



Classical and Metaheuristic MPPT Control Techniques for the Optimization of Photovoltaic Systems

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ABSTRACT

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The conversion efficiency of photovoltaic systems remains relatively modest, typically ranging from 12% to 17%. To enhance the harvested energy, it is essential to employ maximum power point tracking (MPPT) strategies. This work focuses on a comparative analysis between conventional techniques and metaheuristic algorithms applied to PV systems. Traditional methods, such as Perturb and Observe, are easy to implement but their performance decreases under fluctuating irradiance or partial shading. On the other hand, metaheuristic approaches—particularly Particle Swarm Optimization and Grey Wolf Optimization—demonstrate greater robustness and faster convergence toward the global maximum power point. Findings reported in the literature highlight that these intelligent optimization techniques provide a promising solution to the drawbacks of classical algorithms, especially in scenarios involving non-uniform solar irradiation.

1. INTRODUCTION

Maximizing the extracted power from a photovoltaic (PV) generator is a major challenge to improve the overall efficiency of solar systems. Due to the nonlinearity of current-voltage characteristics and their dependence on climatic conditions (irradiance and temperature), the use of MPPT algorithms is essential. Among classical methods, the Perturb and Observe (P&O) algorithm is widely adopted for its simplicity and ease of implementation [1]. However, under rapid irradiance changes or partial shading, P&O may be ineffective since it risks converging to local maxima [2]. To overcome this limitation, metaheuristic optimization techniques, such as Particle Swarm Optimization (PSO) and Grey Wolf Optimization (GWO), have been introduced. Their ability to explore the P-V curve globally enables them to reach the GMPP (Global Maximum Power Point) under complex conditions [3], [4]. This work focuses on comparing P&O and PSO in a healthy state, without shading, to highlight their respective performances and clarify the role of metaheuristic approaches.

2. PV PANEL MODELING

A photovoltaic field based on PV panels is considered and simulated using the single-diode model (Fig. 1). The PV cell is represented as an electric current source in parallel with a diode. The main governing equation is: [5]

$$I_{pv} = I_{ph} - I_{sat} \left[\exp \left(\frac{e(V_{pv} + (I_{pv} * R_{ser}))}{nKT} \right) - 1 \right] - \frac{V_{pv} + (I_{pv} * R_{ser})}{R_{shu}} \quad (1)$$

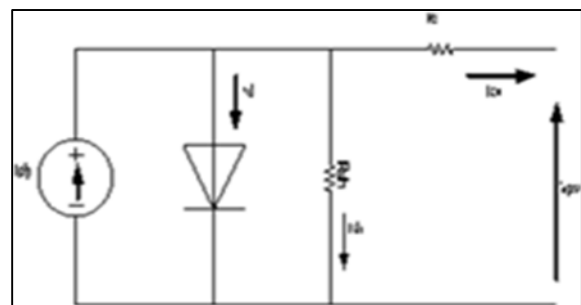


Figure. 1 Model of a photovoltaic solar panel.

3. MPPT CONTROL

The maximum power point corresponds to the intersection between the generator and load characteristics, where the delivered power is optimal. To reach this point, a DC-DC converter, usually of the Boost type, is combined with an MPPT strategy. The duty cycle is continuously adjusted to ensure dynamic matching between the PV generator and the load. [6]

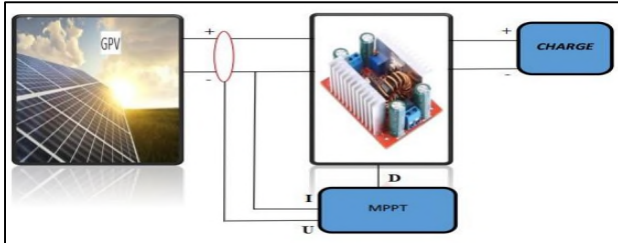


Figure. 2 Synoptic diagram of our system.

4. CLASSICAL MPPT METHODS

4.1 Perturb and Observe (P&O)

This method applies a small perturbation to the generator voltage or current, followed by observation of the resulting power variation.

- Advantages: simple implementation, low computational cost.
- Drawbacks: permanent oscillations around the MPP, slow convergence under rapid irradiance variations, risk of following local maxima under shading.

