convergence factor based on the tangent trigonometric function.

$$\alpha=\alpha_{initial}-(\alpha_{initial}-\alpha_{final})\times\tan(\frac{1}{\varepsilon}\cdot\frac{l}{l_{\max}}\pi) \qquad (8)$$

Where ε is the adjustment coefficient, the current iteration number is 1, $l_{\max}$ is the maximum number of iterations. Additionally, the initial and final are the convergence factor *(a)* initial and final values, respectively. In this study, ε = 4.

The algorithm must simultaneously monitor the (MPP) in real time. To prevent the process from entering an infinite cycle, the power tracking method must be restarted because the PV arrays' output power varies in tandem with changes in the external environment, such as temperature and irradiance. The procedure is restarted after the output power fluctuation meets (9).

$$\frac{|P_{real}-P_m|}{P_m}>\Delta P \qquad (9)$$

In this paper, the PV arrays' output power change threshold is ΔP, set to 0.2, whereas Preal is the arrays' actual output power, and Pm is their output power at MPP under current operating conditions. It is important to note that the "duty cycle xi" being discussed here is a carrier xi with a linear relationship to the true duty cycle, rather than a genuine duty cycle. The modulation wave in this work is the triangle wave. The relationship that exists between D and the carrier (xi) is illustrated in Figure 3. Furthermore, the mathematical equation of the carrier xi and the D is as follows [25]: where A_C is set to 1.

$$d=\frac{A_c+x_i}{2A_c}=\frac{1}{2}+\frac{x_i}{2A_c} \qquad (10)$$

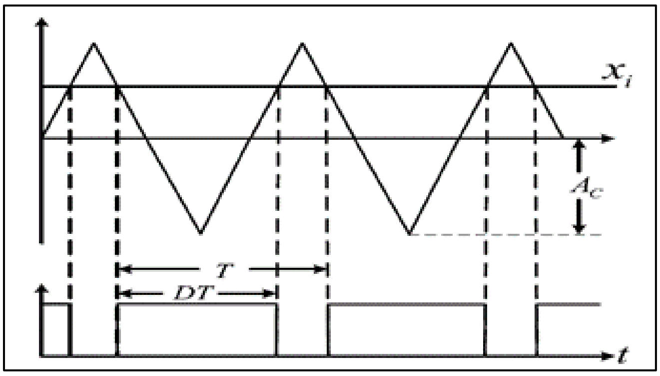

Figure 3: The transformation relationship diagram

4 HILL CLIMBING (HC) MPPT ALGORITHM

The simplicity of the HC MPPT technique is one of its advantages. When the MPPT task is implemented, the D of the DC-DC converter is usually used as a judgment criterion. The achievement of the criterion dP/dD=0 indicates that the MPP has been monitored [26]. Figure 4 displays the HC algorithm's flow diagram. The method utilizes a predetermined step size, designated as step, to systematically adjust the d, denoted as d(k), in a direction that increases the power. Tracking does not progress toward the MPP if PK is less than PK-1, which indicates that the perturbation direction is reversed, which can be clearly demonstrated in the following equation:

