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A new approach to solve the problem of partial shading in a photovoltaic system

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ABSTRACT

This paper introduces a novel global maximum power point (GMPP) tracking method that addresses the challenges of efficiency and power quality degradation in photovoltaic (PV) systems caused by inadequate tracking of the GMPP. The proposed approach employs a cuckoo search algorithm with proportional, integral, and derivative (CSPID). A bio-inspired optimization technique, to effectively track the GMPP under varying weather conditions. To demonstrate its effectiveness, the CSPID algorithm is comprehensively evaluated against two well-established methods, particle swarm optimization (PSO), and cuckoo search algorithm traditional (CSA). The evaluation includes three different scenarios with gradual changes in irradiance and temperature, these tests show the ability of the algorithm to handle the condition of partial shading. The results reveal that the CSPID method achieves an average tracking time of 0.098s and an average tracking efficiency of 99.62%, thereby significantly improving the efficiency and quality of photovoltaic energy production.

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1. INTRODUCTION

The growing consumption of electricity is leading to the use of dirty energy sources like conventional fossil fuels such as coal, gas and oil. Which poses a problem for the environment. This has prompted the world to look for alternative energies like renewable energy. It features prominently in most development plans, with its remarkable advantages. In the world, the most popular renewable energy source is photovoltaic (PV) solar energy, it is a renewable non-fossil source of energy that generates no harmful emissions, requires no frequent maintenance and is available worldwide [1]. It is important to note that these advantages do not come without some challenges, especially when it comes to the maximum power point tracking (MPPT) of PV systems [2]. For several years, researchers have been interested in optimising the production of solar energy based on the control of a maximum power point (MPP). To achieve this, a many approaches have been suggested,which can generally be grouped into two categories:

- Methods of conventional treatment: in general, by studying the PV properties, e.g. the perturb and observe commands [3]–[5]. The hill climbing technique [6]. Fractional open circuit voltage or short-circuit current [6], [7] and incremental conductance (IC) [8], [9].

- Methods of intelligent treatment : such as fuzzy logic controllers (FLC), neural networks [10], [11], particle swarm optimization (PSO) [12], [13] and cuckoo search algorithm traditional (CSA) [14].

But in populated areas, we find that PV panels are usually installed around buildings and trees, causing partial shading, which leads to the production of several peak powers (P-V) [15], which makes the above methods incapable of choosing global maximum power point (GMPP). This leads to a decrease in the efficiency and, quality of the energy produced. For this several research has investigated the effect of partial shading conditions (PSC) on the performance of PV systems, and found that PSC causes significant reductions in system efficiency of up to 70% in conventional MPPT systems [16]. Thus, to overcome this PSC problem, more sophisticated trackers must be designed. In recent years, researchers from various countries have proposed various advanced MPPT algorithms to resolve the GMPP tracking problem under PSC namely: the design of a FLC to optimise the operation of MPPT using a genetic algorithm (GA) [17], the proposal of the PSO algorithm to efficiently perform the GMPP tracking [18] and artificial intelligence (AI) techniques [19]. The purpose of our article is to optimize the performance of a PV system under PSC. For this, we are used a traditional cuckoo search algorithm with a proportional, integral, and derivative (CSPID) to track the GMPP in a PV system. The new technique proposed using a mix of the traditional cuckoo search algorithm and the proportional, integral, and derivative (PID). The structure of this work is organized as: section 2 reviews the related work, covering PV system modules in different weather conditions and the basic MPPT algorithms PSO and CSA. Section 3 introduces our proposed GMPP tracking method. Section 4 presents diverse simulations and quantitative studies. Finally, the paper concludes with our findings and conclusions.

2. RELATED WORK

2.1. PV system modelling irradiated uniformly

PV cells are the basic units of PV systems, in order to generate electricity, they transform solar energy, the power of which is very low. PV modules are formed by PV cells connected in parallel and in series for electrical applications. For this reason, most electrical applications require high power. A number of factors influence the performance of these PV modules, including weather conditions, the nature of the connected load, trees, clouds or even buildings can play a role in the occurrence of the PSC phenomenon. Modelling a PV system is therefore a fairly complex process. A single diode model [20] was chosen to model the PV cell Figure 1.

