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Research Article

Improved particle swarm optimization based on buck-boost converter (IPSO-BBC) for photovoltaic system applications

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ABSTRACT

Nowadays, energy access and demands are of high importance. In some remote areas where the main energy grids are difficult to access, photovoltaic solar standalone systems are highly recommended for utility operation. In order to achieve and maintain successfully the required output power at maximum levels under any variable environmental conditions, high PV solar powers are necessary to feed efficiently the output. In this paper, an improved particle swarm optimization-based buck-boost converter (IPSO-BBC) for optimum standalone load charging is investigated. The proposed IPSO-BBC algorithm utilizes the PV solar voltage and current as two inputs based on PSO parameters. Solarex-MSX photovoltaic solar panel of 60 watts maximum power is used for the whole system operation. In order to harvest the maximum power for the output satisfaction, therefore; for this purpose, the IPSO-BBC algorithm approach is implemented. The PSO is used to monitor the PV voltage and current and BBC for the duty cycle settlement in various environmental conditions. The IPSO-BBC approach optimally presents a very good efficiency of 98.24% and a tracking factor of 0.93 with PV solar power generation performance under partial shading conditions. The entire simulation is carried out by MATLAB/Simulink.

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INTRODUCTION

In recent decades, the terrestrial globe is influenced by the effects of climate change issues caused by some natural factors. An example of fossil fuel [1]. The high increase in raw oil and fossil fuels are some of the main issues related to the environment's adverse outwardness. That is primarily understood through disruptions produced by climatical inconsistency involving global warming, depletion of ozone layers, carbon emissions rise, high wind, high temperature, and other unknown disasters. On the other hand, The PV solar system is expanding rapidly across the world, whereas the solar power flexibility delays its infiltration into the power grid [2]. Besides as the world's energy segment moves away from fossil fuels toward renewable energy sources. Therefore, computational optimization techniques can be used to drastically increase the economics and decrease the environmental impact of the energy technologies by using the carbon dioxide capture and storage (CCS) method. The CCS system accounts for the irregularity and inconsistency of renewable power production resulting in reduced cost of capture compared to non-optimized methods. The optimization has been applied to many technologies. In the work of [3], the renewable energy source incorporations are

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designated as the electric power production (EPP) mitigation methodology.[4] defines the tabu search optimization (TSO) technique for removing the parasitic parameters of PV solar modules under various climate change conditions. [5] Proposed a multi-adaptive PSO technique in order to find the global peak of PV modules under partial shading conditions. In complete radiation variation conditions, the traditional algorithms effectively track the MPP of the PV array, but they did not succeed to track the MPP under partial shading or varying environmental conditions. The design [6] is appropriate for solving uninterrupted optimization problems with high performance among the PSO variants.

LITERATURE REVIEW

The literature [8] observed that the buck-boost converter is appropriate for any load resistance connected to the PV system. In order to harvest the produced power of the PV system and optimally exploit the captured solar energy, [9] treats with a novel artificial neural network particle swarm optimization approach (ANN-PSO). In [10], a review is developed on the potential of particle swarm optimization for solving various types of optimizations in chemometrics. Moreover, another review is introduced by [11], where the origin, background, and theoretical analysis of PSO were carried out. [12] presented a master-slave swarm shuffling evolution algorithm combined with self-adaptive particle swarm optimization (MSSE-SPSO) where its results amazingly improve the calculation accuracy and show an efficient approach for the hydrological model calibration. However, the PSO performance is drastically impacted by the control parameters selection and the velocity implementation strategies. Therefore, a self-adaptive PSO with various velocity approaches is proposed by [13] to improve the performance of PSO. This paper [14] introduced several mutation operators to enhance the PSO performance. [15] developed an MPPT mechanism based on the novel hybrid particle swarm optimization algorithm without losing the efficiency of the battery obtained from the source.[16] proposed a novel hybrid series salp particle Swarm optimization (SSPSO) which is highly required for suburb area applications where the partial shading conditions are frequent. [17] has explored an improved salp swarm algorithm based on particle swarm optimization for maximum power point tracking of optimal photovoltaic systems.[7] The PSO traditional technique was supposed to be the most efficient method of tracking the maximum power in the pattern shading situations.

