International Journal of Energetica (IJECA)
https://www.ijeca.info
ISSN: 2543-3717 Volume 9. Issue 1. 2024
Page 17-23

Application of Grey Wolf Optimization Algorithm for Maximum Power Point Tracking of Solar Panels

Fethi Khelaifa [1*], Kheireddine Lamamra[1], Djaafar Toumi[1]

[1]*Laboratory of Electronics and New Technologies-LENT-, Larbi Ben M'hidi University Oum El Bouaghi, ALGERIA*

**Corresponding author: Email: fethi.khe01@gmail.com*

Abstract – *One of the applications of evolutionary algorithms is increasing the efficiency of photovoltaic (PV) systems. The main problem with using standard algorithms like the Incremental Conductance (IC) controller for maximum power point tracking (MPPT) under partial shading conditions (PSC) is that they do not provide reliable tracking of the global peak of the volt-watt characteristic, leading to increased losses and reduced power plant performance. Furthermore, there is currently no methodology for selecting the optimal sampling time of soft computing algorithm-based maximum power trackers for PV systems. The aim of this paper is to apply the Grey Wolf technique with optimally selected sampling time, which will result in fast and reliable tracking of the global maximum point of the PV panels. The results show that the selected optimal sampling time for the digital MPP controllers can increase the performance and efficiency of MPPT controllers. A DC-DC boost converter is used to match the PV panels with the resistive load. Several simulations were performed using MATLAB/Simulink to examine the performance of the proposed system. The results demonstrate that the proposed Grey Wolf algorithm can quickly capture the GMPP within 0.2 seconds under different shading conditions of the PV panels.*

Keyword: MPPT, partial l shading, tracking time, grew wolf optimization, Dc-DC converter

Received: 06/02/2024 – Revised: 22/03/2024 - Accepted: 08/04/2024

I. Introduction

The sun is a highly promising and compelling energy source due to its inherent qualities of being free, environmentally friendly, and an inexhaustible reservoir of energy. Currently, photovoltaic (PV) systems are gaining significant attention and are being widely applied in various contexts, including water pumping systems [1-4], particularly in isolated areas where electricity is inaccessible. Additionally, recent applications focus on using solar energy for standalone electric vehicle (EV) charging [5, 6].

In direct-coupled PV panel-to-load systems, the operating point can be anywhere on the power-voltage (P-V) curve, rarely coinciding with the maximum power point (MPP). This misalignment reduces energy utilization efficiency and leads to the over-sizing of the system, resulting in additional costs. The primary challenge is the dynamic nature of the MPP position, which fluctuates based on weather conditions and variations in the connected load. Therefore, achieving optimal power extraction under varying irradiation and temperature conditions is imperative, given the relatively high cost of PV energy. To address this, an efficient Maximum Power Point Tracking (MPPT) control mechanism is crucial [7, 8].

The complete solar system comprises a PV module, an MPPT controller, a DC-DC boost converter, and the load to be charged. The DC-DC boost converter is employed to elevate the PV voltage to the desired load voltage, thereby ensuring that the load receives the maximum power from the solar PV module. Various MPPT algorithms, including modified Perturb and Observe (P&O) and firefly algorithms, are utilized to maintain the PV module at its MPP. These algorithms adjust the duty cycle applied to the main switching component of the DC-DC boost converter, commonly a MOSFET switch [9].

Various conventional methodologies, including Perturb and Observe (P&O), incremental conductance, constant voltage, and others, have been devised to determine the MPP of a solar array operating under uniform solar irradiance within a PV system. While these techniques demonstrate effectiveness in identifying local maxima, they fall short in accurately extracting the global maximum power point (GMPP) in scenarios of partial shading conditions (PSC) affecting PV panels [10].

In instances of PSC, the photovoltaic characteristics become notably intricate, featuring multiple local peaks (LPs) alongside a singular global MPP. This complexity arises due to the deployment of bypass diodes aimed at mitigating the hot spot effect [11].

