A Hybrid CSO-P&O based Global MPPT for PV Generators Working under Partial Shading Scenarios

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Abstract- The present research introduces a hybrid approach for global maximum power point tracking (MPPT) in photovoltaic generators that operate under partial shading scenarios. The proposed strategy combines the cuckoo search optimisation (CSO) technique with the perturbation and observation (P&O) approach to achieve efficient and accurate power generation from the PV modules. By integrating the CSO and P&O, the MPPT system can effectively handle the challenges posed by PSCs. The P&O component provides intelligent decision-making capabilities to adaptively adjust the operating point, while the CSO algorithm facilitates the global search for global MPP. The performance of the hybrid CSO-P&O based GMPPT strategy is exanimated through Matlab/Simulink simulations and compared with particle search optimisation (PSO), cuckoo search optimisation (CSO) and grey wolf optimisation (GWO) based MPPT techniques. Furthermore, the suggested approach was validated on the Arduino Due board using the processor-in-loop (PIL) technique. The simulation and processor-in-loop results prove that the suggested approach is more powerful in terms of tracking precision, convergence speed and efficiency under situations of partial shading.

Keywords Photovoltaic energy, partial shading scenario, boost converter; cuckoo search algorithm, metaheuristic algorithms.

1. Introduction

The significant growth in demand for electricity, the rapid depletion of fossil resources, concerns about climate change, and the need to reduce carbon emissions pose serious challenges [1]. These challenges motivated scientists to focus on investigating and optimising the use of renewable sources [2]. Among various electrical production sources, solar energy utilizing the photovoltaic effect is emerging as a highly competitive power generation option. This is primarily due to its benefits, which include zero fuel consumption, minimal maintenance requirements, the abundance of solar energy resources, and its environmentally friendly nature with no emissions [3]. Solar energy is experiencing rapid growth and is being recognized as a sustainable and promising solution in the quest for clean and renewable energy [4]. In the previous decade, a considerable growth in the implementation of photovoltaic plants has been recorded in autonomous and grid-connected energy production stations. PV arrays are frequently employed in numerous applications, such as distributed power generation, building-integrated PV, and isolated production systems for remote and rural areas. In real time applications, photovoltaic generators are combined in series or parallel to provide the required voltage or current value. The solar PV array has a non-linear performance feature due to weather intermittency, which seems to have a considerable influence on the total power generated by the photovoltaic plant [5]. The requirement for MPPT regulator to operate at maximum power in a variety of weather scenarios is a significant drawback of PV systems. This topic has attracted attention over the years because of its crucial importance in optimally operating PVs [6]. Therefore, the characteristic curves of PV modules exposed to uniform irradiance only show a single maximum power point (MPP) [7]. In this situation, any conventional MPP technique can be employed to produce the maximum power without any issues. [8].On the contrary, in a situation of PSCs, the P-V characteristic curve of the PV generator contains several

MPPs. The global MPP (GMPP) is one of these maximums, while others are known as local MPPs (LMPPs). In this specific scenario, traditional tracking strategies like the P&O approach [9] and the incremental conductance strategy (INC) [10] are insufficient to reach the global MPP, leading to a significant reduction in PV system efficiency [11]. Consequently, a reliable strategy is necessary to achieve the GMPP with accuracy without sticking on the local MPP[12]. In this context, several MPPT strategies based on fuzzy logic controllers [13][14], artificial neural networks [15][16] and genetic algorithms[17] [18] have been suggested to reach GMPP. Their performance is mainly dependent on rigorous training, which often requires a long time and significant processing power. Metaheuristic algorithms, like particle swarm optimisation technique[19] [20], Cuckoo Search (CS) based global MPPT [21], grey wolf algorithm [22] [23], Salp-Swarm based MPPT strategy [24] and whale optimisation combined with differential evolution (WODE) technique [25]. Eltamaly et al [26] have conducted a comprehensive assessment and examination of these strategies. The performance of these algorithms relies on several factors, such as population numbers, velocity, search space, iteration count and the efficiency of information exchanging within the mechanism. In this context, this paper proposes a hybrid approach for GMPPT in PV generators operating under PS scenarios. The hybrid technique combines P&O tracking strategy and the cuckoo search optimization (CSO) algorithm to achieve precise and effective MPPT. The CSO approach, based on cuckoo bird reproductive behaviour, facilitates the global search for the GMPP. When The P&O component provides intelligent decision-making capabilities, allowing the system to vary its operating point enhancing the tracking precision and convergence speed. The objective of this research is to assess the capacity of the proposed approach and compare its results to those of PSO and GWO-based MPPT approaches under PS scenarios. Through simulations, processor in loop and performance analysis, the efficiency and the superiority of the suggested hybrid approach will be demonstrated in terms of tracking precision, time response and overall effectiveness.

The rest of the present research is structured in this order: the next section provides the modelling of PV generators under PS conditions. In Section 3, the PSO, GWO, and the proposed CSO-P&O algorithms are explained. In Section 4, the results of simulation and the processor-in-loop of the suggested approach are discussed. Finally, the last section provides the conclusion of this study.

