

# Improved Maximum Power Point Tracking for Solar PV Systems under Partial Shading using Grey Wolf Optimization Based Incremental Conductance Method

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**Abstract**—Maximum Power Point Tracking (MPPT) is essential for improving the efficiency of solar photovoltaic (PV) systems. Under partial shading conditions (PSC), multiple power peaks occur in the power–voltage (P–V) characteristic curve, making it difficult for conventional methods such as Incremental Conductance (INC) to track the global maximum power point (GMPP). This paper proposes an improved MPPT technique by combining Grey Wolf Optimization (GWO) with the INC method. The GWO algorithm is used to locate the global peak, while the INC method ensures fast and accurate tracking of the maximum power point. The proposed GWO-INC approach reduces tracking time, minimizes power loss, and improves overall system efficiency. Simulation results demonstrate that this method performs better than traditional MPPT techniques under varying environmental conditions.

**Index Terms**—MPPT, Solar Photovoltaic Systems, Partial Shading Conditions (PSC), Grey Wolf Optimization (GWO), Incremental Conductance (INC) Method, Hybrid MPPT Algorithm, Global Maximum Power Point (GMPP), Swarm Intelligence, Metaheuristic Algorithms, DC-DC Converters.

## I. INTRODUCTION

The increasing global demand for clean and sustainable energy has accelerated the adoption of solar photovoltaic (PV) systems. Among various renewable energy sources, solar PV is widely preferred due to its abundance, environmental friendliness, and ease of installation. However, the efficiency of PV systems is significantly affected by environmental conditions such as temperature, irradiance, and especially partial shading conditions (PSC). Under PSC, multiple local maxima appear in the power–voltage (P–V) characteristics of the PV array, making it extremely difficult to track the true global maximum power point (GMPP). Conventional MPPT methods, such as Perturb and Observe (P&O) and Incremental Conductance (INC), are simple and widely used under uniform irradiance. However, these techniques often fail under partial shading, as they can get trapped in local maxima, resulting in reduced system efficiency and power loss.

To overcome these limitations, advanced optimization- based MPPT techniques have been introduced. Metaheuristic algorithms, inspired by natural phenomena, have shown strong potential in solving complex nonlinear optimization problems. Among these, Grey Wolf Optimization (GWO) is an effective algorithm that mimics the leadership hierarchy and hunting behavior of grey wolves. GWO offers advantages such as fast convergence, simplicity, and high capability to locate the global optimum.++

In this paper, an improved MPPT technique is proposed by integrating Grey Wolf Optimization with the Incremental Conductance method. The hybrid approach leverages the global search capability of GWO to identify the region of the GMPP, while the INC method ensures accurate and stable tracking. This combination enhances tracking efficiency, reduces oscillations, and improves performance under partial shading conditions.

## II. LITERATURE SURVEY

A comprehensive review of existing MPPT methods and optimization algorithms is presented in Table I. The survey covers twenty notable contributions spanning ontology- based modeling, classical MPPT techniques, nature-inspired metaheuristics, and deep learning approaches.

**TABLE I**

*Literature Survey of Existing MPPT Techniques*

## III. PROBLEM STATEMENT

Solar

Sl.	Author	Description	Methodology	Key Findings
1	Pileggi & Lamia (2020)	Climate change ontology for structured knowledge	Ontology-based modeling	Enhances structured storage and retrieval of climate data
2	Ibrahim & Aslan (2023)	Review of solar PV water pumping systems	Comparative analysis of PV pumping	Solar PV systems provide sustainable irrigation with reduced cost
3	Verma et al. (2021)	Metaheuristic optimization for MPPT	Review of PSO, GA, and hybrid algorithms	Metaheuristics improve MPPT efficiency under variable conditions
4	Kumar (2024)	MPPT using P&O and INC	Simulation-based comparative study	INC performs better in dynamic environments

PV systems are highly affected by partial shading conditions caused by clouds, trees, buildings, or environmental changes. Under partial shading, the power– voltage (P–V) curve contains multiple peaks, which makes it difficult for conventional MPPT methods like Incremental Conductance to identify the GMPP. Instead, these methods may get trapped in local maximum points, resulting in reduced power output and low efficiency.

