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Performance Comparison of Grey Wolf Optimization and Horse Herd Optimization for MPPT in Solar Photovoltaic Systems

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***Abstract*— This research paper presents a comprehensive comparative analysis of the Grey Wolf Optimization (GWO) and Horse Herd Optimization (HHO) algorithms for Maximum Power Point Tracking (MPPT) in solar photovoltaic systems. Both metaheuristic algorithms were implemented in a MATLAB/Simulink environment and evaluated on a PV system consisting of three series-connected modules with 60 cells. Performance was assessed under both uniform irradiation and challenging non-uniform irradiation conditions (1000 W/m², 800 W/m², and 300 W/m²) to test their ability to track global maximum power points while avoiding local maxima. Results demonstrate that both algorithms successfully tracked the global maximum power point in all test scenarios, with HHO exhibiting slightly faster convergence characteristics while GWO demonstrated superior steady-state stability after convergence. The HHO algorithm's multi-behavior approach (grazing, hierarchy, sociability, imitation, defense, and roaming) provides rich search capabilities, while GWO's simpler hierarchical structure offers implementation advantages for resource-constrained systems. Control signals generated by both algorithms remained stable with minimal oscillations around optimal points. This research contributes valuable insights for optimizing renewable energy systems and suggests potential future research directions, including hybrid approaches combining the strengths of both algorithms, real-time implementation under varied environmental conditions, and integration with advanced power electronics topologies and solar technologies.**

***Keywords*— PV System, MPPT Tracking, MATLAB/Simulink, HHO, GWO**

I. INTRODUCTION

Photovoltaic solar power systems are a crucial component of sustainable energy generation, as shown by the global shift to renewable energy sources [1]. These systems convert solar irradiance into electrical power using semiconductor materials, but their efficiency is generally low typically around 16-17% and strongly affected by external factors like ambient temperature and solar irradiation [2]. As a result, Maximum Power Point Tracking (MPPT) is essential to ensure that PV systems operate at their optimum power point under varying environmental conditions [3]. The challenges in solar energy utilization include the non-linear relationship between irradiance, temperature, and the generated power of PV modules, which requires MPPT algorithms for optimal energy harvesting. The algorithms used in MPPT are important to boosting the overall effectiveness as well as performance of the systems, as they dynamically adjust operating points to optimize power output in changing environmental conditions. MPPT can be achieved either by physical methods (adjusting panel tilt) or electrical techniques (adjusting voltage/current via controllers) [4]. However, traditional MPPT methods like Perturb and Observe (P&O) and Incremental Conductance (IC) suffer from slow convergence and instability, especially in the presence of partial shading conditions (PSC), which introduce multiple local maxima on the power-voltage(P-V) curve [5].

To overcome these challenges, metaheuristic algorithms, inspired by nature and artificial intelligence [6], have gained popularity in recent years. These methods are known for their ability to explore complex, non-linear search space and avoid local optima [7]. Several such algorithms have been proposed for MPPT, including Genetic Algorithms (GA) [8], Deep learning[9], Cuckoo Search (CS) [10], Grasshopper Optimization Algorithm (GOA) [11], Dragonfly Algorithm (DA) [12][13], and Fuzzy Logic Controllers 9FLC) [14].

The combination of metaheuristic MPPT algorithm with various power electronic topologies, including as boost, buck, buck-boost, and Cuk converters, has also been an area of recent research to improve MPPT performance under practical circumstances [15]. Among the emerging MPPT strategies, Grey Wolf Optimization (GWO) [16], [17]and Horse Heard Optimization (HHO) [18], [19] have shown promising results due to their fast convergence and effective exploration-exploitation balance.

GWO provides a strong search mechanism that strikes an appropriate equilibrium between exploration and exploitation. Due to its versatility in solving intricate optimization challenges, it is often employed for MPPT in solar energy systems. In contrast, HHO, a more contemporary algorithm that draws guidance from horse herds' behavioral patterns, exhibits quick convergence and flexibility, making it a competitive option in dynamic optimization situations.

This research presents a comparative analysis of the GWO and HHO algorithms in MPPT for PV systems. By implementing these algorithms in a MATLAB Simulink environment and evaluating their performance using real-time temperature and sun irradiance data. The goal is to evaluate their performance bades on tracking speed, accuracy, stability, and ability to avoid local maxima.

