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Novel initialization strategy: Optimizing conventional algorithms for global maximum power point tracking

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ABSTRACT

In this research, a novel initialization strategy for conventional MPPT algorithms is proposed to define the best position for the tracking process to start over the P–V curve. Consequently, the global maximum power point (GMPP) becomes the nearest or first maximum among the existing multiple MPPs under the partial shading condition (PSC). In addition, the step size of the applied conventional algorithm is minimized based on its proximity to the actual GMPP. Therefore, the tracking speed is improved, and the power loss can be reduced by the proposed approach. The major advantages of this approach are eliminating the need to modify the original algorithm, hybridizing with other algorithms, or employing any complex procedures, as in metaheuristic and optimization MPPT algorithms. Hence, it is overcoming the main drawbacks of conventional MPPT. In this work, the proposed initialization approach is applied to the simplest conventional MPPT technique, which is the perturbation and observation (P&O) algorithm, to show the enhancement in performance without the need to introduce any complex processes. MATLAB/Simulink simulation model and hardware implementation based on digital signal processing (DSP) controller TMS320F28335 are two distinct methodologies used to validate the outperformance when applying the proposed initialization technique under PSC and various weather fluctuations. The outcomes show that the proposed initialization technique was successful in extracting the maximum power peak while also improving time response, accuracy, and generating oscillations.

1. Introduction

Photovoltaic (PV) technology is increasingly being used to generate electricity. However, its performance is strongly impacted by the weather conditions, especially under partial shading conditions (PSC) [1]. Any obstruction or reduction in incident radiation's ability to reach a group of series modules at the same levels can result in shading. In a PV array, when each series-connected module is exposed to the same amount of radiation, a single power peak can be seen in the P–V curve under uniform weather conditions. The highest power peak that may occur under PSC is known as the global maximum power point (GMPP), and it stands for the most power that a PV array is capable of producing. Therefore, it is imperative to seek out strategies to enhance the energy produced by PV energy systems [2]. Wide ranges of maximum power point tracking (MPPT) algorithms have been developed by researchers, starting from the simplest, which is the perturbation and observation (P&O) MPPT technique and other conventional techniques, to the most complicated, such as metaheuristic and optimization MPPT algorithms [3–5]. In addition, modified and hybrid tracking algorithms could be considered too [6,7]. For conventional algorithm, P&O [8] and incremental conductance (IC) [9] algorithms are the two MPPT algorithms that have been the most thoroughly studied in the literature. These algorithms' primary benefits include being straightforward, inexpensive, and able to track the MPP under uniform radiation situations. However, as most of conventional MPPT algorithms [10], P&O and IC algorithms are suffering from the oscillations they produce around the MPP and

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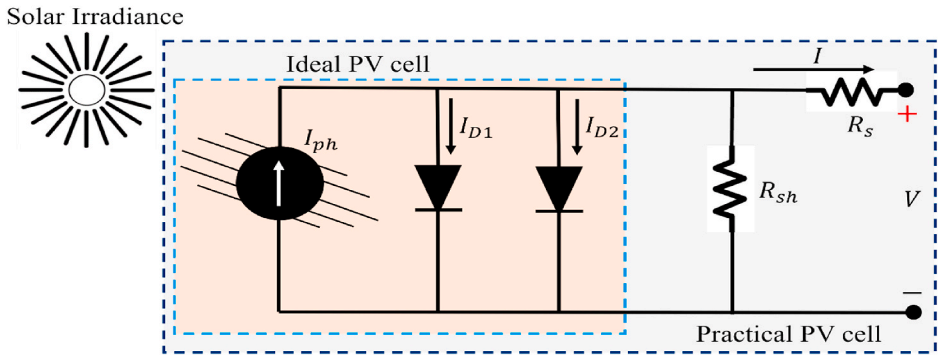


Fig. 1. Double diode model.

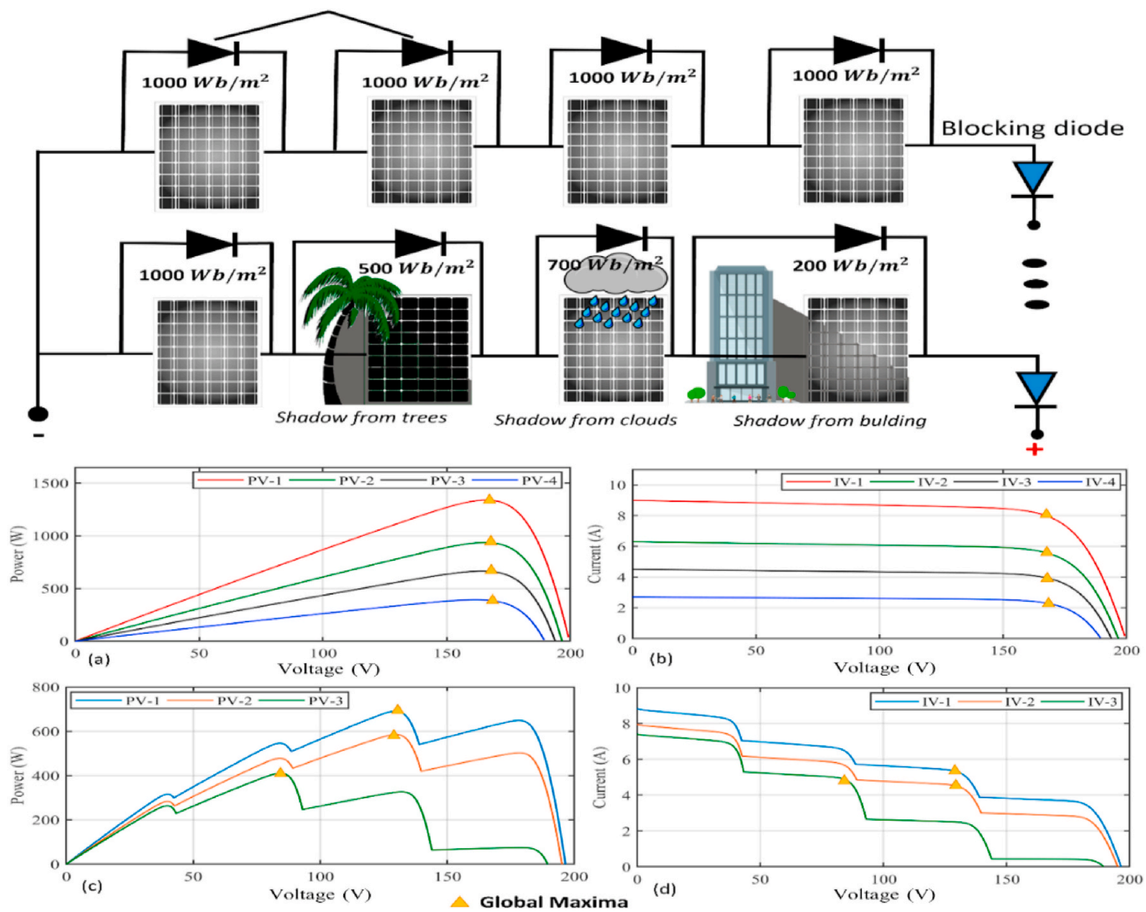


Fig. 2. PV array with series/parallel connected modules under uniform shading and partial shading.

their inability to perform effectively under shadowing cases by limiting themselves to the closest local maximum power point (LMPP). A number of numerical technique approaches were put forth as a far superior choice for tracking maximum power points. Providing quick response times and rapid convergence [11–13]. They can have variable step sizes, and once the system hits its maximum power point, they will not oscillate. The predictor-corrector method was applied in Ref. [14], in order to determine the beginning value at a specific tracking path point, rather than making an initial assumption. Subsequently, that value is employed in an implicit method to more accurately refine it. Under uniform weather conditions, the great performance is evident; nevertheless, under shading conditions, the optimal path toward GMPP tracking remains unidentified. Soft computing MPPT techniques, like artificial intelligence and metaheuristic techniques were proposed in the literature to address the drawbacks of conventional MPPT methodologies. Fuzzy logic algorithm (FLC) [15,16], and artificial neural network (ANN) [17,18] are two examples of artificial intelligence techniques that have been introduced in a variety of research to improve PV performance under PSC. However, in addition to the complexity of hardware implementation, such artificial intelligence algorithms are expensive, sophisticated, and time-consuming to compute. They also require previous knowledge to be handled.

Recently, the metaheuristic MPPT algorithms for GMPP tracking have gained most of the attention. Particle swarm optimization (PSO) [19], levy flight based particle swarm optimizations (LPSO) [20,21], Ant colony optimization (ACO) [22], Mud Ring Optimization [23], differential evolution (DE) [24], butterfly optimization algorithm (BOA) [25], cuckoo search (CS) [26], artificial bee colony [27], grey wolf [28],

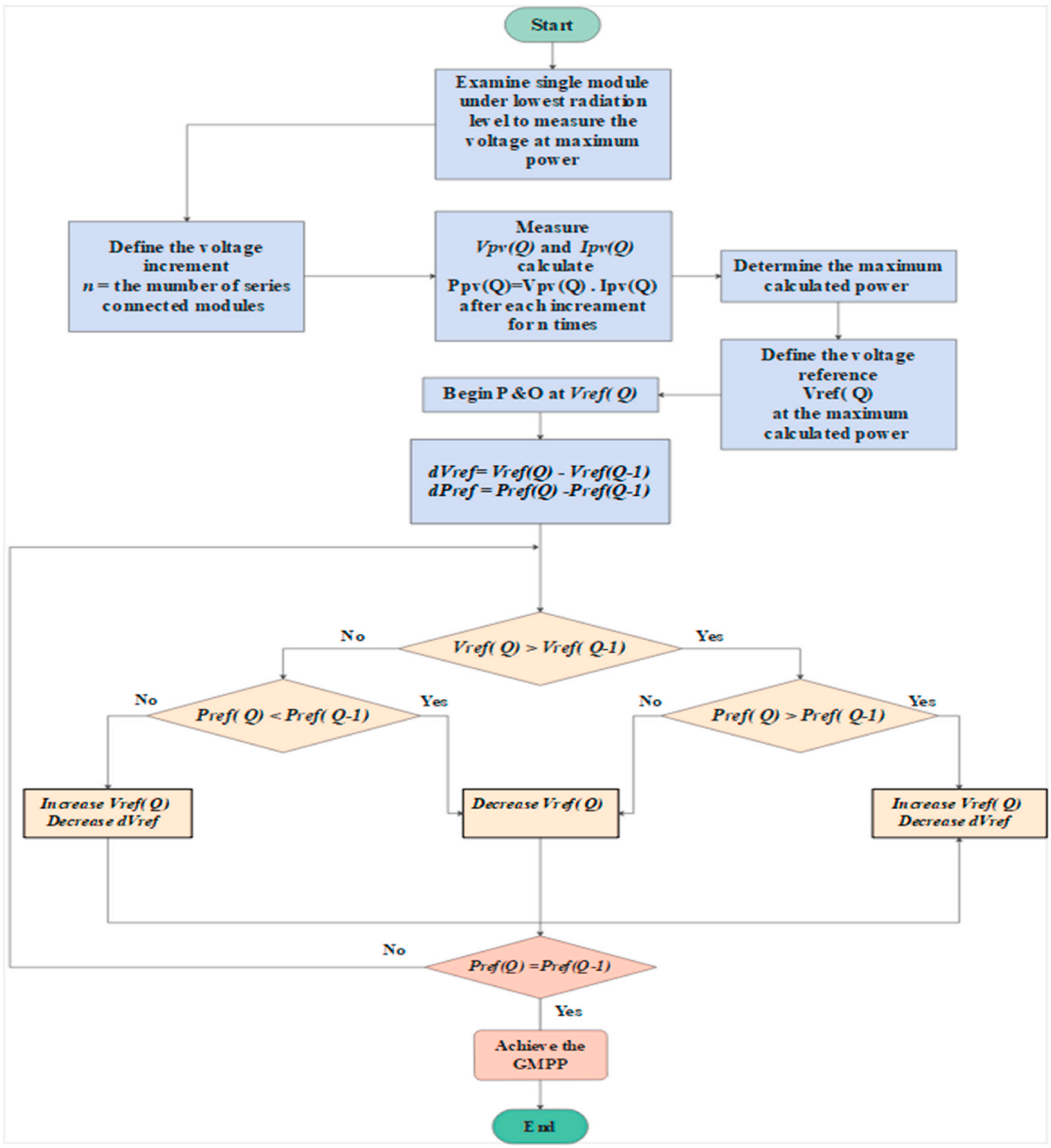


Fig. 3. General process of the proposed initialization approach for deteriorated step size P&O.

