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Optimal Performance of Novel Hybrid Harmony Search Optimization based Maximum Power Tracker Solar PV

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***Abstract*—** In today's quickly evolving renewable energy sector, increasing photovoltaic (PV) system efficiency is crucial, especially as we struggle with growing power demands and seek to diminish the negative impacts of traditional fossil fuels. A novel optimisation method for maximum power point tracking (MPPT) in photovoltaic (PV) systems is highlighted in this article. It is based on the Hybrid Harmony Search (HHS) method and will be directly contrasted with two conventional approaches, Perturb and Observe (P&O) and Particle Swarm Optimisation (PSO). MPPT is an efficiently operated method for improving PV system performance, especially under variations in the environmental conditions where shading occurs and PSD often leads to slow convergence and high sensitivity to parameters, so the proposed novel HHS-based method was developed because of its inherent adaptability and general global search approach to quickly and accurately identify the global maximum power point (MPP). Utilizing MATLAB/Simulink to assess the performance of the proposed HHS-based methods over a range of varying conditions, the results were put in an extensive comparison between the P&O and PSO methods on the designed approaches for test system operation. HHS is known to converge and have better yield convertibility versus traditional particular tracking methods because it combined of the advantage of PSO and DE thus proposed methods identified as a high comparability on real-time optimization processing on Solar PV systems.

Keywords— Photovoltaic (PV) systems, Maximum Power Point Tracking (MPPT), Perturb & Observe (P&O) method, Particle Swarm Optimization (PSO), Hybrid Harmony Search (HHS).

I. INTRODUCTION

THE accelerating demand for clean and sustainable energy has positioned photovoltaic (PV) systems as a cornerstone of the global energy transition. However, the inherently nonlinear characteristics of PV arrays, compounded by environmental variability such as partial shading and cloud-induced irradiance fluctuations, present significant challenges to efficient energy extraction. Within photovoltaic installations, MPPT strategies are essential for maintaining operation at the generator's highest power output [1], [2]. Among these, the Perturb and Observe approach is still extensively used, owing to its straightforward logic and minimal implementation requirements. However, sluggish dynamic response and persistent oscillations at the maximum power point, particularly under quickly changing environmental circumstances, frequently limit their performance [3]. Metaheuristic techniques, particularly Particle Swarm Optimisation (PSO), have been used to improve the tracking effectiveness and flexibility of MPPT controllers in order to overcome these constraints [4]. While PSO exhibits improved global search capabilities compared to conventional techniques, it is still susceptible

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to premature convergence and performance degradation in highly dynamic scenarios [5]. Fuzzy Logic Controllers (FLCs) have also gained considerable traction in the MPPT domain due to their ability to handle system uncertainties and nonlinearities without requiring an explicit mathematical model [6]. Although FLCs can offer smoother control action and better adaptation to variable conditions, their performance heavily depends on the design of the membership functions and rule base, which may require extensive tuning and empirical expertise [7]. Recently, the novel Hybrid Harmony Search (HHS) algorithm has emerged as a promising metaheuristic optimization method inspired by the musical improvisation procedure of achieving aesthetic harmony. Its robust global search capability, adaptive memory consideration, and convergence reliability make it a compelling candidate for MPPT applications [8]. Despite its potential, the use of HS in MPPT remains underexplored, particularly in comparison with established techniques like P&O, PSO, and FLC. Furthermore, combining HS with other intelligent techniques leading to hybrid variants may unlock additional performance gains by synergizing the strengths of individual algorithms. This study introduces a novel MPPT approach based on the Harmony Search algorithm and proposes a novel Hybrid Harmony Search (HHS) variant to further enhance tracking accuracy and dynamic responsiveness. A comprehensive comparative evaluation is conducted among five MPPT strategies: P&O, PSO, Fuzzy Logic, Harmony Search, and Hybrid Harmony Search. The objective is to calculate their performance in terms of convergence speed, power tracking efficiency, and resilience under different irradiance and temperature circumstances. The proposed algorithms are validated through extensive simulation in MATLAB/Simulink, filling a notable research gap in the application of HS and its hybrid forms for MPPT optimization [3]-[6] and [8].

II. METHODOLOGY

This section details the methodological framework used to develop, implement, and evaluate the proposed Hybrid Harmony Search (HHS) based MPPT strategy for photovoltaic (PV) systems. The primary approach involves simulation-based performance analysis within the MATLAB/Simulink platform. The efficacy of the HHS algorithm is benchmarked against widely recognized conventional and intelligent MPPT techniques, namely Perturb and Observe (P&O) and Particle Swarm Optimization (PSO) under various simulated environmental conditions. The equivalent circuit diagram of the solar cell is given in Fig. 1.

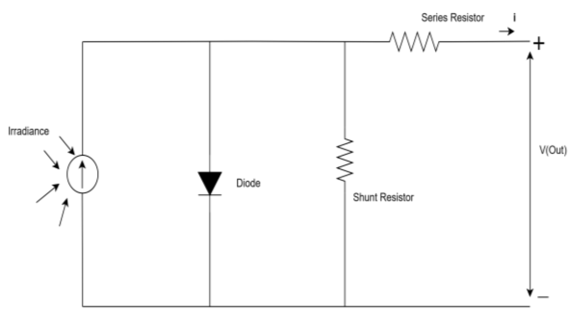

Fig. 1. The equivalent circuit of the solar cell.

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A. Baseline MPPT Algorithms for Comparison

To provide a comparative context for the proposed HHS technique, two well-established MPPT algorithms were selected as baselines:

1. P&O method: As a foundational hill-climbing technique, P&O iteratively adjusts a control variable (e.g., PV voltage V or converter duty cycle D) by a fixed step size (ΔD) and observes the change in output power (ΔP). The direction of the subsequent perturbation is determined by comparing the signs of ΔP and the perturbation, aiming to converge to the MPP [1, 2]. Its implementation simplicity is countered by inherent steady-state oscillations around the MPP and potentially slow dynamic response, especially under rapidly changing atmospheric conditions or with small perturbation steps [3], [22], [26]. Some adaptive variations exist, like those adjusting step size based on operating conditions [22], [26], or using current perturbation [26], but the core principle remains. The flowchart of the P&O based MPPT control technique for real-time cloud adaptation is shown in Fig. 2.

