A Global MPPT Based on Bald Eagle Search Technique for PV System Operating under Partial Shading Conditions

Waleed Al Abri
Department of Electrical and Computer
Sultan Qaboos University
Muscat , Oman
s34675@student.squ.edu.om

Rashid Al Abri
Department of Electrical and Computer
Sultan Qaboos University
Muscat , Oman
arashid@squ.edu.om

Hassan Yousef
Department of Electrical and Computer
Sultan Qaboos University
Muscat , Oman
hyousef@squ.edu.om

Amer Al-Hinai
Department of Electrical and Computer
Sultan Qaboos University
Muscat , Oman
hinai@squ.edu.om

***Abstract*— One of the most prevalent difficulties in PV systems is partial shading condition (PSC), which results in considerable decreases in energy production. Even so, this can create multiple local maximum power points (MPP) (in the PV curve) and can cause conventional and advanced Maximum Power Point Tracking (MPPT) controllers to operate the PV system at a low peak value. Consequently, the PV system's power output is reduced further. By incorporating a global MPP searching method in the MPPT controller, the PV system can operate at its greatest efficiency under PSC. This paper proposes a global MPP (GMPP) method based on Bald Eagle Searching (BES), which finds the maximum value in three stages (selecting space, searching in space, and swooping). This study uses the first stage of the BES method to design the proposed GMPP searching method. The BES method demonstrates better performance than Cuckoo Search (CS) and Particle Swarm Optimization (PSO). Compared with the PSO and CS methods, the proposed method reduces search time (average of all PSC cases) by 36.17% and 40.76%, respectively. Furthermore, it finds the GMPP in all simulated PSC cases without fail. In addition to its excellent performance, the proposed method is simple and easy to implement due to its single tuning parameter, unlike PSO and CS.**

***Keywords*—partial shading; I-V curve tracing; global MPPT; Meta- heuristic methods; Bald Eagle search technique**

I. INTRODUCTION

A PV module has nonlinear characteristics that are solely dependent on solar irradiation and cell temperature, so it is necessary to develop an MPPT technique that will allow the module to push its maximum power available at any given moment [1]. The earlier literature presents conventional MPPT such as Conventional Voltage Tracking (CVT) [2], Open-Circuit Voltage Tracking (OVT) [3], Perturb and Observe (P&O) [4-8], and Incremental Conductance (IC) [9-11]. These MPPTs are very simple both in concept and in methodology [12], and they do not require external sensors or feedback to work effectively. Furthermore, they work well for tracking MPP under uniform irradiance, where a single MPP is found in power against voltage or current curves. On the other hand, such algorithms are not convenient for tracking the global peak under PSC [13], which considerably reduces the possibility of capturing the maximum energy within the PV panels [14]. Numerous studies have been undertaken to improve the efficiency of conventional MPPT methods using machine learning tools, such as fuzzy logic control [15-17] and neural networks [18, 19]. These methods are referred to as advanced intelligent MPPT methods. They are more efficient and stable than traditional MPPT methods [20]. Nevertheless, their implementation is complex due to their heavy calculations [21] and complexity [20]. Additionally, they are not capable of ensuring the operation of global MPPs in all PSC conditions [1]. Therefore, both conventional and intelligent MPPT methods should be supported with a soft searching methods, such as Particle Swarm Optimization [22, 23], Ant Colony Optimization [24], Artificial Bee Colony (ABC) [25], Cuckoo Search [26], Grey Wolf Optimization (GWO) [25] and Firefly Algorithm (FA) [27]. The soft GMPP searching methods have demonstrated high efficiency, better convergence, and robustness in solving various optimization problems [26]. Moreover, the soft GMPP searching methods feature fast and simple design [28]. In addition, they effectively avoid convergence to local minima [29]. They also handle non-linear and stochastic optimizations well and exhibit outstanding performance without requiring complex mathematical calculations, which results in computational simplicity, ease of understanding, reliability, and quick response [30]. All the aforementioned methods have demonstrated good convergence and accurate tracking. Despite this, these methods retain drawbacks such as complexity, increased parameter tuning requirements, and insufficient randomness. Therefore, this article proposes a new technique utilizing Bald Eagle Search (BES) for finding the GMPP. The use of BES has several advantages, including fast convergence and the use of fewer tuning parameters [31]. The main contributions of this work can be briefly summarized as follows:

1- The paper presents a new GMPP searching method based on the BES mechanism.
2- The proposed method achieves excellent-searching performance in terms of convergence time and accuracy.

