IJESG
e-ISSN 2636-7904
International Journal of Energy and Smart Grid
Vol 10, Number 1, 2025
Doi: 10.55088/ijesg.1663310

Research Article

COMPARISON OF PARTICLE SWARM OPTIMIZATION (PSO) AND PERTURB AND OBSERVE (P&O) METHODS FOR MAXIMUM POWER POINT TRACKING IN PHOTOVOLTAIC SYSTEMS UNDER CHANGING CLIMATIC CONDITIONS WITH OPTIMAL PARAMETER SELECTION

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Abstract: *Photovoltaic (PV) systems have low efficiency in electricity generation. In PV systems, Maximum Power Point Tracking (MPPT) algorithms must track the MPPT efficiently. There are both conventional and meta-heuristic methods available to track the maximum power point(MPP) of a PV system. Under Partial Shading Conditions (PSC), local maximum power points (LMPP) and a global maximum power point (GMPP) can occur. The Particle Swarm Optimization (PSO) algorithm can easily and quickly track the global maximum point. Under partial shading condition, the Perturb and Observe (P&O) method tends to get stuck at local maximum power point while tracking maximum power point. As a result, the global maximum power point of the PV system cannot be detected using the perturb and observe algorithm. In this paper, a comparative analysis was performed based on simulation results obtained from Matlab/Simulink circuit models under PSC conditions. It was observed that when the parameters of the particle swarm optimization algorithm are appropriately chosen, the particle swarm optimization method outperforms the perturb and observation method in terms of efficiency in tracking the global maximum power point. According to the simulation results, no oscillations around the global maximum power point were observed with the particle swarm optimization method. Furthermore, in rapidly changing climatic conditions, the particle swarm optimization algorithm tracks the global maximum power point more efficiently, stably, and effectively compared to the perturb and observe algorithm.*

Keywords*: Photovoltaic system (PV) ,Particle swarm optimization (PSO), Perturb and observe (P&O) Partial shading Conditions (PSC), Global maximum power point (GMPP)*

Received: March 23, 2025 *Accepted: May 30,2025*

1. Introduction

In recent years, the depletion of non-renewable energy source and excessive carbon emissions have been causing climate change. For this reason, limitations have been imposed on the use of these aforementioned non-renewable energy source. Due to these factors, there has been a notable increase in the need for renewable energy. The production of electrical energy from PV systems has become particularly attractive due to the fact that solar energy is clean and unlimited. The advantages of this energy source are that photovoltaic panels do not require maintenance and are a clean energy source. Nevertheless, there are some disadvantages associated with this energy source, such as the insufficient efficiency of PV panels and high installation costs. Photovoltaic technologies are primarily used to harness radiation from the sun and generate electrical energy through electronic circuits. [1]. The efficiency of a PV system related to parameters factors such as the amount of solar radiation it receives, temperature, and load values. Under normal temperatures and irradiation conditions, PV panels reach their MPP value. However, PSC are among the factors that significantly limit the P-V characteristics of photovoltaic systems. Some parts of PV panels may receive less sunlight due to shadows from buildings and trees, rapidly changing direction of clouds, or the shadows of adjacent modules on the panels [2]. The operation of bypass diodes prevents damage to shaded cells, resulting in several peak points [3, 4]. When a portion of a PV array is shaded, several constrained power points occur due to the use of bypass diodes [5]. When solar cells are not globally uniform due to factors such as dust accumulation, non-uniform irradiation, moving clouds, cell degradation, partial shading, etc., the output power of a PV array significantly decreases [6]. One of the traditional methods for tracking the MPP value is the P&O method, which is simple and inexpensive to conduct. However, it is not efficient in tracking MPP under changing atmospheric conditions. Moreover, this method causes oscillations around the MPP.

The various conventional MPPT techniques such as fractional open circuit voltage (FOCV) , fractional short circuit current (FSCC) [7], curve fitting (CF) [7]etc. can be observed from the references. The main drawbacks of FOCV and FSCC are less accurate, as they are mostly used for low-power applications [7].

For better steady-state performance, transient behaviour Intelligent MPPT methods such as neural network, fuzzy logic, and ANFIS are used [8,9]. In the method of P&O with multi-layer ANN, the training of the model and the collection of the datasets is a challenging task [10], and the ANFIS technique consolidates the power of fuzzy logic and neural networks but the training process requires more numerical calculations for accurate results, which is tough; if the models are not properly trained, the inaccurate response of the hybrid models contain a greater number of oscillations [11]. A neural network is a fast solution for enhancing efficiency, and it has the ability to deal with uncertainties and can handle the problem without any prior knowledge [12]. Apart from conventional methods, intelligent methods provide a better performance, and the artificial intelligence overcomes drawbacks caused by methods such as Genetic Algorithms (GA) , fuzzy logic (FL) [13], Grey Wolf Optimization (GWO) [14], etc. The category of hybrid methods reflects the combination of two or more methods of the above-mentioned methods, and the combination increases the effectiveness of the models. Hybrid models such as P&O with multi-layer ANN [15], ANN with a variable step size of P&O [16], Genetic Algorithms, P&O with incremental conductance [16], The effective application of algorithm tracking of the maximum power point and the solar panel efficiency can be improved [17].