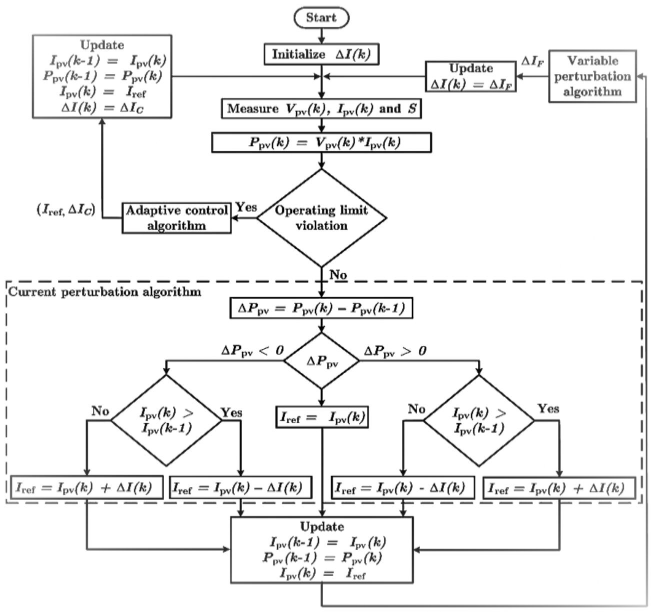

Fig. 2. Flowchart of the P&O MPPT control algorithm for real-time cloud adaptation [22].

2. PSO method: PSO is a prominent metaheuristic algorithm drawing inspiration from swarm behavior [4], [21]. It employs a population of 'particles,' each particle representing a candidate solution (e.g., duty cycle D), exploring the solution space. Each particle's movement is guided by its velocity (v) and position (x), which are updated iteratively based on its own best-found position (p_{best}) and the best position

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achieved by the entire swarm (g_{best}). The standard update rules are generally expressed as:

Velocity Update:

$$v_i(k+1) = w * V_i(k) + C_1 * r_1 * \left(p_{best_i} - x_i(k)\right) + C_2 * r_2 * \left(g_{best}(k) - x_i(k)\right) \tag{1}$$

Position Update:

$$x_i(k+1) = x_i(k) + v_i(k+1) \tag{2}$$

Here, w is the inertia weight, C_1 and C_2 are acceleration coefficients, and r_1, r_2 are random value in between zero and one. PSO variants like those using constriction factors (CFPSO) or variable coefficients (VCPSO) aim to improve convergence and avoid local optima traps [21]. While effective in global search, PSO's performance is sensitive to parameter tuning (w, C_1, C_2, number of particles N, sampling time ts) [19], [21]. Research in [21] suggests methods for optimizing ts based on converter dynamics and analyzing optimal particle numbers. The flowchart of the PSO based MPPT algorithm is shown in Fig. 3.

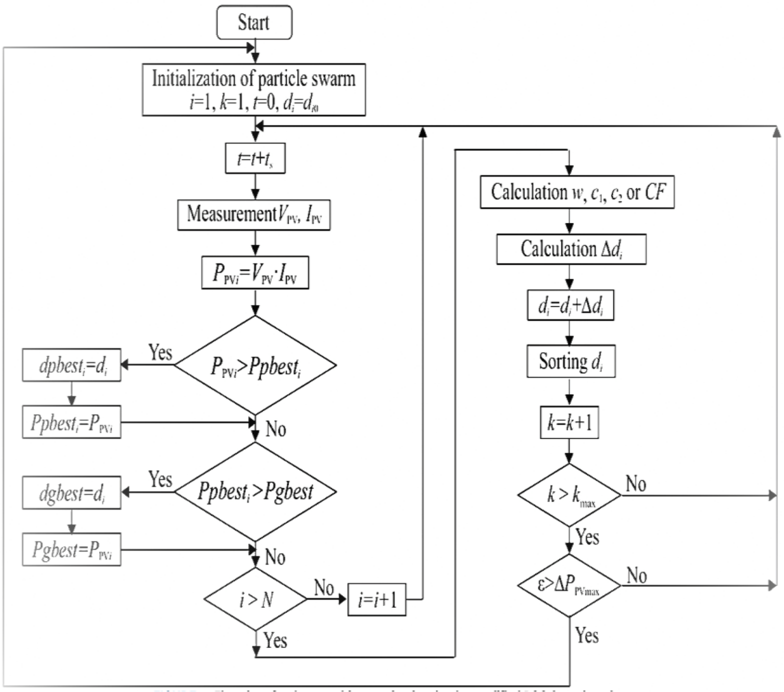

Fig. 3. Flowchart of the PSO based MPPT algorithm [19].

B. Foundational Optimization Concepts for Hybridization

The proposed HHS algorithm synthesizes elements from three distinct optimization paradigms:

1. Harmony Search (HS): Inspired by musical improvisation, HS utilizes a Harmony Memory (HM) to store promising solutions. New solutions are generated through a combination of memory recall (with rate HMCR), pitch adjustment of recalled solutions (with rate PAR and bandwidth bw), and random exploration [9].

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2. Particle Swarm Optimization (PSO): The concept of guiding the search using both individual (p_{best}) and collective (g_{best}) best experiences is adopted to accelerate convergence towards optimal regions.
3. Differential Evolution (DE): DE's strategy of creating new candidate solutions through the mutation operator, often involving vector differences between
4. Existing solutions, is incorporated to enhance population diversity and exploration capability, potentially improving robustness against local optima.