2. Photovoltaic Description System

A PV system was used to examine the reliability of the suggested hybrid GMPPT approach. This system comprises a photovoltaic panels and a DC-DC Boost power converter with resistive load. The PV generator is formed by four PV panels associated in series, capable of generating approximately 800W under standard test conditions (STC).

2.1. Photovoltaic Generator Modelling

Several models exist for the characterization of solar photovoltaic cells, and the single diode type is among the best-known models. The relation between the module output voltage (Vpv) and its current (Ipv) is shown in equation (1)[27].

$$\mathrm{Ipv} = \mathrm{I_g} - \mathrm{I_s}\left(\exp\left(\frac{\mathrm{q}\left(\mathrm{v_{pv}}+\mathrm{IpvR_s}\right)}{\mathrm{nkT}}\right) - 1\right) \qquad (1)$$

In the given equation, the symbol "n" represents the ideality factor of the PN Junction, "k" denotes the constant of Boltzmann, "T" signifies the temperature of the PV cell in Kelvin, "q" represents the electron charge, "Rs" corresponds to the equivalent of series resistance in Ohms, and "Is" denotes the saturation current[28].

2.2. P–V Characteristics under PSCs

In the situation of partial shading scenarios, the PV generator characteristic presents several peaks. Fig. 1 presents the configuration of the four PV generator associated in series. Table 1 lists the values for each PV module irradiance level (shading scenario). The P-V characteristic of different cases are illustrated in Fig. 2.

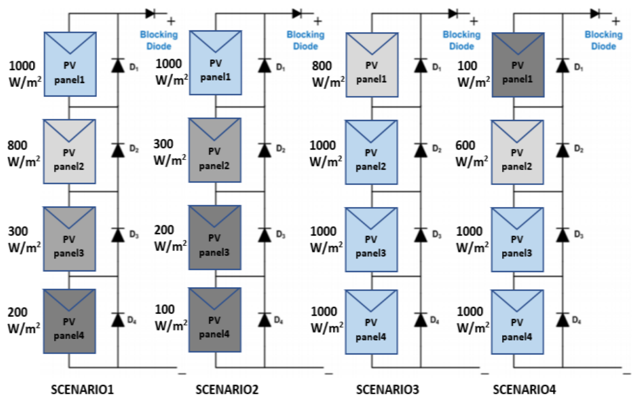

Fig. 1. PV generator configuration under partial shading scenarios.

The PV module used in this study is the Zhejiang Guangyi optical technology GYP-200P, and its specifications under standard test conditions (STC) can be found in Table2.

Table 1. Partial shading scenarios

Scenarios	Panel1	Panel2	Panel3	Panel4	Pmpp
Scenario1	1000	800	300	200	327.82
Scenario2	1000	300	200	100	181.72
Scenario3	800	1000	1000	1000	697.82
Scenario4	100	600	1000	1000	396.48

Table 2. Details of the PV panel GYP-200P

Parameter	Value
Power at MPP PMPP	199.98W
Current at MPP IMPP	7.49A
Voltage at MPP VMPP	26.7V
Short circuit current ISC	8.16A
Open circuit voltage VOC	32.7V
Number of series cells	54

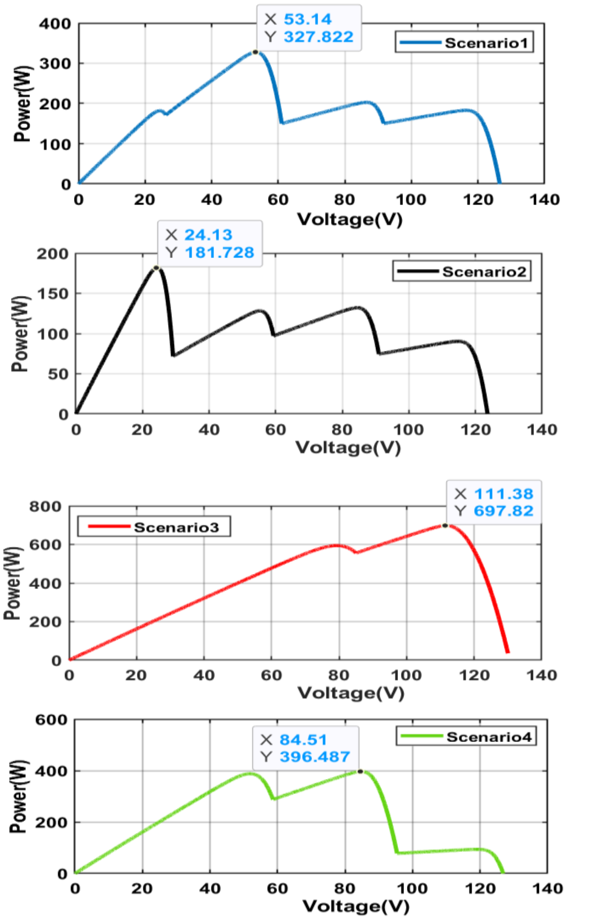

Fig. 2. Power-voltage characteristics of PV array under PSCs.