The paper is organized as follows. Section II presents the BES method overview. In Section III, GMPPT (Global Maximum Power Peak Tracking) based on the BES method is introduced. Section IV describes and illustrates the results of Testing the proposed Method in MATLAB. The conclusion is given in Section V.

II. THE BES SEARCH METHOD OVERVIEW

The BES is a recently developed intelligent meta-heuristic optimization algorithm [31]. It imitates the behavior of bald eagles when hunting. In order to achieve the greatest hunting success, bald eagles usually hunt in three stages (selecting space, searching in space, and swooping). In the first stage, the eagles fly randomly to various pre-selected locations to gather preliminary information about the search area. Then, they determine the current best location based on the information collected. Finally, they move randomly toward new places around the best location to learn new information and identify the location that holds a large number of prey. They will keep exploring the area until the most prey can be found. [31] depicts mathematically the eagles' behavior at this stage in Equation (1). The eagles, when they search for the best location, appear to solve an optimization problem of one dimension.

$$P_{new,i} = P_{best} + \alpha * r(P_{mean} - P_i) \quad (1)$$

where:

$P_{new,i}$	the new updated position of the eagle.
P_i	the old position of eagle.
α	the parameter for controlling the changes in the position.
r	a random number between 0 and 1.
P_{best}	denotes the search space that is currently selected by bald eagles based on the best position identified during their previous search.
P_{mean}	indicates that these eagles have used up all information from the previous points.

During the second stage (searching in space stage), the eagles move through the spiral space inside the selected location from the first stage to fast-track their search for a tasty meal. It appears to eagles that the prey is standing in a coordinate plane of two axes, so they have to solve another optimization problem of two dimensions, as in Equation (2). As of this stage, it is expected that one eagle can spot good prey faster than the others.

$$P_{new,i} = P_i + y(i) * (P_i - P_{i+1}) + x(i)(P_i - P_{mean}) \quad (2)$$

where:

$$x(i) = \frac{xr(i)}{\max(|xr|)} \ and \ y(i) = \frac{yr(i)}{\max(|yr|)}$$

$$xr(i) = r(i) * \sin\theta_i \ and \ yr(i) = r(i) * \cos\theta_i$$

$$\theta_i = a * \pi * rand$$

$$a \ is \ a \ value \ between \ 1 \ and \ 5$$

$$r_i = \theta_i + R * rand$$

$$R \ is \ a \ value \ between \ 0.5 \ and \ 2$$

In the third stage (swooping stage), the successful eagle just swoops toward the identified coordination point of the prey and all other eagles change their flying directions toward that point, as described in Equation (3).

$$P_{new,i} = rand * P_{best} + x1(i) * (P_i - c1 * P_{mean}) + y1(i)(P_i - c2 * P_{best}) \quad (3)$$

III. BES-BASED OPTIMAL GMPPT

The GMPP search in the PV curve is considered to be a simple one-dimension optimization problem since the PV array output power depends on only one variable (the PV array voltage V). In light of that, this paper proposes a GMPP method based on the BES's first stage with one very minor change, which is to fix the alpha value instead of allowing it to fluctuate. The algorithm of the proposed GMPP searching method is illustrated in the flowchart in Figure. 1. As the first step, the population of particles is set at a certain number, and the values of all particles are randomly initialized within the limits specified by the minimum and maximum voltages, and then their averages are calculated. Each particle (the particles in this case are defined as the values of the PV reference voltages, i.e., Vi (i = 1, 2. . .n)) value is subsequently applied to the PV system in order to measure the output voltage and current and calculate the power output of the system. When all particle values have been sent to the PV system in full, the maximum output power is found and saved as a global power and as the best power. Next, a new set of particle values is generated by using Equation (4). Then, the new particle values are pushed to the PV system, where their corresponding powers are computed. Once this is done, the highest output power is saved as the new best power. If the new best output power is higher than the stored global power, then it is selected as the current global power. If it is lower, then the stored global power value is not updated, nor is its particle value. The algorithm repeats this process until all particles end up at the same value, which the PV system operates at the GMPP.