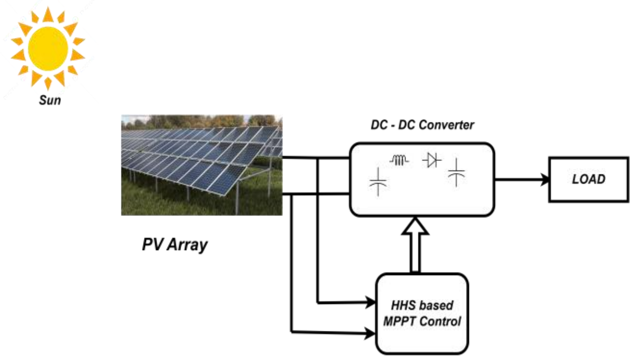

Fig. 4. Block diagram of PV system

C. Proposed Hybrid Harmony Search (HHS) MPPT Algorithm

This study introduces a novel HHS algorithm specifically tailored for the MPPT problem in PV systems. The typical block diagram of PV system is shown in Fig. 4. The application of solar PV using boost converter implementation is shown in Fig. 5. The core innovation lies in the hybrid mechanism for generating new candidate solutions (duty cycles D), which probabilistically integrates search operators inspired by HS, PSO, and DE. This hybridization strategy is designed to capitalize on the exploratory strengths of DE and HS randomization, the exploitation capabilities of PSO's p_{best} and g_{best} guidance and the refinement potential of HS pitch adjustment and memory consideration.

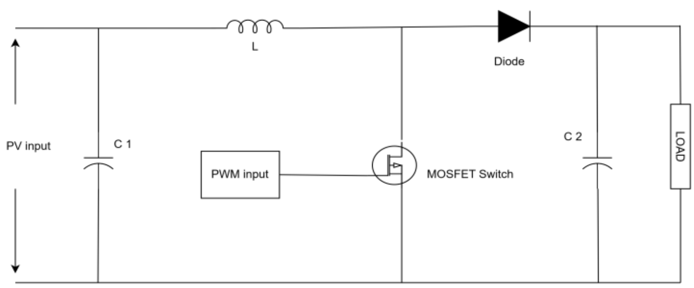

Fig. 5. Schematic depiction of the boost converter implemented.

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The generation of a new candidate duty cycle, D_{new}, at iteration $i+1^{\text{th}}$ within the HHS framework proceeds as follows:
At each iteration we draw one random number r ∈ [0,1] and compute the candidate duty cycle D_{new} as follows:

1. Memory pick

$$\text{If } r < P_m\ (\approx 0.10), \qquad D_{new} = D_{HM}$$

Where D_{HM} is the best duty cycle stored in harmony memory.

2. HS pitch adjustment

$$Else\ if P_m \le r < Pm + P_{pa}pa(\approx 0.19 total),$$
$$D_{new} = D_{HM} + \delta$$

$where\ \delta\ is\ a\ small\ random\ offset\ chosen\ uniformly$
$$from\ [-bw, +bw]\ (here\ bw = 0.02.$$

3. DE-style mutation

$$Else\ if\ P_m + P_{pa} \le r < P_m + P_{pa} + P_{DE}\ (\approx 0.081),$$
$$D_{new} = D_{base} + F(D_{r1} - D_{r2})$$

where D_{r1},D_{r2} are two randomly picked harmonies and F=0.5 is the DE method's scaling factor.

4. Pure random Otherwise (≈ 0.0–0.09 remaining probability),

D_{new} is drawn uniformly from the full range $[D_{min}, D_{max}]$.

This integrated approach allows the HHS algorithm to adapt its search behavior dynamically, potentially leading to faster convergence, better avoidance of local MPPs (especially under PSC), reduced steady-state oscillations, and overall improved tracking performance compared to the baseline algorithms. The specific parameters governing the HHS algorithm's behavior were set as follows: detailing: initialization of decision vector (x), harmony memory size (HMS), harmony memory considering rate (HMCR), and pitch adjustment rate (PAR); generation of new (child) harmonies via the HHS method; updating the HMS matrix; equality check of the first two rows of the fitness value (FV) matrix; and termination criterion. The flowchart of the proposed hybrid harmony search (HHS)–based MPPT algorithm is given in Fig. 6.

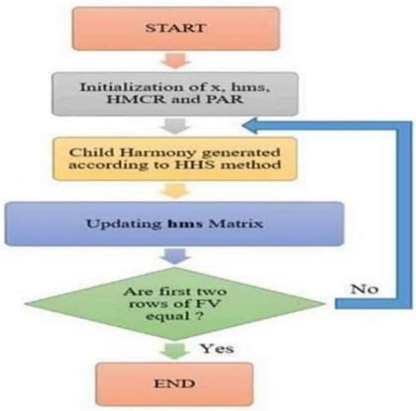

Fig. 6. Flowchart of the proposed hybrid harmony search (HHS)–based MPPT algorithm [9]

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D. Simulation Environment and System Modelling

The performance evaluation was conducted using the MATLAB/Simulink platform.

1. PV System Model: The PV array was modelled using the standard single-diode equivalent circuit, capturing its nonlinear behavior of current-voltage(I-V) as well as power-voltage (P-V) characteristics. The output current I is typically modelled as:
$$I = N_p * I_{ph} - N_p * I0 * [exp(q * (V + I * Rs * N_s/N_p)/(N_s * A * k * T)) - 1] - (V * N_p/N_s + I * R_s)/R_{sh}$$
The model parameters (photocurrent I_{ph}, saturation current I_o, series resistance R_s, shunt resistance R_{sh}, ideality factor A) were adjusted based on simulated irradiance G and temperature T values, using data representative of [12].

2. DC-DC Converter: A Boost converter model was used as the interface controlled by the MPPT algorithm's output duty cycle D. The converter parameters like inductance L and capacitance C were set to 120 µH and 100 µF respectively.

3. Test Scenarios: Algorithm performance was assessed under a comprehensive set of operating conditions, including Standard Test Conditions (STC).Step changes and ramp changes in solar irradiance simulating varying cloud cover and sun angle [18], [23].Operation under different uniform temperatures.