3. Metaheuristic MPPT Approaches

The MPPT algorithms used in this work, including the particle swarm optimisation-based MPPT, the grey wolf optimization-based MPPT technique, the cuckoo MPPT method, and the proposed hybrid CSO-P&O methodology, are discussed in the rest of the present section. The idea of the suggested CSO-P&O-based GMPPT is explained as follows: 1) the global peak region is explored using the cuckoo search algorithm. 2) After reaching the GMPP region, the suggested approach switches from CSO-based MPPT to the perturb and observe technique to maintain the MPPT control.

3.1. MPPT Technique using PSO Algorithm

Various engineering optimisation problems with multiple peaks have been successfully solved using the population-based evolutionary technique known as particle swarm optimisation [5]. The particle swarm strategy is a metaheuristic optimisation approach designed to imitate the exploration for food of animals or fishes, in which each individual particle randomly explores the area of search, and the particle that discovers the greatest quantity of food shares its location with the other members of the swarm to guide all the particles towards the best position for feeding [6]. Each particle has two parameters: velocity and position. The distance between each particle and the food is represented using these two factors. After each iteration, the algorithm updates the position and the velocity using equation 2.

$$v_i(t+1) = v_i(t) + c_1 + r_1 x\left(p_{ibest} - x_i(t)\right) + c_2 x r_2 x\left(g_{ibest} - x_i(t)\right) \quad (2)$$

The fitness function in this study is the PV array output power, and the location of the particle is used as DC-DC converter duty cycle control. The particle location di is updted using the next equation [28].

$$d_i^{k+1} = d_i^k + v_i^{k+1} \quad (3)$$

$$v_i^{k+1} = w v_i^k + c_1 r_1 \left(p_{best} - d_i^k\right) + c_2 r_2 \left(g_{best} - d_i^k\right) \quad (4)$$

Where;

Pbest represent best location of particle i;

Vi represents speed component at the k+1 iteration;

Gbest represent best location in the entire swarm;

w represents inertia value;

c1, c2 represent acceleration parameters;

r1, r2 represent random values;

Fig. 3 exhibits the diagram for exploring process by PSO MPPT approach.

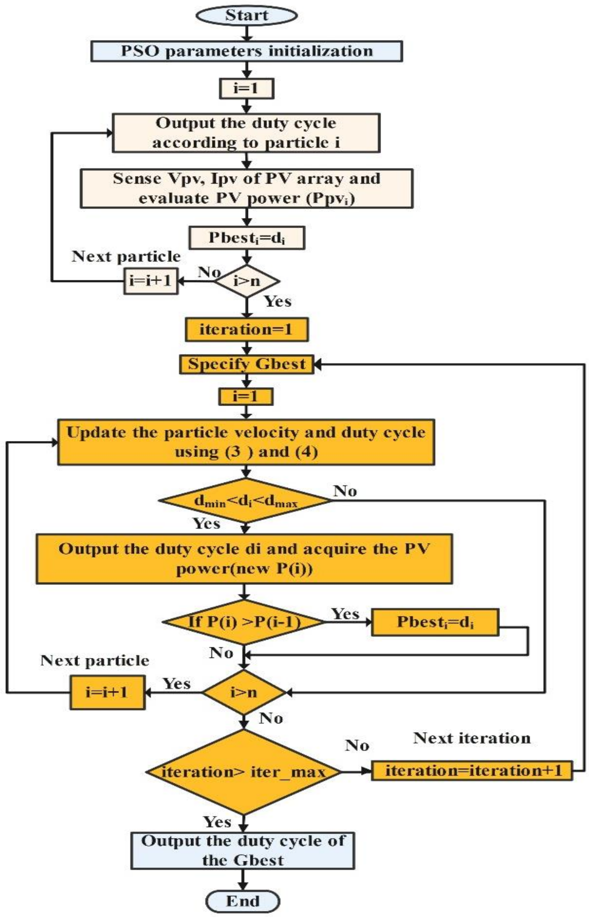

Fig. 3. The PSO MPPT diagram [21].