II. SYSTEM DESCRIPTION

The photovoltaic (PV) system under study is modeled using MATLAB/Simulink, comprising a PV array, a DC-DC boost converter, a resistive load, and a dynamic control block implementing the MPPT algorithms- Grey Wolf Optimization (GWO) and Horse Heard Optimization (HHO). This setup is designed to evaluate the tracking performance of both algorithms under dynamic irradiance conditions.

A. PV Array Configuration

The PV array itself is made up of three identical series-connected modules, with each module consisting of 20 PV cells, totaling a total of 60 cells per string. This arrangement provides an adequately high voltage output with resolution in modeling under the two main irradiation scenarios is done:

- Under irradiance: All modules receive 1000 W/m^2.
- Non-uniform irradiance: Modules receive 1000 W/m^2, 800 W/m^2,300 W/m^2, respectively.

The non-uniform state is utilized to mimic partial shading, which adds several local maxima on the power-voltage (P-V) curve and tests the MPPT controller to keep away from suboptimal power points [8], [20].

PV Module Electrical Parameters. Table 1 lists the key specifications of the simulated PV modules

Table 1. Specification of PV system.

Parameter	Value
Number of modules (in series)	3
Number of cells per module	20
Total number of cells	60
Maximum Power (Pmax)	83.28 W
Open Circuit Voltage (Voc)	12.64 V
Short Circuit Current (Isc)	8.60 A
Voltage at MPP (Vmp)	10.32 V
Current at MPP (Imp)	8.07 A

III. GREY WOLF OPTIMIZATION ALGORITHM FOR MPPT

A population-based metaheuristic optimization method that is bioinspired, the grey wolf optimization (GWO) algorithm mimics the social structure and hunting tactics of grey wolves in the wild. The candidate solution population (search agents) is devided into four hierarchical levels [21]:

- Ǘ(alpha): the optimum best thus far,
- ɓ (beta) and ǚ (delta): second and third best,
- ɤ (omega): all the remaining agents following the top three.

The Fig. 1 shows how the groupôs members are all subject to an extremely rigid social dominance hierarchy.

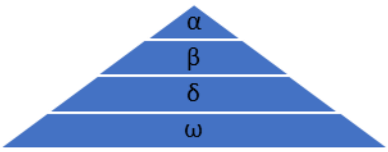

Fig.1. The social organizational structure of Grey Wolves

The architecture replicates the cooperative alpha leader-dependent hunting behaviour in wolf packs. The location of every search agent is updated using the locations of Ǘ, ɓ, and ǚ wolves.

The main phases of the hunting process are:

- Encircling the prey
- Hunting in packs of elite wolves
- Attacking and converging on the prey

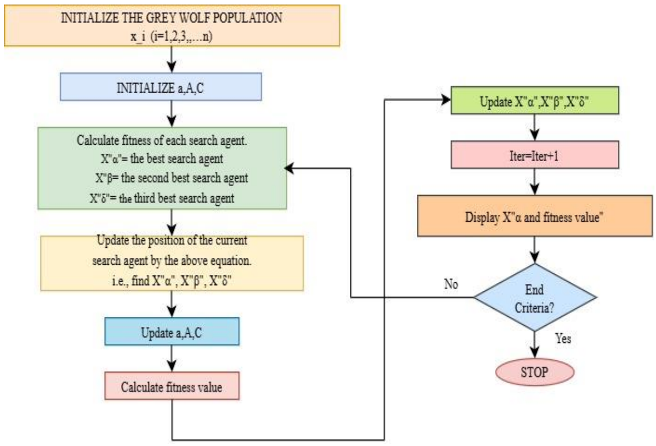

Fig.2. Flowchart of GWO-based MPPT

A. Mathematical Modeling of GWO

The position update equations in GWO are as follows [10]:

Encircling behavior:

$$\vec{D} = |\vec{C}\cdot\vec{X_p} - \vec{X}(t)| \quad (1)$$

$$\vec{X}(t+1) = |\vec{X_p}(t)\ \text{ï}\ \vec{A}\cdot\vec{D}| \quad (2)$$

Where,

- $\vec{X_p}$ is the prey (estimated best solution),
- $\vec{X}$(t) is the current position,
- $\vec{A}$, $\vec{C}$ are coefficient vector defined as:
  $\vec{A} = 2\,\vec{a}\,.\vec{r1}\ \text{ï}\ \vec{a}$, $\quad \vec{C} = 2.\vec{r2}$
- $\vec{r1}, \vec{r2}$ are random vector in [0,1],
- $\vec{a}$ decreases linearly from 2 to 0 over the course of iterations.

