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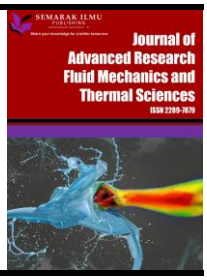

The Study on the Performance of Different Optimization Algorithms in Maximum Power Point Tracking for a Standalone Photovoltaic System

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ABSTRACT

Performance evaluation of maximum power point tracking with a boost converter was presented in this paper. Several MPPT methods have recently been considered as alternatives to conventional MPPT methods, which have high steady-state oscillation and low efficiency. In order to solve the aforementioned issues, a soft computing method is suggested. Under MATLAB/Simulink, the efficiency of P&O, PSO and SSA was evaluated. The MPPT algorithms were tested under three main conditions which are under high irradiance (1000 W/m^2), medium irradiance (600 W/m^2,) and low irradiance (200 W/m^2). Based on the simulation results, Salp Swarm Algorithm (SSA) method shows the best MPPT method with 89.95%, 99.90% and 98.38% tracking efficiency under high, medium and low irradiances respectively. SSA was the best method in terms of high efficiency, no steady-state oscillations and fast convergence.

1. Introduction

Net zero emission by year 2050, has urged a lot of sectors including industries and private sectors [22]. There are many possible ways to achieve zero carbon dioxide (CO_2) emissions globally. One of the most potential alternatives is by eliminating the use of fossil fuels and boosting the transition towards clean energy resources. Out of all of the clean energy resources solar is the most prominent candidate due to its availability and its environmentally friendly [7,8]. In addition to having lower operational and maintenance costs than other renewable energy sources, solar PV also has the potential to lessen carbon dioxide emissions, which are a contributing factor to the greenhouse effect in the earth's atmosphere [6,10]. The price of a PV module in the market has decreased recently due to improvements in semiconductor technology and rising demand. Solar PV's efficiency is still constrained, though. However, solar energy's non-linear properties, which are dependent on temperature and environmental variations, provide the biggest drawback [8,28]. The aforementioned elements affect the I-V and P-V properties differently [15,30]. In order to maximize the solar system's maximum output, maximum power point tracking is introduced [4,6].

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Researchers and academicians have proposed a number of maximum power point tracking (MPPT) methods, including perturb and observe (P&O) [33], hill climbing (HC) and incremental conductance (IC) [17]. Due to their simplicity and convenience of use, traditional methods are becoming more and more popular among researchers and the industrial sector [27,33]. However, the major concern of these methods is on the limitation of tracking and high steady-state oscillations [9,27]. These conventional methods only work well under homogeneous illumination and fail when the environment varies dynamically [11]. Additionally, once it had attained the ideal point of motion, it was difficult to track [5]. As a result of the aforementioned drawbacks, researchers and engineers from all over the world are developing fresh ideas for improved tracking techniques [25].

Soft computing method is seen as one of the most potential candidates over traditional MPPT methods [15]. Soft computing methods is known on its robustness in complex problems and on its accuracy [31]. There are two major methods in soft computing methods which are artificial intelligence [27]. Bio-inspired gains more popularity nowadays due to its characteristic which use biological behaviours of living to optimize the problems [10-12]. Particles Swarm Optimization (PSO), Deterministic Particle Swarm (DPSO) [20], Grey Wolf Optimization (GWO) [21], Cuckoo Search Algorithm [3], Salp Swarm Algorithm [25] and Artificial Bee Colony Algorithm (ABC) [32] are among the bio-inspired algorithms used in MPPT. However, the main challenge in these bio-inspired methods is on determining its population number, initial condition, boundaries of the searching space and the parameters to balance the exploration- exploitation [10,25,26,32].

Inspired by the above aforementioned challenges, further study on the traditional MPPT and bio-inspired methods are evaluated. This paper proposed an evaluation performance of existing MPPT methods for a standalone PV system. In this paper, the MPPT methods such as Perturb and Observe (P&O), Particle Swarm Optimization (PSO), Deterministic Particle Swarm Optimization (DPSO) and Salp Swarm Optimization (SSA) are analysed. The advantages and disadvantages of each method are further discussed. The remaining content of the paper is divided into the following sections, Section 2 presents on the methodology, Section 3 elaborates on the results and Section 4 completes the paper with the conclusion.