$$D_K = D_{K-1} + step \times slop \quad (\text{if } P_K > P_{K-1}) \tag{11}$$

$$D_K = D_{K-1} - step \times slop \quad (\text{if } P_K < P_{K-1}) \tag{12}$$

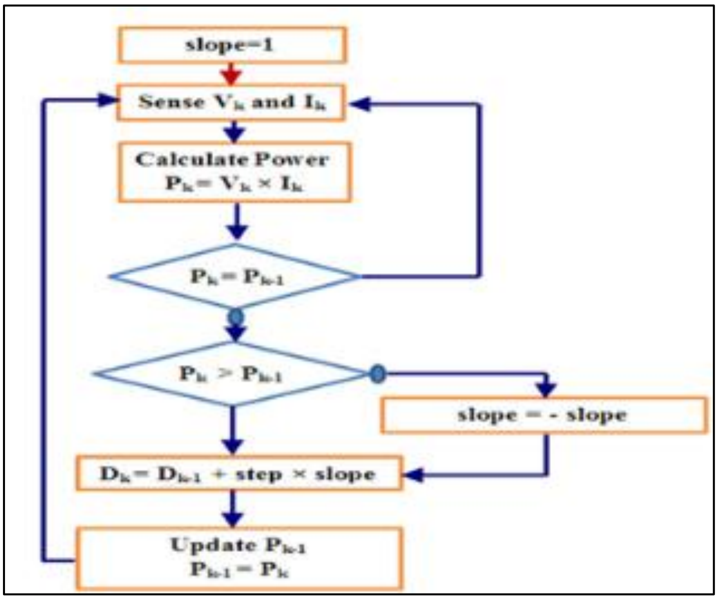

Figure 4: Flowchart of HC MPPT Algorithm

5 THE PROPOSED IGWO-HC MPPT ALGORITHM

A new algorithm, the Hybrid Improved Grey Wolf Optimization and Hill Climbing Algorithm (IGWO-HC) is depicted in Figure 5, is used to locate GM in the MPPT system. IGWO-HC employs the optimal characteristics of the Grey Wolf Optimization (GWO) and the Hill Climbing algorithm. The proposed IGWO-HC has many features, such as being highly efficient, having low oscillations, as well as fast convergence towards the Global Maxima. The IGWO MPPT algorithm usually uses the output voltage (Vpv) and current (Ipv) of the PV array to find a variable step size (D), which is usually used as a step variable size (step) in the HC algorithm for fast tracking of MPP. Figure 6 shows the flowchart of the proposed IGWO-HC MPPT algorithm