3.2. MPPT Technique using Grey Wolf Optimisation

According to Mirjalili et al.[6], the grey wolf is an optimisation methodology based on the hunting process and hierarchy organisation of grey wolf packs. The algorithm imitates the hunting strategy and group organisation of grey wolves. Four categories are used to group them: α, β, δ, and ω. Each category represents the class system of the wolves [7]. The wolves alpha, beta, delta and omega depict the pyramid leadership structure, in which the optimal solution is alpha. Beta and delta groups represent the second and third best solutions. The last solution is omega [29]. The fundamental scenes of the GWO strategy are hunting, chasing, surrounding and attacking. The surrounding operation is modelled using equations (5) and (6).

$$\vec{D} = \left|\vec{C}\vec{X}_p(k) - \vec{X}_p(k)\right| \tag{5}$$

$$\vec{X}(k+1) = \vec{X_p}(k) - \vec{A} \cdot \vec{D} \tag{6}$$

Where X represents the grey wolf location vector, and Xp represents the target position vector, k is the iteration number, D, A, and C represent the value of coefficient vectors. The vectors A and C are determined as in Equations (7) and (8).

$$\vec{A} = 2\vec{a} \cdot \vec{r_1} - \vec{a} \tag{7}$$

$$\vec{C} = 2 \cdot \vec{r_2} \tag{8}$$

Where r1 and r2 represent two vectors with a random value between 0 and 1. Several researchers employ this technique for MPPT applications. The GWO MPPT algorithm is fully described and illustrated in detail in fig. 4.

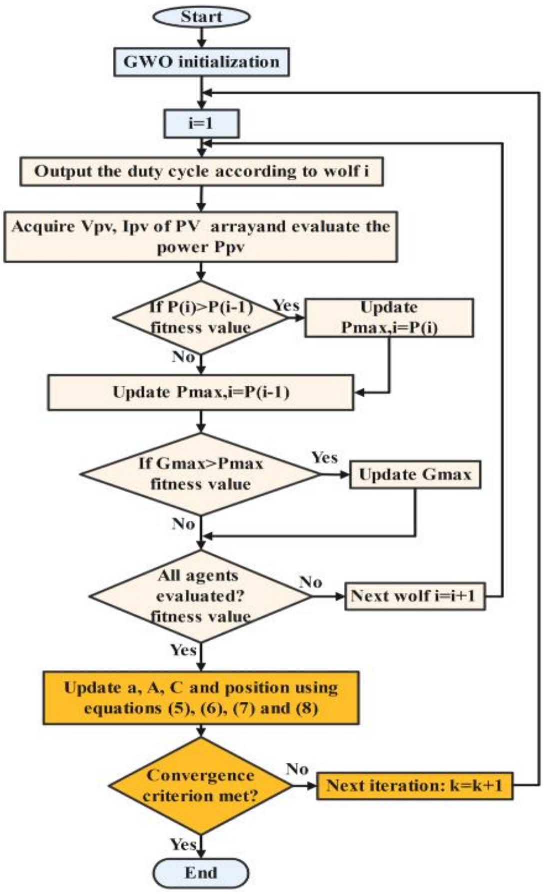

Fig. 4. The GWO MPPT diagram [23].

3.3. MPPT Approach using Cuckoo Search Optimisation (CSO)

In 2009, Xin-She Yang and Suash presented the cuckoo search (CS) methodology as an optimisation method. The CS optimisation is a metaheuristic strategy based on the reproductive behaviour of cuckoo species. These birds are one of the parasitic birds that leave their eggs in the other species nests rather than establish their own. In [30], the CS algorithm has been used to resolve the MPPT problem. Figure 5 provides the diagram of the CS approach for MPPT.

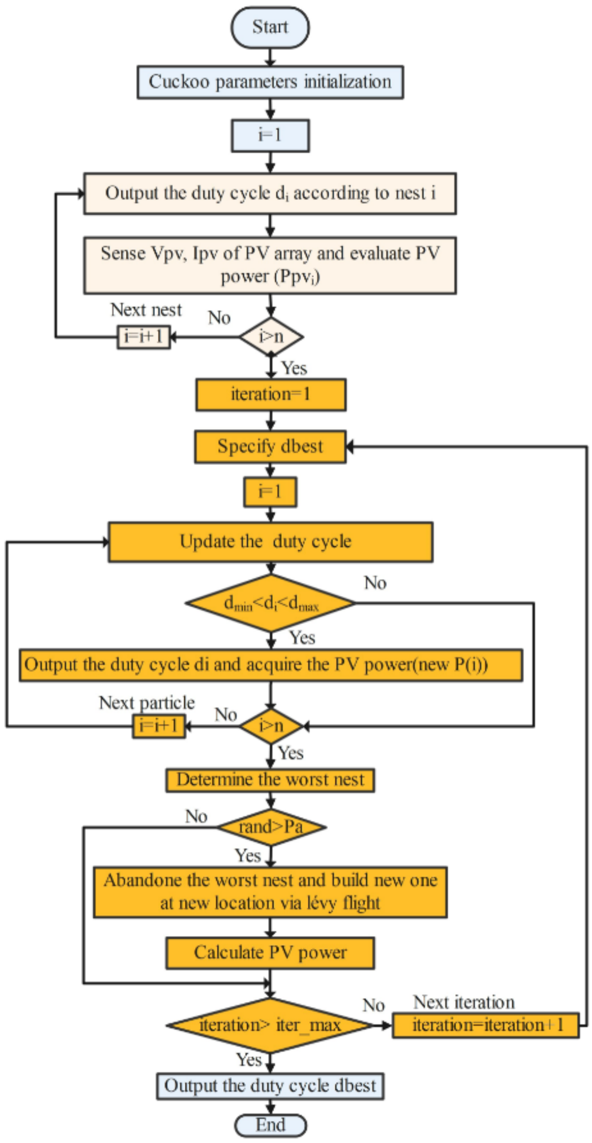

Fig. 5. The flow diagram of cuckoo based MPPT [31].