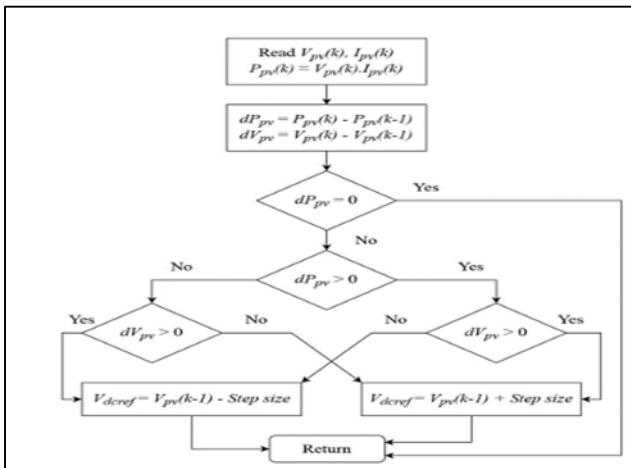


Figure. 3 P&O method flowchart.

5. METAHEURISTIC MPPT METHODS

5.1 Particle swarm optimization (psa)

Inspired by the collective behavior of birds and fish, this technique makes a population of particles converge toward the optimal power point.

- Advantages: fast convergence, robustness under irradiance changes.

- Limitations: possible premature stagnation, dependence on initialization parameters.

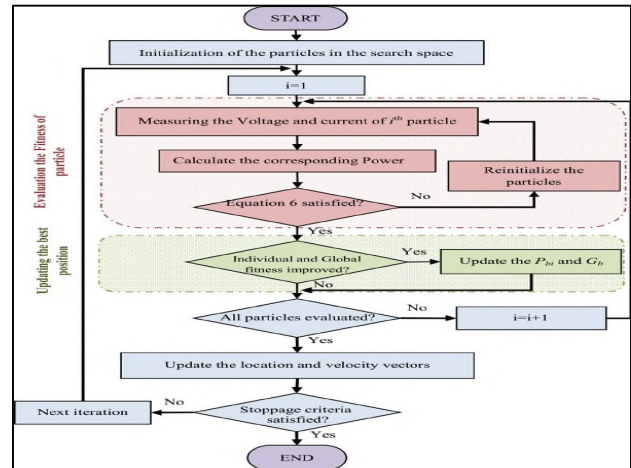


Figure. 4 PSO method flowchart. [8]

5.2 Grey Wolf Optimization (GWO)

This method imitates the hunting strategy of grey wolves, based on social hierarchy and prey encirclement.

- Advantages: better global search, higher accuracy, ability to avoid local maxima.
- Results: Literature shows GWO outperforms PSO and P&O in speed and stability, especially under partial shading.

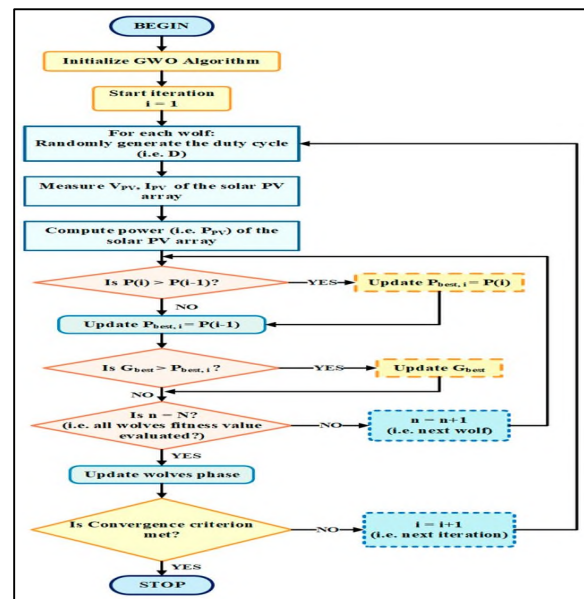


Figure. 5 GWO method flowchart. [8]

6. PARTIAL SHADING EFFECT AND PROTECTION SYSTEM

Partial shading leads to multiple local power points, making classical methods inefficient for finding the global MPP. To protect modules, bypass and blocking diodes are used to reduce losses and avoid cell degradation.