Therefore, there is a critical need for an improved MPPT technique that can accurately track the global maximum power point, improve tracking speed, and increase the overall efficiency of solar PV systems under partial shading

conditions. incremental conductance ( $\Delta I/\Delta V$ ) with the instantaneous conductance ( $I/V$ ). However, since partial shading creates multiple local peaks in the P–V curve, the Grey Wolf Optimization algorithm is introduced to enhance the search process.

GWO, inspired by the hunting behavior of grey wolves, helps in exploring the solution space and identifying the GMPP by avoiding local maxima. The IC method provides the basic tracking mechanism, while GWO continuously optimizes and guides the search toward the global peak. Performance is evaluated through simulation using a DC– DC converter and MPPT controller, analyzing tracking speed, power output, and efficiency under partial shading.

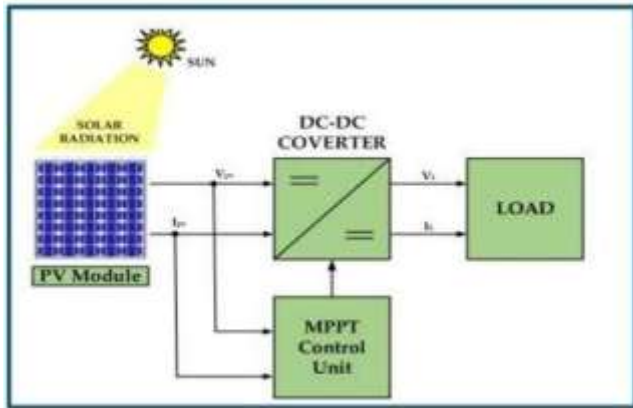


Fig. 1. Block diagram of the proposed MPPT system.

## V. SYSTEM DESIGN AND IMPLEMENTATION

### A. Simulink Model

## IV. METHODOLOGY

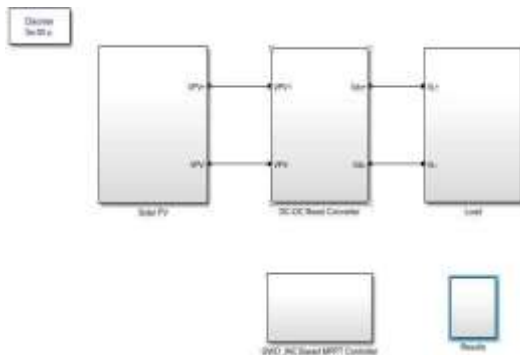


Fig 1 :Block diagram of MPPT

The proposed work uses a hybrid MPPT approach by combining the Incremental Conductance (IC) method with Grey Wolf Optimization (GWO) to improve the performance of solar PV systems under partial shading conditions. First, a PV system model is developed and simulated under varying irradiance levels to represent real- world partial shading scenarios.

The Incremental Conductance method estimates the direction of the maximum power point by comparing the

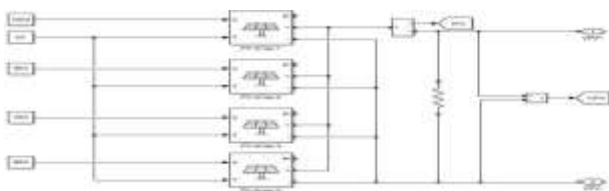


Fig 2:simulink model of proposed system

Fig. 2 shows the overall Simulink model of the proposed system, which integrates a solar PV array, a DC–DC boost

converter, and an MPPT control unit. The PV array generates electrical power from solar irradiance, which is then fed to the boost converter to regulate the output voltage. A GWO-based Incremental Conductance MPPT controller continuously tracks the maximum power point, even under partial shading conditions. Based on the controller output, the duty cycle of the converter is adjusted to extract maximum power and efficiently supply it to the load.