Modern algorithms vary in their effectiveness, complexity of circuits, and convergence speed. For good results, traditional methods can be combined with alternative methods to track MPP under varying conditions [18,19,20]

In this paper, a comparison between the PSO algorithm and the traditional method of P&O algorithm is drawn in order to determine the MPP from PV panels under PSC. The PSO algorithm demonstrates high efficiency, reliability, and robustness in both handling nonlinear systems and tracking the GMPP under PSC. To validate the accuracy of the proposed methods, the MATLAB/Simulink circuit models were used for both the PSO and the P&O methods. Three series-connected PV panels were used for both methods under partial shading conditions. The simulation results for both methods were compared at 25°C and under four distinct irradiation conditions. It was demonstrated that GMPP could be effectively tracked if the appropriate measures for the PSO algorithm are chosen, and that power losses were significantly reduced in comparison to the P&O method. The performance of the PSO algorithm in tracking the GMPP under PSC has been compared with the P&O algorithm through Simulink results, demonstrating superior performance

2. Materials and methods

2.1. Equivalent Circuit of the Solar Cell

The solar cell primarily consists of PV chips [21]. Electric energy is produced directly from solar radiation, transmitting electricity without causing any mechanical effect. Electrical power is directly obtained from the PN junction of the semiconductor; therefore, a solar cell is also referred to as a photovoltaic cell [22]. Various mathematical models of PV cells have been used in different studies. The single-diode circuit is used to represent the circuit of the PV cell due to its simplicity and uncomplicated mathematics. Figure.1. shows the circuit of the PVcell. In this figure, I've represents the photon current generated by the cell, In the equivalent circuit, the diode current (Id) is depicted.

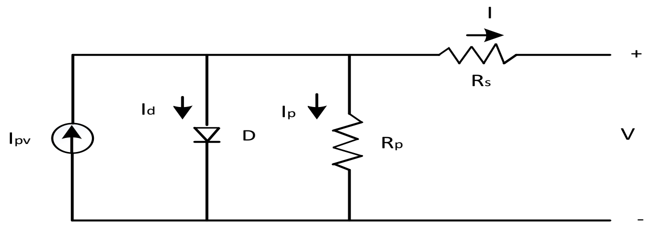


Figure. 1. Single-diode circuit diagram for the PV cell

The diode current is expressed as follows:

$$I_D = I_D\left(e^{\frac{V_D}{aV_T}} - 1\right) \quad (1)$$

The V_T expression is written as follows;

$$V_T = \frac{kN_ST}{q} \quad (2)$$

Ns: Number of series-connected cells. q: Electron charge (1.6x10-19 C), T: Cell temperature in Kelvin [12,23]. the of the output current in the equivalent circuit given in Figure 1. is obtained by using Kirchhoff's Current Law as follows;

$$I = I_{PV} - I_D - I_P \quad (3)$$

The expression for the output current is given as follows;

$$I = I_{PV} - I_0\left(e^{\frac{V+IR_S}{aN_ST}} - 1\right)q - \frac{V+IR_S}{R_P} \quad (4)$$

When there is a high energy demand in PV systems, PV panels are connected in series and parallel. The mathematical expression of the PV array is written as follows [24];

$$I = N_P I_{PV} - N_P I_0 \left(e^{\frac{q\left(\frac{V}{N_S}+\frac{IR_S}{N_P}\right)}{aN_S T}} - 1 \right) - \frac{V\left(\frac{N_P}{N_S}\right) + IR_S}{R_P} \quad (5)$$

Here, I_0 : Reverse saturation current, a: ideality factor, and V_D: Diode terminal voltage. V_T : Represents the thermal voltage across the diode. N_P: Number of PV modules connected in parallel, N_S: number of PV modules connected in series. To achieve high energy production, solar cells are connected in parallel or series to form PV arrays and PV panels [14,25].

2.2. DC-DC Boost Converter

The boost converter is a circuit that increases the input voltage and transfers it to the output [15,26]. The traditional design of the Direct Current – Direct Current (DC-DC) boost converter is depicted in Figure 2. It is a switching power converter that regularly switches between its ON and OFF states. A simple boost converter circuit is formed by an input voltage source entitled Vin, an inductor entitled L, a diode entitled D, a controlled semiconductor switch entitled S that can be a Mosfet, an output capacitor entitled C_2 ,and a load resistance entitled R_L. The boost converter can track the maximum power point of the PV panel by adjusting the duty cycle D [16,27].
V_{in}:The input voltage of the circuit, V_{out} :The output voltage of the circuit
D: represents the duty cycle, The output voltage is expressed as follows:

$$V_{out} = \frac{V_{in}}{1-D} \quad (6)$$

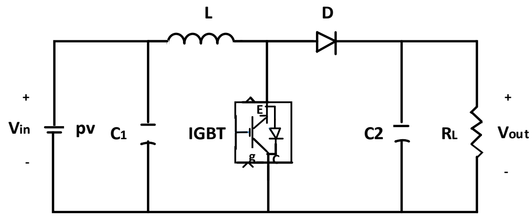


Figure.2. Circuit diagram of the DC-DC boost converter

PV panels that continue to operate normally can damage those that are operating under partial shading conditions[28]. To prevent this damage, bypass diodes connected in parallel to the PV panel are used. The high current that occurs passes through the bypass diode and prevents damage to the remaining PV panels [30]. Under partial shading conditions, the power-voltage characteristic curve of the PV system exhibits several local maximum power points (LMPP) and one global maximum power point with the highest output power. potentially damaging the PV module cells through overheating and thus causing damage to the PV panels themselves.