Position update using Ǘ, ɓ, ǚ Wolf:

$$\vec{X1} = \vec{X\alpha}\ \text{ï}\ \vec{A1}\ .\ |\vec{C1}.\vec{X\alpha} - \vec{X}(t)| \quad (3)$$

$$\vec{X2} = \vec{X\beta}\ \text{ï}\ \vec{A2}\ .\ |\vec{C2}.\vec{X\beta} - \vec{X}(t)| \quad (4)$$

$$\vec{X3} = \vec{X\delta}\ \text{ï}\ \vec{A3}\ .\ |\vec{C3}.\vec{X\delta} - \vec{X}(t)| \quad (5)$$

$$\vec{X}(t+1) = \frac{1}{3}(\vec{X1} + \vec{X2} + \vec{X3}) \quad (6)$$

This allows all other Wolf to update their positions concerning the top three leaders, guiding convergence toward the best solution. And in the context of MPPT, each search agent represents a potential duty cycle for the boost converter. The fitness function is defined as the instantaneous power output of the PV systems:

$$\text{Fitness} = P(t) = V_{pv}(t) \,.\, I_{pv}(t)$$

IV. HORSE HEARD OPTIMIZATION ALGORITHM FOR MPPT

Metaheuristic optimization techniques have recently become popular in many applications for designing MPPTs installed with solar PV systems. It is a relatively recent nature-inspired metaheuristic designed to solve complex, high-dimensional

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optimization problems by modeling the herd behavior of horses [11].

Horses share a variety of behaviors based on social stats and age. Population in HHO is divided according to age ranges, each set with a selection of motion dynamics:

Maximum lifetime of a Horse is about 25-30 years.

δ = 0-5 years

γ = 5-10 years

β = 10-15 years

α = Horses older than 15 years

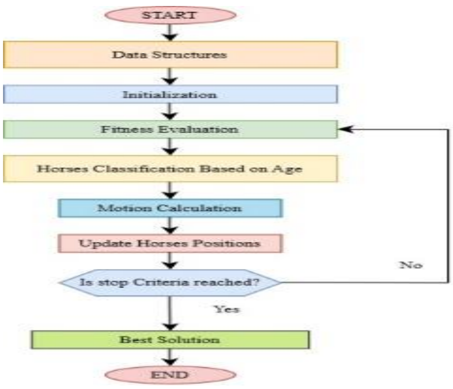

Fig.3. Flowchart of HHO-based MPPT

A. Mathematical Modeling of HHO

Each horse's new position is determined by its current velocity and position:

$$X_i^{age} = X_{i-1}^{age} + V_i^{age} \quad (7)$$

Where:

- X_i^{age} is the updated position (duty cycle) at interation I,
- V_i^{age} is the velocity vector depending on behavioral factors,
- "age" denotes one of the four horse classes (α, β, γ, δ).

The velocity V_i^{age} is computed as a weighted sum of behavior-based motion vectors:

For example, for middle-aged horses (γ):

$$V_i^{\gamma} = G_i^{\gamma} + H_i^{\gamma} + S_i^{\gamma} + I_i^{\gamma} + D_i^{\gamma} + R_i^{\gamma} \quad (8)$$

In this equation, each component is updated in each iteration using specific equations and a damping factor. These vectors drive exploration (grazing, roaming) and exploitation (hierarchy, imitation, defense).

For example:

- Grazing behavior

$$G_i^{age} = g_i\,(U + pL).X_{i-1}^{age} \quad (9)$$

Where U, L are upper/lower bounds, p is a random number in [0,1].

- Imitation and sociability help to learn from the best performers

$$I_i^{\gamma} = {}_i^{\gamma}\,(1/pN \sum_{j=1}^{pN} \hat{x}_j) \quad (10)$$

Where pN is the number of top-performance individuals (usually 10%).