Fig. 2. Simulink model of the proposed GWO-INC MPPT system.

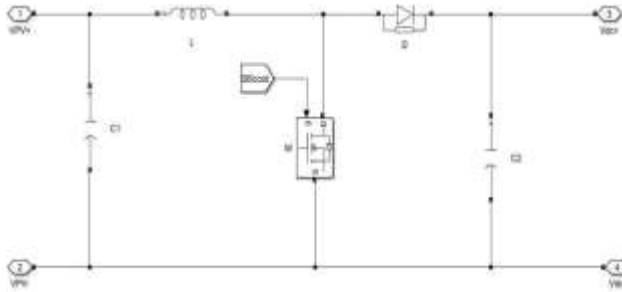


Fig 3 : Simulink model of the solar PV array under partial shading

The PV array model (Fig. 3) simulates partial shading conditions using multiple PV array blocks connected together. Each PV array receives different levels of irradiance (1000, 950, 700, 650 W/m<sup>2</sup>), simulating real-time shading effects. The arrays are connected to form the overall PV system output, where voltage (VPV) and current (IPV) are measured. This setup is used to analyze PV system behavior under non-uniform sunlight and to study the MPPT controller performance in extracting maximum power..

Fig4: Simulink model of DC-DC Boost converter

Fig. 4 shows the DC-DC boost converter circuit, used to step up the lower PV input voltage to a higher output voltage. The input (VPV+ and VPV-) is filtered by capacitor C1, while the inductor L stores energy when the MOSFET switch M is turned ON. When the switch turns OFF, stored energy in the inductor is released through diode D to the output side, increasing the voltage. Capacitor C2 smooths the boosted output voltage (Vdc+ and Vdc-). The switching signal (SBoost) controls the MOSFET, regulating the output voltage level.

Fig. 4. Simulink model of the DC-DC boost converter.

#### D. System Parameters

The simulation parameters for the boost converter and the solar PV module are listed in Table II.

TABLE II

#### Simulation System Parameters

Boost Converter Parameters	
Input Capacitance (Ci)	47 $\mu$ F
Inductance (L)	1.1478 mH
Output Capacitance (Co)	470 $\mu$ F
Output Load (R)	10 $\Omega$
PV Module Parameters	
Maximum Power (PMPP)	21.83 W
Open Circuit Voltage (VOC)	5.425 V
Short Circuit Current (ISC)	5.34 A
Voltage at MPP (VMPP)	4.35 V
Current at MPP (IMPP)	5.02 A

### E. GWO-INC MPPT Controller

Fig. 5 depicts the MPPT control system block diagram. PV voltage ( $V_{pv}$ ) and PV current ( $I_{pv}$ ) are fed into the GWO\_INC\_MPPT algorithm block, which determines the optimal duty cycle to extract maximum power. The duty cycle signal is then sent to a PWM generation block, which produces the switching signal (SBoost) for the DC-DC converter. An alternative PSA-based MPPT block is also included for comparative evaluation.

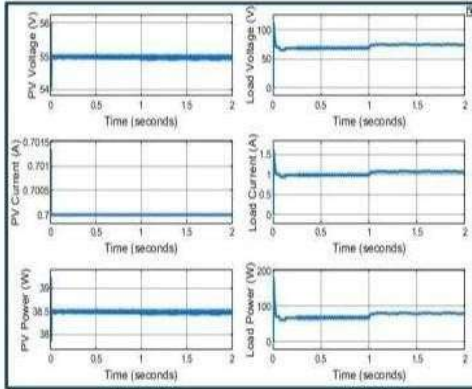


Fig. 5. Simulink model of the GWO-INC MPPT controller.