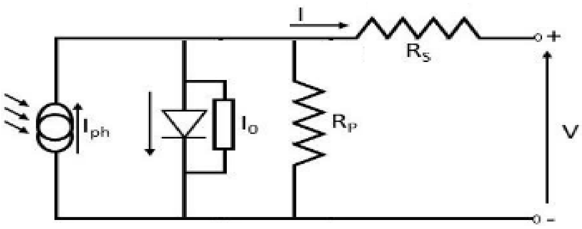


Figure 1. A PV cell with one diode model

The (1) and (2) [20] show the characteristics of I(V) from Figure 1;

$$I = I_{ph} - I_{S0}.\left(e^{\frac{V+IR_S}{\alpha V_T}} - 1\right) - \frac{V+IR_S}{R_P} \tag{1}$$

$$V_T = \frac{K.T}{q} \tag{2}$$

where, α is an ideality factor, I_{S0} Indicates the inverse saturation current, RP is the parallel resistance and RS is the series resistance. Arranged the number of cells in parallel (NP_{cel}) and the number of cells in series (NS_{cel}) and from (1) we can deduce the photovoltaic module characteristic (composed of $NS_{cel} \times NP_{cel}$ PV cells) Figure 2.

The characteristic I-V of a PV array fabricated NS×NP PV modules are described by (3) [21]. Formed by arranged in parallel and series PV arrays;

$$I = N_P\left(I_{ph} - I_{SO}\left(e^{\frac{V+IR_S}{\alpha V_T N_S}} - 1\right) - \left(\frac{V+IR_S}{N_S.R_P}\right)\right) \tag{3}$$

in (3) shows that the characteristic curves of a PV array are strongly influenced by irradiation and temperature, explaining the non-linearity of the PV's charactericric curves.

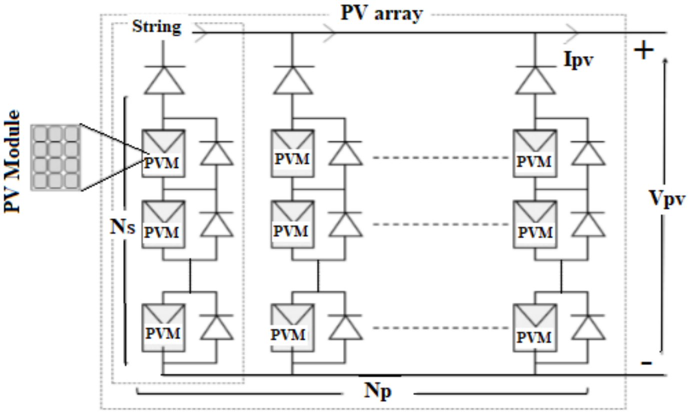


Figure 2. PV module under uniform irradiation

2.2. PV system modelling under PSC

Solar cells are normally installed in series to make PV modules. Figure 3 shows that PV cells in the shaded part of a PV module receive less light intensity than those in average light conditions. A shaded PV cell will be reverse biased when it receives more current than it produces, resulting in a negative voltage. As a result, the energy of the unshaded cells is consumed by the shaded cells in series, and this energy dissipates as heat, creating a hot spot phenomenon that damages the shaded cells. A bypass diode is branched in parallel on one side of the PV cell to avoid this, and an isolation diode is connected to the bypass port in series to prevent the reverse current at night and the potential difference in the grid from damaging the PV cell. Due to these diodes, high currents generated by the non-shaded cells will find an additional pathway, resulting in a reduced threat of hot spots [22], [23].