2. Standalone Photovoltaic System

A standalone maximum power point tracking photovoltaic system made up of a PV array, boost converter, MPPT controller and a load that utilise solar energy—a renewable and limitless resource—to produce electricity (Al-Juboori). In MATLAB Simulink, a standalone maximum power point tracking photovoltaic system similar to that in Figure 1 is designed [14].

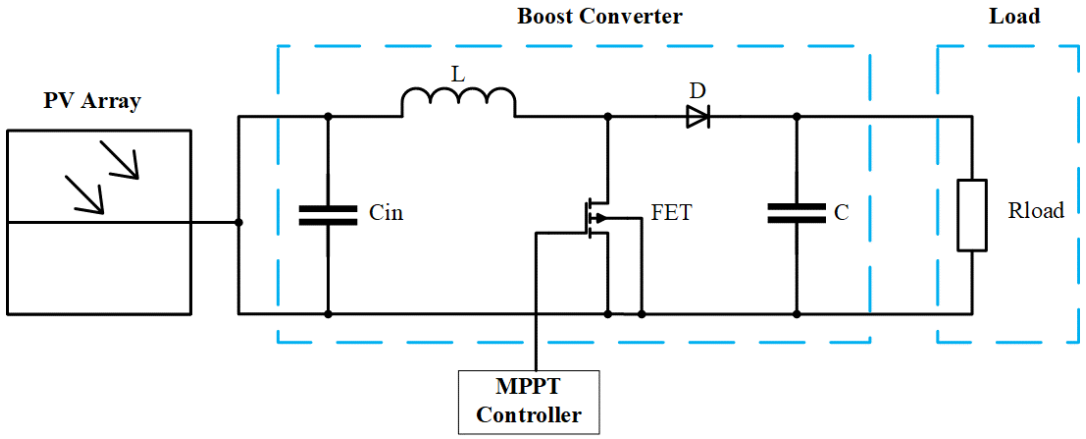


Fig. 1. A standalone MPPT system with boost converter

A solar power system was modelled in MATLAB/Simulink in this study to assess the efficacy of the MPPT algorithms. It demonstrates a boost converter and dc load connected to a DC supply system powered by PV as an input source.

In the simulation, a boost converter with the following specifications in Table 1 is used.

Table 1
Specification of boost converter

Parameters	Rating
Inductance	270 uH
Input capacitance	220 uF
Output capacitance	100 uF
Switching frequency, f_{sw}	20 kHz

The BP50SX photovoltaic module's specifications are listed in Table 2. The MPPT algorithm's primary inputs are PV voltage and PV current, which are fed into the voltage and current sensors. The MOSFET receives the controller's output at the best possible power level. P&O, PSO, DPSO and SSA are the algorithms that were examined under three main condition which are under high irradiance (1000 W/m^2), medium irradiance (600 W/m^2) and low irradiance (200 W/m^2).

Table 2
Specification of BP50SX photovoltaic module

Parameters	Rating
STC power rating, P_{max}	50.04 W
Open circuit voltage, V_{oc}	22.5 V
Short circuit current, I_{sc}	3 A
Voltage at maximum power, V_{mpp}	18 V
Current at maximum power, I_{mpp}	2.78 A
Number of cells	36

3. MPPT Algorithms

3.1 Perturb and Observe (P&O)

Perturb and Observe is one of the most widely used in PV system. In P&O methods, the perturbation is done by observing the power in which by looking at the point is located at which side of the MPP either in the left or right of the MPP. The voltage is incrementing; thus, power is increasing if the operation on the left of the MPP [33]. Meanwhile, if it is at the right of the MPP, the power is decreasing and voltage is decrementing. The operation of the P&O is as shown in Figure 2. This method comes with advantages in simplicity and ease of use [27]. The main disadvantage of this method is fixed step-size and high steady-state oscillation which caused the optimum point still moving forward and backward even the optimum point is reached [17,23]. Thus, cause low efficiency obtained in the system [23,33].