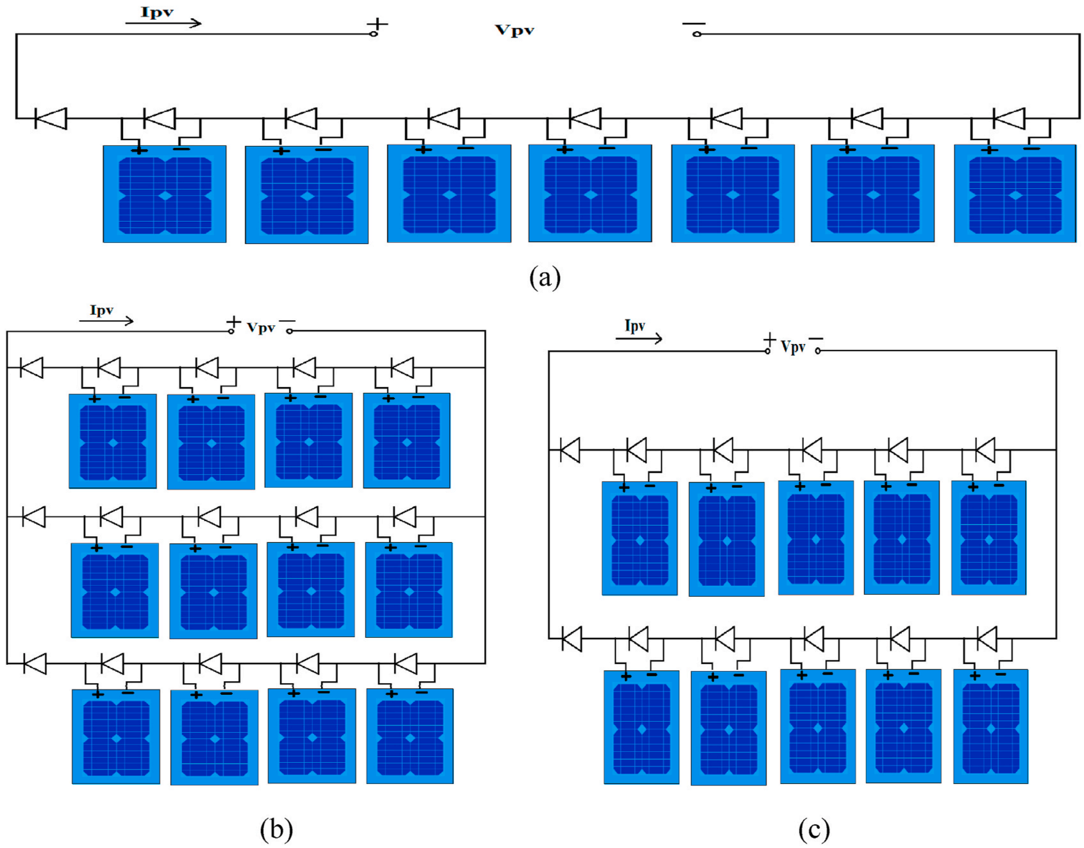


Fig. 4. Three PV array configurations. (a) 7S, (b) 4S3P, and (c) 5S2P.

whale optimization algorithm (WOA) [29], immune algorithm (IA) [30], chicken swarm optimization (CSO) [31], grasshopper optimization [32], Harris Hawk optimization [33,34], monkey king evolution (MKE) [35], cat swarm optimization (CSO) [36], bat optimization (BA) [37] and squirrel search algorithm (SSA) [38] are all new MPPT algorithms that have been lately suggested for GMPP tracking. The above-mentioned metaheuristic algorithms may often exhibit strong performance when utilized under PSC. However, they all have significant drawbacks that may affect the efficiency of PV systems. Since tracking the GMPP requires a very large population size and numerous rounds, computational complexity is inevitable. Additionally, the random searching processes can quickly cause PV systems to experience significant power fluctuations. Moreover, these techniques examine the search particle repeatedly at each iteration until the process is complete, increasing the tracking time compared to other techniques. Such significant shortcomings motivate researchers to focus more on enhancing the original conventional MPPT algorithms than on the necessity of metaheuristic MPPT or hybridization with them. An improved P&O MPPT process was suggested by Ref. [39] to boost system performance under fast-varying atmospheric conditions. The current-voltage curve is used in this technique to distinguish between changes in the operating point and changes in the environment. This method has limited responsiveness or significant steady-state oscillations caused by the use of a fixed voltage step size. The checking approach used through the P&O technique boosts tracking effectiveness under PSC, although the GMPP tracking algorithm [40] is an enhancement on that approach. In contrast, the suggested method of disruption raises in tandem with the power up until the power reaches a peak, at which time it increases even more. Significant voltage changes cause steady-state fluctuations. The MPPT can scan different regions of the I–V or PV curves by employing an adaptive P&O technique with a skipping capability that was demonstrated in Ref. [41]. It becomes faster and more accurate than conventional MPPT algorithms to track global peaks. But in order to achieve the necessary performance, the recommended approach depends on a number of basic characteristics that must be properly modified. Moreover, tracking speed changes according to the shaded pattern that is taken into account. The addition of a skipping algorithm increases the complexity of the traditional MPPT.

An enhanced adaptive step size P&O MPPT that can perform admirably under PSC was presented in Ref. [42]. By adding a series of structured comparison processes that successfully lead to the GMPP, the conventional method was enhanced. The complexity and time response of the tracking process are impacted by the additional lengthy operations. A new modification on the P&O method was recently proposed in Ref. [6], and it is capable of distinguishing the real GMPP from the other maximum peaks that may be existed when PSC is present in the P–V curve. The P&O technique uses the trapezoidal rule concept for the first time as a new factor in the tracking procedure based on splitting the P–V curve into trapezoids of equal width. The significant enhancement and success of the suggested P&O based on the trapezoidal rule algorithm have been adequately validated. However, the tracking procedure necessitates a thorough scanning of the P–V curve to recognize the trapezoid with the greatest area to extract the GMPP.

The vast majority of global MPPT strategies that have been proposed in the literature show that one aspect of performance is enhanced with the loss of the other. It is therefore extremely difficult to improve tracking algorithm performance under PSC without also increasing complexity, accuracy, and response time. This research introduces a novel concept that can address the majority of the conventional MPPT algorithms drawbacks under PSC while maintaining the simplicity of the original approach, improving tracking time, and reducing power losses. This paper proposes a novel initialization strategy for MPPT algorithms that can locate the best starting position for the tracking path. The tracking process can be initialized at the point where the GMPP becomes

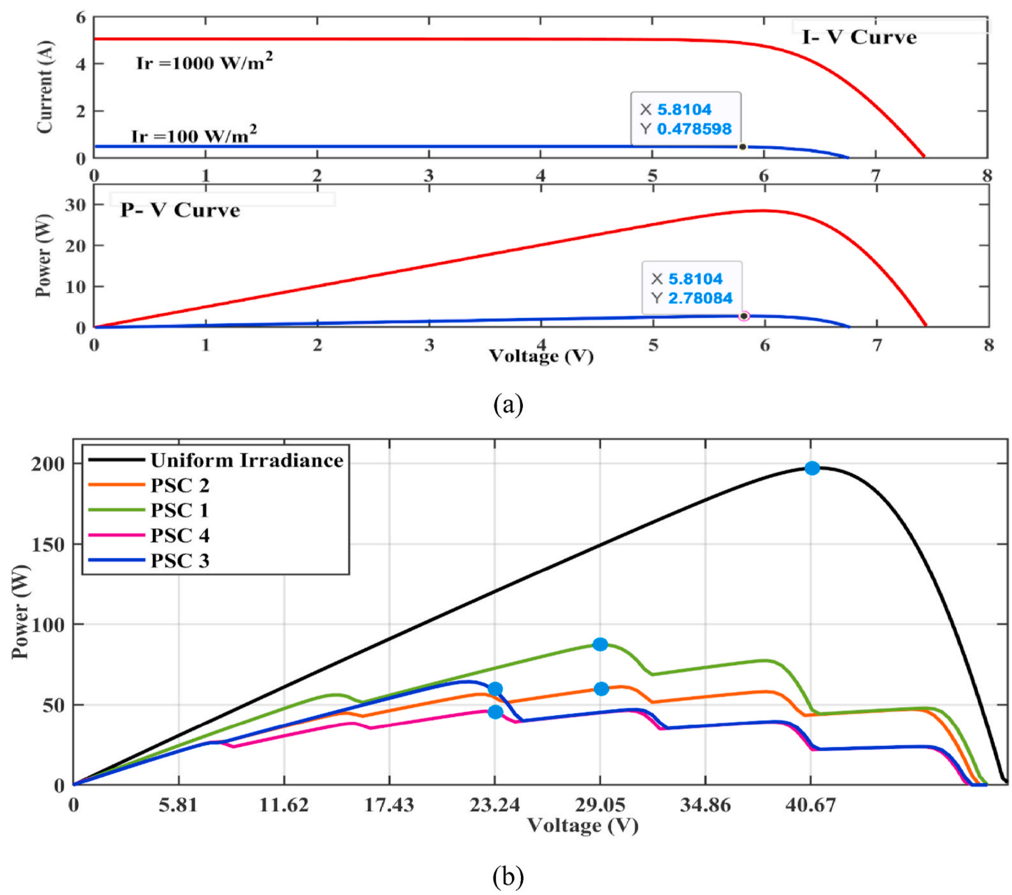
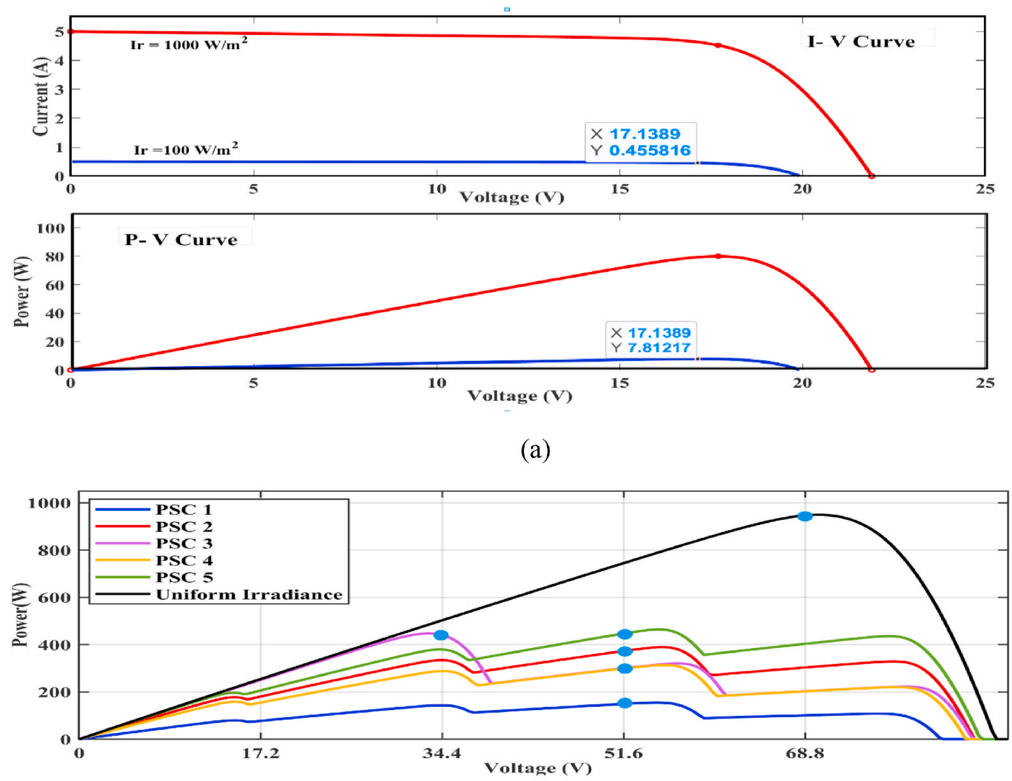


Fig. 5. Characteristic curve for 7S PV array. a) simulation results under 100 W/m^2 b) P–V curve showing the highest power under PSC levels.



(a)

(b)

Fig. 6. Characteristic curve for 4S3P PV array. a) simulation results under 100 W/m^2 b) P–V curve showing the highest power under PSC levels.

the nearest maximum peak under PSC. The proposed initialization strategy aids in employing a conventional tracking algorithm with a deteriorated step size in order to diminish the generated oscillations.