METHODOLOGY

In this paper, we realized a compound system made of PV solar panels, a DC-DC buck-boost converter, the proposed MPPT technique, and the end-use (load). The power from the PV array is transferred through the buck-boost converter which plays the role of an impedance matching device, and a booster system called the MPPT technique which increased the power level to that of load requirements when less power is provided from the PV solar panels side. The whole system is presented in Figur 1 below.

For the study organization, the paper content consists of the introduction section, literature review section, methodology section (PV array, buck-boost converter, and the proposed technique), results and discussion section, and finally the conclusion section.

1. System Modeling

1.1. System Description

In order to clearly investigate the system working principle and components details, the circuit diagram below Figure 1 is required.

1.2. Solar Cell Circuit Description

By the electrical model, the solar cell is characterized as shown in Figure 2. In the following Eq. (1) the current-voltage characteristics are termed as:

$$I = I_L - I_O \left\{ exp\left[\frac{q(V+IR_S)}{nkT}\right] - 1\right\} - \frac{V+IR_S}{R_{SH}} \quad (1)$$

From the above Eq. (1) I output current and V output voltage, dark saturation current I_O, electron charge q, Boltzmann constant k, the diode quality or ideality factor A, the absolute temperature T, the solar cell series and shunt resistances R_S and R_{SH} are all necessary parameters for PV solar circuit. Through, the semiconductor material and solar panel, the R_S resistance is offered. The complexity exists in describing the shunt resistance R_{SH}. For the p-n junction of non-ideal nature, a short circuit path is given around the junction due to the presence of the impurities located near the cell edges. In an ultimate case, R_S is 0 whereas R_{SH} is

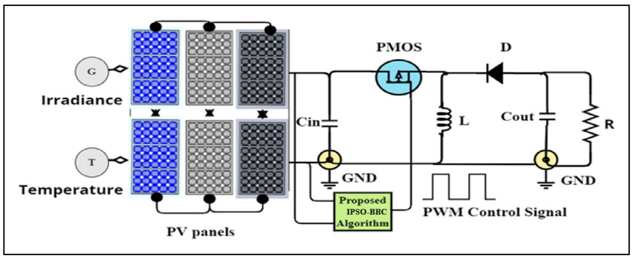

Figure 1. Diagram Circuit of the proposed system.

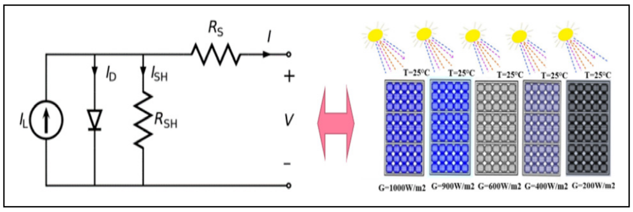

Figure 2. Circuit of Solar panel and its equivalent panels series.

infinite. To improve the products, the manufacturers try to minimize the resistance effect. Similarly, the ultimate set-up is not possible.

The R_{SH} outcome is not considered. R_{SH} is infinite for simplification, thus Eq. (1) last term is abandoned.

1.3. Higher Power-Point, Short Circuit Current, and Open-Circuit Voltage

Dual significant current-voltage points are the short circuit current I_{SC} and open-circuit voltage V_{OC}.

The power generation is 0 at both points. From (1) V_{OC} can be approximated when I= 0, the R_{SH} is discarded shown in Eq. (2) the I_{SC} is at V= 0 and nearly same as the light generated current I_L as shown in Eq. (3).

$$V_{OC} \approx \frac{nkT}{q} \ln\left(\frac{I_L}{I_O} + 1\right) \quad (2)$$

$$I_{SC} \approx I_L \quad (3)$$

By means of solar circuit, the maximum power is generated at MPP and the current-voltage characteristics which are distinctive at various temperatures are shown in following Figure 3.

1.4. Effect of Temperature and Irradiance

The temperature and irradiation are the significant factors to be noted. It leads to the module characteristics which are getting affected. During the day times, the MPP varies and that's why MPP is tracked constantly and assured about the maximum available power received from the panel. On voltage-power (V-P) and voltage-current (V-I), the irradiance effect is shown in Figure 4, the current and voltage which are using I_{SC} and, V_{OC} normalized respectively. The irradiation increment resulting in the maximum current generated by the photovoltaic system is related directly to the irradiance level. Furthermore, a short circuit is not an operating point (no generating power), the PV current is termed as Eq. (1). With irradiation, the characteristics of voltage-current vary.