- Defense behavior to avoid bad solutions by pushing the hose away from worst positions

$$D_i^{\beta} = -d_i\,(1/qN \sum_{j=1}^{pN} \hat{x}_j - X_{i-1}) \quad (11)$$

The HHO algorithm aims to maximize the PV power output, defined by the fitness function:

$$\text{Fitness} = P(t) = V_{pv}(t)\,.\,I_{pv}(t)$$

V. RESULT

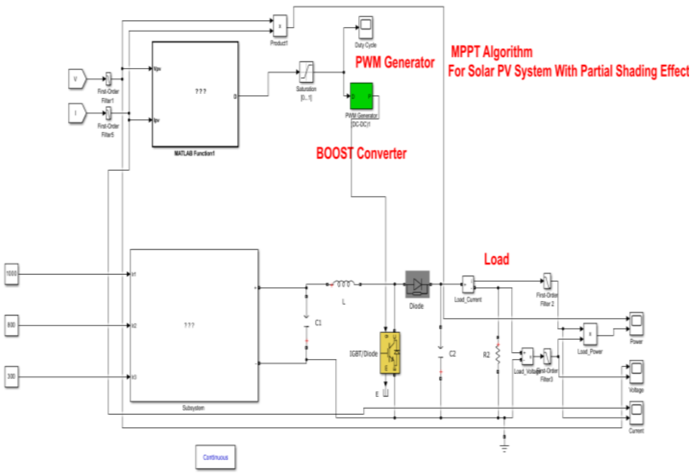

Fig.4. Overall MATLAB/ Simulink diagram

To compare the tracking performance of Grey Wolf Optimization (GWO) and Horse Herd Optimization (HHO) algorithms, the simulations were performed in the MATLAB/Simulink environment under uniform and non-uniform irradiance. The system was exposed to a partial shading case with irradiance of 1000 W/m^2, 800 W/m^2, 300 W/m^2 on three PV modules respectively.

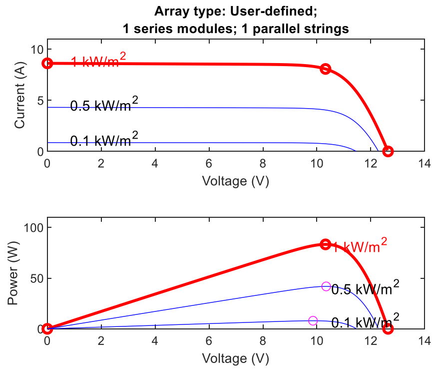

Fig.6. (I-V) and (P-V) Characteristics Curve

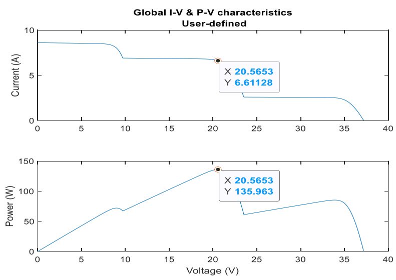

Fig.7. I-V and P-V Characteristics Curve for non-uniform shading condition

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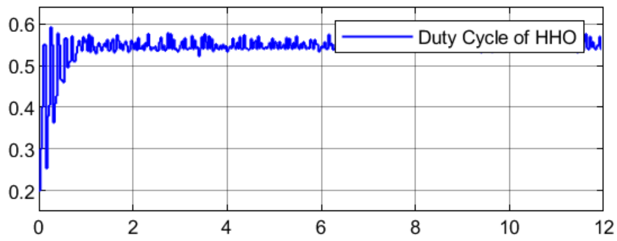
Three consistent but highly time-varying irradiation levels are depicted using I-V and P-V characteristic curves in Fig. 6 for example. The curve indicates that power and current change proportionately to an increase in irradiation. The P-V curve displays a single peak value when the radiation levels of the three PV modules are equal. However, under partial shading, as shown in Fig.7. Multiple peaks appear, making it challenging for traditional MPPT methods to locate the true GMPP.

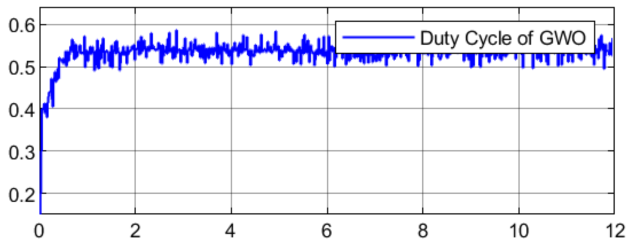
In the non-uniform case:

- The global maximum power reached was 135.96 W at 20.56 V.
- Multiple local maxima were observed, confirming the need for advanced MPPT algorithms.

Figure 8 shows the duty cycle signals generated by both algorithms.