Figure. 6 Ombrage partiel. [7]

7. THE STUDIED SIMULATION MODEL

To validate the presented MPPT control algorithms, a photovoltaic system model was developed in the MATLAB/Simulink environment (see Fig. 7).

Photovoltaic generator (PVG): composed of solar modules connected in series and parallel, modeled using the single-diode equation.

DC-DC converter: a Boost-type chopper, used to adapt the voltage and ensure maximum power extraction.

Load: an equivalent resistance representing the electrical demand.

MPPT control: integrated into the converter to track the maximum power point in real time.

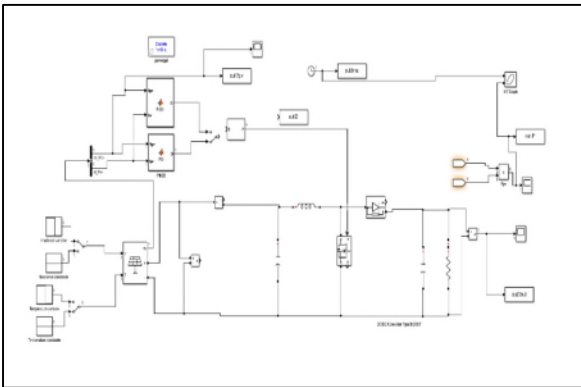


Figure. 7 The studied simulation model.

Table 1. Model parameters

Parameters	Value
Power	59.85W
Vmp	17.1V
Imp	3.5A
Voc	21.1V
Isc	3.8A

The simulations were carried out under two scenarios:

7.1 Uniform irradiation

Allowing the comparison of the performance of the classical P&O method and the metaheuristic PSO method under standard conditions.

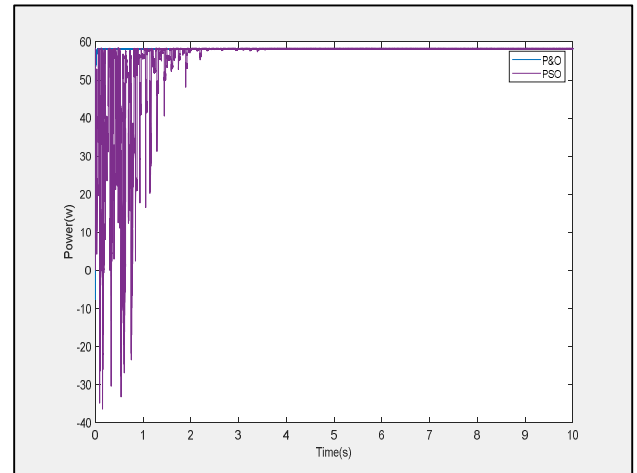


Figure. 8 PV power.

The simulation results under uniform irradiance conditions ($E = 1000 \text{ W/m}^2$, $T = 25^\circ\text{C}$) show that the P&O method exhibits a shorter response time and lower residual oscillations compared to the PSO algorithm. This can be explained by the simplicity of the P&O logic: it applies local perturbations and instantly corrects the control, ensuring rapid convergence to the MPP when the P-V curve contains a single well-defined global maximum. In contrast, PSO, which relies on a stochastic exploration of the search space, requires more computational resources and introduces broader adjustments, which may delay stabilization and generate oscillations.

However, it is important to emphasize that metaheuristic methods (PSO, GWO, etc.) find their full usefulness only in contexts where irradiance is variable or in the presence of partial shading. In such situations, the P-V curve presents multiple local power points, and classical algorithms such as P&O risk getting stuck in a local maximum. Metaheuristics, thanks to their global exploration capability, can then locate the GMPP (Global Maximum Power Point) and ensure optimal power extraction. Thus, the observed superiority of P&O under uniform conditions does not undermine the relevance of metaheuristic approaches but rather highlights their complementarity depending on the operating conditions of the photovoltaic system.

7.2 Partial shading

Allowing the comparison of the performance of the classical P&O method and the metaheuristic PSO method under standard conditions.

First shading profile

The simulation results are illustrated in Figure 9. Under the first shading profile, there is one global peak (GP) and one partial peak (PP) of maximum power. Figure 10 shows that, under these conditions, only the advanced algorithms PSO and GWO detect the global maximum power (GP =

113.5 W). It is also important to note that the PSO power curve (Ppv) presents too many oscillations before reaching the maximum point.