Under normal operating conditions without partial shading, bypass diodes remain in a passive state and do not negatively impact the system. However, under partial shading conditions, the bypass diode circuits in the shaded PV panels become active, providing protection against circumstances in which some spots get hotter than others. Despite the a fore mentioned advantages of bypass diodes, they also involve certain issues. Such a problem is that the bypass diode circuit cannot generate energy in the affected part of the PV panel, resulting in a decrease in the maximum power level.
Consequently, multiple peaks form in the PV energy system's (V-P) curve, making the system more complex [30].

2.3. Maximum Power Point Tracking

The objective is to achieve high efficiency with regards to the electrical energy generated from PV cells. Maximum power is obtained from PV systems under normal sunny weather conditions. The MPP of PV systems varies depending on panel temperature, solar irradiance, and load changes. It is observed that the PV system cannot track the MPP, especially when the system is directly connected to the load. For this reason, MPPT methods must be used to enhance the efficiency of the PV system as well as to ensure that maximum power can be acquired from the PV panels [31]. Various methods are often applied in order to produce the maximum possible power from PV energy systems. One of such method is electronic tracking. In this method, the PV energy system identifies the point where the power value is maximum. For this purpose, metaheuristic algorithms are used to track the MPP and target efficiency. The operations are performed using a software algorithm in the system. The block diagram of the system is shown in Figure.3 In this system, the measured power values adjust the duty cycle in pulse width modulation (PWM) through an algorithm used within the MPPT method. The duty cycle obtained with the algorithm in the MPPT method is applied to the switching element of the DC-DC converter to regulate the output power. MPPT methods differ from each other in terms of complexity, tracking speed, accuracy, method recognition, and cost [32]. Two fundamental methods are commonly used in the literature; Traditional MPPT methods and metaheuristic MPPT methods. Traditional methods accurately perform MPPT tracking under evenly distributed solar irradiation and unchanging temperature conditions. However, they may not be able to accurately track the MPP under changing atmospheric conditions. This is due to the fact that PV modules have several LMPP and only one GMPP under changing atmospheric conditions. Thus, traditional methods can get stuck at the LMPP, failing to track the GMPP. To overcome this problem, metaheuristic-based algorithms have been developed [29]. Compared to other algorithms, the PSO algorithm demonstrates high tracking speed, medium complexity, very high accuracy, and high efficiency [29].

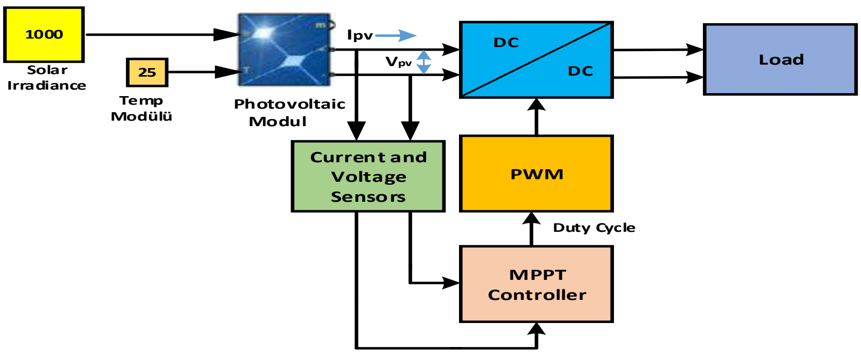


Figure 3. Block diagram of the MPPT system

2.4. Perturb and Observe (P&O) Algorithm

In commercial product applications, P&O is frequently utilized due to its simplicity of implementation, robustness, superior convergence, and its need for comparatively fewer sensors [33]. This technique involves changing the duty cycle at well-designed intervals, and when the power of the PV system is obtained, a study is conducted for the slope of the PV curve [34] The slope of the MPP is used in this method. In this method, MPP tracking is performed by changing the reference voltage. Then, the direction of the next change in system voltage is determined [35]. The flowchart of the P&O algorithm is depicted in Figure 4. The algorithm of this system is explained with mathematical expressions. To the left of the MPP.

$$\frac{dP_{PV}}{dV_{PV}} > 0 \tag{7}$$

$$V_{PV} = V_{PV} + K \tag{8}$$

To the right of the MPP;

$$\frac{dP_{PV}}{dV_{PV}} < 0 \tag{9}$$

$$V_{PV} = V_{PV} - K \tag{10}$$

At the MPP;

$$\frac{dP_{PV}}{dV_{PV}} = 0 \tag{11}$$

$$V_{PV} = V_{PV} \tag{12}$$

Here, K represents a voltage step size (K) for the implementation of the P&O algorithm [33]. Despite its many features this algorithm encounters two major problems, one such issue is its exhibition of continuous oscillation around the MPP. The other is that P&O fails under rapidly changing atmospheric conditions. These two issues cause power loss in PV systems [36].