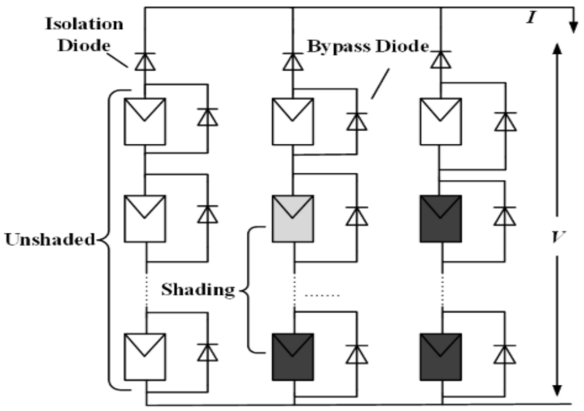
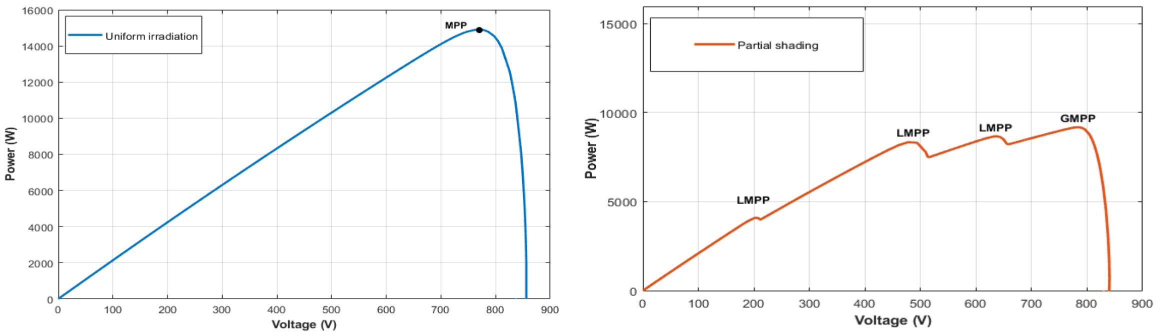


Figure 3. Photovoltaic module under PSC

Figure 4 shows the direct connection between a load and a PV system, such as in PV cells, there is only one maximum peak in the power curve, MPP under uniform irradiation conditions Figure 4(a). However, PV systems under PSC with bypass diodes receive different irradiance and their P-V curves have multiple peaks Figure 4(b). This is due to the use of bypass diodes, in which the number of multiple peaks depends on the number of different solar radiation cells. The maximum values vary depending on the number of irradiation levels. The GMPP is considered the peak corresponding to the highest power, while the other is considered the peak corresponding to the lowest power the local maximum power point (LMPP). Figure 4(b) shows the P-V curve of photovoltaic modules under partial shading conditions.



(a) (b)

Figure 4. Direct connection between a load a PV system (a) under uniform irradiation and (b) under PSC

Figure 4(a) illustrates the simulation results of a direct PV system under uniform irradiation, exhibiting a single MPP. On the other hand, Figure 4(b) shows the PV system under PSC, where multiple peaks are observed. Among these peaks, the highest one is referred to as the GMPP, while the others are referred to as LMPP.

2.3. Basics algorithm for MPPT

In this study, we present a simple study of two methods: the PSO and the CSA algorithms. The main objective of this analysis is to clarify and better understand the inherent strengths and weaknesses of the two methods. By examining these two optimization techniques in order to compare them with our proposal.

2.3.1. Particle swarm optimization

MPPT has recently been implemented with PSO [24], [25]. In iterative optimization, the measure of quality is given by the improvement of a candidate solution. A simple mathematical formula exploits the position and velocity of these particles to move around in the search space. Based on the best-known positions in the search space and on its own best position, each particle is guided by the best position of its neighbors.

2.3.2. Cuckoo search algorithm traditional

Yang and Deb [26] Yang and Deb propose three rules based on the parasitism of cuckoo behavior: i) at time. A cuckoo lays one egg and places it in a randomly selected nest; ii) the best nest with the best egg quality will be passed on to the next generation; and iii) a fixed number of nests are available and a fixed probability Pa is maintained by the host bird in discovering eggs, where 0<Pa<1. Cuckoo eggs can be destroyed or abandoned by the host bird. A new nest with a probability of Pa will be generated if the cuckoo's eggs are discovered. Figure 5 summarizes the CSA based on these three rules [27].