7.2.1 First shading profile

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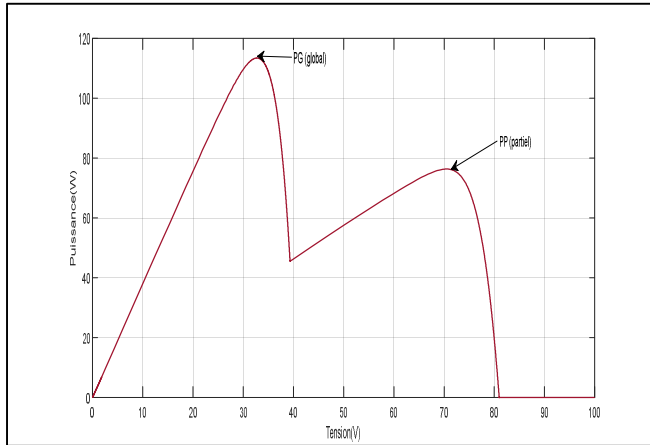


Figure. 9 Ppv = f(Vpv) characteristic under partial shading.

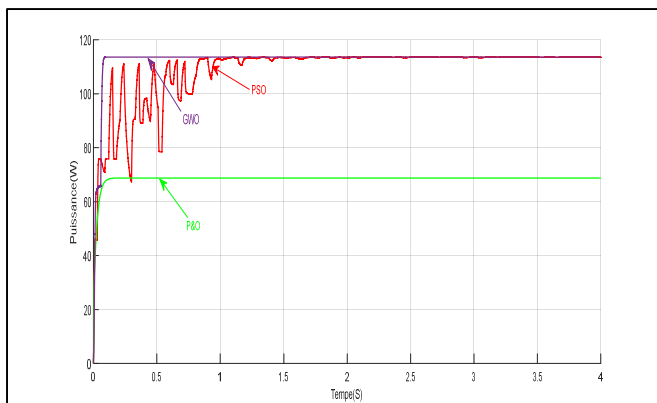


Figure. 10 PV power.

7.2.2 Second shading profile

The simulation results are illustrated in Figure 11 under the second shading profile. There is one global peak (GP) and two partial peaks (PP1 and PP2) of maximum power. Moreover, Figure 12 shows that, under this condition, all the algorithms — P&O, PSO, and GWO — detect the global maximum power.

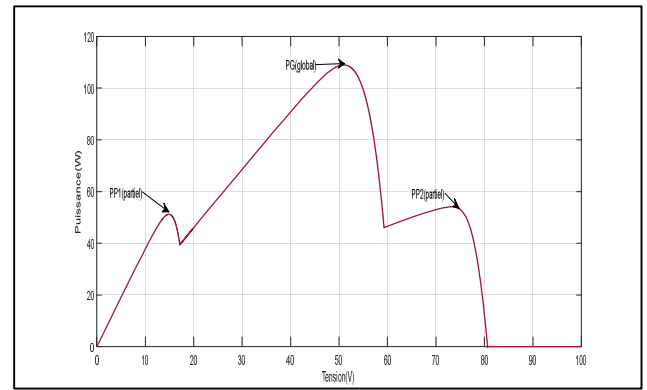


Figure. 11 Ppv = f(Vpv) characteristic under partial shading.

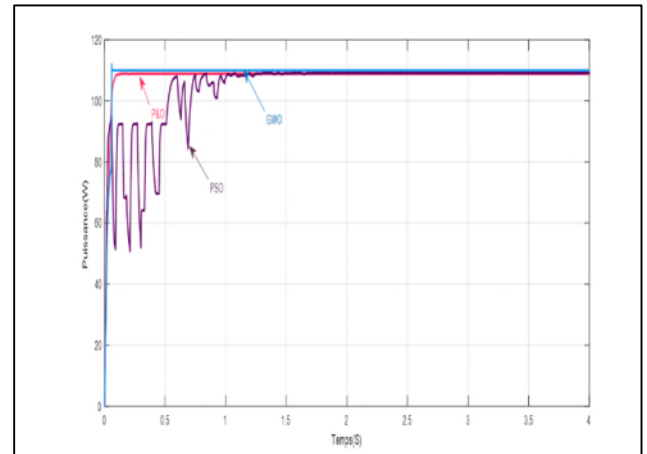


Figure. 12 PV power.