$$V_{i\_new} = V_{best} + \alpha * r\left(V_{mean} - V_{i\_old}\right) \quad (4)$$

IV. MATLAB SIMULATIONS AND DISCUSSION

A. Description of the GMPPT Testing Model

To test the effectiveness and performance of the proposed method, a testing model is developed in SIMULINK-MATLAB. The testing model consists of a PV array of six PV modules, labeled as PV Module 1–6 connected in series, and a voltage source connected across the PV array. All PV modules' specifications are the same as in Table 1. As shown in Figure.2, the model is built in a way that the searching algorithm of the GMPP feeds the reference voltage to the controlled-voltage source connected across the terminals of the PV array. Accordingly, the controlled-voltage source applies the reference voltage that imposes the PV array to produce a corresponding current based on the I-V curve characteristics. The outputs of the voltage and current of the PV array are measured for calculating the the output power.

B. *P-V curves of PV system under different PSC cases*

Figure. 3 illustrates power against voltage curves of the PV system under uniform irradiance of $1\,kW/m^2$ and four different cases of PSC. The description of these four PSC cases is as follows:

Case 1: A solar irradiance of $100\ W/m^2$ strikes PV Module 1 and others receive $1\ kW/m^2$.

Case 2: Case 1 + A solar irradiance of PV Module 2 goes down to $300\ W/m^2$.

Case 3: Case 2 + A solar irradiance of PV Module 3 goes down to $500\ W/m^2$.

Case 4: Case 3 + A solar irradiance of PV Module 4 goes down to $700\ W/m^2$.

From Figure. 3, it can be seen that the P-V curve of each PSC case has multiple power peaks because of the different irradiance levels impacting the PV panels. In general, the highest peak is considered a global power peak and the remaining ones are local power peaks.

C. *Simulation Procedure*

As a way of demonstrating the capability of the proposed method, its performance needs to be compared to two popular GMPP searching methods. CS and PSO are chosen as benchmarks due to their good results shown in [26] and [32], respectively. For objective comparison, the number of particles and their initial values are set the same for all three methods: the PSO, the CS, and the proposed method. Then, the parameters of these methods are tuned to converge to the GMPP value. The tuned parameters are shown in Table 2. Finally, the algorithms of the methods are subject to the PSCs described in section IV.

TABLE 1. PV MODULE SPECIFICATIONS

Parameter	Value
V_{MPP}	30 V
I_{MPP}	8.3 A
P_{MPP}	249 W
V_{OC}	36.8 V
I_{SC}	8.83 A
Bypass Diodes	3
PV Cells	60

D. *Results and Discussion*

MATLAB simulations have been carried out under the various PSC cases described previously to evaluate the effectiveness of the proposed method and compare its performance with both the PSO and the CS methods. After the solar panels have settled at the MPP under uniform distribution of solar irradiance, the four PSC cases are applied. Figure 4 illustrates how the three methods converge to the GMPP for the four PSC cases with different convergence times. In the first PSC case, the proposed method, PSO, and CS all converge to the GMPP within 0.157s, 0.25s, and 0.209s, respectively, according to the detailed simulation results (power and voltage) shown in Figure 5. The proposed method, therefore, reduces searching time by 37.2% and 24.8% compared to the PSO and CS methods, respectively, for determining the GMPP.