This paper presents an innovative algorithm for MPPT control. The algorithm proposed herein bases its decision-making process for the optimal duty ratio value on Grey Wolf Optimization (GWO) with random motion. This approach ensures swift responsiveness through the continual updating of the attractive part within the potential solutions derived from the classical algorithm. Subsequent to the algorithmic development, MATLAB programs were developed to evaluate the system's performance. The main contribution of this research paper is to develop the Grey Wolf technique for fast tracking of the global maximum power point of the PV panels under PSC [12].

II. Mathematical modelling of PV panel

II.1. Characteristics of the PV cell

The prevalent model for photovoltaic cell representation is the single diode model, d incorporating five parameters: (Iph): photocurrent, (Is): diode saturation current, (a): factor r ideality, (Rs): series resistance, (Rsh): shunt resistance. A depiction of this s PV model is shown in n Figure 1 [11].

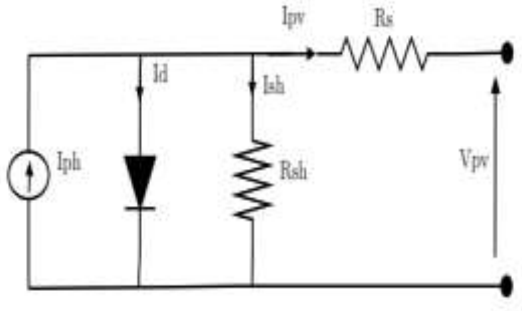

Figure.1. Equivalent e electrical circuit of a single d diode model l for a photovoltaic c cell

The relationship p expressing the current p produced by the photovoltaic c cell is as follows [12]:

$$I_{pv} = I_{ph} - I_s\left[\exp\left(\frac{V_{pv}+I_{pv}R_s}{aV_t}\right)-1\right] - \frac{V_{pv}+I_{pv}R_s}{R_{sh}} \quad (1)$$

Vt is defined as kT/q, where T denotes s the temperature of the cell in Kelvin, q represents the e charge of an electron (1.6×10-19 C), k present Boltzmann n Constant (1.38×10-23 J/K).The crucial parameters s indispensable for modeling photovoltaic c panels are specified under standard test conditions (STC), n as outlined in Table 1.

Table 1. Photovoltaic panel parameters under Standard Test Conditions

Parameters	**Value**
Max power (P_m) [Watts]	320.4
Open c circuit voltage (OCV) (V_{oc}) [Volts]	49.5
Short-circuit c current (SCC) (I_{sc}) [Amperes]	8.6
Voltage t at Maximum n Power Point (V_m) [Volts]	40.1
Current at Maximum p Power Point (I_m) [Amperes]	7.99
Number of cells	72

II.2. Effect of partial l shading upon the PV characteristics

A PV module consists of numerous identical solar cells connected in series and parallel l configurations to enhance its voltage and output power capabilities [13-16]. In practical applications, PV modules frequently encounter PSC c, which can be caused by various s obstructions such as clouds, trees, buildings, and towers. To illustrate the effects of shading on a PV module, configuration, designated as 3S1P, includes four PV modules connected in series-parallel, with each string comprising four modules, each rated for a maximum power output of 320.4 W [17-22]. The total output power of this configuration is approximately 9.6 kWp. Four different t PSC scenarios are detailed in Table 2. The corresponding voltage-power (V-P) and voltage-current (V-I) characteristics for these s scenarios are illustrated d in Figure 2.

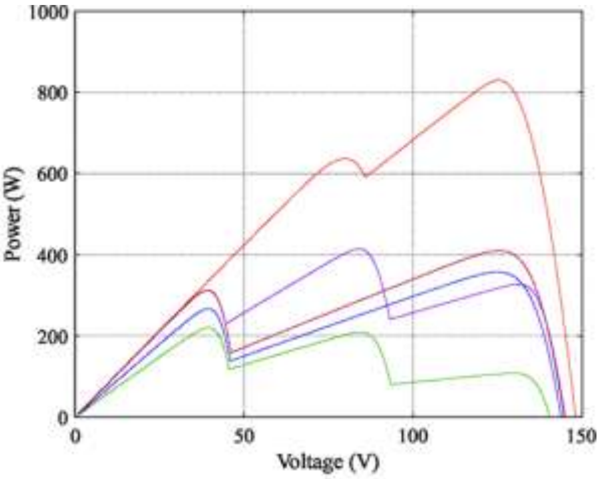

Figure 2. Power-voltage c characteristics in case of p PSC

Table 2. Shading patterns details and the n maximum power of the cases under study