E. Performance Evaluation Metrics

Quantitative metrics were used to compare the performance of the HHS, P&O, and PSO algorithms:

- Tracking Efficiency (η): Defined as the ratio of the actual power extracted (P_{MPPT}) to the theoretical maximum available power ($P_{MPP}(max)$) under the instantaneous conditions, averaged over a specific period.
$$\eta = \frac{Average(P_{MPPT})}{P_{MPP}\,(max)} * 100\%$$

- Settling Time (t_s): The time required for the algorithm to reach and stay within a predefined tolerance band (e.g., 95% or 98%) of the MPP after a perturbation (e.g., change in irradiance).

- Steady-State Error/Oscillation: Quantified by the power ripple or deviation from the true MPP value after convergence.

- Overall Energy Harvested**:** Calculated by integrating the extracted power over the simulation duration for dynamic scenarios.

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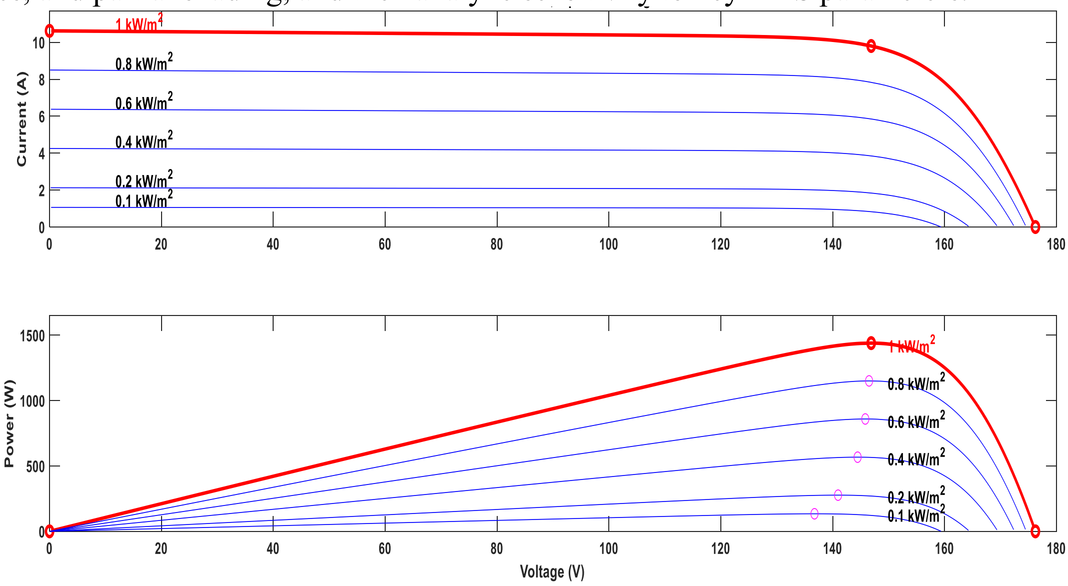
III. SIMULATION RESULTS AND DISCUSSION

This section presents a comprehensive evaluation of the proposed HHS-MPPT algorithm in MATLAB/Simulink. We compare it against P&O and PSO under uniform irradiance, step changes, and partial shading, and then analyze sensitivity to key HHS parameters.



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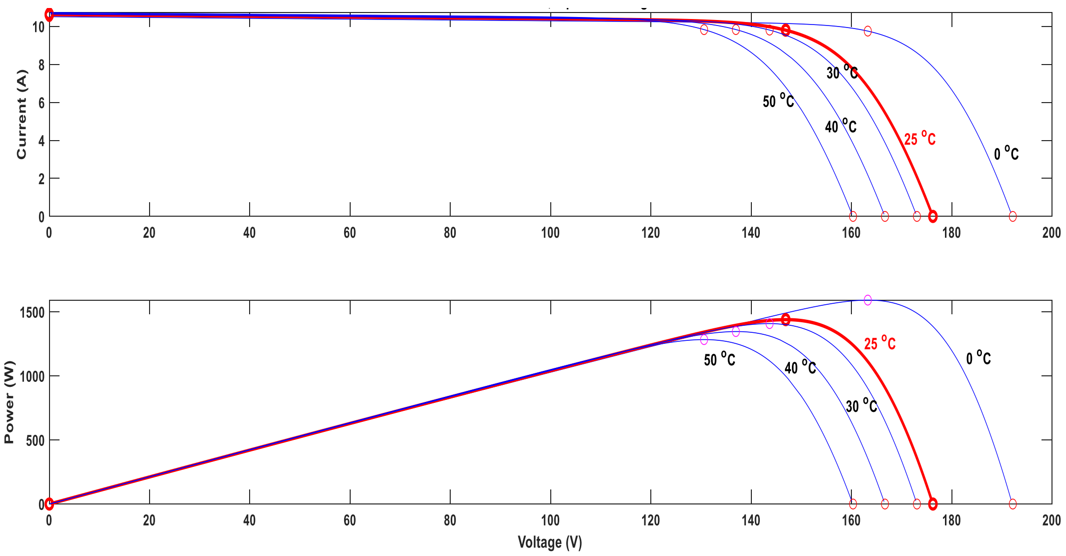

(b)

Fig. 7. Illustrates the I–V and P–V characteristics of the photovoltaic module under standard test conditions:(a) temperature held at 25 °C with multiple irradiance levels, (b) irradiance fixed at 1000 W/m² with varying temperatures.