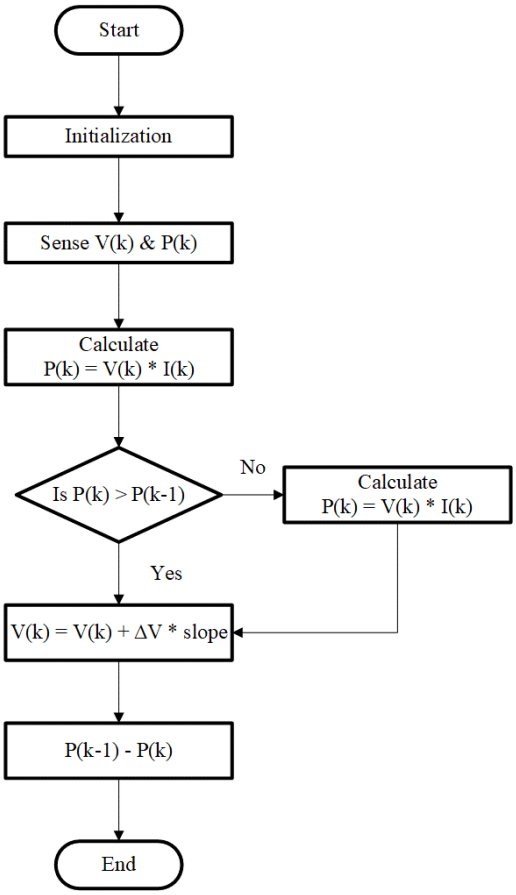


Fig. 2. Perturb and observe (P&O) method

3.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization is inspired by a flock of birds in searching for food [13]. This population-based algorithm uses each individual solution and comparing it's with one global best solution in obtaining the optimize solution [4]. In PSO, each particle must adhere to two fundamental principles in which firstly by tracking the best particle in the population and secondly is identify the global best particle as the reference to the local best particle [12,13]. The main benefit of the PSO method is that, once all the particles arrived the MPP, their velocities become zero [24]. Once convergence is attained, this greatly permits zero steady-state oscillation. This drastically lowers the losses and increase the efficiency of the system [31]. However, if compared this method over traditional method it has a slower tracking speed than the gradient identification method as this method requires initializing in the search [32]. Figure 3 shows the flow chart for PSO in MPPT.