Case No.	**Solar irradiance, G_i (W/m^2)**			**P_{MPP}, (W)**	**V_{MPP}, (V)**	**I_{MPP}, (A)**
	G_1	G_2	G_3			
1	1000	1000	1000	961.2	120.2	8.00
2	1000	600	450	481.1	128.8	3.74
3	1000	700	300	478.6	82.8	5.78
4	1000	300	100	312.3	38.5	8.10

By simulating these PSC scenarios, we can analyze the impact on the performance and efficiency of the PV system. Understanding these characteristics is crucial for optimizing PV system design and developing robust MPPT algorithms that can effectively handle the variability introduced by PSC [23-28].

II.3. DC-DC boost converter

Figure 3 illustrates the schematic representation of a PV system transferring power to a RL (Resistive Load) via a DC/DC converter regulated by an MPPT command. This command enables automated tracking of the (MPP) irrespective of v varying weather or load conditions. The PV system comprises a 320 W PV panel (Kyocera Solar KD320GX-LPB), and the essential specifications are provided in Table 1.

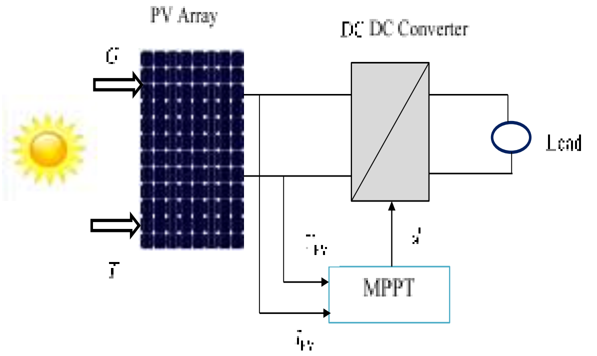

Figure 3. Schematic representation of the PV system regulated by MPPT control

Our study uses a Boost-type converter. The relationships between the inputs V_{pv} and I_{pv} from the photovoltaic panel and the outputs (V_o and I_o) of the boost converter r are established as follows [17]:

$$\mathbf{V_0 = \frac{V_{pv}}{1 - D} \qquad I_0 = (1 - D)I_{pv}} \tag{2}$$

Where D denotes the duty cycle.

If we assume the converter is functioning at maximum efficiency y (100%), the power produced by this PV panel can be expressed as:

$$\mathbf{P_{pv} = \frac{V_0^2}{R_L} \quad \Rightarrow \quad P_{pv} = (\frac{1}{1 - D})^2 \frac{V_{pv}^2}{R_L}} \tag{3}$$

Thus, achieving optimal power involves appropriately tuning the duty cycle control of the DC/DC converter. The DC/DC converter connected to R_L is represented equivalently as a variable resistance e R_{opt}, as depicted in Figure 4.

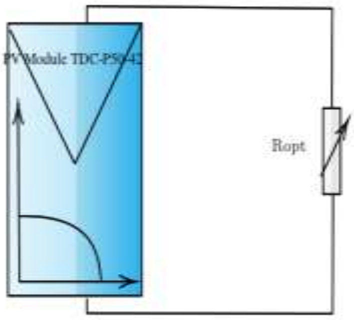

Figure .4. Synoptic representation of photovoltaic p panel linked to the load $R_{opt.}$

To achieve effective MPP p tracking, load sizing becomes crucial. In continuous conduction mode, the relationship between the two resistances (RL) and (Ropt) can be derived from equation Eq. (4).