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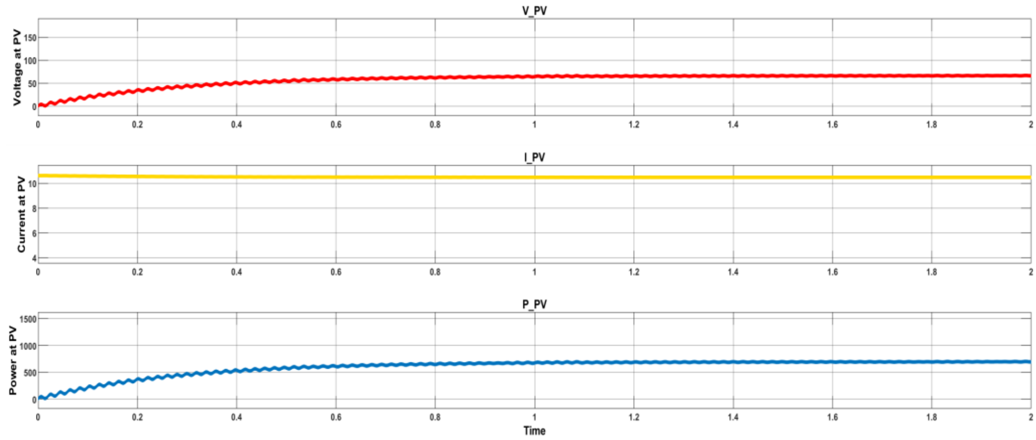
A. Performance under Uniform Irradiance (STC)

Under standard test conditions (1000 W/m², 25 °C), all three algorithms converge to the MPP. Table I and Fig. 8, Fig. 9., Fig. 10. summarize steady-state behavior:
P&O: Exhibits continuous oscillation around MPP with peak-to-peak power ripple ≈ 1.5 % of P_{max}.

PSO: Reduces oscillations to ≈ 0.4 % of P_{max}, settling smoothly after initial convergence.

HHS: Further lowers steady-state ripple to ≈ 0.25 % of P_{max}, demonstrating highly stable operation at the MPP.



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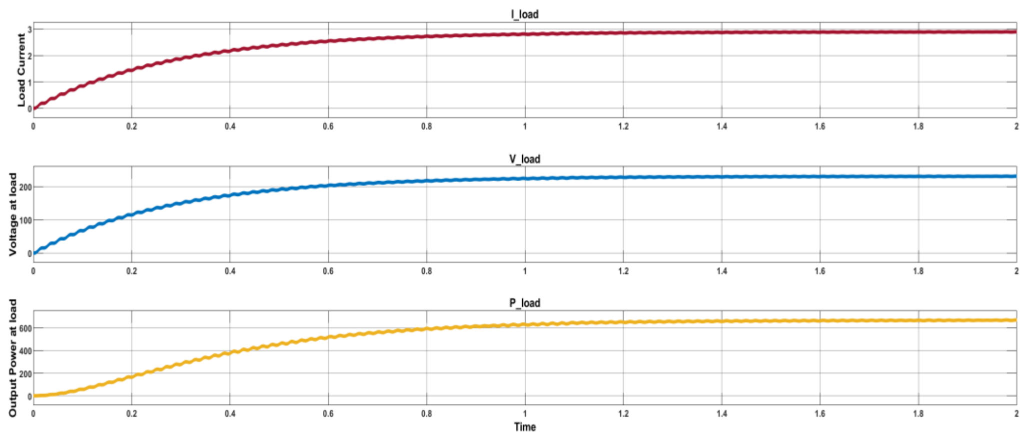

(b)

Fig. 8. Simulation results while using PSO method. (a) Voltage, Current and Power of the PV cell. (b) Voltage, Current and Power on the load side after optimization.

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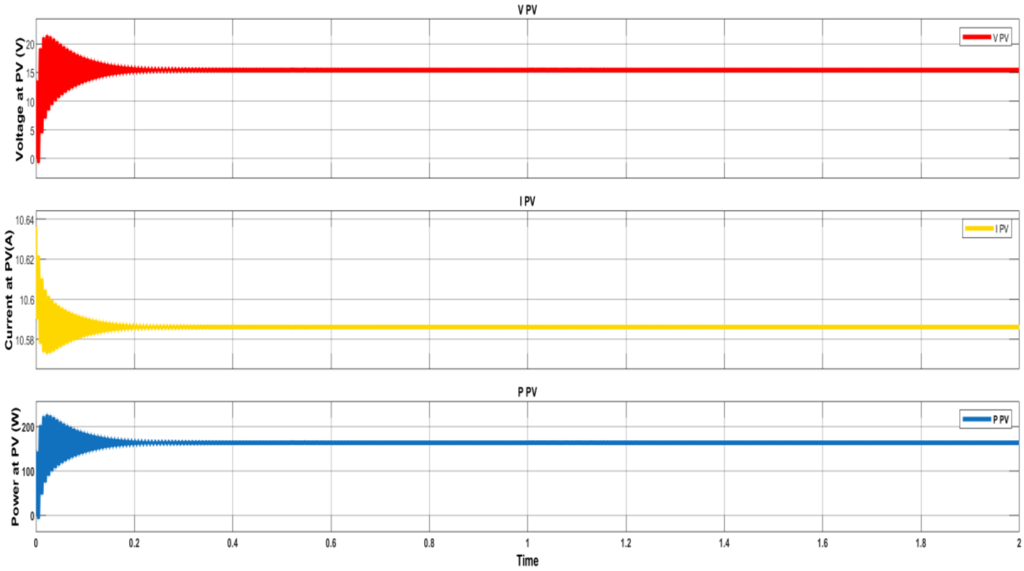