7.2.3 Third shading profile

Under the effect of this third shading profile, the Ppv = f(Vpv) characteristic is shown in Figure 13. It presents one global peak (GP) and three partial peaks of maximum power. The three profiles were selected according to the position of the global maximum power point. It can be observed that, for the first profile, it is located at the far left, for the second profile in an intermediate position, and for the third profile at the far right.

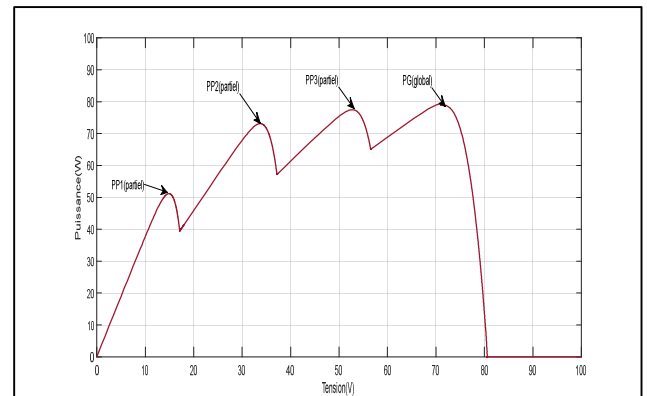


Figure. 13 Ppv = f(Vpv) characteristic under partial shading.

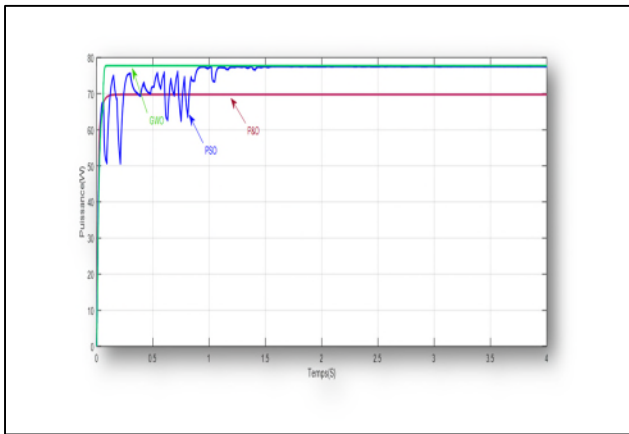


Figure. 14 PV power.

A The MPPT methods Perturb and Observe (P&O), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO) differ in terms of complexity, computational cost, and performance. P&O, simple and easy to implement, has a low computational cost but may oscillate around the maximum power point and is less effective under partial shading. PSO, inspired by swarm behavior, offers a good ability to find the global MPP and adapts well to changing conditions, but requires more computational resources and is more complex to implement. GWO, based on the social behavior of grey wolves, combines a high global search capability with moderate complexity, providing high robustness and accuracy, but also requires significant computational resources. In summary, P&O is ideal for simple and cost-effective solutions, PSO excels in complex environments, and GWO offers a good balance between performance and complexity.

The choice of the MPPT method strongly depends on the specific requirements of the PV system and operational constraints. P&O remains a viable option for systems requiring simplicity and low cost, while PSO and GWO are better suited for complex environments demanding greater robustness and accuracy. Simulations clearly show that GWO can provide optimized performance with manageable complexity, positioning this method as an excellent compromise for many advanced photovoltaic systems.

8. Conclusion

The study conducted under uniform irradiance conditions shows that the classical P&O algorithm offers better performance than PSO, both in terms of response time and reduction of oscillations around the MPP. This efficiency is explained by the local and reactive nature of the method, which is perfectly suited to a stable environment where the P–V curve presents only a single global maximum. On the other hand, the results highlight that metaheuristics, although less effective under uniform conditions, play a fundamental role in situations of variable irradiance or partial shading, where their ability to globally explore the search space enables them to detect the GMPP and ensure better power extraction. Thus, the complementarity between classical and metaheuristic methods represents a promising direction for designing hybrid

strategies, combining the speed and simplicity of P&O with the robustness and accuracy of intelligent approaches.