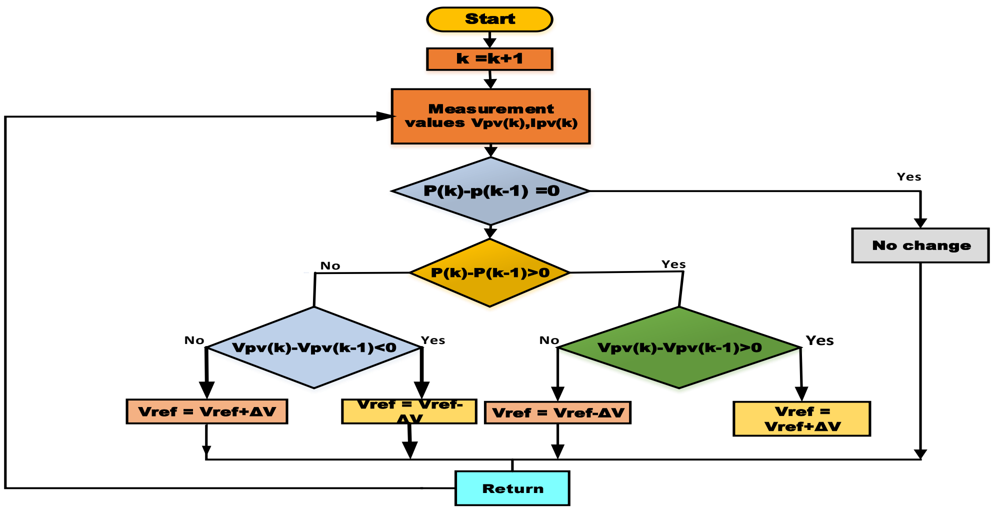


Figure 4. Flowchart of the P&O algorithm

2.5. Particle Swarm Optimization (PSO) Algorithm

PSO is a simple biologically inspired technique used for nonlinear optimization problems. PSO operates based on two main principles; learning from past data and sharing current information among swarm agents [37]. The PSO technology consists of a set of particles. Each particle suggests a solution with the aim of finding the best one by modifying the data obtained during the search process. The movement of the particles in the search area is expressed with a simple mathematics [38]. The position and velocity of the particles are expressed by equations (13) and (14). In this study, the fitness function is the power of the PV system, and the particle swarm position is used as the duty cycle. The particle position di is updated according to the following equations [39];

$$d_i^{k+1} = d_i^k + v_i^k \tag{13}$$

Here: vi is the step size in the k+1 iteration.

$$v_i^{k+1} = wv_i^k + c_1 r_1 \left(P_{best} - d_i^k\right) + c_2 r_2 \left(G_{best} - d_i^k\right) \tag{14}$$

Here: and $\mathbf{r_1}$are random values from [0,1]; w is the inertia weight;$\mathbf{c_1}$ and $\mathbf{c_1}$ are acceleration coefficients; $\mathbf{G_{best}}$ is the best position in the entire population. $\mathbf{P_{best}}$ is the best position of particle, The PV system, in its nature, has an inherent maximum power point However, under shading conditions, the system has several LMPP and one GMPP the desired work is the determination of the GMPP. If the resulting power (fitness) is better, the duty cycle is updated to the best position. c1 and c2 can distribute the tracking capabilities of PSO they do so by influencing the directions of different particles. Usually c1 and c2 range from 0 to 2[40]. This process ends when the GMPP is found [41]. Table1 depicts the values of the parameters used in the PSO algorithm. Figure.5. depicts the flow diagram of the PSO algorithm.

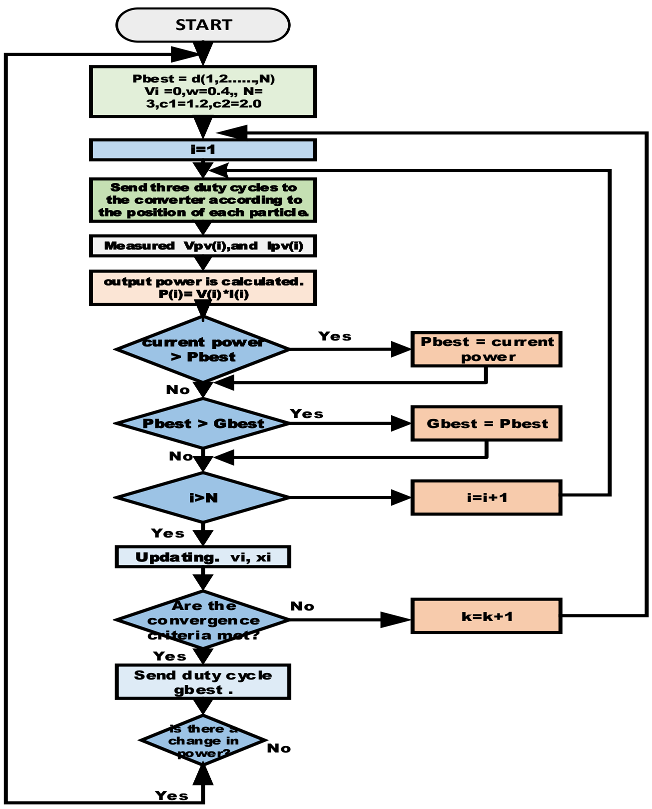


Figure 5. Flow chart of the PSO algorithm.