The Figure 5 illustrates the guidelines used for the implementation of the conventional CSA in MPPT. These guidelines serve as a framework to guide the behavior of the algorithm and help achieve efficient and accurate tracking of the MPP in PV systems. By following these guidelines, we can better understand and use this MPPT search algorithm.

```
Begin
Objective function;
Generate initial population of n host nest;
While (t<Max generation or stop criterion)
        Get a cuckoo randomly by levy flight
            Evaluate its quality/fitness,
        Choose a nest among n (say, j) randomly
        If ()
            Replace j by the new solution
        End
      A fraction (Pa) of worst nest occurs;
          Worst nests are abandoned and new nests are built;
      Keep the best solutions;
      Rank the solutions and find the current bests;
End while
Post process of results and visualization;
End
```

Figure 5. Pseudo-code for cuckoo search algorithms for MPPT

3. PROPOSED METHOD

The primary objective of this research paper is to develop a PV system capable of accurately tracking the GMPP. The proposed approach incorporates a novel combination of the CSA algorithm and PID control (CSPID) to achieve the task of tracking the GMPP. The complete simulation model includes the three sub-model CSA, PSO and CSPID are implemented in MATLAB/SIMULINK is shown in Figure 6. Each sub-model in our study consists of four essential blocks, namely: i) PV Array Modules: we are using "Aavid Solar ASMS-165P PV Module" types, where each module includes 4 PV cells connected in series and 4 connected in parallel; ii) DC/DC boost converter: this block comprises an inductor, diode, and MOSFET transistor; iii) the load as resistance; and iv) MPPT controller, this block is a critical part of our studies, and we have implemented three different algorithms for MPPT namely CSA Algorithm, PSO algorithm and CSPID algorithm. The MPPT controller is responsible for regulating the output power of the PV array effectively. The optimized power output is then transmitted to the load. The parameter the converter is output capacitance (Cout)=60 uF, input capacitance (Cin)=10 uF, inductor value (L)=1 mH, input voltage (Vin)=10 V, and switching frequency (fs)=50 kHz.