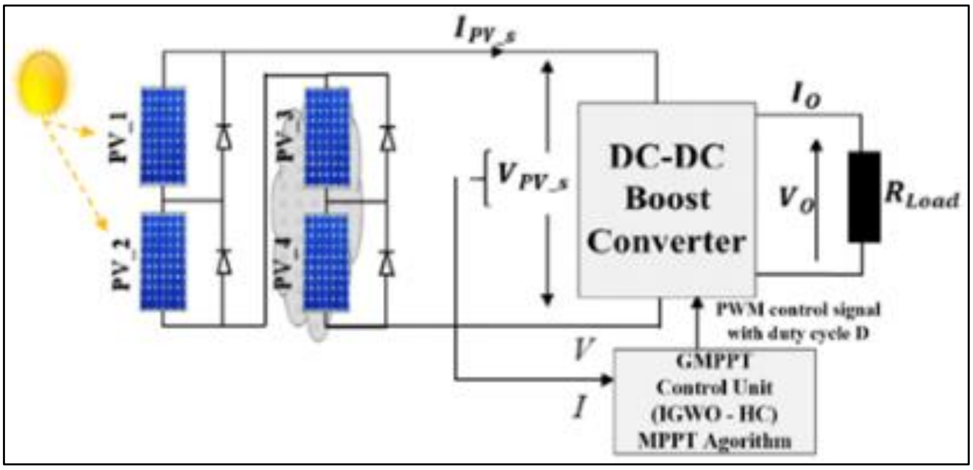

Figure 5: PV systems with the proposed (IGWO – HC) MPPT algorithm

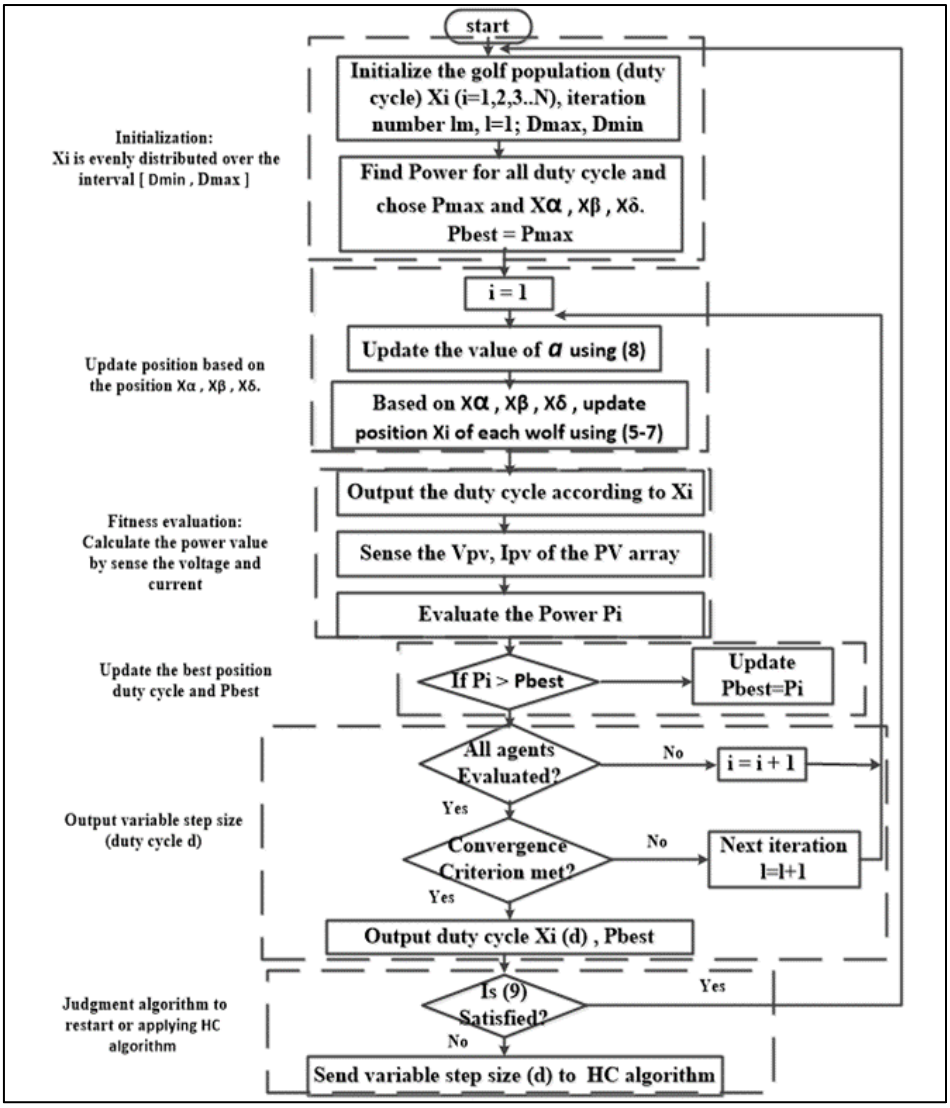

Figure 6: The IGWO-HC MPPT proposed algorithm flowchart

6 SIMULATION RESULTS AND DISCUSSION

The presented hybrid model (IGWO-HC-MPPT) algorithm and DC-DC Boost converter were created using the MATLAB/Simulink environment. The proposed algorithm's performance evaluation over IGWO and Hill Climbing (HC) algorithms, in order to ascertain the most efficacious approach, two scenarios were simulated, with the level of partial shading constituting the decisive factor. In addition, the selection of the most appropriate method was based on numerous factors, which included dynamic response, power oscillations, convergence to GMPP, and implementation complexity, as shown in Table 2. In the photovoltaic model, two scenarios were connected in series, as explained in Figures 7 and 8. The presence of variable irradiance levels on the PV modules led to the manifestation of the mismatch effect, resulting in the emergence of numerous peaks on the P-V curve. Each photovoltaic (PV) module's terminal incorporates a bypass diode, a specialized electronic component that facilitates the safe conduct of high currents.

Firstly, it is applied to the six PV panels that are in series connected with a different irradiance under Partial Shading Conditions (PSCs), and it is compared with the IGWO and Hill Climbing (HC) algorithms, as shown in Figure 9. Similarly, it was repeated for the second scenario, which is connected with also connected. Furthermore, it is compared with the IGWO and Hill Climbing (HC) algorithms as shown in Figure 10. Figures 9 and 10 show the proposed MPPT, which clearly tracks the GMPP with faster convergence and lower oscillations compared to IGWO and HC MPPT techniques. Table 1 lists the PV module characteristics, and the DC-DC converter components that were used for the simulation setup are chosen as L= 3mH, Cin=220μF, Cout=220μF, and fs= 50kHz