REFERENCES

- [1] Talha, F., Benmouiza, K., Birane, M. (2025). In-depth comparison of PV array configurations and boost converter topologies using P&O and PSO techniques. *Journal of Electrical Systems and Applications*, 25 June 2025.
- [2] Veerasamy, M., Ali, S.M., Sher, H.A. (2023). Comparative analysis of classical and metaheuristic MPPT algorithms in PV systems under uniform conditions. In: *Advances in Electrical and Computer Technologies*. Springer, 771-781.
- [3] Oubelaid, A., Bouyghf, H., Bakhouya, A., El Kamoun, M. (2024). In-depth comparison of PV array configurations and boost converter topologies using P&O and PSO techniques. *Journal Européen des Systèmes Automatisés*, 57(3): 271-277.
- [4] Jha, A.S., Rallabandi, V.B. (2024). Comparative assessment of P&O, PSO sliding mode, and PSO–ANFIS controller MPPT for microgrid dynamics. *Elektronika ir Elektrotechnika*, 30(2): 35-43.
- [5] Benabda, A., Kelaiaia, M.S., Labar, H., Logerais, P.O., Durstanti, J.F. (2017). Boost chopper MPP assessment based on solar irradiance and predictive duty cycle applied to a PV system. *International Journal of Hydrogen Energy*, 42(30): 19403-19411. <https://doi.org/10.1016/j.ijhydene.2017.06.022>
- [6] Veerasamy, M., Ali, S.M., Sher, H.A. (2023). Comparative analysis of classical and metaheuristic MPPT algorithms in PV systems under uniform conditions. In: *Advances in Electrical and Computer Technologies*. Springer, 771-781.
- [7] Duranay, Z.B., Güldemir, H. (2025). Examination of the effect of shading on a photovoltaic system performance. *Dicle University Journal of Engineering (DUJE)*, 16(1): 89-95.
- [8] Verma, P., Alam, A., Sarwar, A., Tariq, M. (2021). Meta-heuristic optimization techniques used for maximum power point tracking in solar PV system. *Electronics*, 10(19): 2419. <https://doi.org/10.3390/electronics10192419>
- [9] Yakubu, A., Adigüzel, E., Ersoy, A. (2023). Enhanced particle swarm optimization and P&O for MPPT of photovoltaic systems under partial shading conditions. *International Journal of Energy Applications and Technologies (IJEAT)*.
- [10] Liu, L., et al. (2025). Photovoltaic MPPT control and improvement strategies considering environmental factors: based on PID-type sliding mode control and improved grey wolf optimization. *Measurement and Control*, 58(2-3): 228-240.
- [11] Lakhdara, A., Bahi, T., Moussaoui, A. (2021). MPPT techniques of the solar PV under partial

shading. In: Proceedings of the 18th International Multi-Conference on Systems, Signals & Devices (SSD).

- [12]Khelaifa, F., Lamamra, K., Toumi, D. (2021). Application of Grey Wolf Optimization algorithm for maximum power point tracking of solar panels. International Journal of Electronics and Computer Applications (IJECA).
- [13]Abo-Khalil, A.G., El-Sharkawy, I.I., Radwan, A., Memon, S. (2023). Influence of a hybrid MPPT technique, SA-P&O, on PV system performance under partial shading conditions. Energies, 16(2): 577.
- [14]A novel hybrid MPPT technique to maximize power harvesting from PV system under partial and complex partial shading. (2022). Applied Sciences, 12(2): 587.

NOMENCLATURE

Ppv	Photovoltaic power, W
Vpv	Photovoltaic voltage, V
Ipv	Photovoltaic current, A
MPP	Maximum power point
GMPP	Global maximum power point
D	Duty cycle of the Boost converter
G	Solar irradiance, W.m-2
T	Cell temperature, °C
Voc	Open circuit voltage, V
Isc	Short circuit current, A
Vmp	Voltage at maximum power point, V
Imp	Current at maximum power point, A
Greek symbols	
η	Efficiency of the PV system, dimensionless
Subscripts	
pv	Photovoltaic
mp	Maximum power point
oc	Open circuit
sc	Short circuit