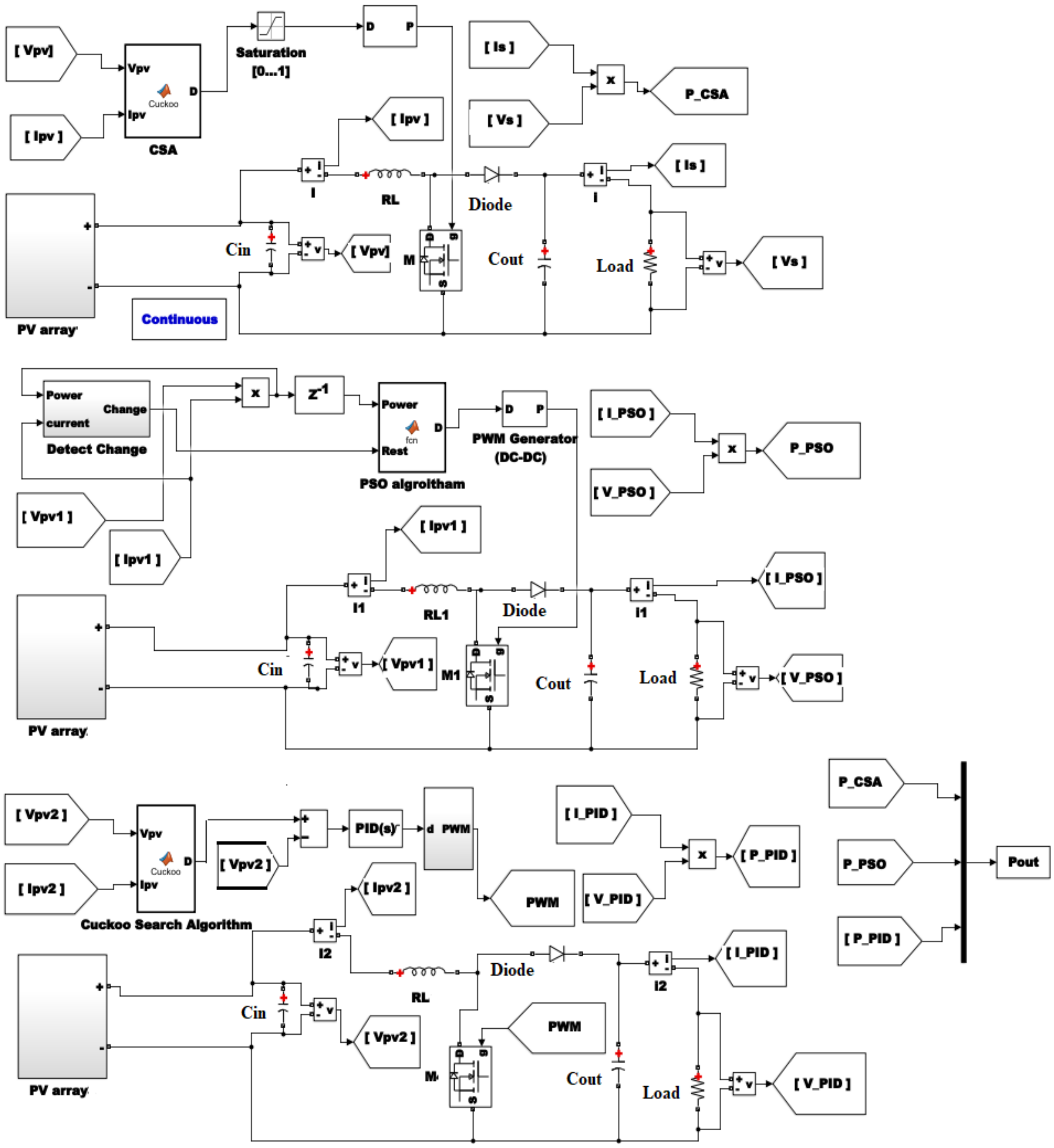


Figure 6. The complete model simulation

4. RESULTS AND DISCUSSION

To verify the performance of our system, and more specifically the block of CSPID for MPPT Figure 6, we carried out three different simulations under MATLAB/SIMULINK platform for partial shading conditions, namely PSC1, PSC2 and PSC3. For each simulation PSC, the solar panels receive five different irradiation Figure 7 and Table 1. To do this, we divide this section into two steps.

4.1. Step 1

In Figure 7, we present the results of simulations illustrating a direct connection between the solar panels and the load (without control). The simulations are carried out for three different cases of partial shading. The data used to generate these results comes from Table 1. From the analysis of Table 1 and Figure 7, it is evident that each PSC yields a distinct curve. These curves exhibit four peaks in total-one being the global maximum and the remaining three being local peaks. Furthermore, the position of the global maximum peak varies for each curve, appearing either on the left, right, or in the middle. This diversity in peak positions poses a challenge for numerous algorithms in accurately selecting the global maximum peak for each curve, which in turn determines the optimal maximum power. Addressing this challenge forms the core of our proposed solution.

Table 1. Different radiation scenarios for the simulation

Case	DATA					RESULTS (Figure 7)		
	Radiation intensity (W/m^2)					Power at GMPP (W)	Voltage at GMPP(V)	Location of GMPP
	PV Module 1	PV Module 2	PV Module 3	PV Module 4	PV Module 5			
1-PSC1	900	900	600	600	700	8106.9	787.64	Right
2-PSC2	700	700	500	500	300	5490.62	456.66	Middle
3-PSC3	800	800	200	200	100	4268.64	356.62	left