Figure 4 depicted that by comparing with voltage, the change in current is greater. The dependency of voltage on irradiation is frequently abandoned. When the irradiation rises from the positive value of the current and the voltage, the power is also positive. Thus, more power is generated when more irradiation results.

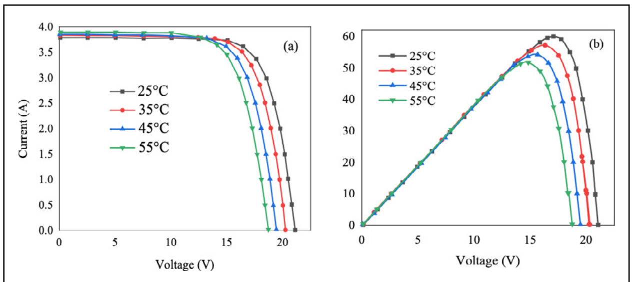

Figure 3. Solar panel characteristic curves at constant irradiation and varying temperatures.

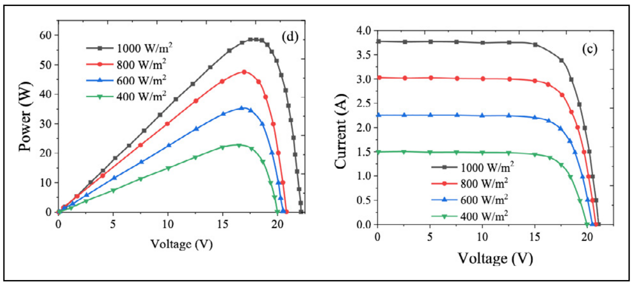

Figure 4. At constant temperature and four variation isolation values of V-I and V-P curves.

On contrary, the voltage is affected mostly by temperature. On the temperature, the open-circuit voltage is linearly dependent as shown in Eq. (5).

$$V_{OC} = \frac{kT}{q} \ln\left(\frac{I_{SC}}{I_O} + 1\right) \quad (4)$$

Based on Eq. (4) the temperature effect on V_{OC} shows negative since the voltage decreases when the temperature increases. The little increase with current doesn't compensate for voltage decrease due to the rise in temperature and thus a reduction in power is seen. When the temperature changes, the higher power point, short circuit current, and open-circuit voltage vary.

2. Buck-Boost Converter

The switch-mode power supply (SMPS) converters are mostly used in recent electronics applications.

The inverting buck-boost (IBB) converter is one type of SMPS converter where the voltage range can be regulated up or down based on the load requirements. However, it provides a negative output voltage, the IBB is simple in design and has a cost-effective tradeoff (inexpensive). The applications such as batteries, home electronic consumers, DC-DC regulated buses for communication or industries often rely on IBB converters. This converter has a PMOS switch connected to the inductor which acts as an energy storage reservoir providing power to the load when the PMOS switch is off. Moreover, a diode acts as a current path in reverse biased operation. Figure 5 shows a simplified schematic of the switching inverting converter and its different components.

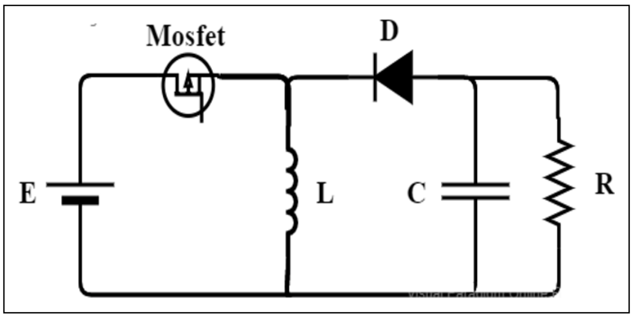

Figure 5. Configuration of a conventional inverting buck-boost (IBB) converter.

The input voltage and output voltage relationship

$$V_0 = \frac{D}{1-D} V_{in} \text{ with the duty cycle} \quad (5)$$

The peak-to-peak inductor ripple current is deduced as following

$$\Delta L = D(1-D)\frac{V_0 + V_{in}}{f_p L} \quad (6)$$

The input current and output current relationship

$$I_{in} = \frac{D}{1-D} I_0 \quad (7)$$

The maximum peak-to-peak inductor ripple current

$$\Delta L_{max} = \frac{V_0 + V_{in}}{4 f_p L} \quad (8)$$

3. Proposed IPSO-BBC Algorithm

The particle swarm optimization (PSO) technique is a very well-known bio-inspired metaheuristic type algorithm. Its concept is developed based on the nature and motion of the flock of birds in the real world.