Table 1. Parameters values for PSO

PSO Parameters	Symbols	Values
Particle Swarm Size	N	4
Number of Iterations	Counter	300
Maximum Duty Cycle	$\mathbf{D_{max}}$	0.9
Minimum Duty Cycle	$\mathbf{D_{min}}$	0.1
Inertia Coefficient	W	0.4
Cognitive Coefficient	$\mathbf{C_1}$	1.2
Social Coefficient	$\mathbf{C_2}$	2.0

3. Simulation Implementation and Results

3.1. Matlab Simulink Model

The proposed system consists of three PV panels, a boost converter, and an MPPT controller, all modeled in MATLAB/Simulink. The power and voltage characteristics of the PV panels are analyzed under partial shading conditions (PSC) at a constant temperature of 25°C and varying irradiation levels. The study investigates three different irradiation scenarios under PSC:
Case 1: 200 W/m², 400 W/m², 800 W/m² Case 2: 400 W/m², 800 W/m², 1000 W/m² Case 3: 400 W/m², 1000 W/m², 1000 W/m². Two MPPT algorithms Particle Swarm Optimization (PSO) and Perturb & Observe (P&O) are implemented to identify the maximum power point (MPP) under these conditions. One of the main challenges in PSC is accurately detecting the global maximum power point (GMPP), as multiple local maxima (LMPP) may appear in the power-voltage (P-V) curve. In such cases, optimization-based methods like PSO can offer advantages.

Simulation results from MATLAB/Simulink are used to compare the performance of both algorithms in terms of their ability to track the GMPP. The results show that increasing irradiation levels lead to higher current and power output. Each algorithm determines the optimal duty cycle for the boost converter to reach maximum power. Figures 6 and 7 illustrate the Simulink circuit models using PSO and P&O algorithms, respectively.

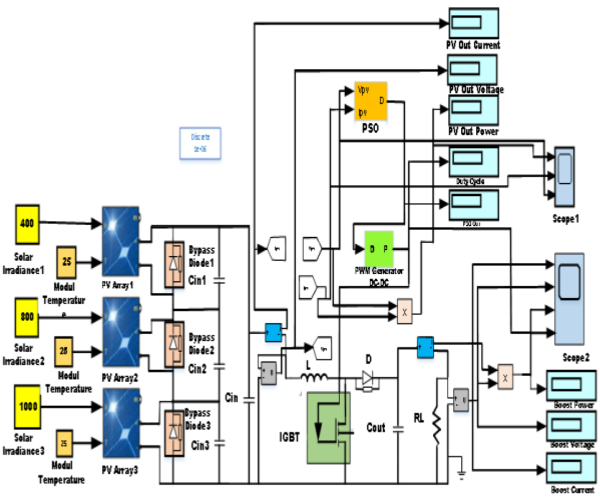


Figure 6. Simulink circuit model of the system using the PSO algorithm under PSC

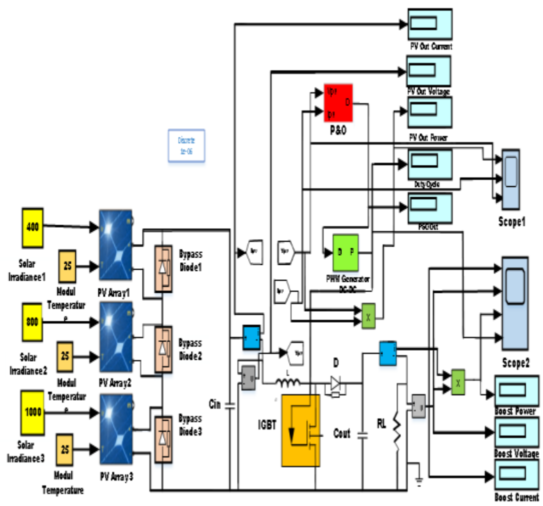


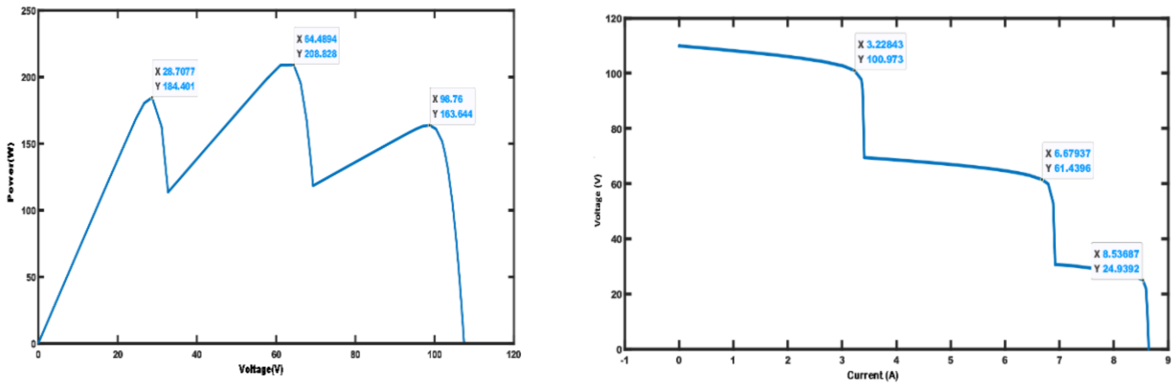
Figure 7. Simulink circuit model of the system using the P&O algorithm under PSC

3.2. Simulation Results

In this study, two different PSO and P&O algorithms were used in the MPPT control system in order to track the GMPP under partial shading conditions. The implemented system was simulated at 25°C, in 3 different Cases, each with 3 different irradiation levels. Simulation results based on this system were then collected. These results were analyzed and compared in terms of their robustness, efficiency, convergence speed, stability, steady-state transition times, rise times, oscillations around the steady state, and the complexity level of each method.