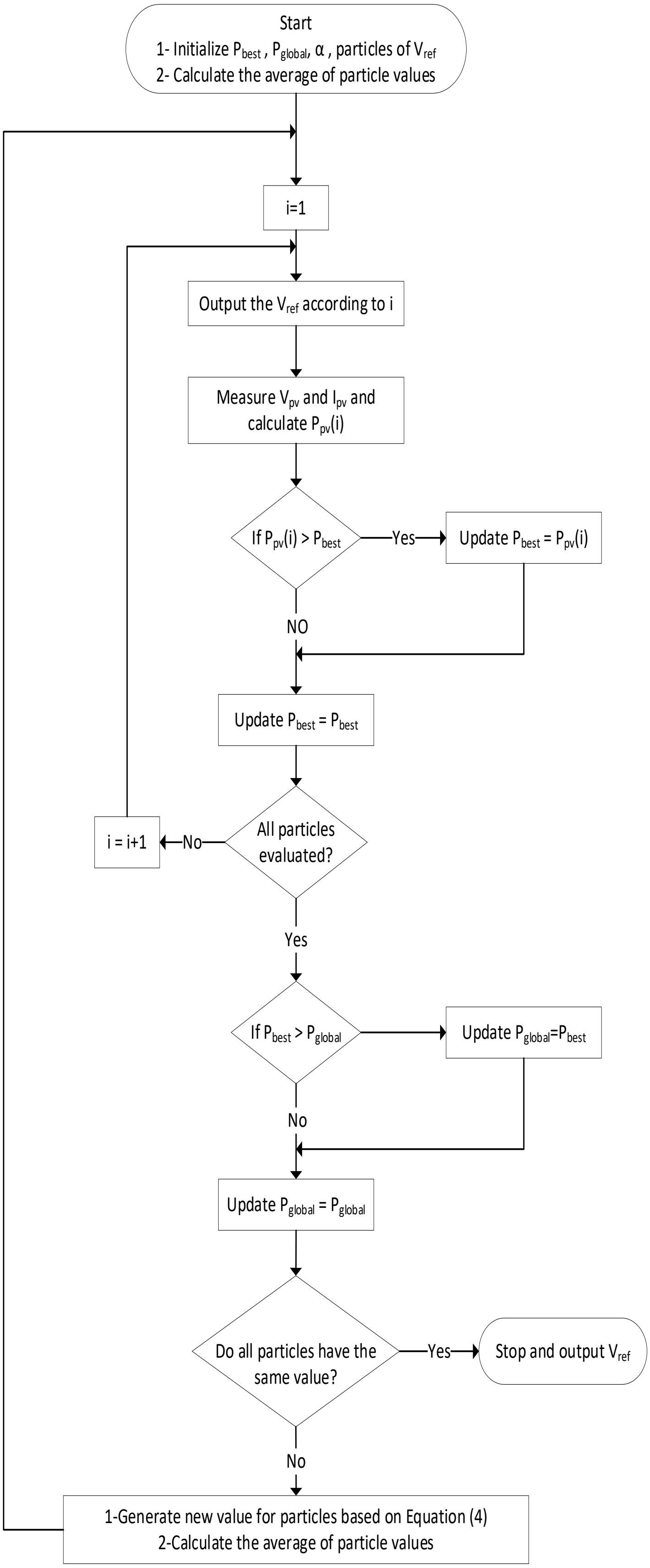

Figure. 1. Flowchart of the proposed GMPPT method based on the BES technique.

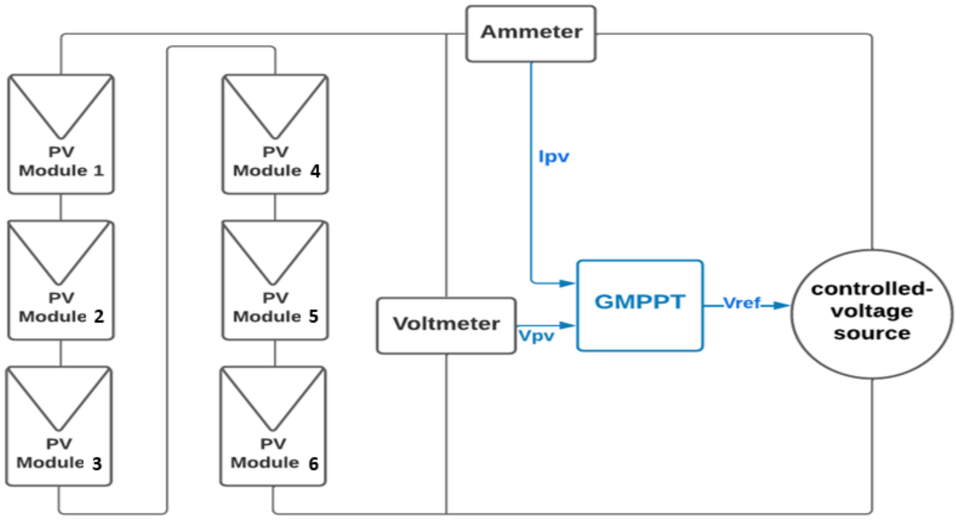

Figure 2. GMPPT Testing Model.