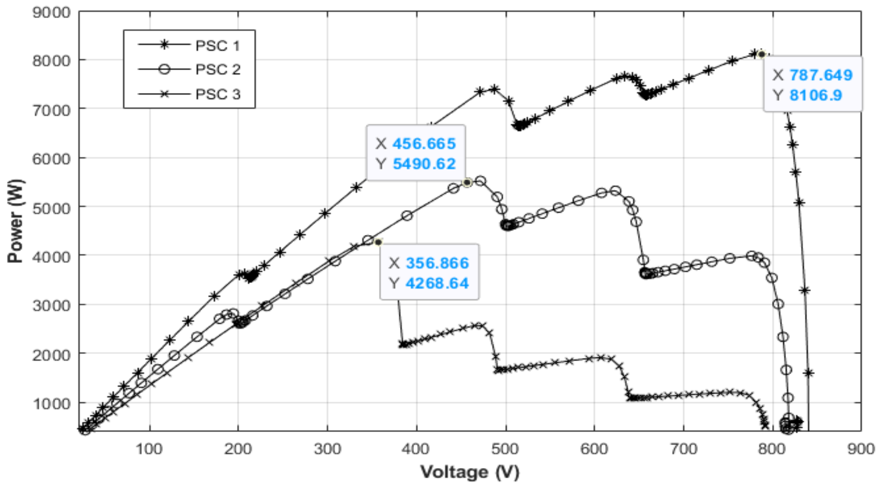


Figure 7. Direct connection between a load and a PV generator for three cases

4.2. Step 2

In this phase, we aim to demonstrate the efficacy of our proposal. To achieve this, we conduct a comparative analysis of the simulation outcomes for the PV model system. Specifically, we evaluate the performance of our proposed CSPID against two alternative algorithms, namely PSO and CSA, in three different partial shading cases (PSC1, PSC2, and PSC3). The comparison is based on the efficiency of the photovoltaic system such as the algorithm that follows GMPP.

4.2.1. Case 1: PSC1

In Figure 8, the power versus time simulation results for the complete photovoltaic system is shown, under the SC 1. Three distinct algorithms are used in the simulations to study their impact on system performance. The graph provides a comprehensive comparison of how each algorithm handles the partial shading scenario over time.

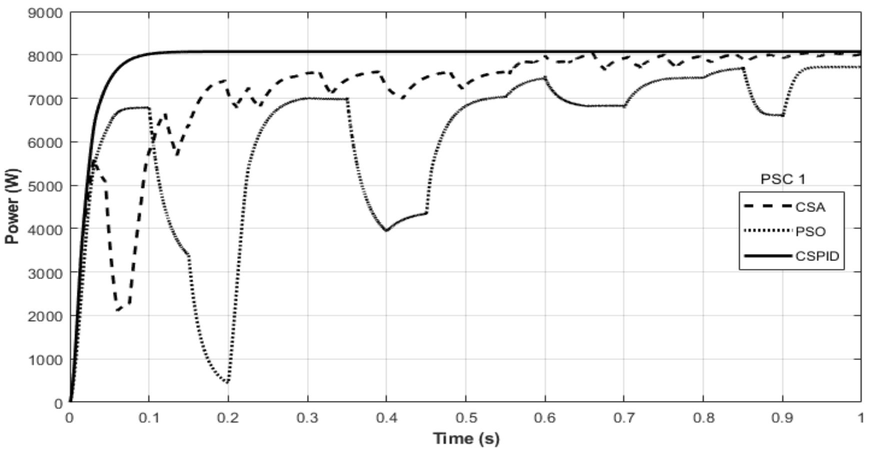


Figure 8. Simulation results of PV system power PSC1 case 1

As observed in Figure 8, the CSPID algorithm demonstrates a notably shorter rise time and superior stability in comparison to the other algorithms. The simulation is made under the PSC1. The graph clearly illustrates how the CSPID curve outperforms the alternative approaches, due to its performance.

Table 2 offers a complete comparison of simulation results for the PV system using three separate algorithms in case 1 (PSC1). The table displays various performance measures and results derived from each algorithm, allowing a detailed assessment of their individual efficiency in the management of partial shade scenarios. This information can help us make informed decisions regarding the selection of algorithms to optimize performance of the PV system.