$$\frac{V_{pv}^2}{P_{pv}} = R_L(1-D)^2 \quad \Rightarrow \quad R_{opt} = R_L(1-D)^2 \qquad (4)$$

Thus, the load R_L is expressed as follow [12]:

$$R_L = \frac{R_{opt}}{(1-D)^2} \qquad (5)$$

Since $$D_{min} < D < D_{max} \qquad (6)$$

Then: $$\frac{R_{opt}}{(1-D_{min})^2} \leq R_L \leq \frac{R_{opt}}{(1-D_{max})^2} \qquad (7)$$

At Standard Test Conditions, the optimal resistance (R_{opt}) required for attaining the maximum power p point is expressed as:

$$R_{opt} = \frac{V_{mpp}}{I_{mpp}} \qquad (8)$$

In our specific examination, R_{opt} is determined to be 8.78 Ω for a duty cycle ranging g from 0.2 to 0.89. The selected load resistance (R_L) falls within the range of 13.71 Ω to 519.52 Ω. For our case, we opted for a load resistance of 31 Ω. Table 3 presents the diverse parameters of the converter u utilized to maintain c continuous conduction mode operation.

Table 3. Parameter values for the Boost converter components

Parameters	Value
Cin [µF]	20
Inductance[µH]	800
C_{ou} [µF]	20

II.4. Grey wolf algorithm

The Grey Wolf o Optimizer (GWO) n is a metaheuristic technique inspired by the social hierarchy n and hunting methods of grey wolves, as detailed in [18]. This approach simulates a four-tier leadership structure mirroring the natural order among wolves. These tiers are characterized as alphas s (α), betas (β), deltas s (δ), and omegas (ω). In this hierarchy, the alpha (α) symbolizes the optimal solution, followed by beta (β) and delta (δ), representing the second and third most viable solutions, respectively. The omega (ω) represents the rest of the solutions. The GWO's method of encircling prey is mathematically expressed through the following equations [19]:

$$D^{\rightarrow} = \left| C^{\rightarrow}.X_r^{\rightarrow}(t) - X^{\rightarrow}(t) \right| \qquad (9)$$

$$X^{\rightarrow}(t+1) = X_P^{\rightarrow}(t) - A^{\rightarrow}.D^{\rightarrow} \qquad (10)$$

Where, $A^{\rightarrow}, D^{\rightarrow}$ and $C^{\rightarrow}$ are the vectors of coefficients, $X_P^{\rightarrow}$ is the prey position vector, $X^{\rightarrow}$ denotes the grey wolf position vector, and t indicates the current iteration.

Figure 5 illustrates the process of updating g the positions of search h agents within the search space.

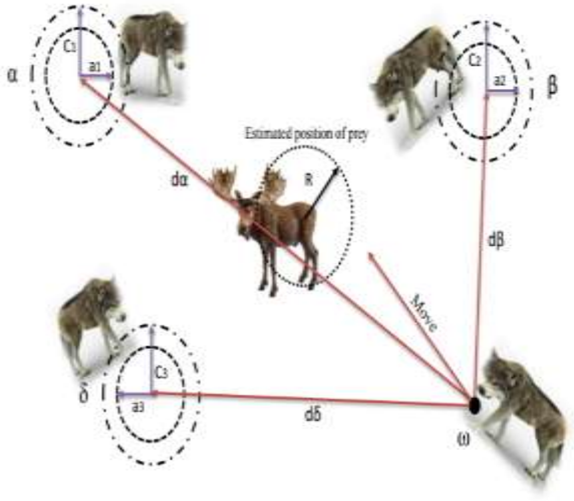

Figure.5. Process of updating search agent positions in the GWO algorithm

III. Simulation results

To evaluate the performance and effectiveness of g GWO-based optimizers, comprehensive MATLAB b simulations were performed. In these simulations, the tracker was employed as a controller to regulate the d duty cycle of the converter, facilitating an analysis of the PV system's performance across different patterns of Partial l Shading Conditions (PSC) c. The boost DC/DC c converter functions in continuous current mode, with a switching frequency of 30 kHz and a resistive load of 31 Ω.