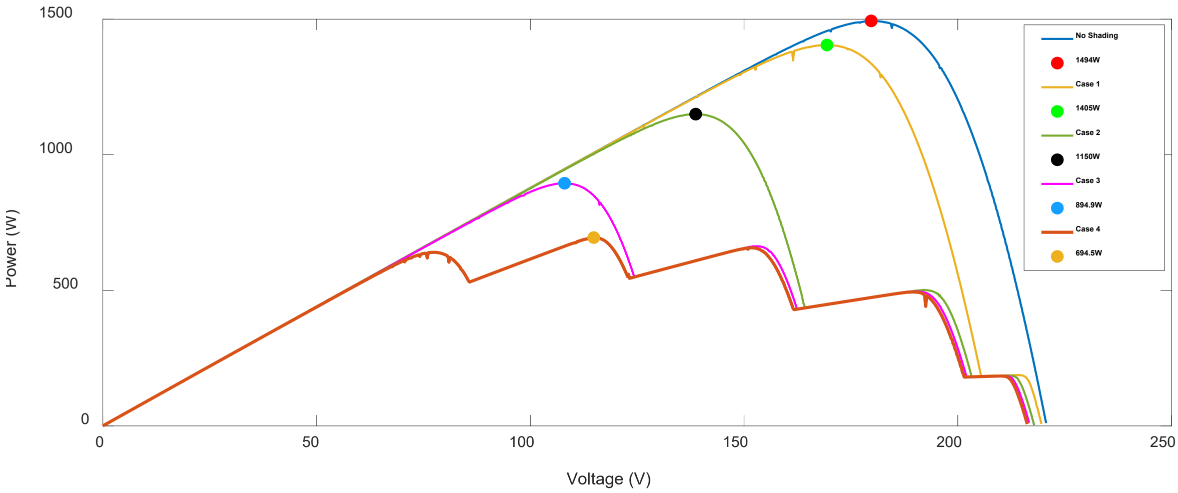

Figure 3. Power versus voltage of PV system under uniform irradiance and PSC.