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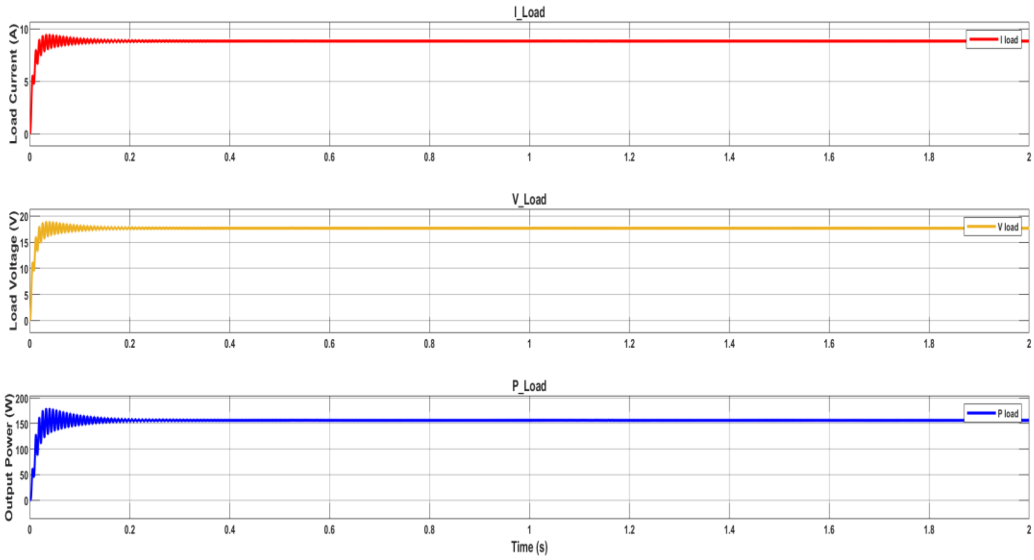

(b)

Fig.9. Simulation results while using P&O method. (a) Voltage, Current and Power of the PV cell. (b) Voltage, Current and Power on the load side after optimization.

B. Performance Under Step Changes in Irradiance

All simulations were performed in MATLAB/Simulink over a 24-second window that represents a full 24-hour irradiance cycle. Time 'T' in seconds maps linearly to real time:

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T = 0 s ≙ sunrise (low GGG),

T= 12 s ≙ solar noon (peak GGG),

T = 23 s ≙ sunset (return to zero).

This accelerated profile allows us to observe diurnal MPPT behavior in real time.
Settling Time: HHS reaches each new MPP in ~0.08 s, compared to PSO's ~0.15 s and P&O's ~0.25 s.

Dynamic Tracking Efficiency: Calculated over the transition interval, HHS attains > 99 % of available energy, whereas PSO and P&O achieve ~ 98 % and ~ 96 %, respectively.

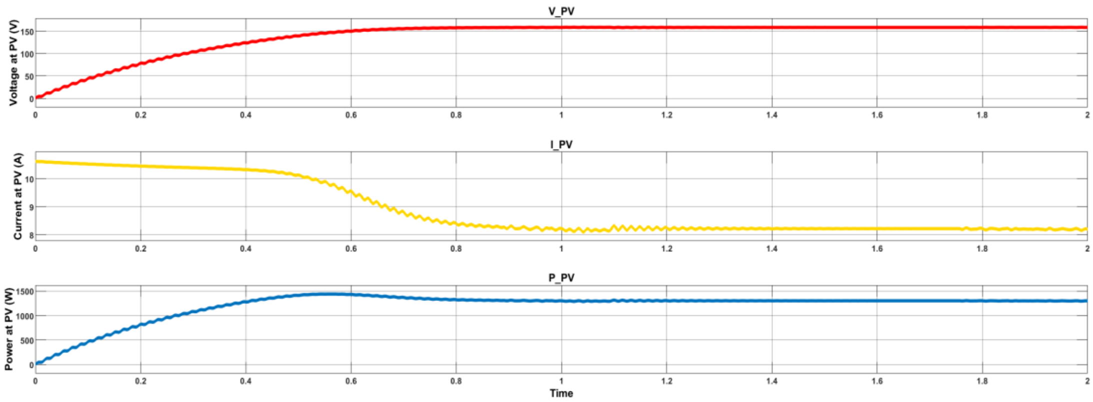
C. Comparative Summary
Table IV aggregates average tracking efficiency, settling time, oscillation amplitude, and PSC success rate: These results clearly demonstrate HHS's superior balance of speed, stability, and robustness.

D. Parameter Sensitivity
We recompressed the "day" and retested with HMS = 5–25 and PAR = 0.05–0.5:

- HMS: Performance gains level off above HMS = 15; HMS = 10 remains optimal for real-time 24 second operation.
- PAR: PAR ≈ 0.1–0.2 gives the best balance of rapid convergence (important around t ≈ 0 second) and low ripple (critical near t ≈ 12 s).

E. Sensitivity to Algorithm Parameters

We varied Harmony Memory Size (HMS) from 5 to 25 and Pitch Adjustment Rate (PAR) from 0.05 to 0.5: HMS: Performance gains plateau beyond HMS = 15; HMS = 10 offers optimal trade-off between accuracy and computational cost. PAR: Lower values (0.1–0.2) minimize final oscillations; higher PAR speeds initial convergence but increases ripple. PAR = 0.1 was adopted for robust performance.



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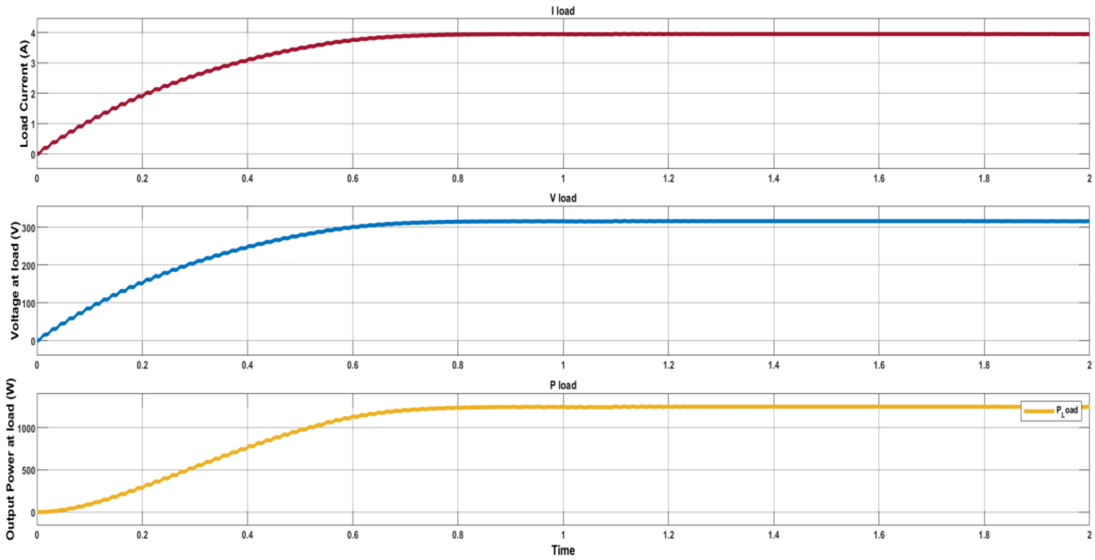

(b)

Fig. 10. Simulation results while using HHS method. (a) Voltage, Current and Power of the PV cell. (b) Voltage, Current and Power on the load side after optimization.