Figure 6 depicts a SIMULINK n model of the complete PV system, which incorporates a Global Maximum Power r Point Tracker (GMPPT) t. The subsequent four cases illustrate the efficacy and efficiency of the proposed trackers in identifying the GMPP p under varying irradiance shading scenarios.

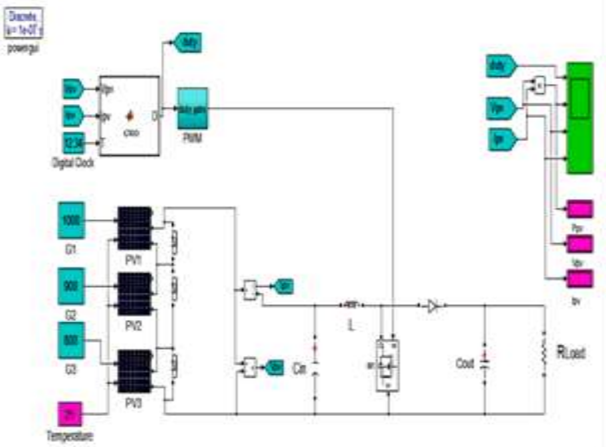

Figure 6. MATLAB/Simulink k model of the proposed g GWO-based tracker for the PV system

Figure 7 presents s the results of modeling the operating modes of the photovoltaic system, which utilizes a GWO algorithm-based controller. During this computational experiment, the lighting g conditions of the power supply were altered 0.5 seconds into the model simulation, corresponding to the test l lighting conditions defined I in Table 2 for cases s 1-4.

The simulation results depicted in Figure 7 demonstrate that the g GWO algorithm, with the chosen parameter values, delivers reliable and efficient Maximum Power Point t (MPP) tracking. This efficiency was consistently observed across all 10 test cases, VCPSO provided more accurate and faster MPP t tracking compared to SPSO, while the MPP detection efficiency was no less than 99.93%, and the tracking time did not exceed 0.26 s. The efficiency of the GWO o algorithm for tracking the GMPP for 3SIP configuration under PSC c are shown in Table 4.

Table 4 . Efficiency and time tracking of g GWO technique for 3S1P configuration under different PSC

Case No.	**GWO**	
	η, %	***t*$_{\text{MPP}}$, s**
1	99.99	0.22
2	99.95	0.24
3	99.87	0.26
4	99.91	0.26
Average value	**99.93**	**0.24**