1.1. Contributions and paper organization

A new initialization strategy for conventional MPPT algorithms is presented in order to address the shortcomings of conventional MPPT. GMPP detection capability under PSC, reduced power oscillation, and increased efficiency are the improvements of the suggested approach. The performance of the proposed initialization strategy for the deteriorated step size P&O technique is compared with that of conventional P&O and IC. The implemented approach can track and successfully reach the GMPP in comparison to conventional techniques under various PSCs.

- The proposed initialization strategy can effectively enhance the conventional MPPT algorithms performance under PSC, keeping their simplicity level.
- The proposed initialization strategy diminishes the GMPP tracking path.
- The proposed initialization strategy reduces power loss.
- The implementation complexity of the proposed initialization strategy is very low.
- Comprehensive weather fluctuations have been experienced to demonstrate the high performance of the proposed initialization strategy.

The rest of this paper is structured as follows: The modeling of solar PV arrays under PSC is illustrated in Section 2. Section 3 illustrates the proposed approach development. The results, discussion, and evaluation of the simulation and experimentation are investigated in Sections 4 and 5. Finally, Section 6 summarizes the key findings and conclusions.

2. PV arrays operation under PSC

2.1. Double diode model

The double-diode model is a widely used mathematical model that represents the electrical behavior of a photovoltaic (PV) cell more accurately than the simpler single diode model. It considers the complex nature of the physical processes occurring within the PV cell, such as recombination and resistance effects. The double-diode model provides a more accurate representation of the current-voltage (I–V) characteristics of a PV cell. The double diode model is shown in Fig. 1. The double-diode consists of two diodes connected in parallel: one diode represents the recombination and resistive losses within the cell, and the other diode represents the recombination and resistive losses at the cell's junction. The model also includes a series resistance and a shunt resistance. The mathematical equations of the double-diode model are as follows:

Current equation: The total current (I) through the PV cell can be expressed as the sum of the diode currents and the shunt and series resistive losses:

$$I = I_{ph} - I_{D1} - I_{D2} - I_{Rsh} - I_{Rs} \tag{1}$$

where I_{ph} is the photocurrent generated by the incident light, I_{D1} and I_{D2} are the currents flowing through the two diodes (representing recombination and resistive losses), I_{Rsh} is the current due to the shunt resistance, and I_{Rs} is the current due to the series resistance.

Diode current equations: The diode currents can be described using the diode ideality factor (n) and the diode reverse saturation currents (I_0):

$$I_{D1} = I_{O1} * \left(\exp\left(\frac{q(V + I * R_s)}{n * k * T}\right) - 1\right) \tag{2}$$

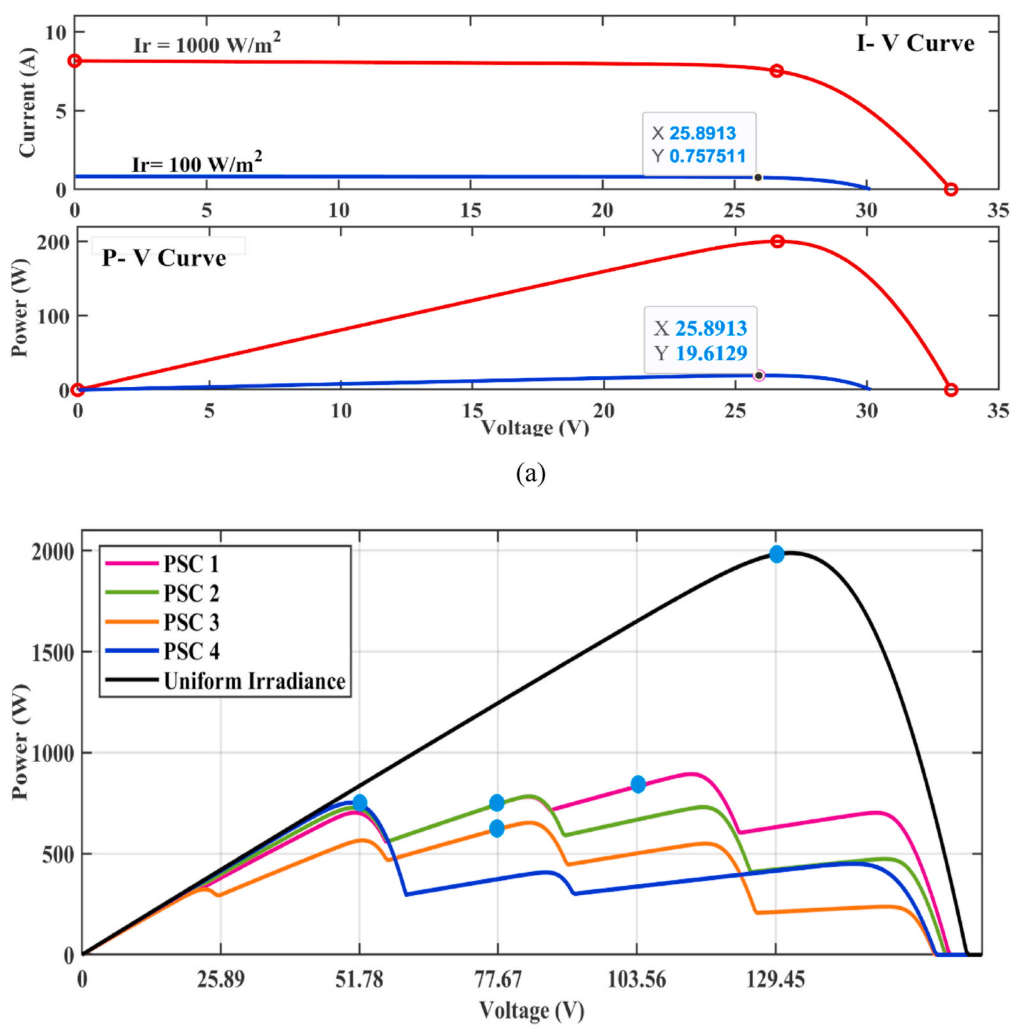


Fig. 7. Characteristic curve for 5S2P PV array. a) simulation results under 100 W/m^2 b) P–V curve showing the highest power under PSC levels.

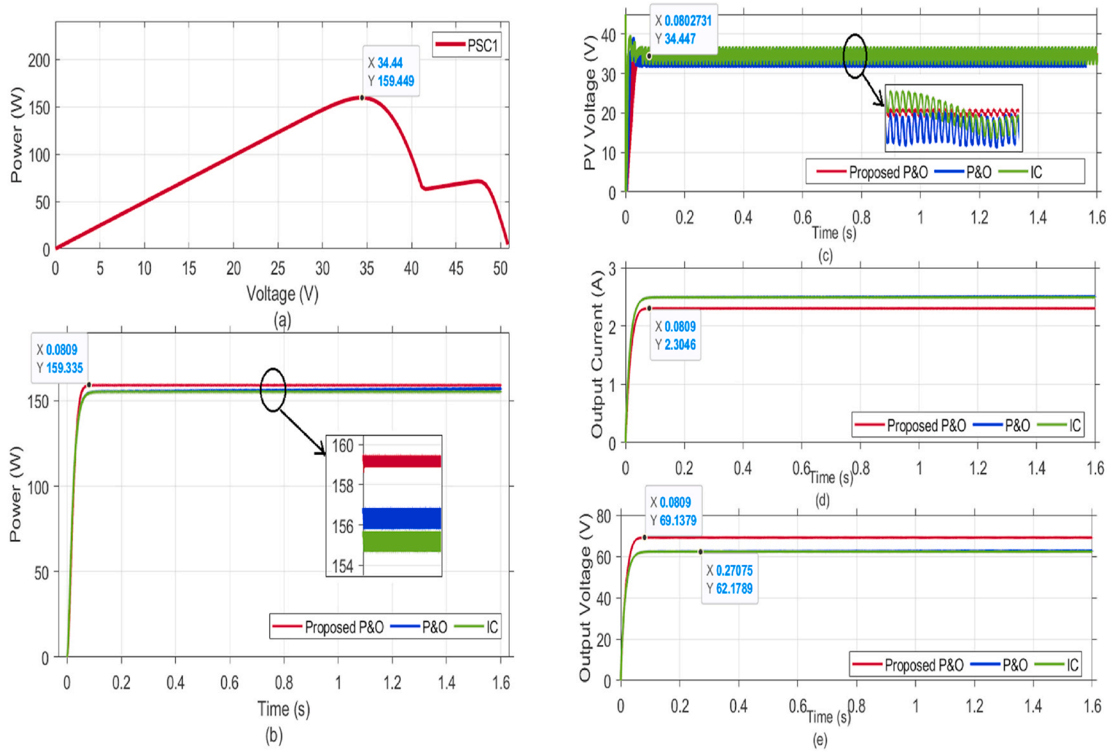


Fig. 8. Results from simulations for the weak partial shading case of PSC1.

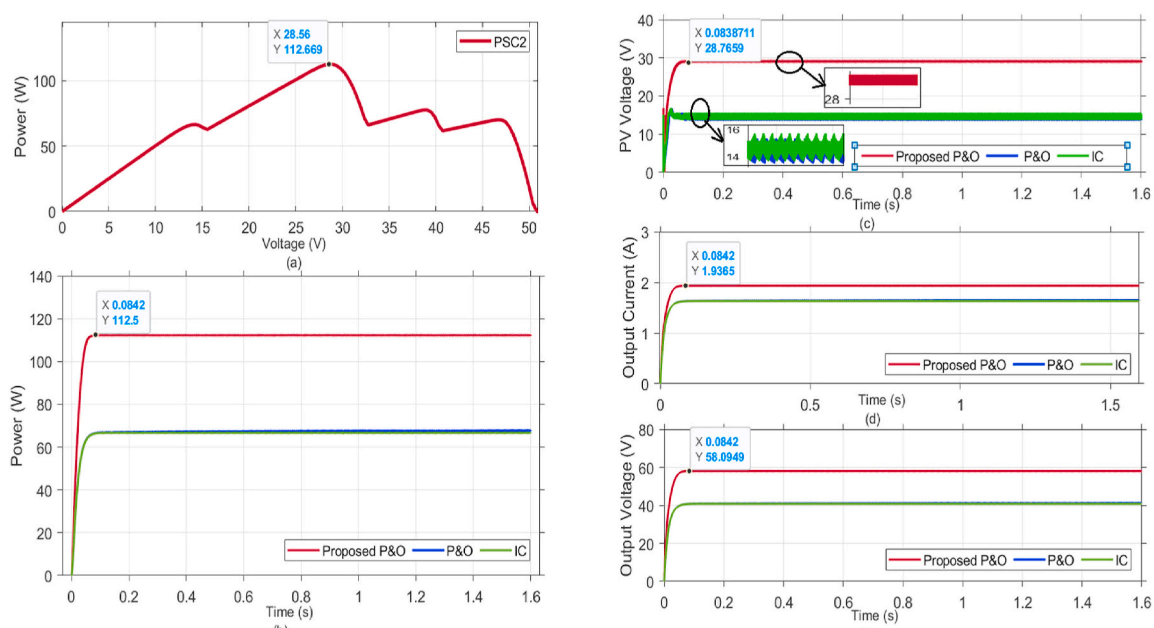


Fig. 9. Results from simulations for the moderate partial shading case of PSC2.

$$I_{D2} = I_{O2} * \left(\exp\left(\frac{q(V + I * R_s)}{n * k * T} \right) - 1 \right) \tag{3}$$

Where R_s is the series resistance, q is the elementary charge, T is the temperature in Kelvin, I is the current flowing through the PV cell, k is the Boltzmann constant, and V is the voltage across the PV cell terminals.