3.4. *The Proposed Hybrid P&O-CSO GMPPT*

The proposed approach in this study involves the fusion of the CSO and P&O strategies. The idea behind this strategy is to take advantage of these two approaches and bypass their limitations. The CSO is most effective and catches the GMPP of PV modules quickly [30]. However, when changing from one pattern to another, it shows significant fluctuations around the global MPP. The P&O is entirely the opposite of CSO in terms of advantages and disadvantages. However, it could fall in one of the nearby peaks (LMMPs), it exhibits very little oscillation near the GMPP when using very low perturbation step. In order to deal with this issue, CSO has been employed in the initial phase to accurately identify the GMPP region. In the second phase, the P&O begins to operate as an MPPT controller with very low fluctuations using a low perturbation step. Therefore, the advantages of CSO in tracking the GMPP without falling into one of LMPPs are exploited. Additionally, the drawback of excessive oscillations is eliminated by terminating the operation of CSO controller and providing the opportunity to P&O MPPT to continue the tracking with very low oscillations at the GMPP. The condition for changing the CSO and giving the control to the P&O to reach the GMPP that has already been detected using the following conditions:

$$|P_{new} - P_{old}| \leq \varepsilon \tag{9}$$

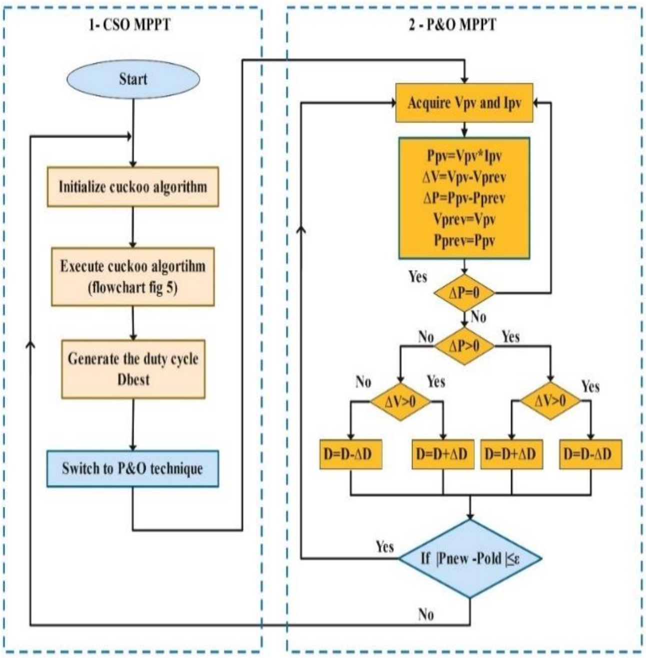

Fig. 6. The diagram of the suggested hybrid CSO-P&O based MPPT.

In the case of output power variation superior to a given power ε. The suggested algorithm reinitialise the global MPP searching using in this time the CSO technique.

4. Results and Discussion

4.1. Simulation Results

To assess the effectiveness of the proposed CSO-P&O approach and its suitability for MPPT (Maximum Power Point Tracking) applications, simulations were conducted using four distinct shading patterns, as depicted in Section II. These tests involved a setup of four PV generators associated in series and a DC-DC power converter as presented in fig.7. Through the simulation outcomes, a quantitative comparison was drawn between the suggested CSO-P&O, Particle Swarm MPPT technique, Grey Wolf MPPT approach, and Cuckoo Search method, considering efficiency and convergence time. The Matlab/Simulink environment was employed to develop the algorithms and conduct simulations for the given photovoltaic system. The algorithms under examination were meticulously implemented, and their parameters were finely adjusted to ensure comparable performance. Table 3 summarizes the key parameters of the tested algorithms, such as the number of particles, the initial positions of these particles, and other parameters.