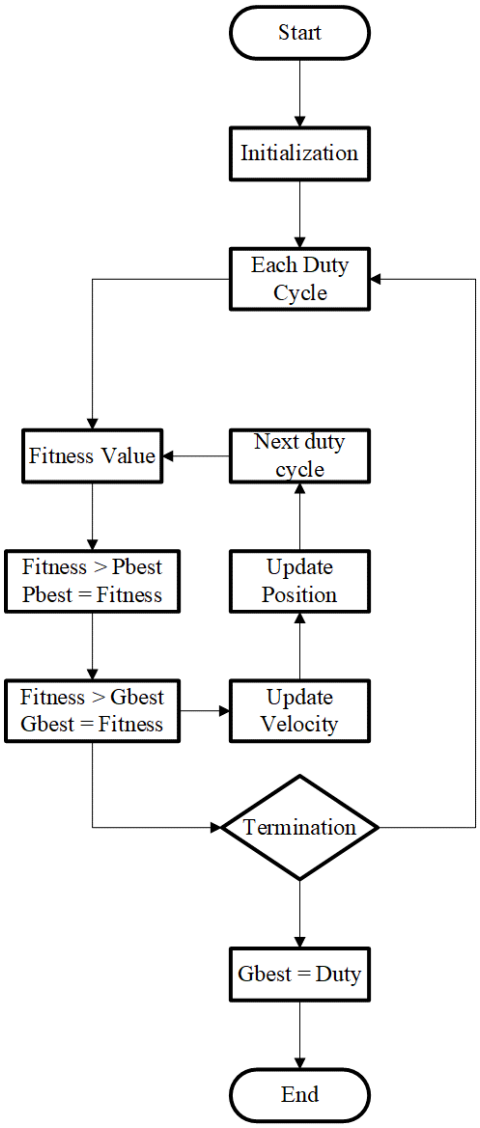


Fig. 3. Particle swarm optimization (PSO) method

3.5 Salp Swarm Algorithm (SSA)

Salp is a marine creature that has a translucent, barrel-shaped body and swims similarly to how jellyfish do [26]. Salps pump water through their tubular body to move forward. The primary driving force behind salp swarm behaviour is the foraging and coordination modifications needed to locate the best position for food [11]. Only one salp serves as the chain's leader, while the others are referred to as follower [29]. Figure 4 shows the operation in SSA in MPPT application. The advantage of utilising this method will reduce power loss and have a convergence speed around MPP [26]. However, this SSA method has challenge in order to determine the right parameter to use in the search and to determine its initial state condition [4,10,11,13].

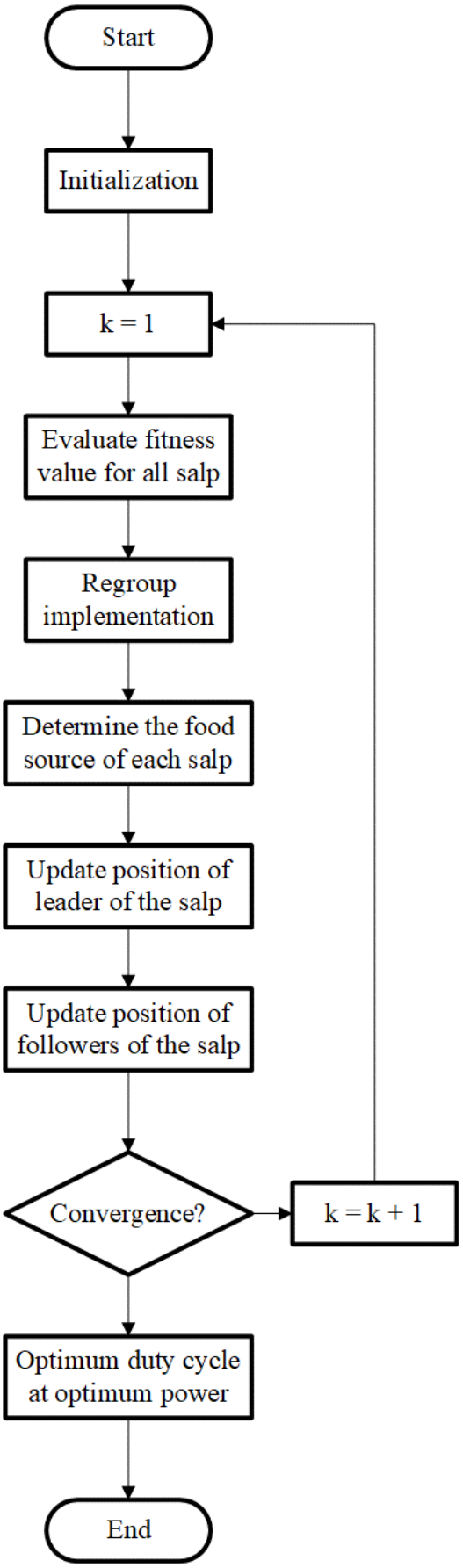


Fig. 4. Salp swarm algorithm (SSA) method

Table 3 shows the summary table for all the three methods, P&O, PSO and SSA.