The characteristics of a PV array can be varied when it is fully or partially covered by clouds, tall trees, dust buildup, or nearby structures, or when one PV array casts a shadow over another in an outdoor setting [43]. This therefore causes non-uniform irradiation conditions as shown in Fig. 2. There are two primary problems with the PV panels used by PSC. First, hotspots in shaded PV panels cause power loss that can be reduced by connecting bypass diodes parallel to the shaded modules [44]. The second is current that is flowing backwards, thus each PV string is linked to blocking diodes in series to safeguard the complete PV array [45]. When bypass diodes are used, a multi-peak characteristic is produced, and the total number of irradiance levels affects how many

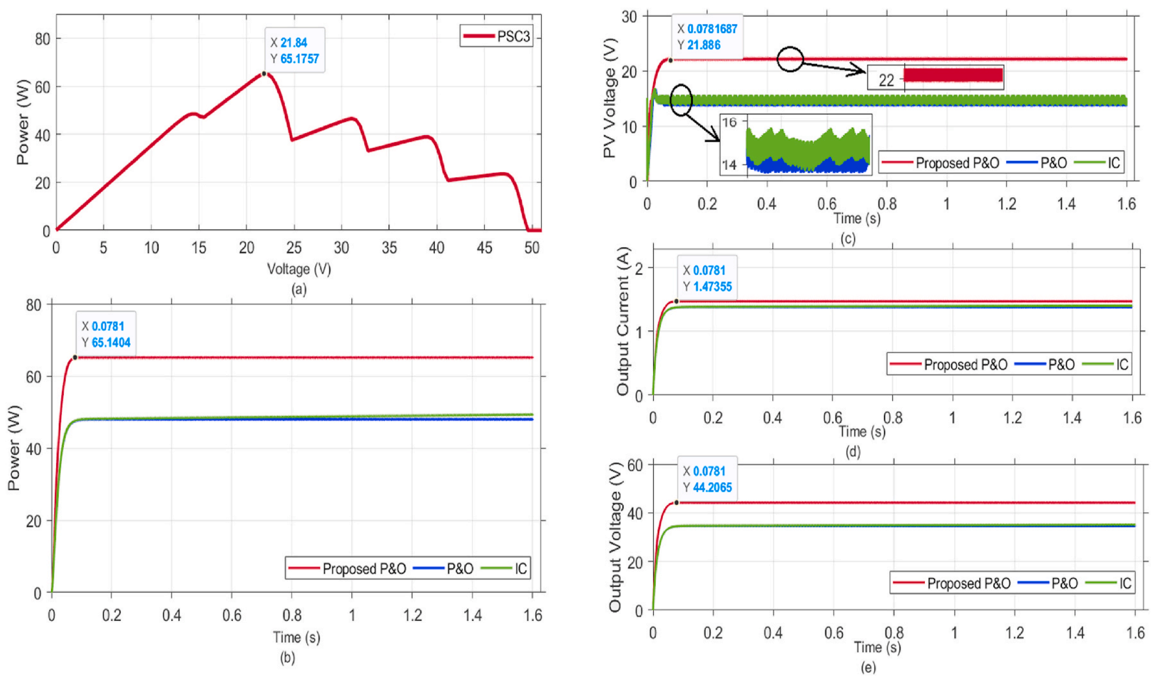


Fig. 10. Results from simulations for the strong partial shading case of PSC3.

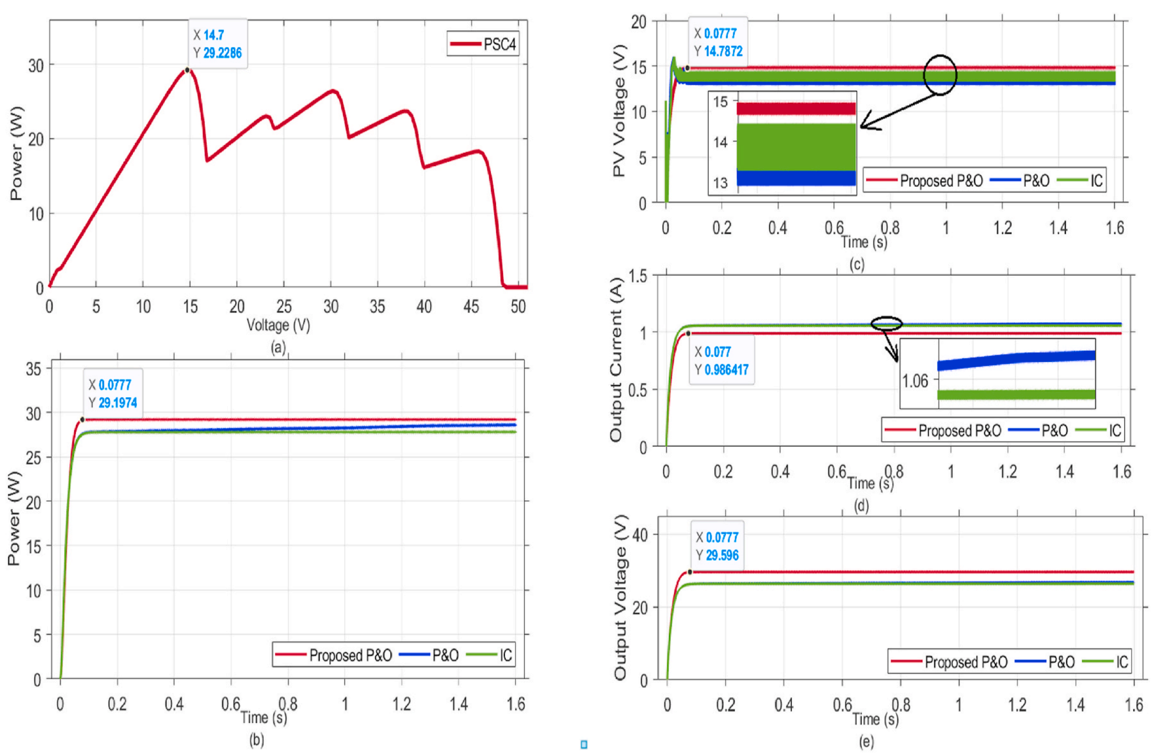


Fig. 11. Results from simulations for the strongest partial shading case of PSC4.

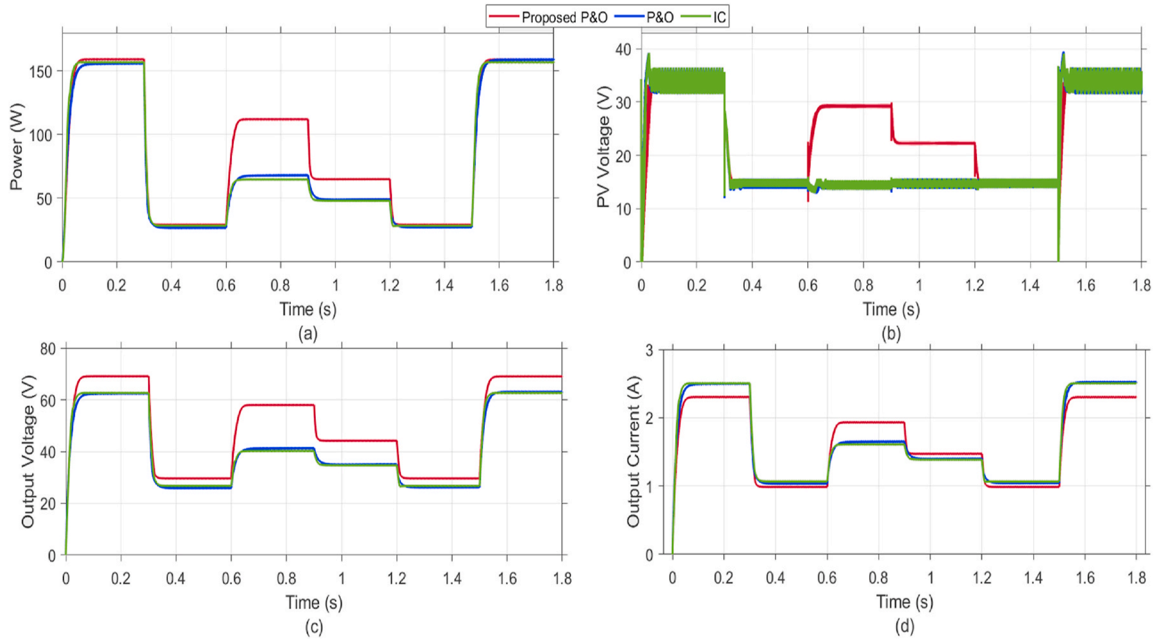


Fig. 12. Results from simulation for the changing partial shading PSC1-PSC4-PSC2-PSC3-PSC4-PSC1.

Table 1
An analysis of the proposed approach's performance under arrangement of PSC levels.

Partial shading patterns	Time period	Power at MPP	Tracking time of the proposed algorithm	Efficiency of the proposed algorithm
Weak partial shading (PSC1)	0–0.3 s	159.4 W	70 ms	100%
Strongest partial shading (PSC4)	0.3–0.6 s	29.2 W	65 ms	99.9%
Moderate partial shading (PSC2)	0.6 s–0.9 s	112.5 W	70 ms	99.9%
Strong partial shading (PSC3)	0.9 s–1.2 s	65.1 W	70 ms	99.9%
Strongest partial shading (PSC4)	1.2 s–1.5 s	29.2 W	60 ms	99.9%
Weak partial shading (PSC1)	1.5 s–1.8 s	159.3 W	70 ms	99.9%

peaks there are. The highest-power peak is known as the GMPP, while the other peaks are known as LMPPs [46]. Fig. 2(a) displays the PV array's P–V curves under the four uniform radiation levels of PV-1, PV-2, PV-3, and PV-4. Part (b) displays the corresponding I–V curves for IV-1, IV-2, IV-3, and IV-4. On the other hand, Fig. 2(c) presents the characteristic curves under the three different PSC levels of PV-1, PV-2, and PV-3 together with the matching IV curves in Part (d). A power conversion unit is required for enhancing the performance of the PV system. The boost converter is employed in this study to link the PV array with the load to control MPPT operation.

3. The proposed MPPT algorithm

This paper proposes a novel initialization strategy for MPPT algorithms. A smart start-up for the tracking process can ensure fast, accurate, and robust tracking of the highest PV array power under PSC and variable weather conditions. Consequently, there is no longer a need to modify the original algorithm or combine it with additional MPPT algorithms. To demonstrate the improvement in performance without the need to incorporate any complicated processes, the suggested initialization strategy is applied to a conventional MPPT in this study. The conventional P&O algorithm is considered because it is the simplest MPPT algorithm in terms of concept, structure, implementation, and cost. The P&O algorithm performs very well under uniform weather