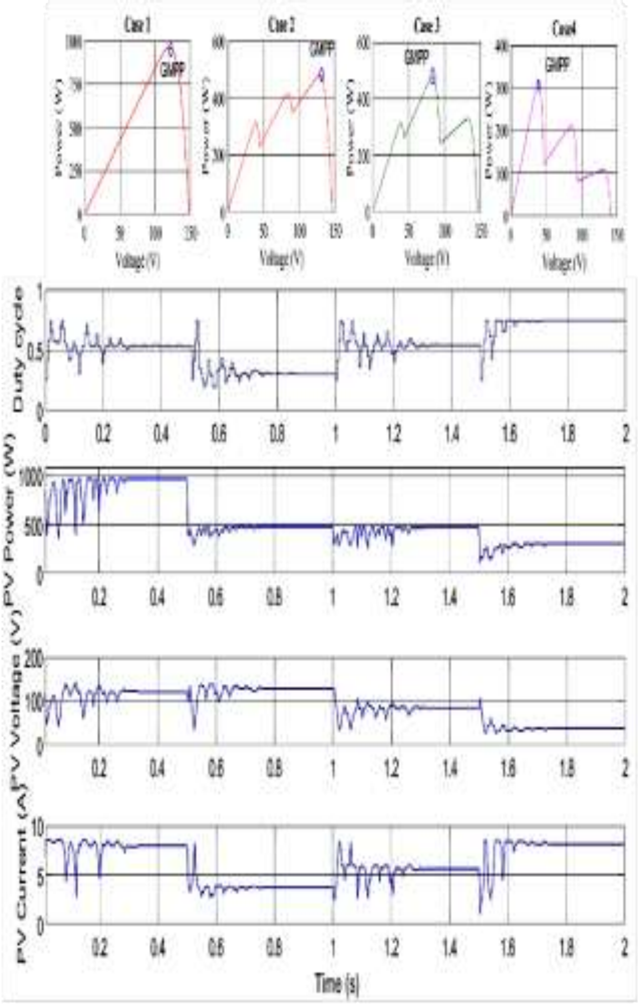

Figure 7. Detailed simulation results for PV system under the fast variation of the solar irradiance of the PV array

IV. Conclusion

This paper introduces the implementation of the Grey Wolf Optimizer (GWO) algorithm aimed at increasing the efficiency of photovoltaic (PV) systems under partial shading conditions (PSC). The primary motivation behind the proposed algorithm is to identify the Global Maximum Power Point (GMPP) amidst the multiple local peaks caused by varying irradiance levels. The simulation results demonstrate that the GWO algorithm, with the selected parameter values, provides reliable and efficient Maximum Power Point (MPP) tracking. In all four test cases, the GWO algorithm achieved more accurate and faster MPP tracking. The MPP detection efficiency was at least 99.93%, and the tracking time did not exceed 0.26 seconds.

Possible research applications for future work include:

- The implementation of the GWO technique-based tracker in practical applications;
- The application of GWO optimization techniques in other areas such as electric vehicles, electric buses, and power electronics.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

References

[1] M. Prauzek, J. Konecny, M. Borova, K. Janosova, J. Hlavica, and P. Musilek, "Energy harvesting sources, storage devices and system topologies for environmental wireless sensor networks: A review," Sensors, vol. 18, pp. 2446, 2018.

[2] I. Kashif and Z. Salam, "A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model," Solar Energy, vol. 85, no. 9, pp. 2217-2227, 2011.

[3] U. Yilmaz, A. Kircay, and S. Borekci, "PV system fuzzy logic MPPT method and PI control as a charge controller," Renewable and Sustainable Energy Reviews, vol. 81, pp. 994-1001, 2018.

[4] N.F. Claude Bertin, K.A.M.T.A. Martin, and W.I.R.A. Patrice, "A comprehensive assessment of MPPT algorithms to optimal power extraction of a PV panel," Journal of Solar Energy Research, vol. 4, no. 3, pp. 172-179, 2019.

[5] H. Rezk and A. Fathy, "A novel optimal parameters identification of triple-junction solar cell on a recently meta-heuristic water cycle algorithm," Solar Energy, vol. 157, pp. 778-791, 2017.

[6] H. Rezk, I. Tyukhov, M. Al-Dhaifallah, and A. Tikhonov, "Performance of data acquisition system for monitoring PV system parameters," Measurement, vol. 104, pp. 204-211, 2017.

[7] T.H. Kwan and X. Wu, "High performance P&O based lock-on mechanism MPPT algorithm with smooth tracking," Solar Energy, vol. 155, pp. 816-828, 2017.

[8] N.A. Kamarzaman and C.W. Tan, "A comprehensive review of maximum power point tracking algorithms for photovoltaic systems," Renewable and Sustainable Energy Reviews, vol. 37, pp. 585-598, 2014.

[9] S.G. Obukhov, I.A. Plotnikov, and S.K. Sheryazov, "Methods of effective use of solar power system," Proceedings of the 2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 2016, pp. 1-6.

[10] M.A. Husain, A. Tariq, S. Hameed, M.S. Bin Arif, and A. Jain, "Comparative assessment of maximum power point tracking procedures for photovoltaic systems," Green Energy and Environment, vol. 2, no. 1, pp. 5-17, 2017.

[11] Ahmad, G.E., "Photovoltaic-powered rural zone family house in Egypt," Renewable Energy, vol. 26, pp. 379-390, 2002.

[12] Ghafoor, A., and Munir, A., "Design and economic analysis of an off-grid PV system for household electrification," Renewable and Sustainable Energy Reviews, vol. 42, pp. 496-502, 2015.