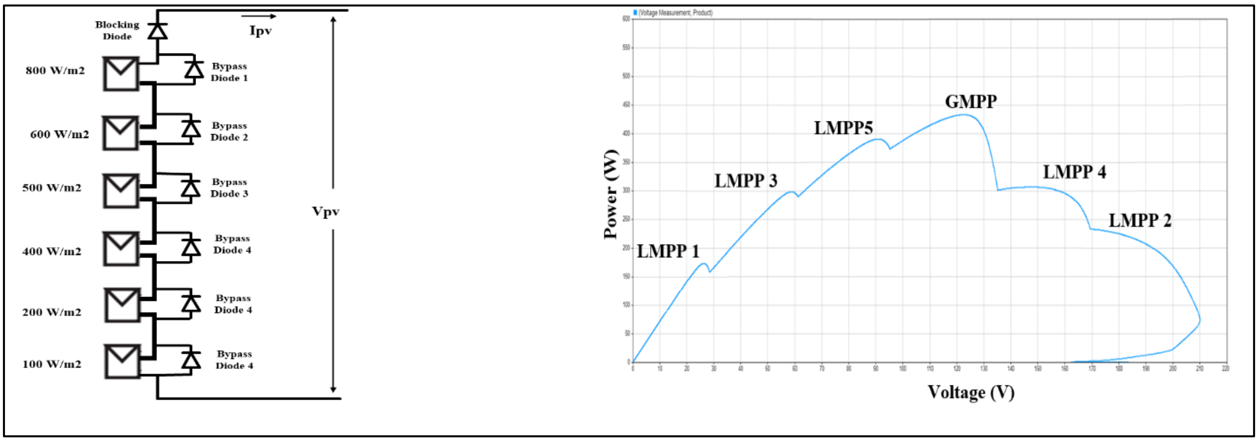

Figure 7: PV array configuration connected in series under Partial Shading conditions (Scenario 1)

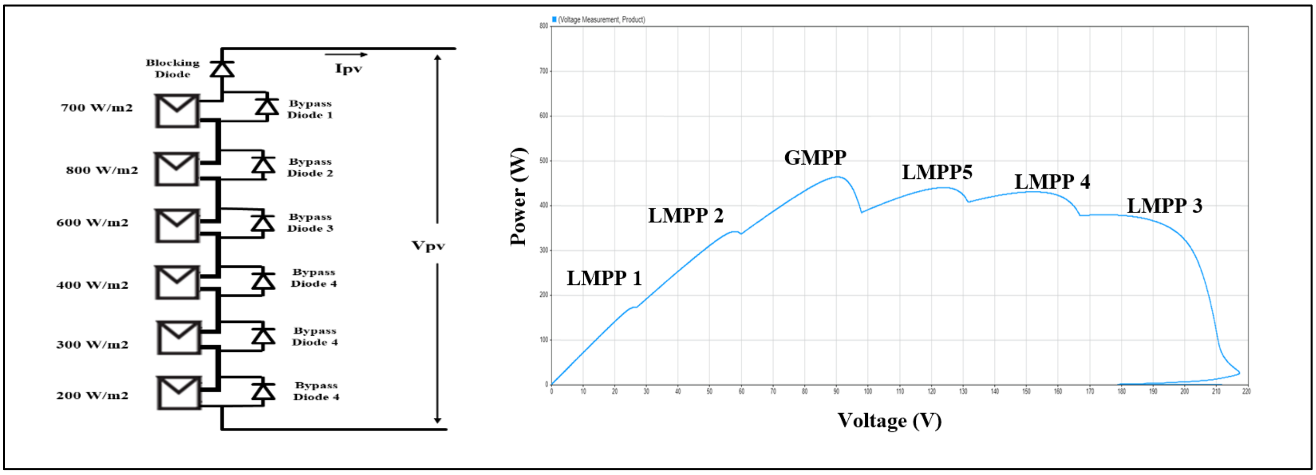

Figure 8: PV array configuration connected in series under Partial Shading conditions (Scenario 2)