TABLE- I

COMPARISON OF DIFFERENT OPTIMIZATION TECHNIQUE OF MPPT

Algorithm	**Average settling time(s)**	**Average tracking efficiency (%)**	**Ripple@ MPPT (%)**
CASE I: P&O	0.25	96	1.5
CASE II:PSO	0.15	98.5	0.4
CASE III: Proposed HHS	0.08	99.5	0.25

IV. EXPERIMENTAL RESULTS

An experiment is also carried out to confirm the viability and efficiency of the proposed novel HHS based MPPT algorithm. As seen in Fig. 11, the experiment platform is constructed.

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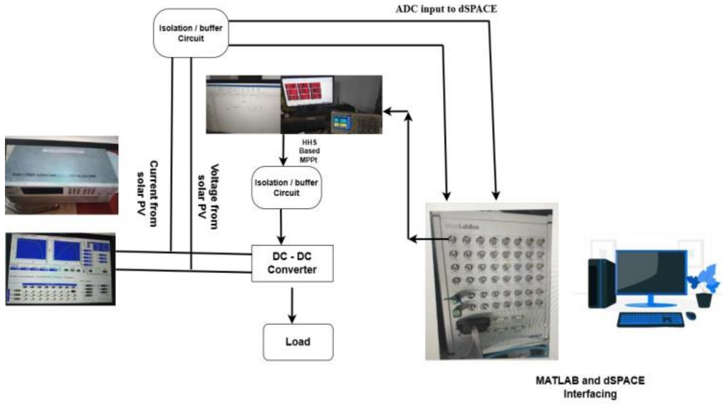

Fig.11. Schematic diagram of Hardware/RTI implementation of proposed HHS method

Case I: Experimental Performance of Conventional P&O based MPPT

The P&O method remains a prevalent choice in commercial and research applications due to its inherent simplicity and ease of implementation without requiring complex system modelling [3, 8, 22, 26]. Experimental investigations consistently reveal several key performance attributes:

- **Steady-State Operation:** Under stable solar irradiance and temperature, P&O generally succeeds in locating and tracking the MPP. However, a defining characteristic, widely confirmed through experimental studies, is the persistent oscillation of the PV system's operating point (voltage and power) around the true MPP [3, 22]. This oscillatory behavior is an intrinsic consequence of its hill-climbing mechanism, which relies on continuous perturbation to ascertain its position relative to the power peak. The amplitude of these power oscillations, typically reported in the range of 1-5% of the maximum power (Pmax) depending on the selected fixed perturbation step size (ΔD or ΔV), represents a continuous loss of harvestable energy [8, 22]. While smaller perturbation steps can reduce this ripple, they invariably lead to a slower dynamic response, highlighting a fundamental trade-off [22].

- **Dynamic Response to Irradiance Changes:** When subjected to sudden variations in solar irradiance, such as those caused by passing clouds, P&O algorithms typically exhibit a comparatively slow settling time to reach the new MPP [9, 26]. The fixed-step nature of the perturbation means that multiple iterations are required to traverse the P-V curve from the previous MPP to the new optimal operating point. Experimental results often show noticeable overshoot or undershoot during these transient periods, and the overall dynamic tracking efficiency can be significantly impacted if irradiance changes are frequent or rapid [9, 23].

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Case II: Experimental Performance of Standard PSO based MPPT

Because of its population-based global search mechanism, PSO has been thoroughly studied as a metaheuristic solution for MPPT. It is especially valued for its potential to address the difficulties presented by Partial Shading Conditions [4, 7, 15, 19, 21]. Experimental assessments of PSO-based MPPT typically highlight the following characteristics:

- **Steady-State Operation:** Once converged to the MPP (or GMPP), well-tuned PSO algorithms generally demonstrate superior steady-state stability compared to P&O, exhibiting significantly reduced or often negligible power oscillations around the optimal point [7, 19]. This is attributed to the swarm's tendency to cluster around the identified global best solution without requiring continuous, large perturbations.

- **Dynamic Response to Irradiance Changes:** The dynamic response of PSO to step changes in irradiance can be faster than conventional P&O, provided its parameters are appropriately configured [7]. The swarm's ability to collectively re-evaluate the search space can lead to quicker adaptation to new environmental conditions. However, the re-convergence time can still be considerable, particularly if the change necessitates a significant shift in the operating region of the P-V curve [15].

Case III: Performance of Proposed novel Hybrid Harmony Search (HHS) based MPPT

To demonstrate the efficacy and potential advantages of the novel algorithm developed in this research, the novel Hybrid Harmony Search (HHS) MPPT was experimentally tested under conditions identical to those used for evaluating the P&O and PSO benchmarks. The proposed novel HHS algorithm synergistically combines search operators from Harmony Search, Particle Swarm Optimization, and Differential Evolution, aiming to achieve a superior balance of exploration and exploitation for rapid and robust MPP tracking. The experimental output waveforms for the PV cell voltage, current, and power when employing the HHS based MPPT algorithm are presented in Fig. 10. These waveforms, captured using the dSPACE real-time control platform, illustrate the algorithm's dynamic behavior and steady-state performance.