Table 2. The comparison of PV system simulation results case 1

Algorithm	MPP (W)	GMPP (W)	Tracking efficiency	Tracking times of power (s)
PSO	7718.82		95.21 %	0.9
CSA	7999.18	8106.9	98.87 %	0.79
CSPID	8076.39		99.62 %	0.098

We observe that, in this condition, the GMPP is located to the right of the P-V curve, with an MPP value of 8106.9 W shown in Figure 7. Upon comparing the results in Table 2, it becomes evident that our proposed algorithm CSPID achieves a power output closer to the global maximum power, thereby demonstrating superior efficiency compared to the other algorithms. Additionally, the CSPID algorithm exhibits a remarkably shorter tracking time, further highlighting its effectiveness and performance advantage.

4.2.2. Case 2: PSC2

Figure 9 illustrates the simulation outcomes of power versus time for the complete PV system. The simulation is made under PSC2. The results compare the performance of the three algorithms.

As depicted in Figure 9, the CSPID curve displays a considerably shorter rise time and greater stability in comparison to the other algorithms. The graph visually highlights the significant performance advantage of the CSPID algorithm, indicating its ability to respond more rapidly and maintain a higher degree of stability under the given conditions. This observation underscores the potential of the CSPID approach as a promising solution for enhancing the efficiency and reliability of systems operating in similar scenarios.

In Table 3, a comprehensive comparison of simulation results for the PV system using three algorithms is presented under PSC2 case 2. The table provides a detailed overview of various performance metrics and outcomes obtained from each algorithm. We can use this data to evaluate and compare the effectiveness of these algorithms in managing the challenges posed by partial shading scenarios in the PV system.

It is evident from Figure 7 that under this particular condition, the GMPP is located in the middle of the P-V curve, with an MPP value of 5490.62 W. Upon examining comparison Table 3, we observe that our proposed CSPID algorithm achieves a power output much closer to the global maximum power, resulting in superior efficiency when compared to the other algorithms. Additionally, the CSPID algorithm demonstrates remarkably short tracking time, further enhancing its performance in MPPT.

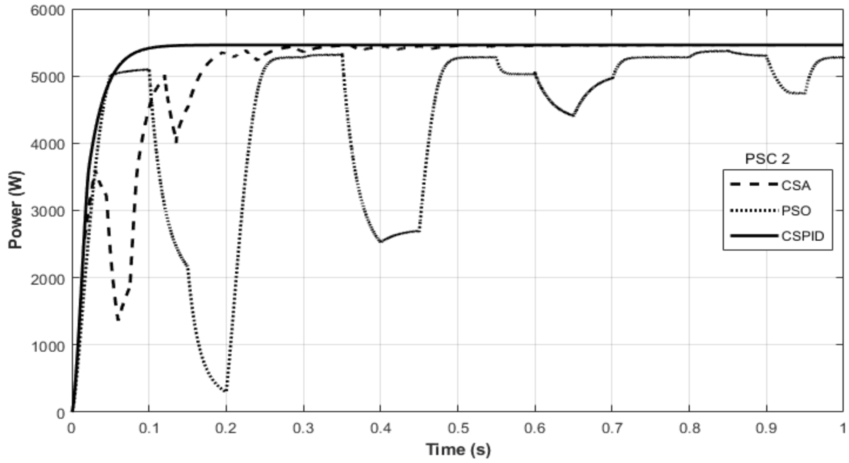


Figure 9. Simulation results of PV system power under PSC 2 cases 2

Table 3. The comparison of PV system simulation results case 2

Algorithm	MPP (W)	GMPP (W)	Tracking efficiency	Tracking times of power (s)
PSO	5258.11	5490.62	95.76%	0.95
CSA	5400.06		98.36 %	0.28
CSPID	5461.6		99.47%	0.1

4.2.3. Case 3: PSC3

Figure 10 presents the power versus time simulation results for the complete PV system under PSC3. The study incorporates three different algorithms to examine their respective effects on the system's performance. Through this graph, a thorough comparison of how each algorithm responds to the partial shading scenario over time can be observed.