Table 3. The key parameters of GMPPT strategies

S. No	algorithm	Parameters
1	P&O-CSO	P&O step Δd=0.001, Number of nests= 5, Beta=1.5, Alpha=0.8, search space =[0.1 0.9]
2	PSO	Population size= 5, Inertial Weight w=0.4, Personal coefficient C_1=2, Global Coefficient C_2=2, Nb of iterations =20, search space =[0.1 0.9]
3	GWO	Population size= 5, Number of iterations =50, search space =[0.1 0.9]
4	CSO	Number of nests= 5, Beta=1.5, Alpha=0.8, search space =[0.1 0.9]

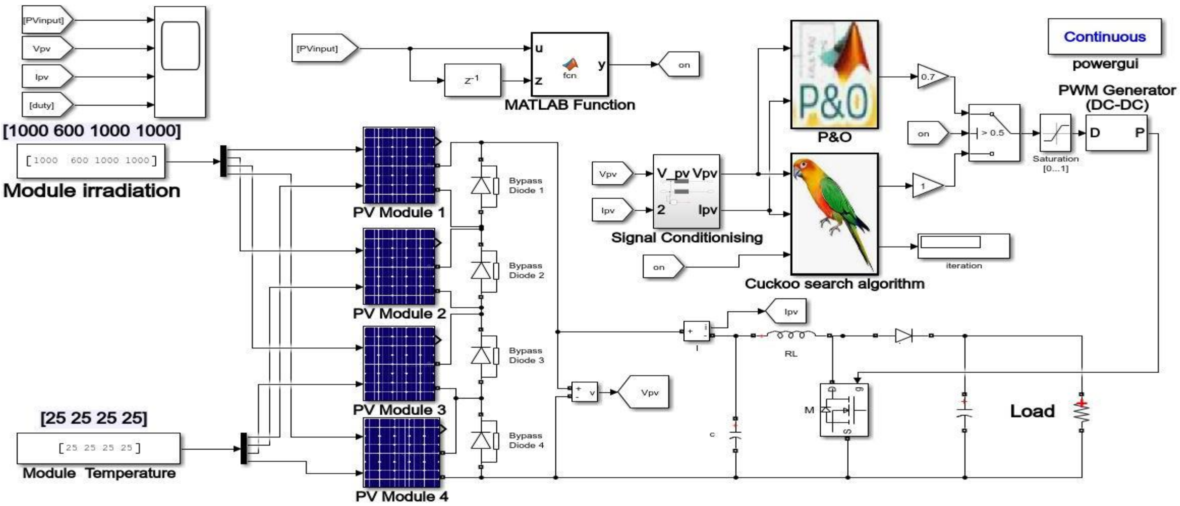

Fig.7. The Simulink scheme of the PV system with the suggested CSO-P&O based MPPT algorithm.