[13] S. Obukhov, A. Ibrahim, A.A.Z. Diab, A.S. Al-Sumaiti, and R. Aboelsaud, "Optimal performance of dynamic particle swarm optimization based maximum power trackers for stand-alone PV system under partial shading conditions," IEEE Access, vol. 20, pp. 1-28, 2020.

[14] M.H. Rashid, Power Electronics Handbook: Devices, Circuits and Applications, 3rd ed., Oxford: Butterworth-Heinemann, 2011, 1409 p.

[15] A. Ibrahim, R. Aboelsaud, and S. Obukhov, “Improved particle swarm optimization for global maximum power point tracking of partially shaded PV array,” Electrical Engineering, vol. 101, no. 2, pp. 443–455, 2019.

[16] S.G. Obukhov, I.A. Plotnikov, and S.K. Sheryazov, “Methods of effective use of solar power system,” in 2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 2016, pp. 1–6.

[17] M. Seyedmahmoudian, B. Horan, T.K. Soon, R. Rahmani, A.M. Than Oo, S. Mekhilef, and A. Stojcevski, “State of the art artificial intelligence-based MPPT techniques for mitigating partial shading effects on PV systems – A review,” Renewable and Sustainable Energy Reviews, vol. 64, pp. 435–455, 2016.

[18] F. Belhachat and C. Larbes, “Comprehensive review on global maximum power point tracking techniques for PV systems subjected to partial shading conditions,” Solar Energy, 2019.

[19] S. Mirjalili, S.M. Mirjalili, and A. Lewis, “Grey wolf optimizer,” Advances in Engineering Software, vol. 69, pp. 46-61, 2014.

[20] C. Muro, R. Escobedo, L. Spector, and R.P. Coppinger, “Wolf-pack (Canis lupus) hunting strategies emerge from simple rules in computational simulations,” Behavioural Processes, vol. 88, no. 3, pp. 192-197, 2011.

[21] A. Ostadrahimi and Y. Mahmoud, “Novel Spline-MPPT Technique for Photovoltaic Systems under Uniform Irradiance and Partial Shading Conditions,” IEEE Transactions on Sustainable Energy, vol. 12, pp. 524–532, 2021.

[22] R.B. Bollipo, S. Mikkili, and P.K. Bonthagorla, “Hybrid, optimal, intelligent and classical PV MPPT techniques: A review,” CSEE Journal of Power and Energy Systems, vol. 7, pp. 9–33, 2021.

[23] N. Kacimi, A. Idir, S. Grouni, and M.S. Boucherit, "Improved MPPT Control Strategy for PV Connected to Grid Using IncCond-PSO-MPC Approach," CSEE Journal of Power and Energy Systems, vol. 9, pp. 1008–1020, 2023.
[24] S.P. Ye, Y.H. Liu, H.Y. Pai, A. Sangwongwanich, and F. Blaabjerg, "A Novel ANN-Based GMPPT Method for PV Systems under Complex Partial Shading Conditions," IEEE Transactions on Sustainable Energy, vol. 15, pp. 328–338, 2024.
[25] A.M. Eltamaly, "A novel benchmark-shading pattern for PV maximum power point trackers evaluation," Solar Energy, vol. 263, 111897, 2023.
[26] A.M. Eltamaly, "A novel musical chairs algorithm applied for MPPT of PV systems," Renewable and Sustainable Energy Reviews, vol. 146, 111135, 2021.
[27] T.B.N. Nguyen and K.-H. Chao, "Fast Maximum Power Tracking for Photovoltaic Module Array Using Only Voltage and Current Sensors," Sensors and Materials, vol. 35, pp. 2619–2635, 2023.
[28] A. Boukadoum, A. Bouguerne, and T. Bahi, "Performances improvement of Shunt active power filter with voltage sensor failure," International Journal of Energetica, vol. 8, no. 1, pp. 38-43, 2023. doi: http://dx.doi.org/10.47238/ijeca.v5i2.129