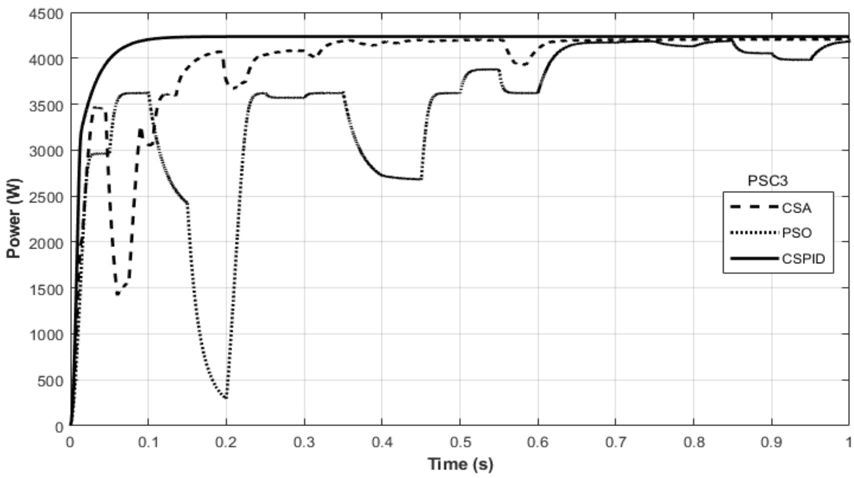


Figure 10. Simulation results of PV system power under PSC3 cases 3

Based on the observations from Figure 10, it is evident that the CSPID algorithm exhibits a significantly shorter rise time and higher stability when compared to the other algorithms. The simulation is made under the PSC3. The graph provides a clear depiction of how the CSPID curve outperforms the alternative approaches, demonstrating its superior performance in handling the partial shading conditions.

Table 4 offers a comprehensive comparison of simulation results for the PV system, considering three distinct algorithms, all evaluated under PSC3 case 3. The table provides an in-depth overview of diverse performance metrics and outcomes derived from each algorithm. This data serves as a valuable resource to assess and contrast the effectiveness of these algorithms in effectively managing the challenges posed by partial shading scenarios in the PV system.

Table 4. The comparison of PV system simulation results case 3

Algorithm	MPP (W)	GMPP (W)	Tracking efficiency	Tracking times of power (s)
PSO	4147.15		97.15%	0.68
CSA	4190.88	4268.64	98.17 %	0.36
CSPID	4235.38		99.22%	0.1

It is observed that the GMPP for this condition is located to the left of the P-V curve with an MPP of 4268.64 W as shown in Figure 7. Upon examining comparison Table 4, it becomes evident that our proposed CSPID algorithm achieves a maximum power value much closer to the global maximum power. Consequently, its efficiency surpasses that of the other algorithms, and its tracking time is notably shorter.

The results are noteworthy as they consistently show that our CSPID method outperforms the PSO and CSA algorithms across all three partial shading scenarios. The CSPID method demonstrates superior efficacy and robustness in handling the challenges posed by partial shading conditions. These findings establish it as a highly powerful and reliable solution for photovoltaic systems operating under varying levels of partial shading.

5. CONCLUSION

This research addresses the challenges posed by PSC in existing MPPT methods, which lead to low efficiency, stability issues, and LMPP drop, ultimately resulting in decreased output efficiency and power quality. To tackle these problems, the paper introduces a novel MPPT algorithm called CSPID. To evaluate the performance of CSPID, we conducted MATLAB/SIMULINK simulations under three different PSC. The comparison was made against two other algorithms, namely PSO and CSA. Remarkably, CSPID demonstrated superior MPPT performance compared to PSO and CSA, irrespective of the location of the GMPP and variations in irradiation. The algorithm's performance in handling partial shading conditions is remarkable, as evidenced by the test results. With an average tracking time of 0.098 s and the efficiency of 99.62%, CSPID has shown a substantial enhancement in the efficiency and the quality of photovoltaic energy production.

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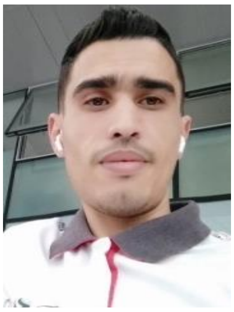

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