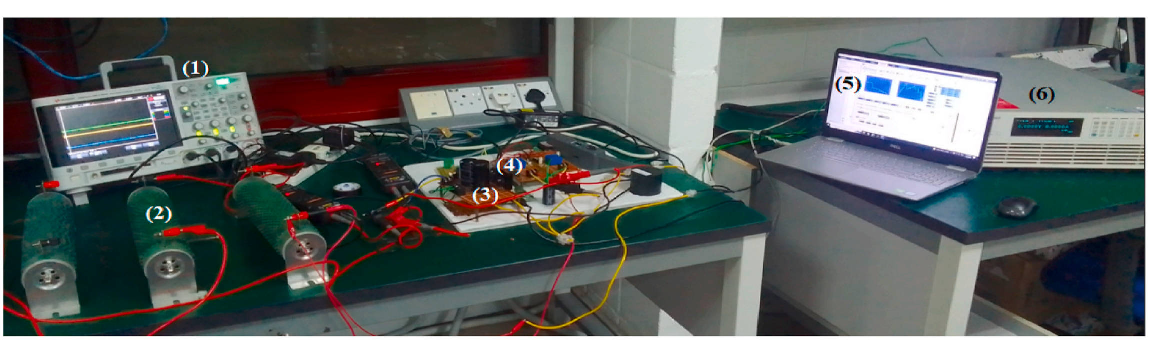
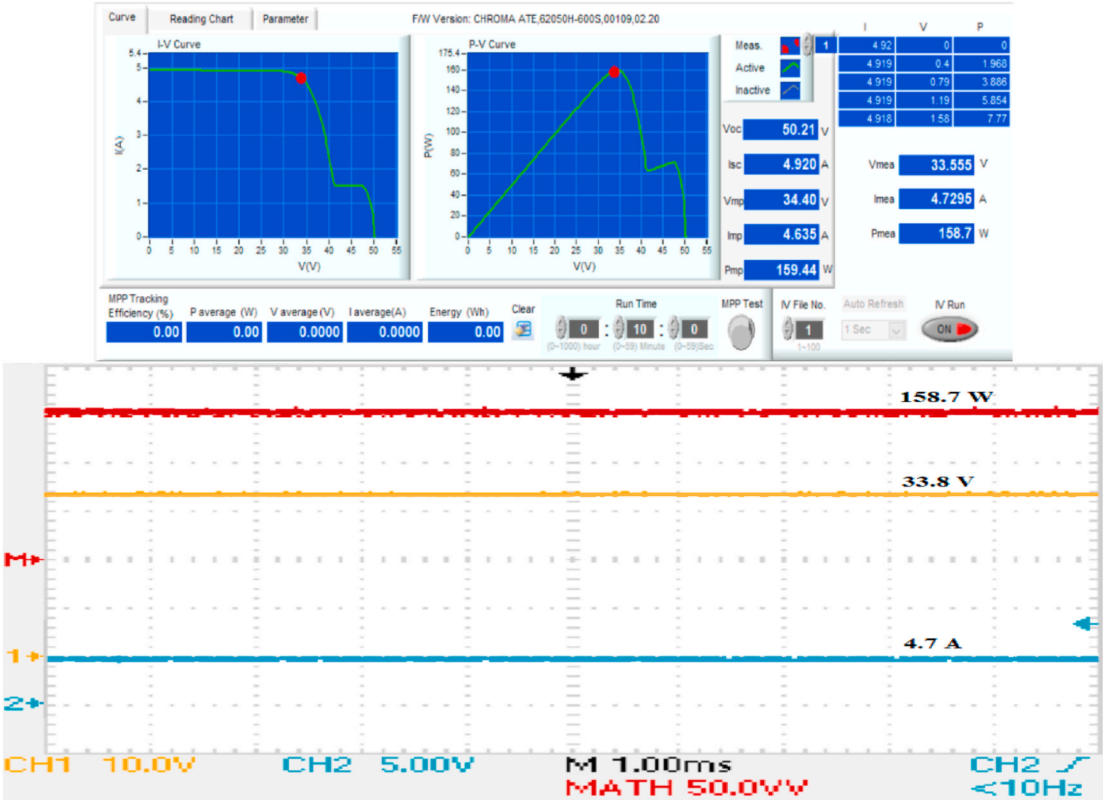
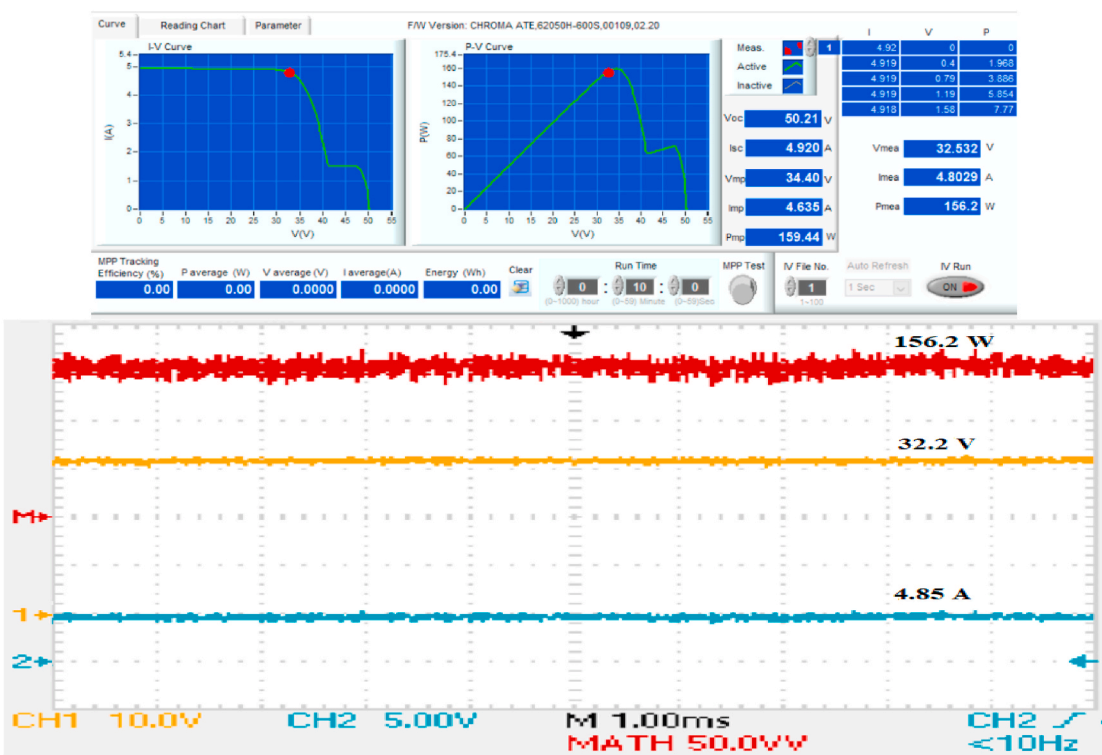


Fig. 13. Experimental setup for the proposed MPPT system. (1) Oscilloscope (2) Resistive load. (3) Boost converter (4) DSP controller TMS320F28335 (5) PC software (6) PV simulator.

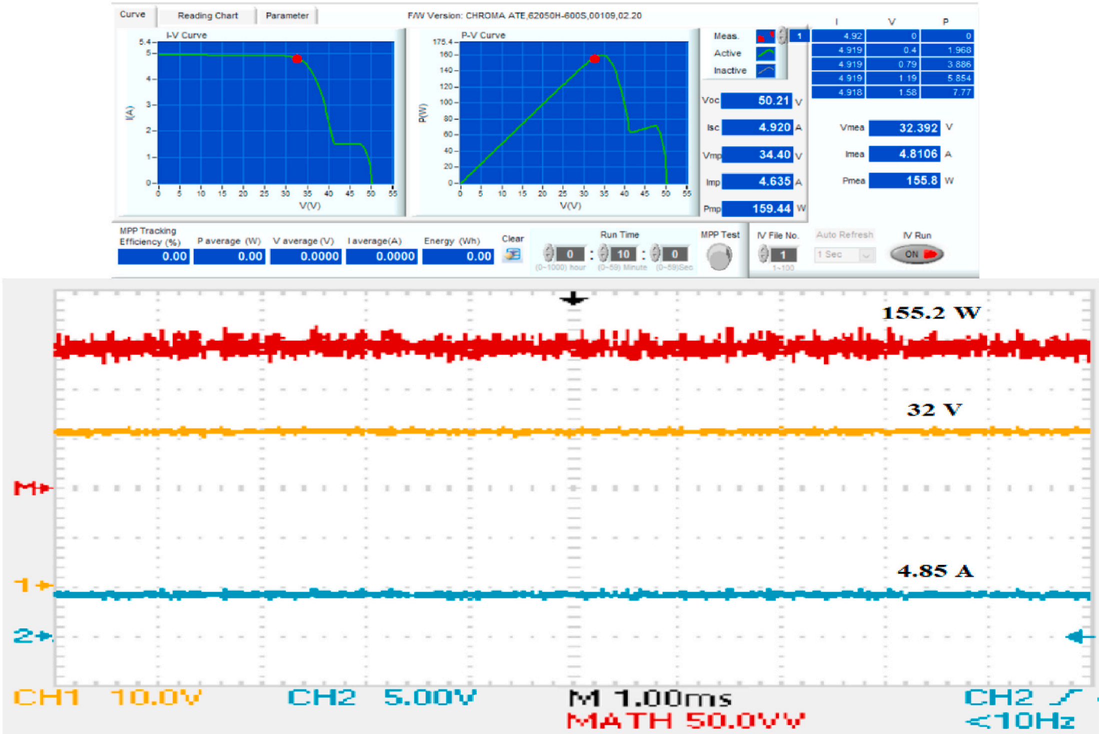


(a)



(b)

Fig. 14. Results of experiments evaluated under PSC 1 for (a) Proposed algorithm, (b) IC and (c) P&O.



(c)

Fig. 14. (*continued*).

conditions when a single MPP exists in the P–V curve, while the main drawback of this tracking process occurs under PSC when multiple MPPs are presented. The correct global MPP tracking path can obviously be missed at the nearest LMPP. The standard P&O MPPT algorithm depends on observing the output power of the array and making perturbations to the array voltage. In order to compare power to the preceding moment, it regularly changes the operating voltage. The operating point is moving on the right track toward the MPP if the power changes are positive. The perturbation's sign must be changed if the change is negative; the process is repeated for the subsequent cycle, up until the first MPP is observed. Without taking into consideration the presence of higher MPPs in the P–V curve, as under shading circumstances where several MPPs are present. Therefore, an optimal initialization can lead the simple P&O process to start just before the actual GMPP, making the highest peak the nearest MPP. On the other hand, a crucial element in regulating system performance is the perturbation step size. Faster response times but increased fluctuation around the recorded MPP are the effects of higher step sizes. On the other side, smaller step sizes lead to less power loss but slower response. In order to improve the response quality in terms of generated oscillations and tracking speed, a deteriorated step size based on the closeness between the operational power and the real MPP can be used. The proposed initialization strategy performs by lowering the step size confidently when it is truly getting close to the P–V curve's highest maximum power. Thus, the proposed novel initialization strategy for MPPT algorithms can define the best position for the P&O process to start over the P–V curve. Then, the GMPP becomes the nearest or first maximum. In addition, the step size of the applied P&O algorithm is minimized based on its proximity to the actual GMPP. Therefore, the tracking speed is improved, and the power loss can be eliminated by the proposed approach.

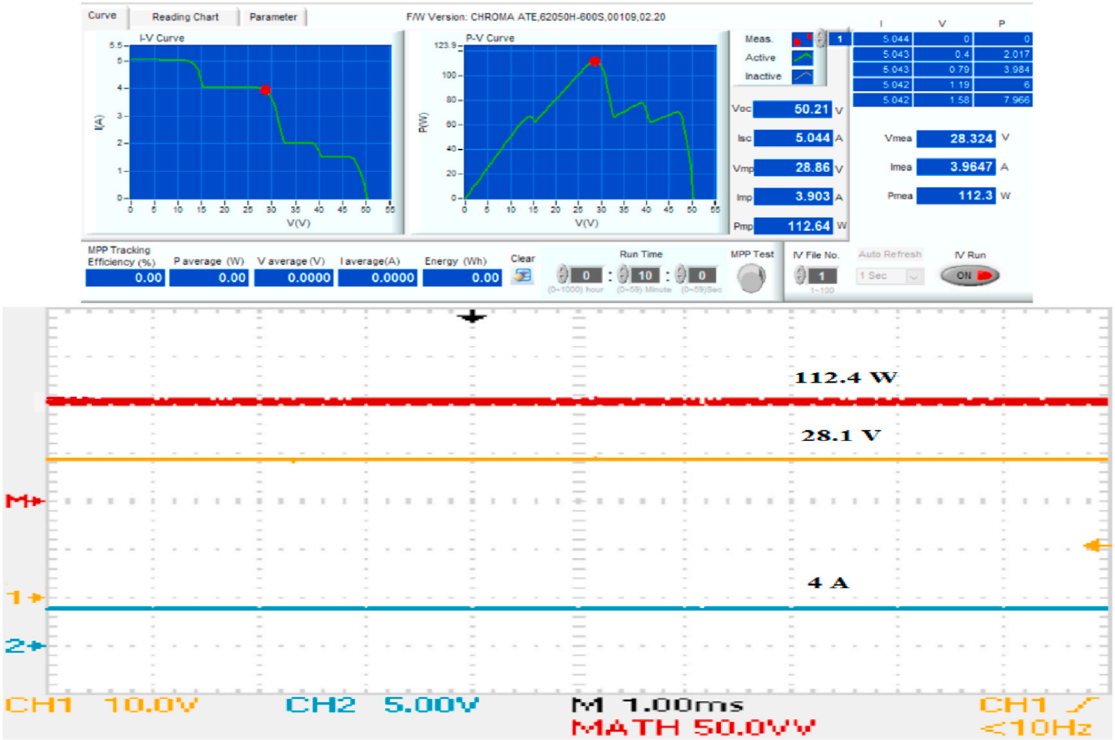
3.1. *The initialization process*

The main target of the proposed initialization procedure is to identify, among a number of distinct points, the reference voltage at the highest power. The number of these particular points corresponds to the number of series-connected modules in the PV array. In order to categorize the point positions, a single module should be tested at the lowest radiation level of 100 W/m^2. The maximum voltage at the maximum power will be the voltage difference between each of the two points. Power is determined only at these points. The voltage at the maximum power will be regarded as the optimal point to start the P&O tracking process, which is able to achieve the GMPP without the need for any modification or adding complex procedures. The tracking path becomes very short and is specified only between the optimal power point and the actual global power point, which should be close together. Fixed step sizes can be replaced with deteriorated step sizes during the required short tracking path to further improve the reduction of generated oscillations. Considering the lowest insolation confirms accurate initialization, which can guarantee the readiness of the tracking approach under the worst cases of weather, where there is no opportunity for a MPP to be detected at voltages below the maximum voltage under the lowest insolation for each module. The general process of the proposed approach is presented in Fig. 3. First, if a single module is tested under the worst case of radiation, the voltage V_{MPP} at the maximum power MPP will be the voltage increment. Consider that n is the number of series connected modules in the PV array, and then the power should be calculated for n times, at the points:

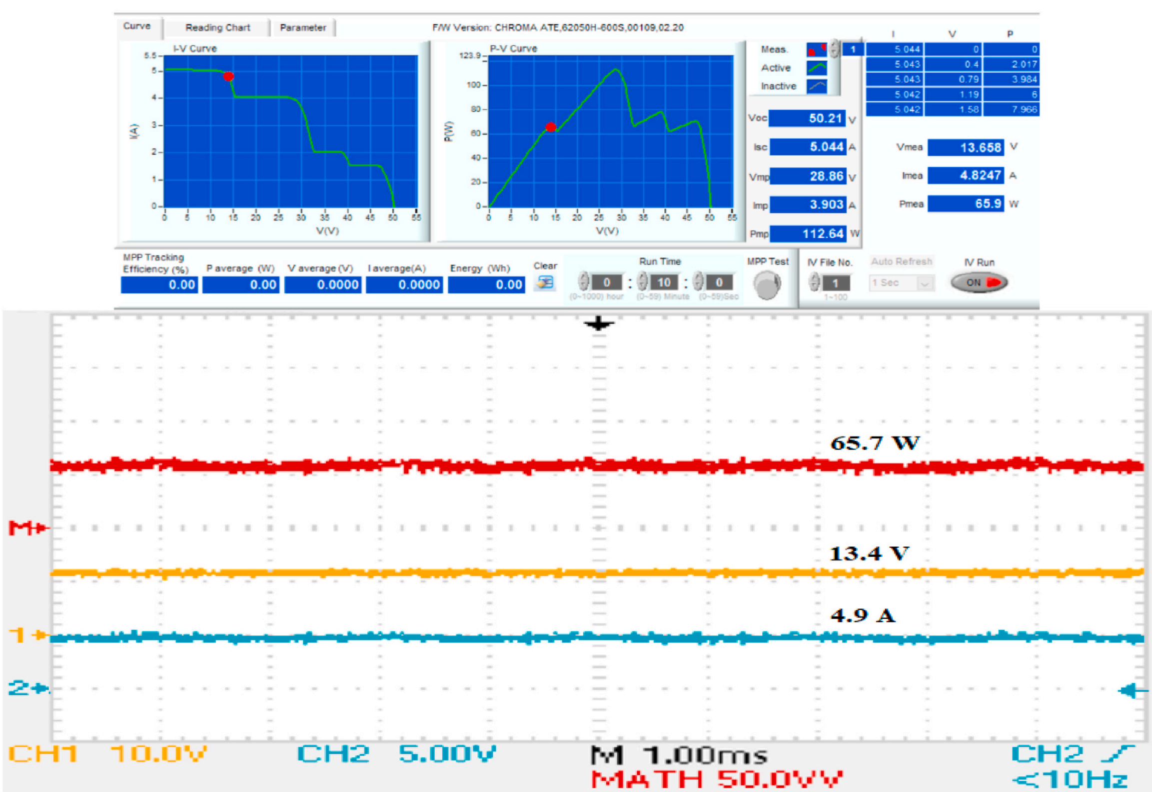
V_{MPP}, $2V_{MPP}$, $3V_{MPP}$ … …, nV_{MPP}.

The reference voltage $Vref$ at the point of highest power among the n points will be considered the optimal operating point to start the P&O tracking. This simple initialization procedure allows the uncomplicated conventional MPPT to extract the GMPP smoothly. Furthermore, the step size can be reduced confidently in the short tracking path between the Vref and the GMPP, which can significantly remove the generated oscillation around the achieved power.

In order to comprehensibly illustrate the proposed initialization

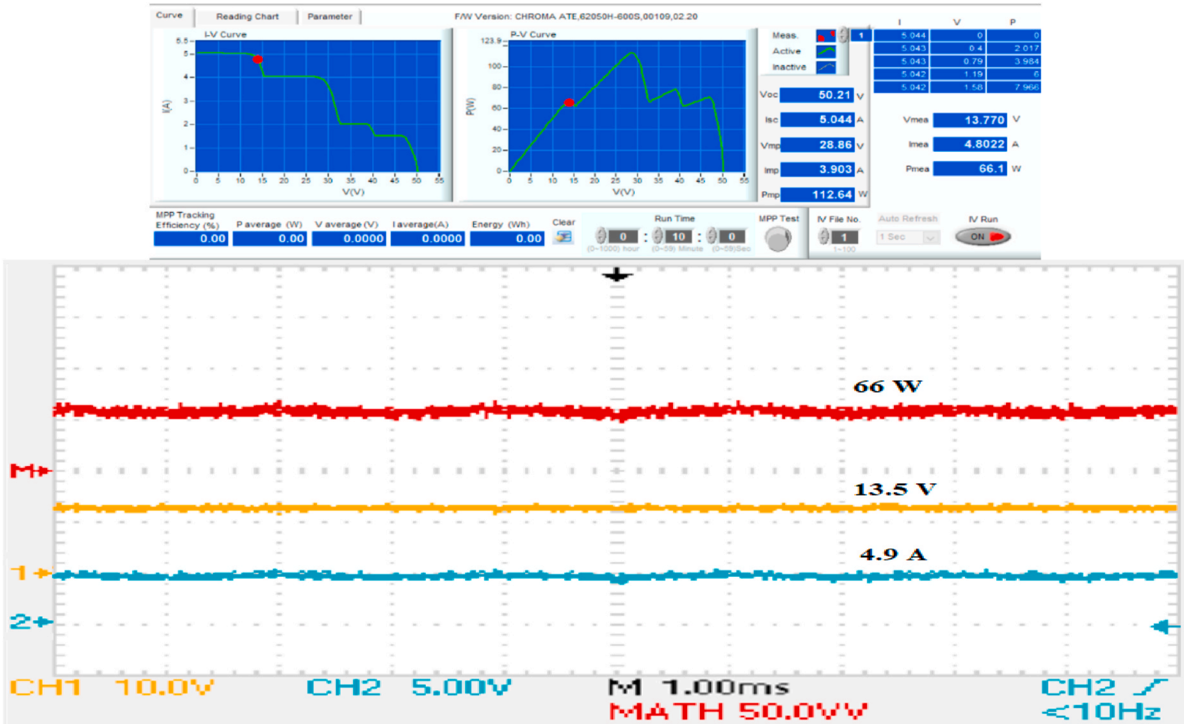


(a)



(b)

Fig. 15. Results of experiments evaluated under PSC 2 for (a) Proposed algorithm, (b) IC and (c) P&O.



(c)

Fig. 15. (*continued*).

strategy, three different PV array configurations have been investigated, and each array employs a different set of solar PV modules. The first array is the seven series modules (7S) with each one of 29 W, the second is three parallel strings of four series modules (4S3P) with each one of 80 W, and the third is two parallel strings of five series modules (5S2P) with each one of 200 W, as shown in Fig. 4.

The output characteristic of a module of 29 W under the lowest radiation is presented in Fig. 5(a). We can observe that the maximum voltage at the maximum power under 100 W/m^2 is 5.81 V, which is fixed as the voltage increment for seven times as the number of the series-connected modules. Therefore, when the 7S array experiences to any PSC pattern, the seven points to be considered are 5.81 V, 11.62 V, 17.43 V, 23.24 V, 29.05 V, 34.86 V and 40.67 V, as shown in Fig. 5(b). Under any shading pattern, the highest power among the seven points will be considered the optimal reference voltage to start the simple P&O process, where the GMPP becomes the nearest peak and can be tracked accurately.

The same procedures have been followed for the other two considered arrays. Fig. 6(a) illustrates that for the module of 80 W, the maximum voltage at the maximum power under the lowest radiation level is 17.2 V. The 4S3P array is tested under six different shading patterns, as shown in Fig. 6(b). The voltage is increased by 17.2 V four times, specifying four power point positions as the number of series-connected modules. It is evident that for each PSC pattern, the highest power among the four power points is the power that is closest to the GMPP, which confirms the efficacy of the suggested initialization method to effectively lead the tracking process to the correct GMPP. The 5S2P array can be tested with the same process. As shown in Fig. 7(a) for the 200 W module, the voltage increment for five times should be 25.8 V. The best position to begin the P&O tracking process under each PSC is at the point with the maximum power among the five, as shown in Fig. 7 (b).

In order to validate the proposed initialization process under PSC, the PV array of the 7S configuration will be considered for simulation and experimental validation. According to PSCs, the total number of modules that are connected to a series for any shading level will not exceed the number of LMPPs that can be formed [47]. To illustrate the features of more PV array configurations with seven series-connected modules, the 7S array is utilized, which could have up to seven maximum power peaks in the P–V curve, allowing the proposed initialization process performance to be demonstrated under a variety of shade arrangements and conditions.

4. Simulation results

The proposed tracking initialization strategy has been evaluated by simulation using MATLAB Simulink (version 2020b), and the solver type is ode23tb with an auto variable-step size. Various shading levels that occur on a 7S configuration are considered in order to demonstrate the effectiveness of the suggested approach to accomplishing the GMPP under any level of weather variation. Four PSC patterns with distinct GMPP positions along the P–V curves have been experienced, as well as the variation between these shading scenarios. The performance of the proposed initialization approach for deteriorated step size P&O has been compared with the performance of the two different conventional algorithms: the conventional P&O and conventional IC algorithms. The simulation results confirm the proposed approach's effectiveness, robustness and accuracy under PSC.

4.1. Four shading patterns (PSC1, PSC2, PSC3 and PSC4)

The first case of PSC1 presents a weak shading level, in which only two LMPPs exist. The GMPP is 159.4 W at a maximum voltage of 34.44 V, as shown in Fig. 8(a). Since the three examined techniques are executed under similar operational circumstances, such as the initial duty cycle, and the GMPP in this case is at the beginning, it is anticipated that the three algorithms will be capable of accomplishing the GMPP within a reasonable range. On the other hand, the proposed