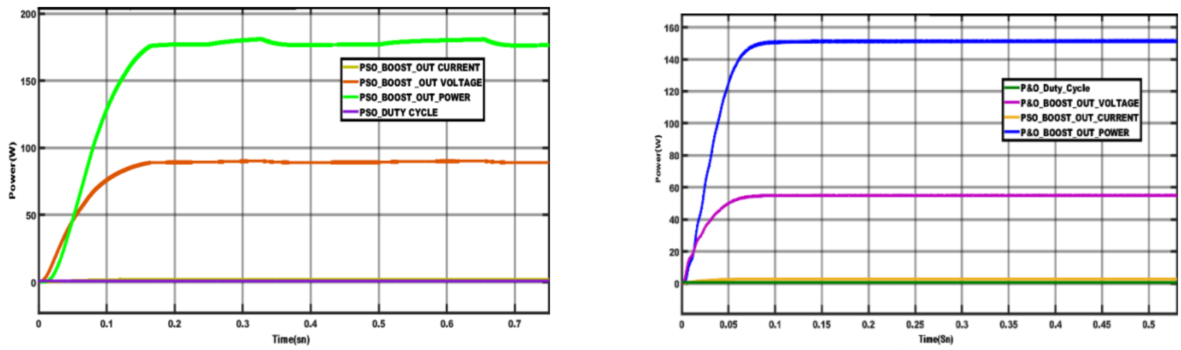
Case-1:

In the first Case, at 25°C and under PSC, three different irradiance levels of 200 W/m^2, 400 W/m^2, and 800 W/m^2 were applied. The MPP value for the PSO algorithm was 181.4 W with a steady-state time of 0.201 seconds, while for the P&O algorithm yielded a MPP value of 151.6 W with a steady-state time of 0.163 seconds. The efficiency of the PSO algorithm and P&O algorithm were 86.51% and 72.45% respectively. The voltage-power (V-P) curve is depicted in Figure.8(a), and the current –voltage (I-V) curve is depicted in Figure.8(b). The SIMULINK circuit model outputs for the PSO algorithm are depicted in Figure.9(a) as the power, voltage, and current graph, and the SIMULINK circuit model outputs for the P&O algorithm are as shown in Figure.9(b) as the power, voltage, and current graph.



(a) (b)

Figure 8. Under PSC for Case-1(a)V-P curve (b)V-I curve

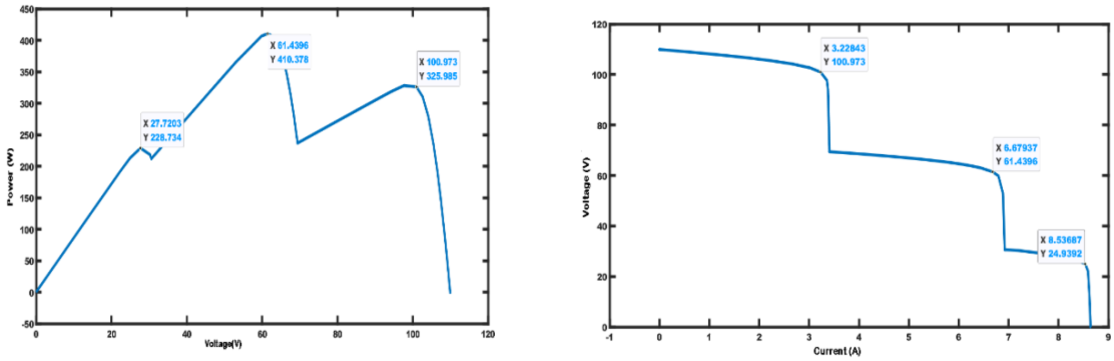


(a) (b)

Figure.9 Power, voltage, and current graphs under PSC for Case-1
(a) PSO algorithm(b) P&O algorithm

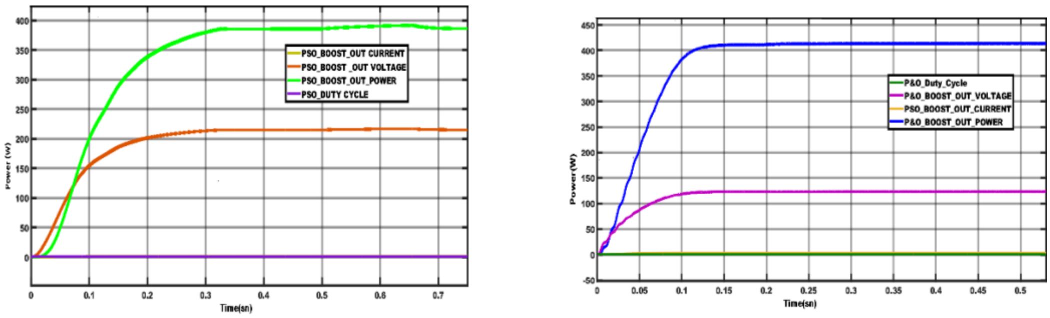
Case-2:

In the second Case, at of 25°C and under PSC, three different irradiance levels of 400 W/m^2, 800 W/m^2, and 1000 W/m^2 were applied. The MPP value for the PSO algorithm was 391.8 W with a steady-state time of 0.328 seconds, while the P&O algorithm yielded a MPP value of 327.8 W with a steady-state time of 0.419 seconds. The efficiency for the PSO algorithm was 95.49%, and for the P&O algorithm, it was 79.89%. Under PSC for Case-2, the voltage- power (V-P) curve is depicted in Figure.10(a) and the current -voltage (I-V) curve is depicted in Figure.10(b). The SIMULINK circuit model outputs for the PSO algorithm are depicted in Figure.11(a) as the power, voltage and current graph, and for the P&O algorithm, the SIMULINK circuit model outputs are as shown in Figure.11(b) as the power, voltage, and current graph.



(a) (b)

Figure 10. Under PSC for Case-2 (a) V-P curve (b) I-V curve

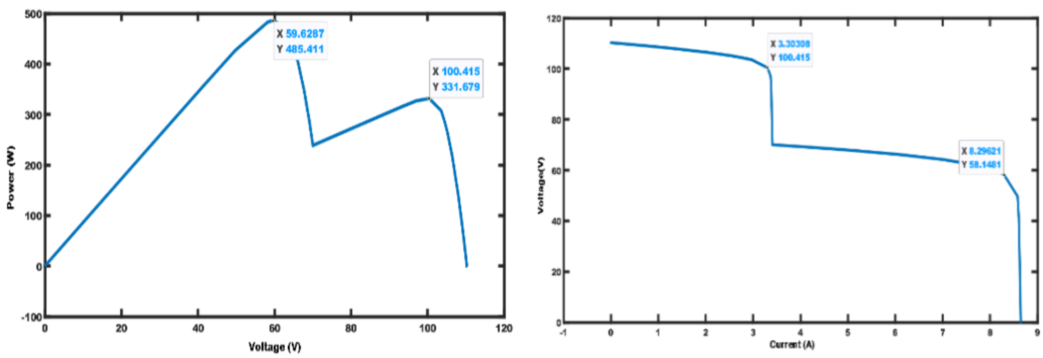


(a) (b)

Figure 11. Power, voltage, and current graph for Case-2 (a) PSO algorithm (b)P&O algorithm

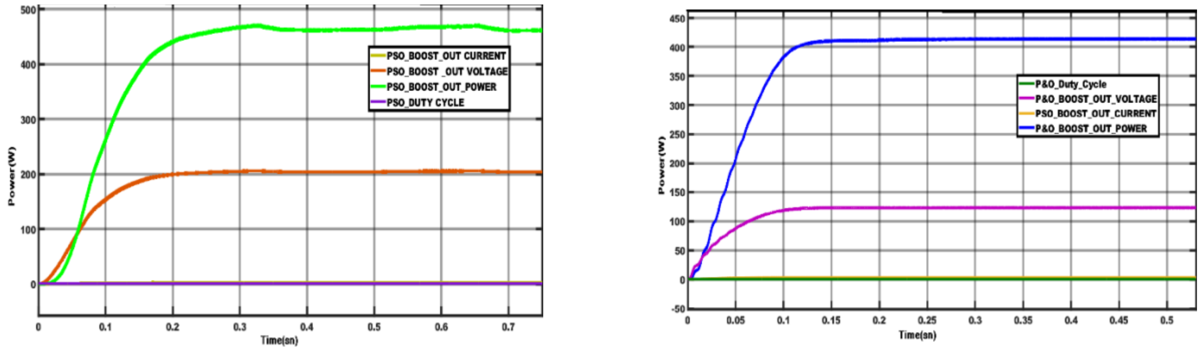
Case-3:

In the third case, at 25°C and under PSC conditions, three different irradiance levels of 400 W/m^2,1000 W/m^2, and 1000 W/m^2 were applied. The MPP value for the PSO algorithm was 470.6 W with a steady-state time of 0.346 seconds, while the P&O algorithm yielded a MPP value was 405.8 W with a steady-state time of 0.296 seconds. The efficiencies were 96.68% for the PSO algorithm and 83.47% for the P&O algorithm, respectively. Under PSC, the voltage-power (V-P) curve is depicted in figure.12(a) and the current -voltage (I-V) curve is depicted in Figure.12(b). The SIMULINK circuit model outputs for the PSO algorithm are depicted in figure.13(a) as the power, voltage, and current graph, and for the P&O algorithm, the SIMULINK circuit model outputs are as shown in figure.13(b) as the power, voltage, and current graph.



(a) (b)

Figure 12. Under PSC for Case-3 (a)V-P curve (b) I-V curve



(a) (b)

Fig 13. Power, voltage, and current for Case-3 under PSC
(a) Graph for the PSO algorithm (b) Graph for the P&O algorithm.