HHO

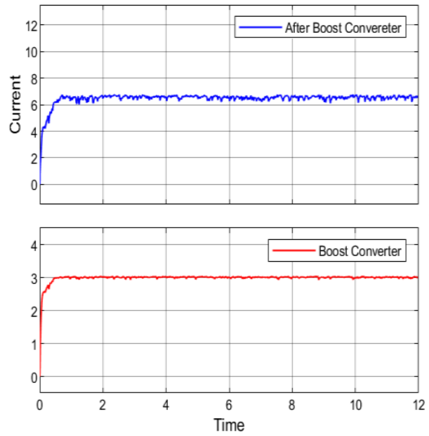


GWO

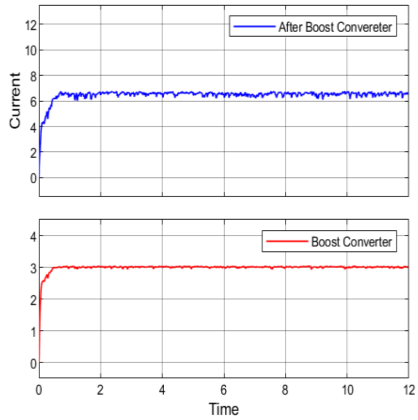
Fig.8. Duty Cycle Response

- HHO algorithm achieves quick convergence with minimal overshoot, which indicates that it can rapidly identify the optimal operating point, making it suitable for real-time tracking in rapidly changing environments.
- GWO algorithm output shows slower rise time but more stable oscillation near the MPP.

Figure 9 shows the input and output current and voltage waveforms of boost converter. Both have constant stability with minor fluctuations.

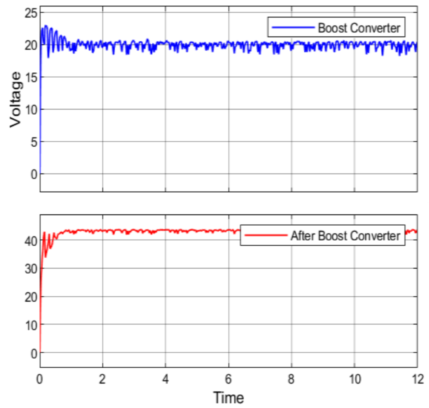


HHO

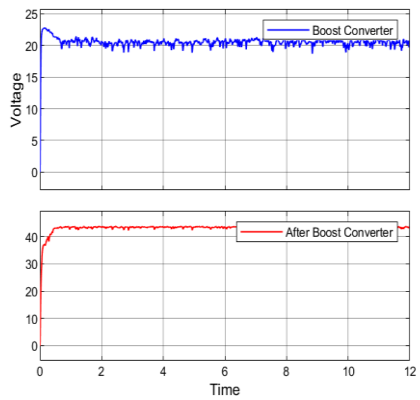


GWO

Fig.9. Current waveforms



HHO



GWO

Fig.10. Voltage waveforms

- HHO output shows slightly faster stabilization of current and voltage waveforms. Due to which HHO is better suited for a dynamic environment.
- GWO output shows lower ripple in steady-state, indicating better long-term voltage stability, which shows that it will perform better in steady conditions.

Figure 11 shows the power outputs of both algorithms. This shows that both methods successfully tracked the global maximum power point, even in the presence of multiple local maxima.

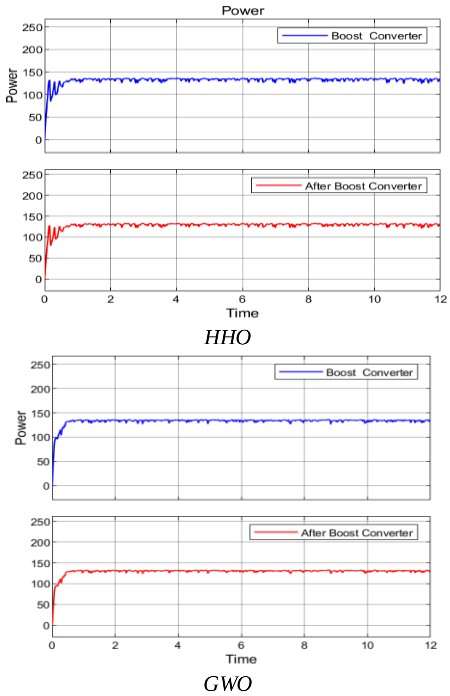


Fig.10. Power Output

- HHO reaches the maximum power level faster. It suggests that HHO is preferable when rapid adaptation is required (e.g., moving clouds).
- GWO demonstrated smoother power tracking post-convergence. It suggests that GWO is advantageous for systems requiring high steady-state accuracy with less oscillation.