As a famous metaheuristic optimization algorithm, PSO is recognized as a swarm intelligence strategy used to solve research problems. It is the most appreciated algorithm due to its simplicity and flexible implementation. The present agent location is found by the velocity expression linked with each particle in PSO. Figure 6 below represents the movement of the particles in the search region.

Generally, in PSO, each particle is represented by its velocity and position.

The velocity can be updated by the following formula:

$$\vartheta_i^{k+1} = \omega \vartheta_i^k + c_1 r_1 \left(pbest_i^k - X_i^k \right) + c_2 r_2 \left(gbest^k - X_i^k \right) \quad (9)$$

Where g is denoted by the current best position, xi is defined as the individual best solution of the particle i.

C1 and C2 are random values taken from the interval of [0,1].

The position can be updated by the following expression:

$$x_i^{k+1} = x_i^k + \vartheta_i^{k+1} \quad (10)$$

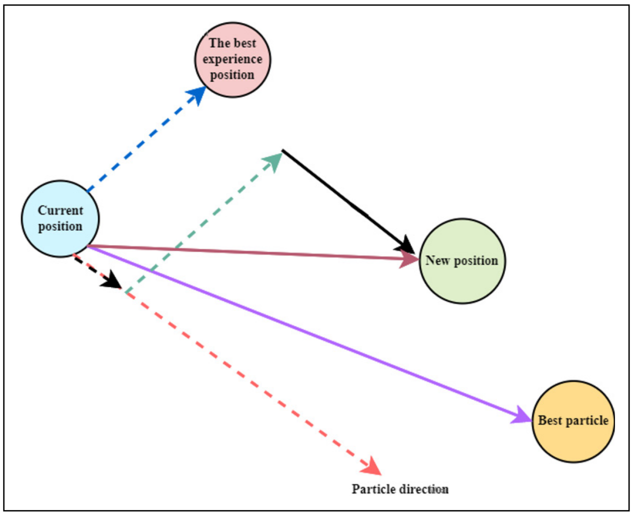

Figure 6. Particles motion inside the search area.

The Flowchart of the proposed IPSO-BBC algorithm is presented in Figure 7.

SIMULATION RESULTS AND DISCUSSIONS

For this work, Solarex-MXS 60 watts is selected for simulation purposes. The paper aims to optimize the PV solar power by taking two inputs of PV to efficiently supply the load. The proposed IPSO-BBC approach encompasses the PV solar module, buck-boost converter, an improved particle swarm optimization-based Buck-Boost converter MPPT controller, and the load mounted in the block diagram is developed in MATLAB/Simulink (Figure 8). The improved efficiency is calculated by the following formula [11]. The buck-boost converter switch gate signal or duty cycle is depicted in Figure 9.

$$\eta = \left(1 - \frac{P_{PV} - Measured\ P_{IPSO-BBC}}{P_{PV}}\right) \quad (11)$$

In Table 1, We used the load power and the PV power based on the formula (11) to demonstrate the performan-