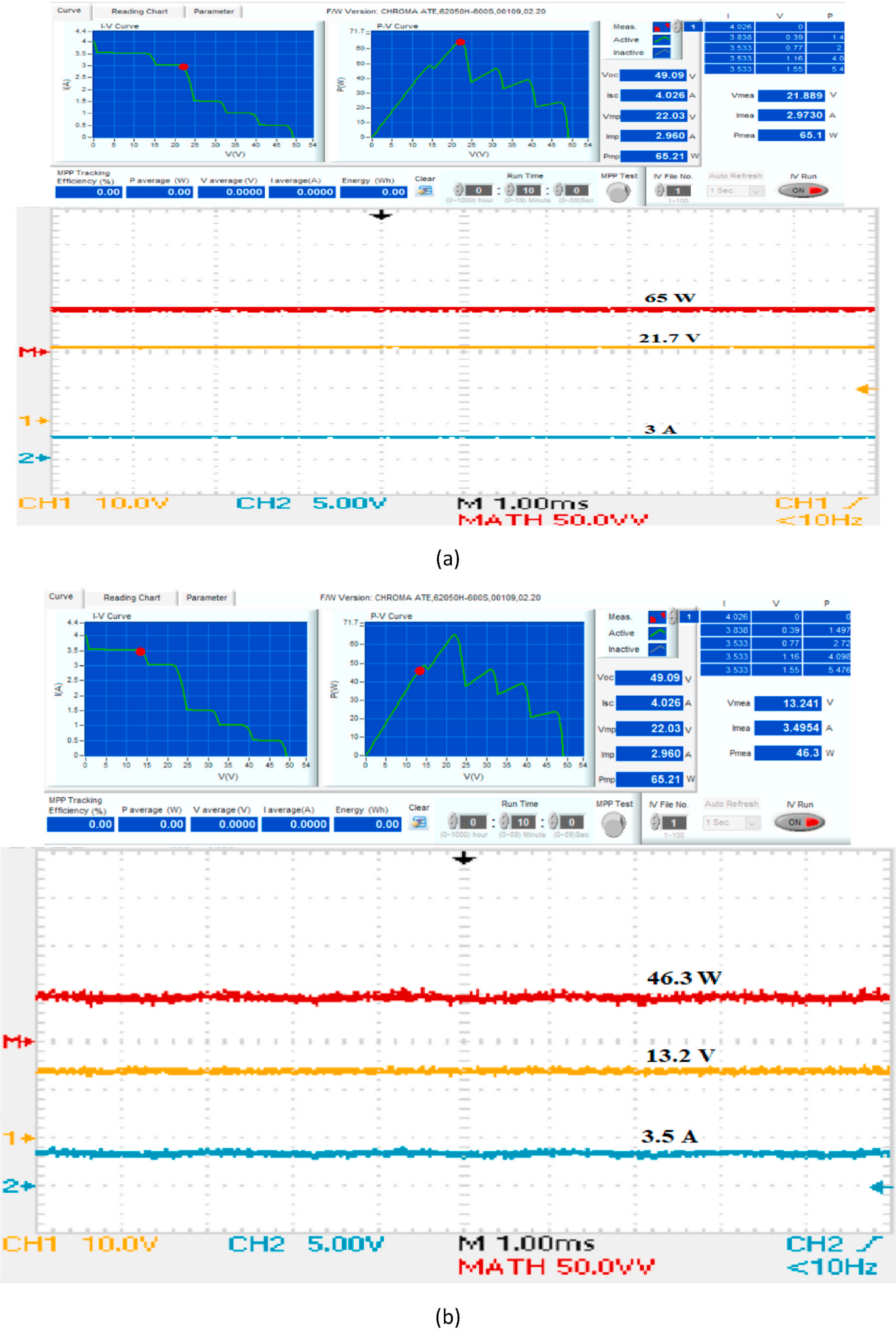
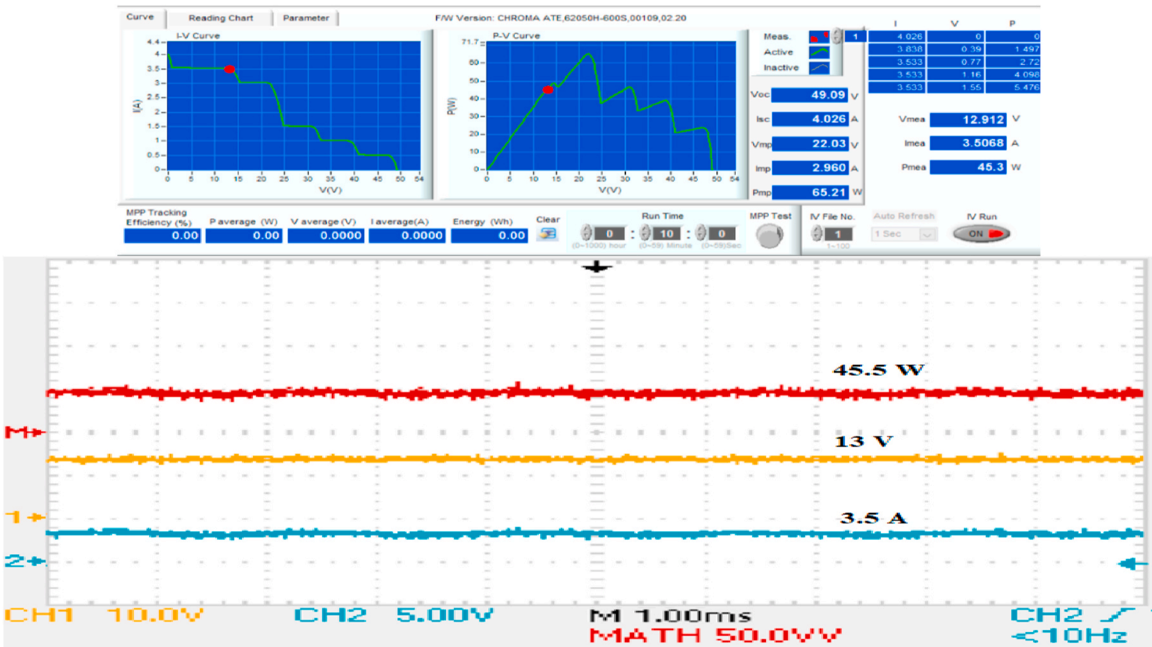


Fig. 16. Results of experiments evaluated under PSC 3 for (a) Proposed algorithm, (b) IC and (c) P&O.



(c)

Fig. 16. (*continued*).

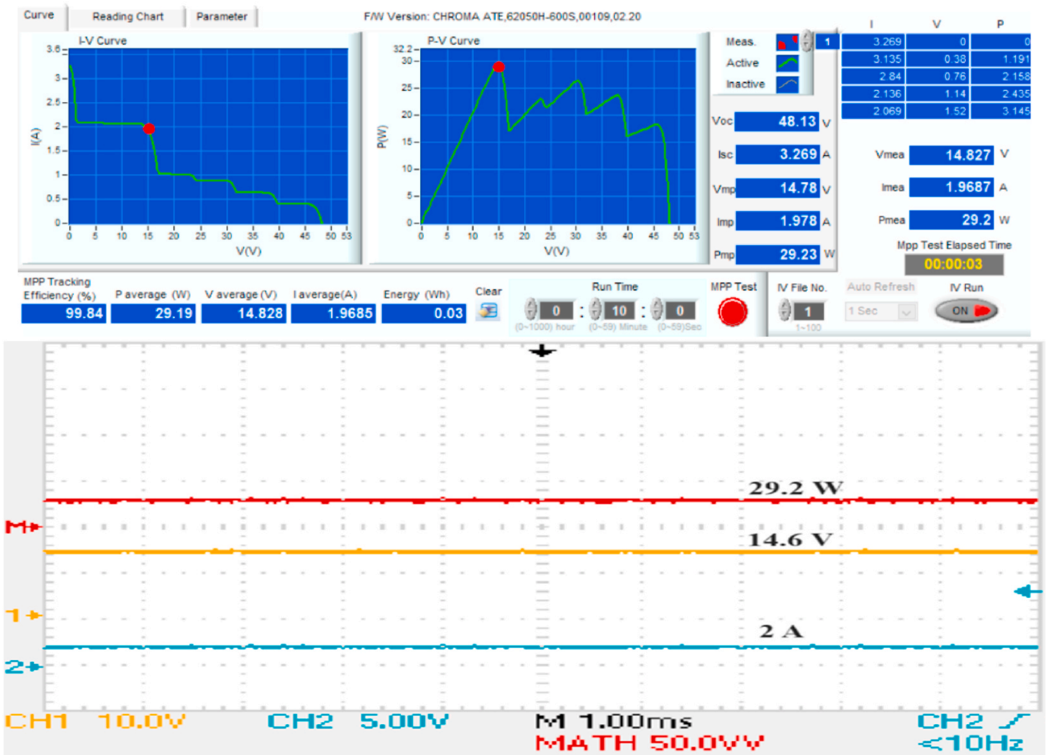
initialization process can boost the tracking performance in terms of efficiency and stability. The simulation results confirm the best performance of the proposed initialization approach for deteriorated step size P&O, which achieves the maximum power of 159.335 W at 34.44 V with an efficiency of 99.9 %, as shown in Fig. 8(b). The conventional P&O and IC algorithms are also able to achieve the GMPP, but with lower efficiency of around 97 %. The high oscillation at the generated PV voltage by both conventional algorithms is clearly eliminated by the proposed initialization approach for deteriorated step size P&O, as shown in Fig. 8(c). Fig. 8(d) and (e) present the current and voltage at the output of the used boost converter, which can confirm the effectiveness of the suggested algorithm to make accurate GMPP tracking compared with the conventional algorithms. According to Fig. 9, the GMPP among the four LMPPs for the moderate shading level of PSC2 is 112.66 W, as shown in Fig. 9(a). The simulation outcomes indicate the potency of the suggested initialization strategy. in the tracking process, accurately distinguishing the GMPP, and achieving 112.5 W at 28.7 V in 84 ms with a 99.8% efficiency. The first LMPP of 66.3 W at 14 V is where the conventional MPPT algorithms get stuck, and their efficiency is only 58.8%. The produced PV voltage stability shows the high accuracy of the suggested method and demonstrates how it can address the primary issues with the conventional P&O and IC algorithms, such as their excessive oscillations and tendency to overlook the proper tracking path under PSC.

With the strong shading level of PSC3, as shown in Fig. 10, five LMPPs are displayed. At 21.8 V, the GMPP is 65.17 W. Based on the initialization process's effectiveness, the suggested deteriorated step size P&O can produce 65.14 W at 21.8 V with a 99.95% efficiency and a time response of less than 78 ms. According to the simulation findings too, both conventional algorithms are locked at the first LMPP of 47.9 W at 14.5 V, with an efficiency of 73.5% and significantly higher oscillations produced. For the final strongest shading level of PSC4, the GMPP is situated as the first maximum as depicted in Fig. 11, which allows the conventional algorithms to obtain roughly the same results in terms of PV power but with bigger oscillations and consequently significant power losses. The proposed initialization approach for deteriorated step size P&O can precisely extract the GMPP of 29.19 W with 99.9% efficiency. Furthermore, both conventional P&O and IC algorithms were caught around the GMPP peak, which is the closest maximum peak. The efficiency for both algorithms is around 95.3%. When compared to the conventional techniques, we can see in the enlarged portions that the proposed approach is capable of obtaining a stable PV voltage with no oscillations. For further evaluation, the performance of the proposed initialization approach for deteriorated step size P&O was tested under transition between PSC patterns to approve the success of the approach under fluctuating weather circumstances. The response is verified in Fig. 12. In the first 0.3 s, the 7S array was exposed to the weak shading level of PSC1, where the GMPP is positioned at the right of the P–V curve. Then, it was suddenly exposed to the case of PSC4, where the GMPP is positioned at the extreme left, which is an intense shading situation. We can see the quick and precise reaction. The shade impact is decreased to the moderate shading level of PSC2 in the time range of 0.6–0.9 s. In such a situation, an increase in power would be from 29.19 W to 112.5 W, which is exactly the required GMPP. The system is subjected to PSC3 for 0.9–1.2 s in order to harvest the most power that is feasible at that moment, which is 65.1 W. At 1.2 s, the system is experienced again to the strongest considered shading of PSC4, then back to the weakest shading level of PSC1 during the last period of 1.5–1.8 s. A summary of the quantitative analysis is presented in Table 1.

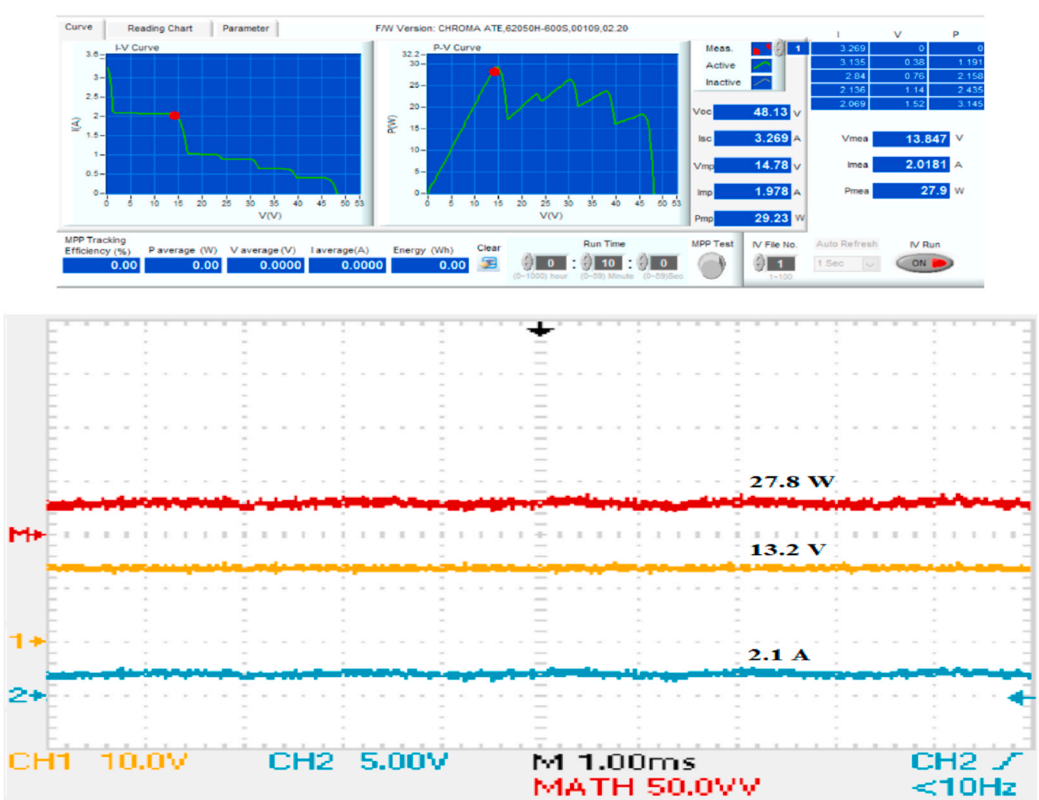
The simulation results demonstrate that the suggested initialization method for deteriorating step size P&O beats the traditional approaches in terms of efficiency, accuracy, produced PV voltage stability, and GMPP tracking under all PSC scenarios, as well as by greatly lowering oscillations.

5. Experimental results

Several experiments have been conducted based on the experimental setup shown in Fig. 13 to assess the suggested initialization strategy's performance even more for deteriorated step size P&O algorithm. In particular, the array of the 7S configuration is simulated using the Chroma Solar Array Simulator (62000H–S). This PV simulator is linked to a DC/DC boost converter, and the output of the converter is coupled to a resistive load. The DSP controller TMS320F28335 is used to execute the proposed approach.