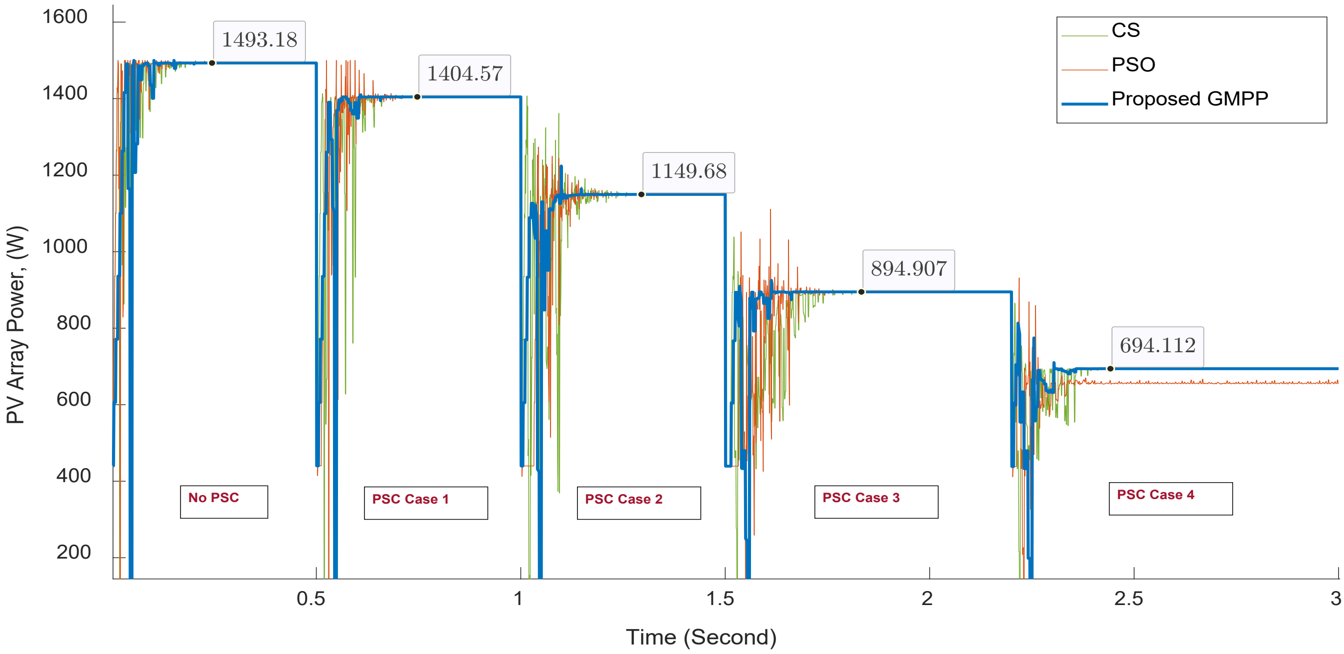

Figure 4. PV system output power for proposed GMPPT, PSO, and CS techniques under different partial shading patterns.

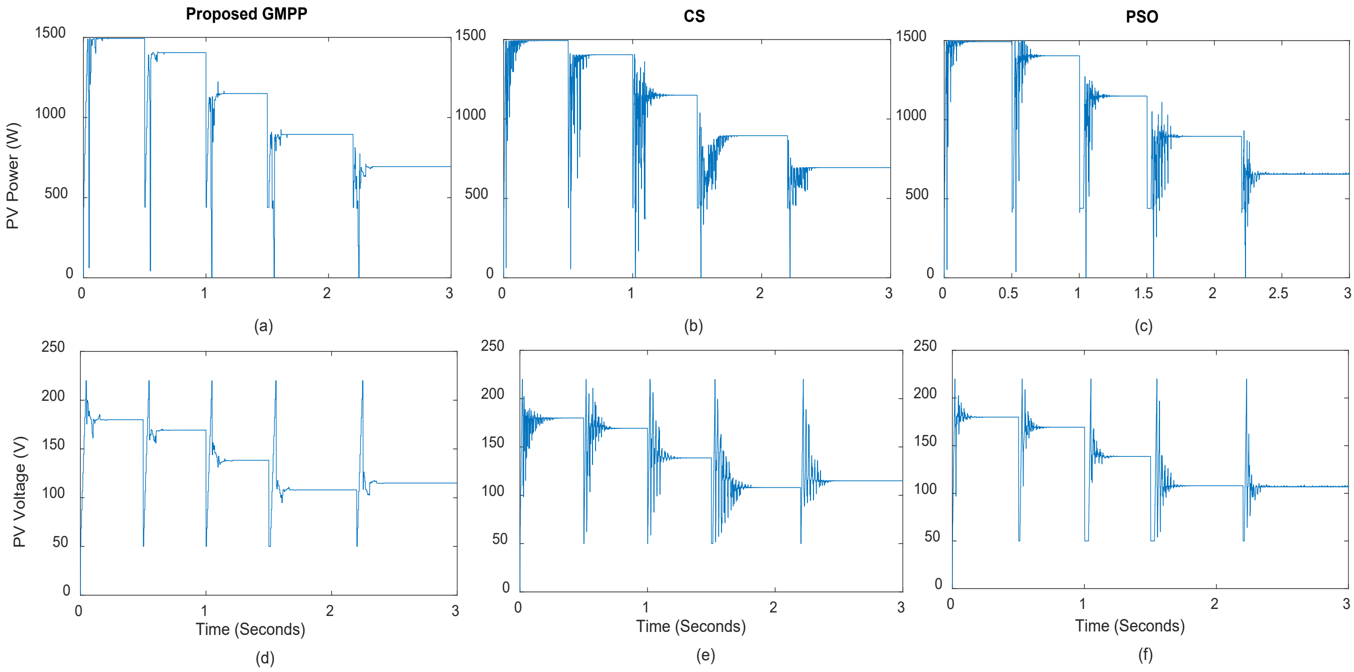

Figure 5. Power and Voltage of the three methods for the PV system under uniform irradiation and four PSC cases.