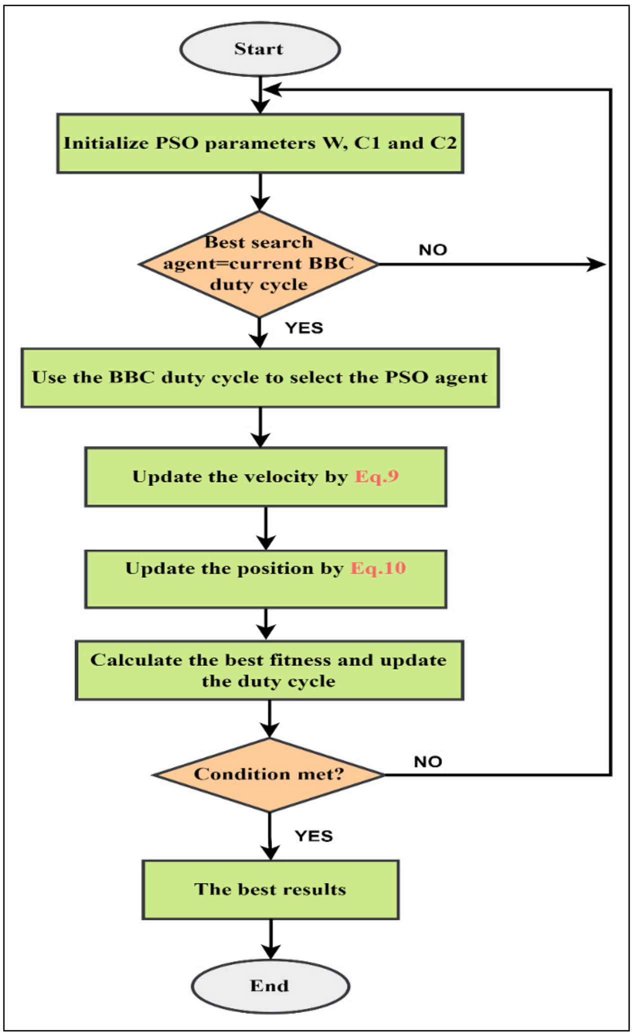

Figure 7. The Proposed IPSO-BBC flowchart.

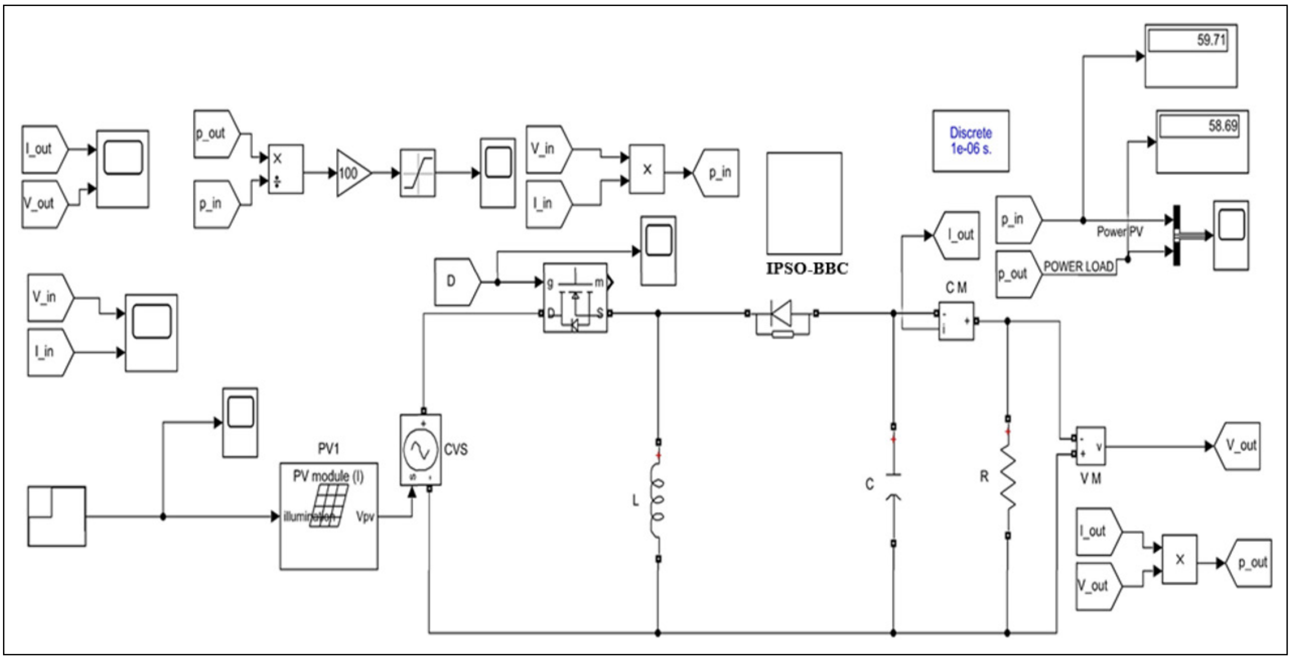

Figure 8. MATLAB/Simulink configuration of the proposed technique.

ce of the proposed IPSO-BBC approach by considering the input parameters. The IPSO-BBC approach presents many advantages such as reducing the number of iterations, optimizing the input power, and giving an excellent efficiency. Based on the different simulations, we have observed that a series of irradiation changes (1000 W/m2, 700W/m2, 500W/m2, and 300 W/m2) at a temperature of 25 °C presents 98% base efficiency and with smooth powers follow-up Figures 10 and 11. Figures 12-13 (zoomed efficiency and non-zoomed efficiency using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C. Figure 14 (PV solar voltage and current using IPSO-BBC algorithm under varying ir-