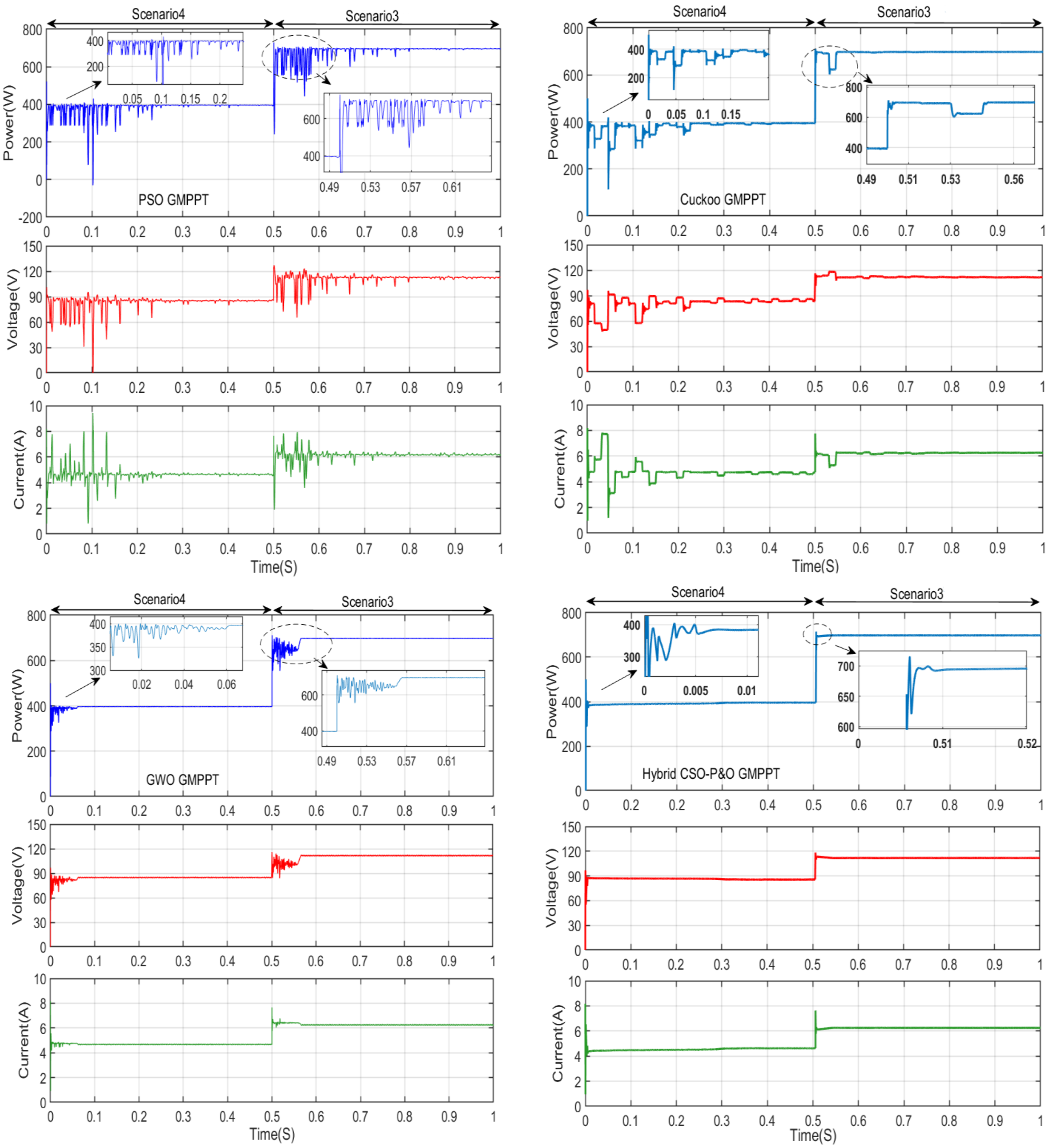

Fig. 8. Simulation results of PSO, GWO, CUCKOO and the suggested Hybrid CSO-P&O GMPPT.

To prove the efficiency of the suggested technique in the setting of partially shaded conditions (PSCs), we set the irradiance levels on the first, second, third and fourth panels at 100, 600, 1000 and 1000 W/m2, respectively, with an assumed ambient temperature of 25°C (scenario 4). Fig. 2 displays the P-V curves for the PV array under investigation, revealing a maximum power generation of 697.82 W. At t = 0.5 s, we altered the irradiances on the panels to 800, 1000, 1000, and 1000 W/m2, (scenario 3) resulting in a maximum power output of 396.48W. A comprehensive presentation of simulation results, including the power Ppv, the voltage Vpv and the current Ipv outputs of the PV generator under these conditions, is provided in fig.8.An analysis of the power output curve clearly indicates that our proposed method swiftly attains the maximum power point in under 0.05 s, achieving a power output of 395.6 W. Additionally, when the scenario change at t = 0.5 s, the method rapidly identifies the new GMPP within less than 0.01 s, converging to a power output of 696.3W as depicted in the following table.

Table 4. MPPT simulation results synthesis

		PSO		GWO		CSO		Proposed	
		$T_{mp(sec)}$	$P_{mpp(W)}$	$T_{mp(sec)}$	$P_{mpp(W)}$	$T_{mp(sec)}$	$P_{mpp(W)}$	$T_{mp(sec)}$	$P_{mpp(W)}$
PSC GMPP=396.0W	Pattern-4	0.25	394.3	0.06	394.8	0.23	393.9	0.05	395.6
PSC GMPP=697.8W	Pattern-2	0.30	695.1	0.07	694.8	0.06	696.2	0.01	696.3

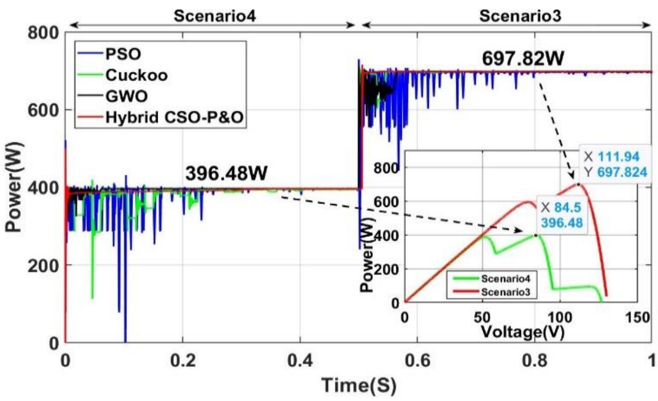

Fig. 9. PV array output power comparison.

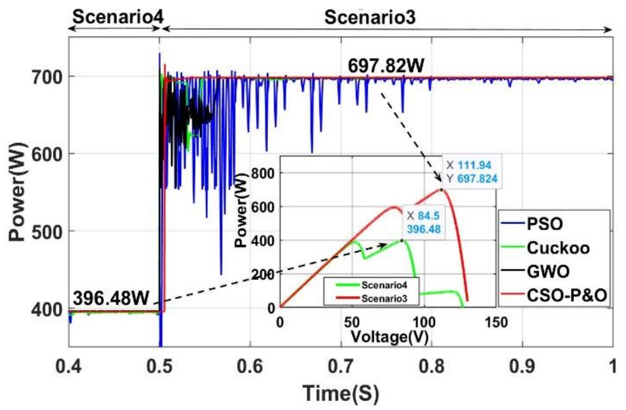

Fig. 10. Zoomed-in PV output power.

The results obtained through various soft computing methods for distinct PV patterns have been organized in Table 4. The data presented in Table 4 demonstrates the good performance of the suggested hybrid CSO-P&O approach compared to other studied techniques.