VI. CONCLUSION

This study presents a deep comparative analysis of GWO and HHO algorithms for MPPT tracking in solar photovoltaic systems. After lengthy simulation and analysis of comprehensive simulations within the MATLAB/Simulink environment, several impressive results emerge.

1. Performance under variable conditions:

• In both uniform and non-uniform irradiation scenarios, both algorithms were able to monitor the global maximum power point.

• The HHO algorithm presented slightly faster convergence characteristics than GWO, especially in changing environments.

• Both methods successfully avoided the local maxima traps during partial shading scenarios, which was a confirmation of their robustness for real applications

2. Control Characteristics

• The control signals generated through both algorithms, duty cycle control, were stable, and HHO possessed marginally smaller oscillations about the optimal point.

• GWO showed excellent steady-state stability after convergence.

• Both algorithms had high tracking accuracy with minor power fluctuations

3. System Output Parameters:

• The output current, voltage, and power waveforms show that the two algorithms effectively optimize the PV system's power extraction.

• Under non-uniform irradiation conditions (1000 W/m², 800 W/m², and 300 W/m²), both algorithms successfully detected and followed the global maximum power point.

• Boost Converter operation depicted reliable performance due to both control strategies

4. Implementation Considerations:

• HHO's multi-behavior approach, including grazing, hierarchy, sociability, imitation, defense, and roaming, offers richer search capabilities.

• GWO has a less complex hierarchical structure and is thus easier to implement, potentially advantageous for resource-constrained systems.

• Both algorithms show good scalability for various configurations of PV systems

These results indicate that though both algorithms are suitable for MPPT applications, the choice might depend on certain implementation conditions. HHO would be preferable if faster convergence is required, while GWO might be beneficial if simplicity of implementation is considered crucial in an application.

A. Possible future research avenues are:

Hybrid approaches: Exploring ways to combine the merits of both algorithms Real-time implementation and validation: Experimentation and validation under different environmental conditions. • Integration of these algorithms with advanced power electronics topologies. • Adaptation of these algorithms to bifacial PV systems and advanced solar technologies This work adds to the literature on the optimization of renewable energy and will provide valuable insights to practitioners and researchers in area of renewable energy systems.

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REFERENCES

[1] M. M, C. V, K. Punitha, and P. A, “Design of Novel Optimization Algorithm based Maximum Power Point Tracking for Solar Photovoltaic Application,” in 2023 IEEE World Conference on Applied Intelligence and Computing (AIC), IEEE, Jul. 2023, pp. 99–105. doi: 10.1109/AIC57670.2023.10263846.

[2] K. Kayisli, “Super twisting sliding mode-type 2 fuzzy MPPT control of solar PV system with parameter optimization under variable irradiance conditions,” Ain Shams Engineering Journal, vol. 14, no. 1, p. 101950, Feb. 2023, doi: 10.1016/j.asej.2022.101950.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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[3] A. Yadav, K. Chandrasekaran, V. Hari Priya, and D. Suresh, Emerging Technologies & Applications in Electrical Engineering. London: CRC Press, 2024. doi: 10.1201/9781003505181.

[4] K. Punitha et al., "An Optimization Algorithm for Embedded Raspberry Pi Pico Controllers for Solar Tree Systems," Sustainability, vol. 16, no. 9, p. 3788, Apr. 2024, doi: 10.3390/su16093788.

[5] E. Halassa, L. Mazouz, A. Seghiour, A. Chouder, and S. Silvestre, "Revolutionizing Photovoltaic Systems: An Innovative Approach to Maximum Power Point Tracking Using Enhanced Dandelion Optimizer in Partial Shading Conditions," Energies (Basel), vol. 16, no. 9, p. 3617, Apr. 2023, doi: 10.3390/en16093617.

[6] A. Hilali, Y. Mardoude, A. Essahlaoui, A. Rahali, and N. El Ouanjli, "Migration to solar water pump system: Environmental and economic benefits and their optimization using genetic algorithm Based MPPT," Energy Reports, vol. 8, pp. 10144–10153, Nov. 2022, doi: 10.1016/j.egyr.2022.08.017.