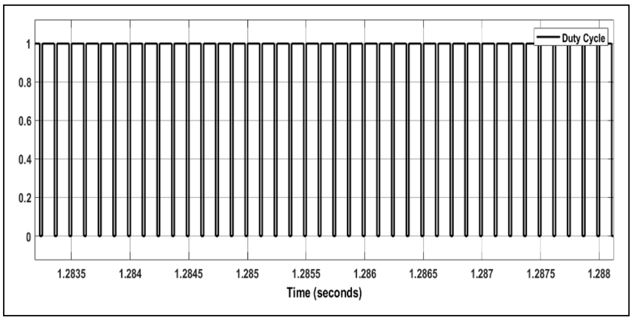

Figure 9. Buck boost converter switch gate signal plot around 1.3 seconds.

Table 1. PSO parameters

PSO	Parameters	Values
	Maximum population size	400
	Number of iterations (N)	4.0
	Inertia weight (W)	0.9
	Personal learning coefficient (C1)	2.0
	Global learning coefficient (C2)	2.0

PSO: Particle swarm optimization.

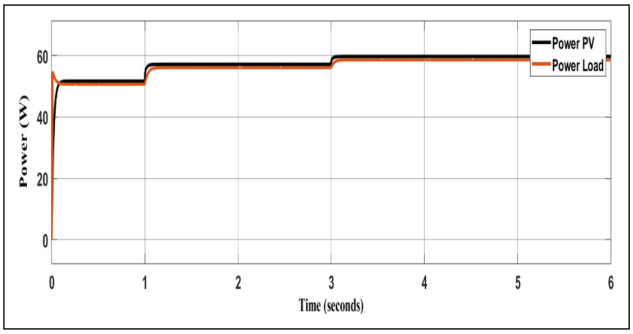

Figure 10. Output and Input powers using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C.

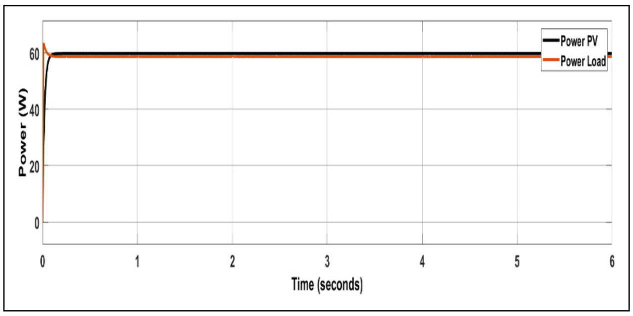

Figure 11. Output and Input powers using IPSO-BBC algorithm at Standard Test Condition (1000W/m2 and 25 °C).

radiation [500 W/m2 to 1000W/m2] at 25 °C) shows that the PV voltage does not change for varying irradiance but only the PV current is slightly affected. Figure 15 (Load voltage and current using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C, shows the resistive load of 50 Ω verified the Ohms relationship of (V=R×I). The powers and efficiencies results are presented in Table 2.

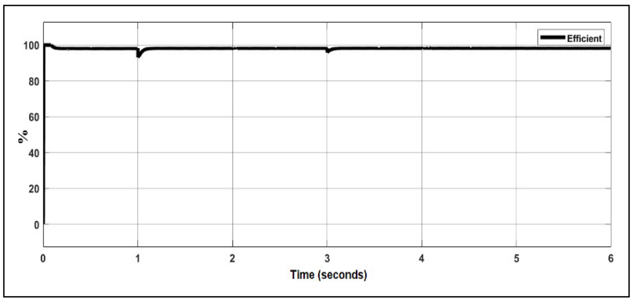

Figure 12. Efficiency using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C.

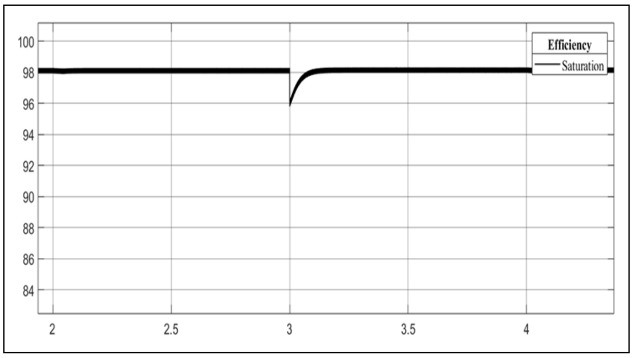

Figure 13. Amplified Efficiency using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C within time interval of 2 to 4 seconds.