4.2. Processor-in-the-Loop (PIL) Implementation

The suggested hybrid CSO- P&O based global MPPT approach is verified through the utilization of a Processor-in-the-Loop (PIL) implementation. The algorithms used in this study are implemented on Arduino Due Microcontroller board, while the PV system components and the PWM generation are represented in MATLAB/ Simulink environment, as depicted in Figure 11.

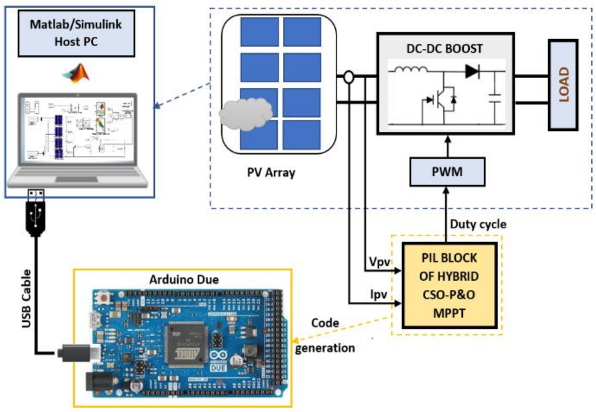

Fig. 11. PIL implementation model.

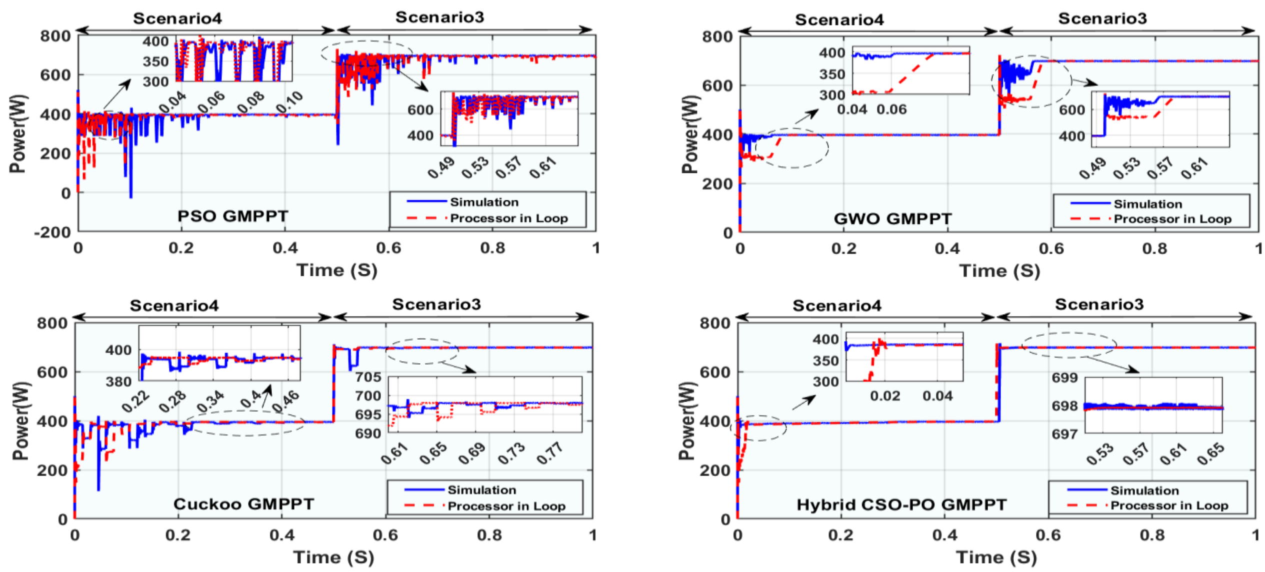

Fig. 12. Comparison between processor in loop and simulation under PS condition.

In this experimental platform, the Arduino Due receives the photovoltaic modules current and voltage as analogue inputs. In addition, it generates the duty cycle and send it to the pulse width modulation generator. The PIL setup wasemployed to test the proposed technique under two shading scenarios. To assess its performance, the PIL test results were compared with the simulation results, as illustrates in fig. 12, which displays the output power of the PV modules using the four algorithms. Notably, the PIL test exhibits the same results with a little retard in converging when compared to the simulation results.

5. Conclusion

In this paper, we present a hybrid global MPPT approach designed for standalone photovoltaic systems operating under PS scenarios. Our proposed CSO-P&O method combines the cuckoo search algorithm with the P&O MPPT controller. The simulation and the processor-in-loop results prove the effectiveness of the suggested method in distinguishing between the GMPP and local LMPPs, ensuring rapid convergence to the GMPP with an impressive efficiency rate of 99.6%, even when confronted with transient changes in shading patterns. When the suggested CSO-P&O approach is compared to the GWO, PSO, and Cuckoo MPPT strategies, it is clear that all four methods can catch the GMPP, but our suggested approach excels the others in terms of response time. This demonstrates the advantages of the suggested CSO-P&O MPPT methodology over other studied MPPT techniques.

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