(a)



(b)

Fig. 17. Results of experiments evaluated under PSC 4 for (a) Proposed algorithm, (b) IC and (c) P&O.

(c)

Fig. 17. (*continued*).

The experimental work uses identical PSC scenarios as were taken into account in the simulation for the 7S array. The four shading patterns of PSC1, PSC2, PSC3, and PSC4 are used to evaluate the three MPPT algorithms. Fig. 14 depicts the experimental results for the proposed deteriorated step size P&O based on the initialization process, P&O and IC under PSC1. The proposed P&O has a 99.5% efficiency and can achieve the GMPP, which is 158.7 W. The conventional P&O and IC each produce 155.8 W and 156.2 W, respectively. The proposed process clearly resolves the shortcomings of conventional techniques in terms of power loss and has a high level of stability and less oscillation associated with the achieved power. The experimental outcomes under PSC2 are shown in Fig. 15. Based on the findings, the proposed deteriorated step size P&O based on the initialization process is capable of achieving the GMPP at 112.4 W with an efficiency of 99.7%. By achieving the first LMPP, IC and P&O techniques reduced efficiency to between 58.3% and 58.6%, respectively, while blatantly failing to differentiate between LMPP and GMPP. Furthermore, the high stability of the proposed approach's performance can be observed, in addition to the low oscillations, which lead to low power losses. Meanwhile, it was evident that the conventional algorithms experienced significant oscillations.

For PSC3, the experimental results shown in Fig. 16 confirm the benefits of employing the proposed initialization approach for deteriorated step size P&O to extract the actual GMPP and reduce the generated oscillations. The proposed P&O achieves a tracked power of 65.1 W with an efficiency of 99.7%. The conventional P&O and IC algorithms achieve efficiency of 69.7 and 71%, respectively. Fig. 17 shows the PSC4 experimental results. The experimental findings are corroborated by their similar outperformance. The GMPP at 29.2 W is trackable by all three methods. This accomplishment is attributable to the GMPP's position in this situation as the first peak in the tracking bath for P&O and IC techniques. The best efficiency, however, is demonstrated by the proposed approach at 100%. However, IC and P&O lower the efficiency to 95.2–97.6%. The outcomes of the completed experimental examinations unequivocally demonstrate that the suggested initialization approach for deteriorated step size P&O algorithm effectively addresses the drawbacks of conventional techniques. The oscillations produced by the presented approach are significantly less than those produced by conventional techniques, approving the tracking process's accuracy under all shading scenarios.

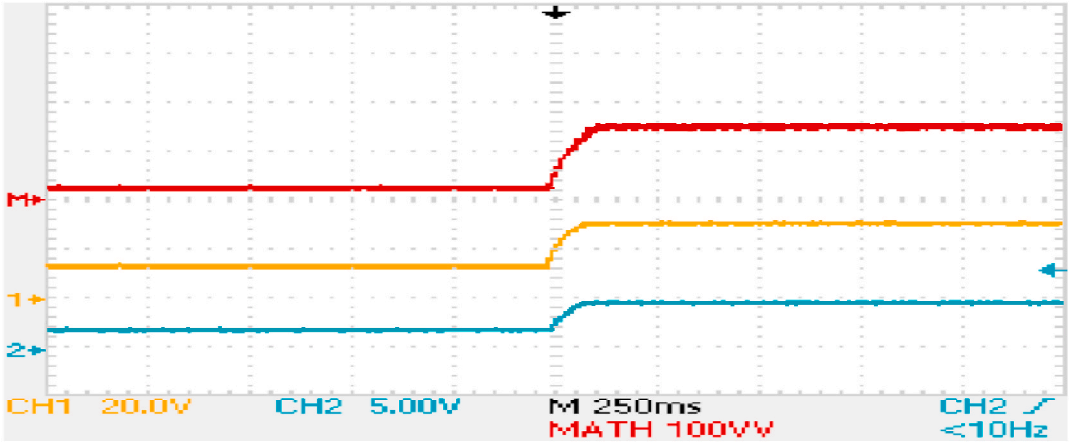
To confirm the high performance of the proposed initialization approach for deteriorated step size P&O under step-change irradiance, the last experimental test is carried out. First, the PV array is subjected to PSC4, which is the worst shading case. Then, a sudden change in radiation presents PSC1, the first case of the considered shading levels. The findings in Fig. 18 demonstrate that the proposed tracking method can successfully harness the greatest power from a PV array while offering the optimum efficiency, minimizing oscillations at PSC4 and PSC1, and responding quickly to sudden changes in incident radiation. Only by using the presented deteriorated step size P&O based on initialization procedure are all these advantages realized without complicating the existing method. The quantitative analysis of both simulation and experimental results is summarized in Table 2.

Finally, it can be observed that, despite the fact that some oscillations were seen during the experimental test, the performance and reaction outcomes of the simulation and experiment are extremely similar. Since we are constrained by the precision of the measurement instruments and in hardware implementation, some measurement disruptions are anticipated; hence, it is probable that the results from simulations and experiments will be different. This is because all experimental measurements should contain some degree of uncertainty.

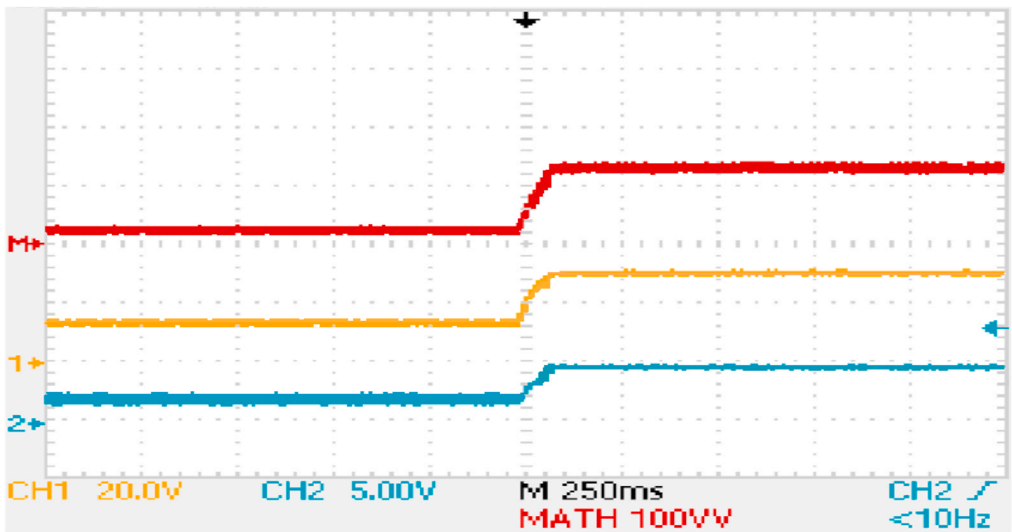
Table 3 shows a comparison of many contemporary GMPP tracking methods with the suggested algorithm based on the experimental results. Among the newly proposed GMPP tracking algorithms in the literature, the proposed tracking initialization process outperforms the others, as confirmed by the summary results.

6. Conclusion

In this paper, a novel initialization technique is proposed that is capable of locating the starting operating point of the tracking path near



(a)



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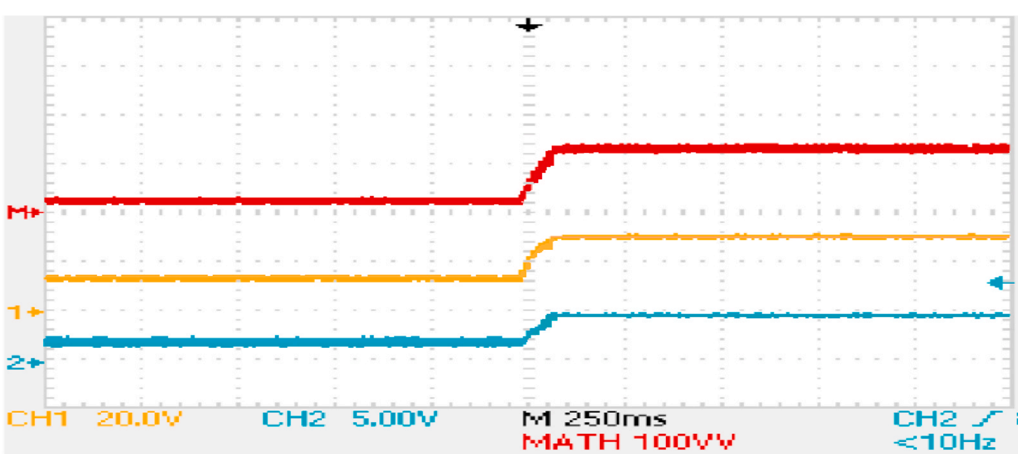

(c)

Fig. 18. Experimental results tested under step change of irradiance, from PSC 4 to PSC1 for (a) Proposed algorithm (b) P&O and (c) IC.

Table 2
Summary of the quantitative analysis of the findings of the simulation and the experiment.

Algorithm	Pattern	Actual Power at GMMP (A)	Simulation measured power (B)	Experimental measured power (C)	**Efficiency for simulation results** $(\frac{B}{A} \times 100)$	**Efficiency for experimental results** $(\frac{C}{A} \times 100)$
Proposed algorithm			159.335 W	158.7 W	99.9 %	99.5 %
IC	PSC1	159.4 W	154.8	156.2	97 %	97.9 %
P&O			156.2	155.2	97 %	97.3%
Proposed algorithm			112.5	112.4	99.8 %	99.7%
IC	PSC2	112.67 W	66.2	65.7	58.8 %	58.3%
P&O			66.4	66	58.8 %	58.6%
Proposed algorithm			65.14	65	99.9 %	99.7%
IC	PSC3	65.17 W	46.5	46.3	73.5 %	71%
P&O			46.3	45.3	73.5 %	69.7%
Proposed algorithm			29.2	29.2	99.9 %	100%
IC	PSC4	29.23 W	27.9	27.8	95.3 %	95.2%
P&O			28	28.5	95.3 %	97.6%

Table 3
Comparison of the proposed algorithm's performance with that of the recent MPPT algorithms (experimental findings).

MPPT technique	Number of existing peaks on P–V curve	DC-DC Converter	Average efficiency (%)	Steady State oscillations	Implementation complexity
The proposed approach	5 Peaks	Boost	99.7	Lowest	Low
Standard PSO [48]	3 Peaks	Boost	98.3	Moderate	High
Enhanced autonomous group PSO [48]	3 Peaks	Boost	98.6	Low	High
Hybrid Teaching-learning and artificial bee colony (TLABC) [49]	4 Peaks	Boost	96.4	Low	High
squirrel search algorithm [38]	3 Peaks	Boost	99.48	Low	High
Hybrid Levy flight and PSO [20]	4 Peaks	Boost	98.93	low	High
Overall Distribution PSO [50]	3 Peaks	Buck	98.5	Moderate	High
Adaptive extremum-seeking control [51]	2 Peaks	Boost	99.47	Moderate	High

the actual GMPP under partial shading. Consequently, global peak detection under partial shading is achievable by the simple conventional MPPT algorithms. It directly eliminates the need to modify the original algorithm, hybridize with other algorithms, or employ any complex procedures. The simplest MPPT method, the P&O algorithm, is employed to demonstrate the proposed initialization approach without the addition of any complicated processes. Moreover, a deteriorated step size P&O is used; hence, the generated oscillations are reduced to a minimal value. The proposed method was simulated and verified experimentally by using several partial shading patterns. Regardless of the GMPP's position on the P–V curve, it can track all GMPPs in all situations successfully with above 99.5 % efficiency. Under identical operating conditions, the experimental findings of the proposed initialization approach for deteriorated step size P&O are compared with those of the conventional P&O and IC techniques. The proposed technique outperformed the others without a rise in the level of complexity or the time to convergence. The primary focus of this research's future study will be to apply the proposed MPPT initialization approach to improve hybrid photovoltaic-thermoelectric generator (PV-TEG) systems' power generation performance in the face of PSC and any sudden weather fluctuations. Furthermore, this work can be expanded to implement the suggested methodology in a grid-tied PV system for optimizing the overall energy extraction process.

CRediT authorship contribution statement

Nedaa Al-Tawalbeh: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Conceptualization. **Muhammad Hamza Zafar:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Mohd Amran Mohd Radzi:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Muhammad Ammirrul Atiqi Mohd Zainuri:** Writing – review & editing, Validation, Supervision, Methodology, Investigation. **Ibrahim Al-Wesabi:** Investigation, Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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