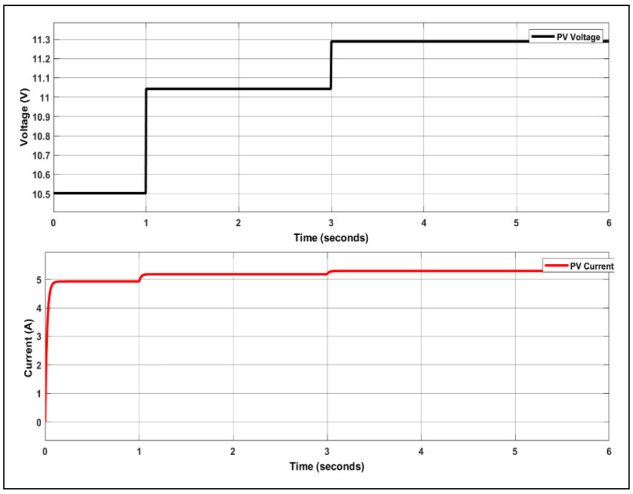

Figure 14. PV solar voltage and current using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C.

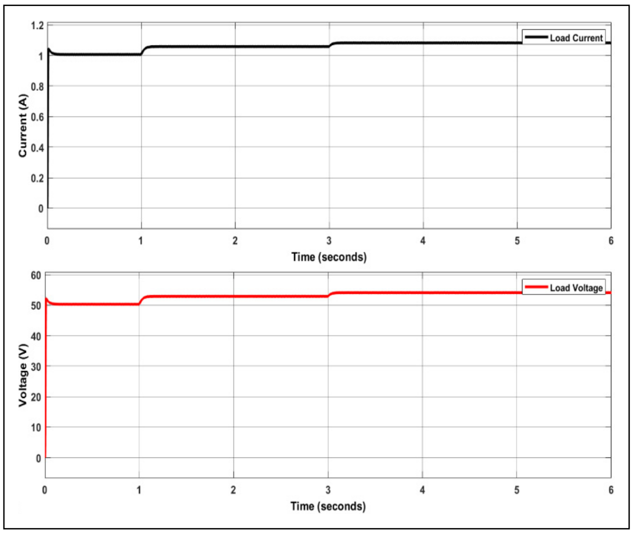

Figure 15. Load voltage and current using IPSO-BBC algorithm under varying irradiation (500 W/m2 to 1000W/m2) at 25 °C.

Table 2. Simulation results of powers with improved efficiencies for various irradiations at 25 °C

Irradiation (W/m2)	Ppv (W)	PLoad (IPSO-BBC)	Efficiency (%)
1000	59.71	58.69	98.29
700	57.14	56.15	98.26
500	55.12	54.15	98.24
300	51.69	50.75	98.18

IPSO: improved particle swarm optimization; BBC: buck-boost converter.

CONCLUSION

This paper presented the performance of metaheuristics swarm-based algorithm, improved particle swarm optimization-based buck-boost converter (IPSO-BBC) MPPT controller to track efficiently and accurately PV solar power under various environmental change conditions. This work enhanced the PV power to be tracked with a reduced number of iterations of the system. The Particle swarm optimization algorithm monitors the duty cycle of the buck-boost converter in order to match input (PV) power to the output (load) power and also controls PV solar model SOLRAEX-MXS60 parameters. The simulation results of the new IPSO-BBC algorithm under MATLAB/Simulink show an average efficiency of the proposed IPSO-BBC approach which is 98.24% and calculated by the ratio of the measured output power by PV actual power at different irradiation levels within the time of 6 seconds. The efficiency of the study is slightly greater than that of similar work efficiency which is 97% [9]. The IPSO-BBC has some advantages of high tracking speed and no oscillations over that of [9] under atmospheric change conditions.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work

DATA AVAILABILITY STATEMENT

The authors confirm that data that supports the findings of this study are available within the article.

The graphs or raw data that support the findings of this study can be requested from the corresponding author.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with regards to research, authorship, and/or publication of the article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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