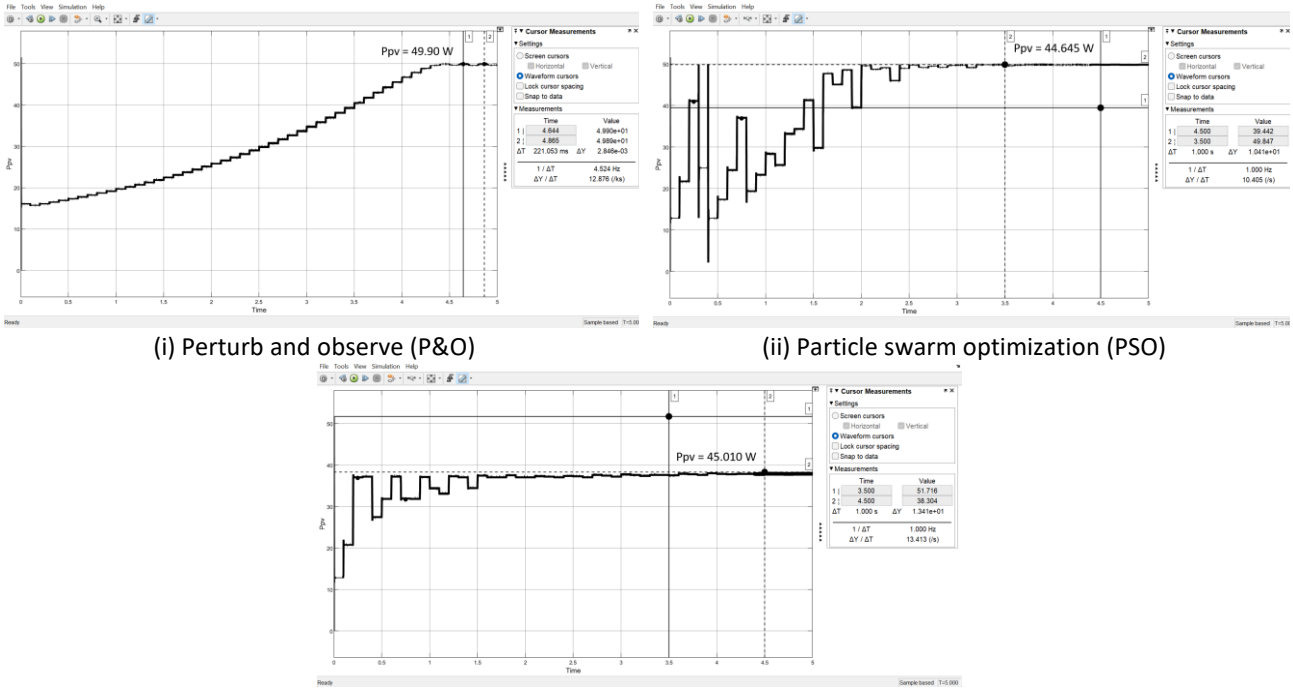
Table 3
Summary table of P&O, PSO and SSA methods

MPPT Algorithms	Parameters	Values
P&O	d	0.01
	w	0.5
PSO	c1	0.4
	c2	0.4
	lb	0
SSA	ub	1
	n	3

4. Results

The performance of all the four MPPT algorithms, P&O, PSO and SSA was evaluated under uniform irradiance which is high (1000 W/m^2), medium (600 W/m^2) and low (200 W/m^2).

Figure 5 shows the results for P&O, PSO and SSA under high irradiance, 1000 W/m^2. Based on the results, Perturb and Observe (P&O) method obtained the almost accurate maximum optimum point of 49.90 W, which was nearest to 50.04 W. It can be observed from the results, P&O suffers from steady-state oscillation compared to other tested MPPT algorithm.