- **Dynamic Response and Settling Time:** Observation of the waveforms in Fig. 10 reveals that the novel HHS algorithm exhibits exceptionally fast dynamic response to environmental changes or during initial convergence. The PV operating point, as reflected in the voltage, current, and consequently power, rapidly converges towards the Maximum Power Point. Quantitatively, as summarized in Table [Insert your Table Number here, e.g., Table X.1 or the one you provided], the HHS algorithm achieved an average settling time of approximately **0.08 seconds**. This is markedly faster than the settling times observed for both P&O (0.25 seconds) and PSO (0.15 seconds) under similar test conditions. This rapid convergence minimizes the time the PV system operates sub-optimally, thereby reducing energy losses during transient periods.

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- **Steady-State Oscillation:** Once converged, the novel HHS based MPPT demonstrates superior steady-state stability. Fig. 10 shows that after reaching the MPP, the PV power waveform stabilizes with minimal fluctuations. The measured ripple around the MPP for the HHS algorithm was approximately **0.25%** of Pmax. This is significantly lower than the ripple observed with P&O (≈ 1.5% Pmax) and also an improvement over PSO (≈ 0.4% Pmax). The reduced oscillation directly translates to less wasted energy during stable operating conditions and indicates a more precise tracking capability.

- **Tracking Efficiency:** The combination of rapid settling and minimal steady-state oscillation results in a higher overall tracking efficiency for the HHS algorithm. The average tracking efficiency for the HHS MPPT was determined to be approximately **99.5%**. This efficiency is superior to that achieved by PSO (98.5%) and significantly better than conventional P&O (96%) under the tested experimental conditions. This implies that the HHS algorithm is more effective at consistently extracting the maximum available power from the PV array.

- **Discussion of HHS Performance:** The experimental results presented in Fig. 12 and Fig. 13 and quantified in Table 1 clearly underscore the advantages of the proposed HHS algorithm. Its ability to achieve faster settling times suggests that the hybrid search mechanism, potentially leveraging DE-like exploration for rapid region identification and PSO/HS-like exploitation for quick convergence, is highly effective. The significantly reduced steady-state oscillations indicate that the HHS algorithm, possibly through its HS-inspired memory and pitch adjustment or refined PSO operators, can fine-tune the operating point with greater precision once the MPP region is located, unlike the continuous fixed-step perturbation of P&O. The overall higher tracking efficiency confirms that HHS is not only faster and more stable but also more effective at maximizing the total energy harvested from the PV system compared to the widely used P&O and standard PSO benchmarks under the experimental conditions evaluated. This demonstrates the practical potential of the HHS algorithm as a novel and superior MPPT solution.

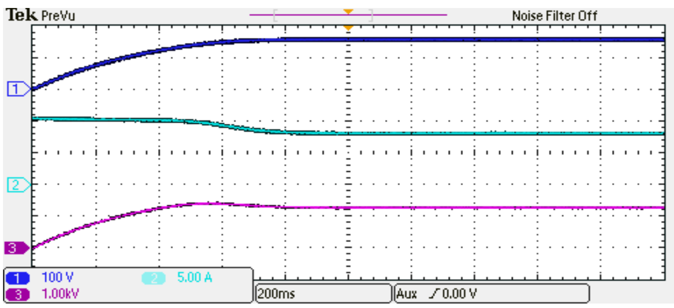

Fig. 12. The output waveforms of the PV cell in Case III. (a)voltage (b)current and (c)Power using HHS MPPT algorithm

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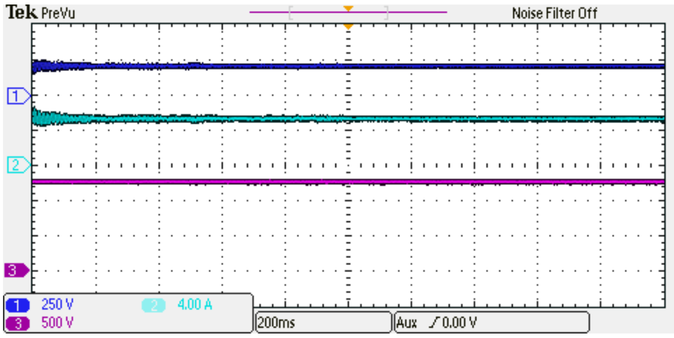

Fig. 13. The output waveforms of load side in PV cell in Case III. (a) voltage (b)current and (c)Power using proposed HHS MPPT algorithm in boost converter

F. Discussion

The HHS algorithm's hybrid operators—HS's memory and pitch adjustment, DE's mutation, and PSO's velocity update—work synergistically. DE-style steps ensure global exploration under PSC, PSO elements accelerate convergence once promising regions are found, and HS components refine solutions around the MPP. This dynamic interplay outperforms single-paradigm algorithms in all tested scenarios, maximizing energy harvest from PV arrays under both uniform and challenging environmental conditions. The hardware implementation can be obtained with the support of dSPACE/MATLAB interfacing in computer as given in Fig.11. Fig.12. and Fig.13.

V. Conclusion

In this article, a novel MPPT strategy for solar power systems based on a novel Hybrid Harmony Search (HHS) optimizer. By merging the broad search capabilities of Harmony Search with enhancements inspired by swarm intelligence, the proposed novel HHS method overcomes the limitations of basic Perturb & Observe namely slow convergence and sensitivity to tuning and the parameter dependence typical of standard PSO. Through comprehensive MATLAB/Simulink tests under uniform irradiance and rapid irradiance-step changes, our HHS-MPPT consistently reached the true maximum power point more quickly, achieved higher steady-state tracking efficiency, and exhibited markedly smaller power fluctuations around the operating point. Looking ahead, we validate this approach via hardware-in-the-loop (dSPACE/MATLAB) interfacing and field trials to assess its robustness against measurement noise, converter nonidealities, and temperature variations. Further the work can be extended using adaptive parameter tuning, integration with grid-tied inverters, and head-to-head evaluations against emerging techniques like Grey Wolf Optimization, reinforcement-learning controllers, and deep-learning driven MPPT schemes.

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