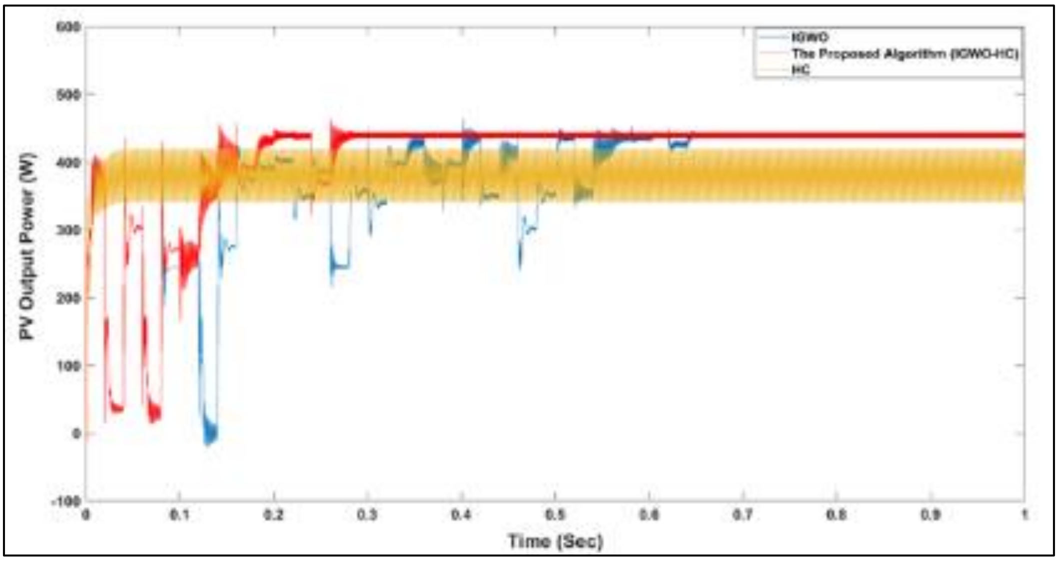

Figure 9: The P_{out} of PV for the conventional HC, IGWO, and IGWO-HC algorithms (Scenario 1)

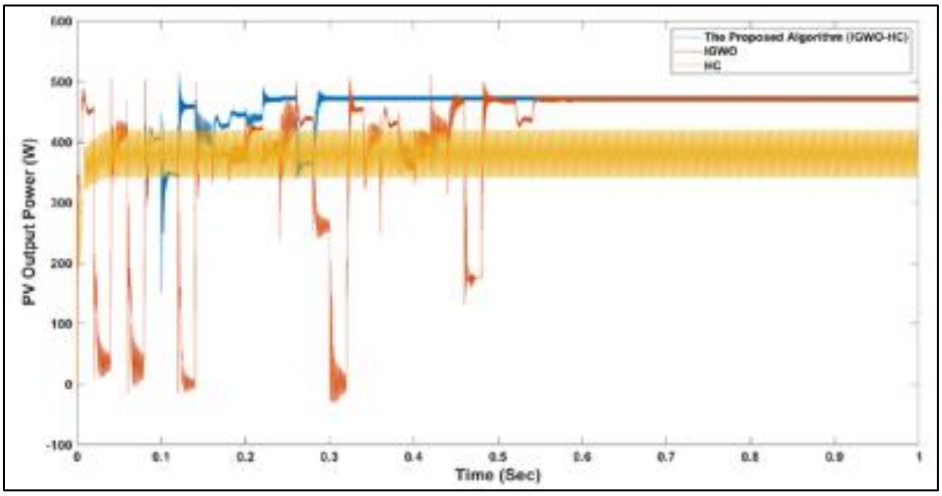

Figure 10: The Pout of PV for the conventional HC, IGWO, and IGWO-HC algorithms (Scenario 2)

Table 1: The PV panel characteristics

P_{max}	**110**
V_{OC}	43.5
I_{SC}	3.45
V_{MPP}	35
I_{MPP}	3.15
Cells per module	60 cells
Temperature coefficient of V_{OC}	-0.36099
Temperature coefficient of ISC	0.102

Table 2: MPPT algorithms characteristics comparison

MPPT methods	**Dynamic response**	**Power oscillations**	**Convergence to GMPP**	**Implementation complexity**
Proposed method	Accurate and fast	Zero	Always guaranteed	Medium
IGWO	Accurate	Zero	Always guaranteed	Medium
HC	Not accurate	Available	Not guaranteed	Easy

7 CONCLUSION

The present paper has delineated the development of a newly conceived IGWO-HC Hybrid-MPPT, an innovative approach to the maximization of power output from a PV system. This novel method has been demonstrated to effectively track GMPP through the utilization of multiple MATLAB simulations, encompassing two distinct scenarios under conditions of partial shading. The present study sought to ascertain the efficacy of the proposed IGWO-HC hybrid MPPT algorithm. This evaluation was done through simulation studies of the PV system. The findings indicate that the introduced MPPT algorithm may facilitate more precise identification of the GMPP compared to alternative algorithms, such as IGWO and HC. Furthermore, the implementation of IGWO, which facilitates an adaptive variable step size, may enable the proposed MPPT algorithm to identify the GMPP more expeditiously and with reduced transitory oscillation compared to conventional methods.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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