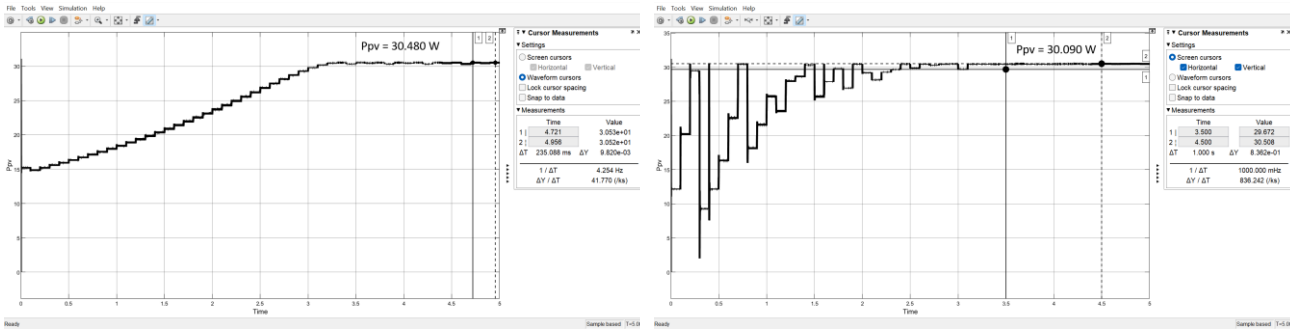


(i) Perturb and observe (P&O) (ii) Particle swarm optimization (PSO)

(iii) Salp swarm algorithm (SSA)

Fig. 5. PPV at high irradiance (1000 W/m^2)

Figure 6 shows the results for P&O, PSO, DPSO and SSA under medium irradiance, 600 W/m^2. Based on the results, Perturb and Observe (P&O) method obtained the almost accurate maximum optimum point of 30.480 W, which was nearest to 30.489 W while the Particle Swarm Optimization (PSO) method obtained the lowest maximum optimum point of 30.090 W. It can be observed from the results, P&O suffers from steady-state oscillation compared to other tested MPPT algorithm.

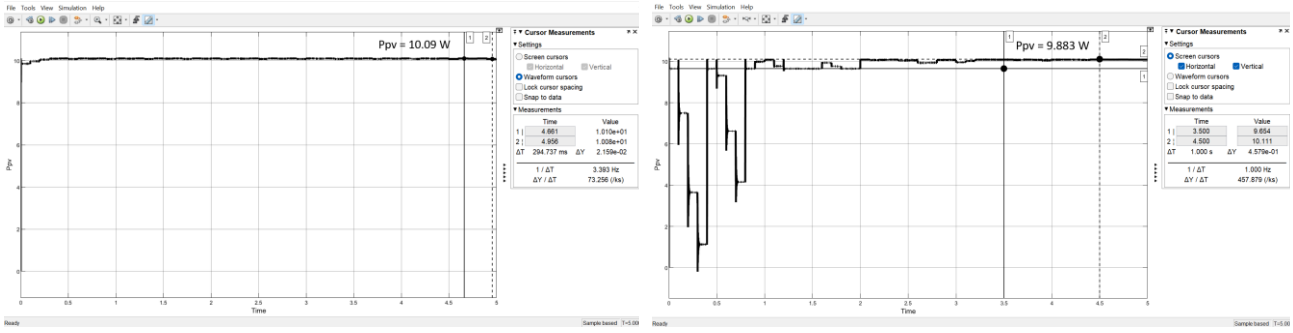


(i) Perturb and observe (P&O) (ii) Particle swarm optimization (PSO)

(iii) Salp swarm algorithm (SSA)

Fig. 6. PPV at medium irradiance (600 W/m^2)

Figure 7 shows the results for P&O, PSO, DPSO and SSA under low irradiance, 200 W/m^2. Based on the results, Perturb and Observe (P&O) method obtained the almost accurate maximum optimum point of 10.09 W, which was nearest to 10.091 W while the Salp Swarm Algorithm (SSA) method obtained the lowest maximum optimum point of 9.928 W. It can be observed from the results, P&O suffers from steady-state oscillation compared to other tested MPPT algorithm.



(i) Perturb and observe (P&O) (ii) Particle swarm optimization (PSO)

(iii) Salp swarm algorithm (SSA)

Fig. 7. PPV at low irradiance (200 W/m^2)

Table 4 shows the summarized performance of the P&O, PSO and SSA. Based on the results, P&O MPPT algorithm shows the best in tracking the maximum power point under high irradiances (1000 W/m^2) compared with other MPPT algorithms with the efficiency of 99.72% while the worst MPPT algorithm in tracking the maximum power point under high irradiances (1000 W/m^2) is the PSO method with the efficiency of 89.22%. However, the P&O method has high oscillation which leads to low performance. Thus, the SSA method is chosen to be best method under high irradiances with low oscillation and fast tracking.