In this study, the results obtained from Matlab/Simulink circuit models of PSO and P&O algorithms were analyzed and compared for PV panels under varying climate conditions, specifically partial shading, at unchanging temperatures. According to the results, the PSO algorithm achieved higher power efficiency across Three different Cases. For three different irradiation levels in each of the three Cases, the PSO algorithm exhibited higher power efficiency increases than the P&O algorithm, with improvements of 14.06% in Case-1, 15.5% in Case-2, and 13.21% in Case-3. Thus, the PSO algorithm demonstrated superior performance compared to the P&O algorithm.The average power efficiency across the three Cases was calculated and determined to be 14.25%. In terms of the convergence speed of the algorithms, the PSO algorithm reached 0.346 seconds in Case 3, while the P&O algorithm converged in 0.296 seconds, indicating a faster convergence rate for the P&O algorithm.The slower convergence speed of the PSO algorithm is attributed to its more complex structure compared to the P&O algorithm. When examining system stability, the PSO algorithm demonstrated greater stability in tracking the GMPP across all three Cases, making it a more stable method than the P&O algorithm. Under varying climate conditions, specifically partial shading, the P&O algorithm tends to face difficulties in the LMPP and fails to differentiate between the GMPP and LMPP. In terms of approaching stable-state transition times, the PSO and P&O algorithms reach the following times: in Case-1, PSO takes 0.201 s and P&O 0.163 s; in Case-2, PSO takes 0.328 s and P&O 0.342 s; in Case-3, PSO takes 0.346 sn and P&O 0.296 sn;. For rise time, the P&O algorithm has a faster rise time than the PSO algorithm. However, oscillations around the LMPP were observed in the P&O algorithm, with magnitudes proportional to the step size of the duty cycle. In contrast, the PSO algorithm demonstrated no oscillations near the GMPP. Simulations under PSC demonstrated that the PSO algorithm follows the GMPP more effectively and is a more stable method than the P&O algorithm. It was concluded that the P&O algorithm follows and gets stuck at the LMPP. Overall, it was found that the PSO algorithm is more robust, stable, and effective than the P&O algorithm in tracking the GMPP. Measurement results for the PSO and P&O algorithms for three different irradiation levels across three Cases are presented in Table 2.

Table 2. Efficiency, power and time values of PSO and P&O algorithms in different radiation conditions.

			PSO		
Cases	**irradiance (W/m2)**	**Temp**	**Power**	**Efficiency (%)**	**Time (sn)**
Case-1	200, 400, 800	25°C	181.4	86.51	0.201
Case-2	400, 800, 1000	25°C	391.8	95.39	0.328
Case-3	400, 1000,1000	25°C	470.6	96.68	0.346

			P&O		
Cases	**irradiance (W/m2)**	**Temp**	**Power**	**Efficiency (%)**	**Time (sn)**
Case-1	200, 400, 800	25°C	151.6	72.45	0.163
Case-2	400, 800 ,1000	25°C	327,8	79,89	0.342
Case-3	400, 1000, 1000	25°C	405,8	83,47	0.296

4. Conclusion

The most significant issue in the generation of electrical energy through the use of PV systems is the system's low efficiency. This study compares the traditional P&O algorithm and the metaheuristic PSO algorithm under PSC in terms of efficiency, robustness, stability, speed, oscillation, cost, and complexity. Under partial shading conditions, multiple maximum points can occur as the maximum power points. There are multiple LMPP and one GMPP. Under PSC, the P&O algorithm, a traditional method, cannot reach the GMP in the MPPT tracking system created with a MATLAB/Simulink circuit model. It faces difficulties with the LMPP. The maximum power levels between Condition 1 and Condition 3 can reach 72,45% and 83.47%, respectively, as shown in Table 2. Under the same conditions, the MPPT tracking system developed using the PSO algorithm in a MATLAB/Simulink circuit model can track the global maximums. The data obtained in Table 3 demonstrates that the maximum power can be tracked at efficiencies of 86,51% and 96,68% in Condition 1 and Condition 3, respectively. These results indicate that the PSO algorithm is superior to the P&O algorithm under PSC. Additionally, the P&O algorithm experiences oscillations at the MPP, and the amplitude of the oscillation depends on the step size of the P&O algorithm. In contrast, no oscillation occurs at the MPP with the PSO algorithm. The application of the MPPT system through the conduction of the P&O algorithm is inexpensive and not complex. However, it cannot respond to rapidly changing environmental conditions as quickly as the PSO algorithm. The PSO algorithm is, additionally, a more complex method than the P&O algorithm. In future studies, the two methods can be implemented and comparative analyses can be conducted to draw conclusions.

Ethical statement

The author declare that this document does not require ethics committee approval or any special permission. This review does not cause any harm to the environment and does not involve the use of animal or human subjects.

Conflict of interest

This study has no conflict of interest.

Authors' Contributions

Ö.F. Ç: Conceptualization, Methodology, Formal analysis, Writing - Original draft preparation

S. A: Resources, Investigation, Formal analysis.

H. C: Resources, Investigation, Formal analysis.
R. T: Resources, Investigation, Formal analysis.
All authors read and approved the final manuscript.

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