[7] S. Sahoo, S. K. M ishra, and J. K. Sahu, "Standalone PV System Integrated with Hysteresis Current Controlled Inverter using MPPT Techniques," in 2019 International Conference on Communication and Electronics Systems (ICCES), IEEE, Jul. 2019, pp. 2024–2029. doi: 10.1109/ICCES45898.2019.9002384.

[8] F. Belhachat and C. Larbes, "Comprehensive review on global maximum power point tracking techniques for PV systems subjected to partial shading conditions," Solar Energy, vol. 183, pp. 476–500, May 2019, doi: 10.1016/j.solener.2019.03.045.

[9] V. S. D. D. V. S. K. Punitha, "Deep learning based maximum power point prediction for Arduino controlled solar water pumping systems," Songklanakarin Journal of Science and Technology, vol. 44, pp. 884–891, 2022.

[10] A. F. Shalal, M. Aljanabi, and A. N. Al-Shamani, "Modified tracking mechanism of horse optimization method (HOM) based MPPT technique for photovoltaic (PV) systems," 2024, p. 060008. doi: 10.1063/5.0200083.

[11] A. Fathy, A. Ben Atitallah, D. Yousri, H. Rezk, and M. Al-Dhaifallah, "A new implementation of the MPPT based raspberry Pi embedded board for partially shaded photovoltaic system," Energy Reports, vol. 8, pp. 5603–5619, Nov. 2022, doi: 10.1016/j.egyr.2022.04.035.

[12] G. Aihua, X. Yihan, and A. Rezvani, "Performance improvement of maximum power point tracking for photovoltaic system using grasshopper optimization algorithm based ANFIS under different conditions," Optik (Stuttg), vol. 270, p. 169965, Nov. 2022, doi: 10.1016/j.ijleo.2022.169965.

[13] B. Aljafari, P. R. Satpathy, and S. B. Thanikanti, "Partial shading mitigation in PV arrays through dragonfly algorithm based dynamic reconfiguration," Energy, vol. 257, p. 124795, Oct. 2022, doi: 10.1016/j.energy.2022.124795.

[14] K. Kayisli, "Super twisting sliding mode-type 2 fuzzy MPPT control of solar PV system with parameter optimization under variable irradiance conditions," Ain Shams Engineering Journal, vol. 14, no. 1, p. 101950, Feb. 2023, doi: 10.1016/j.asej.2022.101950.

[15] K. P. R. M. V. S. V.Seetharaman, "Comparative analysis of PV based Cascaded Buck Boost converter for water pump applications," vol. 63, no. 6, 2020.

[16] T. Nagadurga, P. V. R. L. Narasimham, V. S. Vakula, and R. Devarapalli, "Gray wolf optimization-based optimal grid connected solar photovoltaic system with enhanced power quality features," Concurr Comput, vol. 34, no. 5, Feb. 2022, doi: 10.1002/cpe.6696.

[17] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey Wolf Optimizer," Advances in Engineering Software, vol. 69, pp. 46–61, Mar. 2014, doi: 10.1016/j.advengsoft.2013.12.007.

[18] F. MiarNaeimi, G. Azizyan, and M. Rashki, "Horse herd optimization algorithm: A nature-inspired algorithm for high-dimensional optimization problems," Knowl Based Syst, vol. 213, p. 106711, Feb. 2021, doi: 10.1016/j.knosys.2020.106711.

[19] S. Sarwar, M. A. Hafeez, M. Y. Javed, A. B. Asghar, and K. Ejsmont, "A Horse Herd Optimization Algorithm (HOA)-Based MPPT Technique under Partial and Complex Partial Shading Conditions," Energies (Basel), vol. 15, no. 5, p. 1880, Mar. 2022, doi: 10.3390/en15051880.

[20] E. N. Sholikhah, N. A. Windarko, and B. Sumantri, "Tunicate swarm algorithm based maximum power point tracking for photovoltaic system under non-uniform irradiation," International Journal of Electrical and Computer Engineering (IJECE), vol. 12, no. 5, p. 4559, Oct. 2022, doi: 10.11591/ijece.v12i5.pp4559-4570.

[21] J. Águila-León, C. Vargas-Salgado, D. Díaz-Bello, and C. Montagud-Montalvá, "Optimizing photovoltaic systems: A meta-optimization approach with GWO-Enhanced PSO algorithm for improving MPPT controllers," Renew Energy, vol. 230, p. 120892, Sep. 2024, doi: 10.1016/j.renene.2024.120892.