Table 4
Efficiency of P&O, PSO and SSA under high irradiances (1000 W/m^2)

High Irradiances (1000 W/m^2)	PV Optimum Power (W)	Tracked Output Power (W)	Efficiency (%)
P&O	50.04	49.90	99.72
PSO	50.04	44.645	89.22
SSA	50.04	45.010	89.95

Table 5 shows the summarized performance of the P&O, PSO and SSA. Based on the results, P&O MPPT algorithm shows the best in tracking the maximum power point under medium irradiances (600 W/m^2) compared with other MPPT algorithms with the efficiency of 99.97% while the worst MPPT algorithm in tracking the maximum power point under medium irradiances (600 W/m^2) is the PSO method with the efficiency of 98.69%. However, the P&O method has high oscillation which leads to low performance. Thus, the SSA method is chosen to be best method under high irradiances with low oscillation and fast tracking.

Table 5
Efficiency of P&O, PSO and SSA under medium irradiances (600 W/m^2)

Medium Irradiances (600 W/m^2)	PV Optimum Power (W)	Tracked Output Power (W)	Efficiency (%)
P&O	30.489	30.480	99.97
PSO	30.489	30.090	98.69
SSA	30.489	30.459	99.90

Table 6 shows the summarized performance of the P&O, PSO and SSA. Based on the results, P&O MPPT algorithm shows the best in tracking the maximum power point under low irradiances (200 W/m^2) compared with other MPPT algorithms with the efficiency of 99.99% while the worst MPPT algorithm in tracking the maximum power point under low irradiances (200 W/m^2) is the PSO method with the efficiency of 97.94%. However, the P&O method has high oscillation which leads to low performance. Thus, the SSA method is chosen to be best method under high irradiances with low oscillation and fast tracking.

Table 6
Efficiency of P&O, PSO and SSA under low irradiances (200 W/m^2)

Low Irradiances (200 W/m^2)	PV Optimum Power (W)	Tracked Output Power (W)	Efficiency (%)
P&O	10.091	10.09	99.99
PSO	10.091	9.883	97.94
SSA	10.091	9.928	98.38

Table 7 shows the summary table of the simulation results. Based on the simulation results, the Salp Swarm Algorithm (SSA) method shows the best compared to other methods with lowest oscillation, fastest response time and tracking speed under high, medium and low irradiances.

Table 7
Summary table of results

Algorithms	Comparison under different irradiances					
	200 W/m²		600 W/m²		1000 W/m²	
	Oscillation	Response Time	Oscillation	Response Time	Oscillation	Response Time
P&O	Low	Slow	High	Fail	High	Low
PSO	Low	Medium	Low	Medium	Low	Medium
DPSO	Low	Medium	Low	Medium	Low	Medium
SSA	Low	Fast	Low	Fast	Low	Fast

5. Conclusion

In this paper, an evaluation performance on MPPT algorithms for a standalone PV system with a boost converter was considered. A standalone PV system with a boost converter was constructed under MATLAB/Simulink. The effectiveness of the P&O, PSO and SSA was evaluated under three main conditions such as high, medium and low irradiance. Based on the simulation results, the Salp Swarm Algorithm (SSA) method shows the best MPPT method with 89.95%, 99.90% and 98.38% tracking efficiency under high, medium and low irradiances respectively. The SSA method also shows zero steady-state oscillation and the fastest tracking speed. The P&O method shows the worst with tracking efficiency of 99.72%, 99.97% and 99.99% under high medium and low irradiances respectively. The P&O method also shows high steady-state oscillation and slower tracking speed. Soft-computing shows the best accuracy due to its nature of remaining constant once the optimum point is reached while P&O shows the worst due to fixed step size.

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