TABLE 2. PARAMETERS OF THE GMPP SEARCHING METHODS, PROPOSED MPPGT, CS, AND PSO

GMPP Searching Algorithm	Equation	Parameters	Number of particles
PSO	$v_{i+1} = \omega * v_i + C1 * rand * (V_{best} - V_i) + C2 * rand * (V_{global} - V_i)$ $V_{i+1} = (V_i + v_{i+1})$	ω = 0.22 C1=0.1, C2=1	10
CS	$V_{i+1} = V_i + k * \frac{\lvert u \rvert}{v^{\frac{1}{\beta}}} * (V_{best} - V_i)$ $u \approx N(0,\sigma_u^2)\ u \approx N(0,\sigma_v^2)$	β=5 k=0.27	10

	$\sigma_u = \left(\frac{\Gamma(1+\beta) * \sin(\pi * \frac{\beta}{2})}{\Gamma\left(\frac{(1+\beta)}{2}\right) * \beta * 2^{(\frac{\beta-1}{2})}} \right) and \sigma_v = 1$		
Proposed GMPPT	$V_i = V_{best} + \alpha * r(V_{mean} - V_i)$	α = 0.2555	10

TABLE 3. SUMMARY OF THE COMPARISON BETWEEN THE THREE STUDIED GLOBAL MPP SEARCHING TECHNIQUES

	Partial Shading Condition Cases							
GMPP Search-ing Algorithm	***Case 1***		***Case 2***		***Case 3***		***Case 4***	
	Searching Time (s)	***GMPP Found***	***Searching Time (s)***	***GMPP Found***	***Searching Time (s)***	***GMPP Found***	***Searching Time (s)***	***GMPP Found***
Proposed GMPPT	0.157	Yes	0.152	Yes	0.168	Yes	0.161	Yes
PSO	0.25	Yes	0.278	Yes	0.227	Yes	0.248	No
CS	0.209	Yes	0.313	Yes	0.311	Yes	0.238	Yes

In the second case, it is evident from Figure 4 that the proposed method, PSO, and CS extract the GMPP after 0.152, 0.278 and 0.313 seconds, respectively. In this case, the proposed method also decreased the tracking time by 45.3% in comparison to PSO. With regard to the third PSC case, the proposed method, PSO and CS all locate the GMPP of 894.9 W within 0.161s, 0.248s and 0.238s, respectively. A closer look at Figure 4 shows that in the fourth PSC case, the proposed method and CS methods catch the GMPP, while the PSO traps the local MPPs. A comparison of the three studied GMPP searching techniques is demonstrated in Table 3 in terms of search time and ability to find the GMPP. For all of the different shade cases, the proposed method is significantly faster than the PSO and CS methods. This is because a single equation and a few steps are used in the proposed method to update the particle positions. As opposed to the proposed method, the updating of the particle swarm position in PSO and the host nest position in CS involves multiple equations and steps, which results in the overall searching process taking much longer time.

V. CONCLUSION

The phenomenon of partial shading is one of the more common problems found in PV systems, resulting in significant reductions in production. In order to counteract the effects of PSC, bypass diodes are provided in PV panels that shorten the path of shaded PV cells. This can result in a multi-local maximum power peak (in the PV curve), which can cause conventional and advanced MPPT controllers to operate the PV system at a low-performance local peak, further reducing the system's output. To solve this problem, an MPPT controller could be incorporated with a GMPP searching method so that PV systems can be run at their most efficient under PSC. This paper proposes a GMPP searching method based on the first stage of BES. The effectiveness of this proposed method has been evaluated and compared to that of PSO and CS. The study results indicate that the proposed method has a superior performance in terms of convergence time when compared with CS or PSO for all PSC scenarios. It has reduced search times (average of all PSC cases) by 36.17% and 40.76%, respectively, compared with the PSO and CS methods. Furthermore, it correctly found the GMPP in all simulated PSC cases.

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