### F. Grey Wolf Optimization Flowchart

The GWO algorithm (Fig. 6) begins by initializing a population of solutions along with parameters  $a$ ,  $A$ , and  $C$  based on the objective function. The fitness of search agents ( $\alpha$ ,  $\beta$ ,  $\Delta$ , and  $\omega$ ) is evaluated. The algorithm then checks whether the maximum iteration count is reached. If not, it updates the positions of search agents and adjusts parameter values to balance exploration and exploitation. The fitness evaluation and update cycle repeats until the stopping condition is met. Finally, the best solution from the combined objective function is stored and the process ends.

Fig. 6. Flowchart of the Grey Wolf Optimization algorithm.

## VI. RESULTS AND DISCUSSION

### A. Base Method: PSA Simulation Results

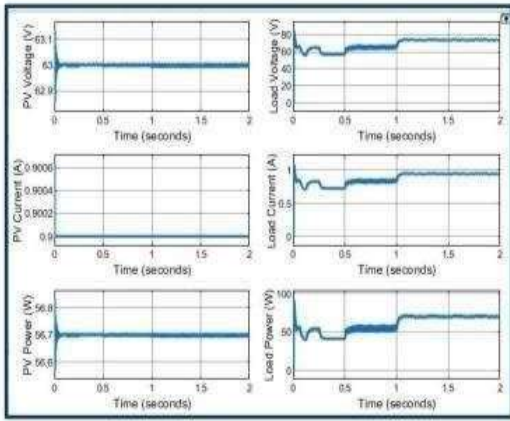
The Projectile Search Algorithm (PSA) based MPPT is evaluated using MATLAB/Simulink. Four PV modules receive varying solar irradiation to simulate different partial shading conditions. Results are presented for four static and one dynamic partial shading scenario.

#### Fig. 5: PSA results — Static Partial Shading (1000, 600, 300, 100) $/m^2$

**Case 1 – Static Partial Shading (1000, 600, 300, 100  $W/m^2$ ):** Under this severe shading condition, the PV array experiences highly uneven irradiance, leading to multiple power peaks in the P–V characteristic. The output power and load voltage exhibit smooth, stable behavior with reduced ripple and minimal oscillations, demonstrating the robustness of the proposed MPPT strategy

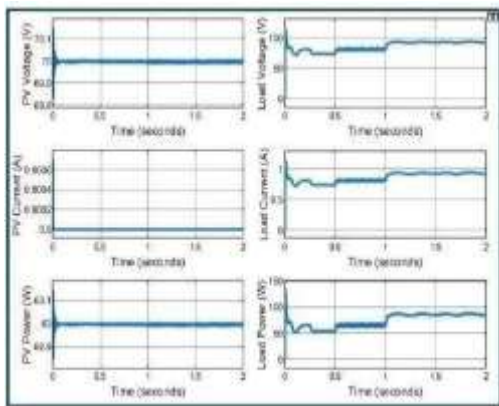
**Case 2 – Static Partial Shading (1000, 900, 500, 400  $W/m^2$ ):** This condition represents a moderate static partial shading pattern where irradiance mismatch exists among the

PV modules but is less severe compared to Case 1. Multiple power peaks still form in the P–V characteristic curve.



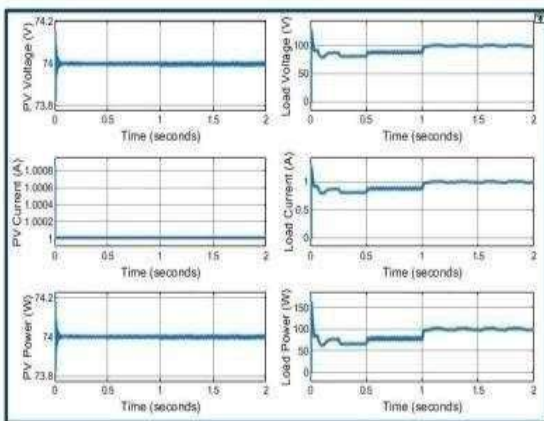
**Fig. 6:PSA results — Static Partial Shading (1000, 900, 500, 400) W/m<sup>2</sup>.**

**Case 3 – Static Partial Shading (1000, 1000, 1000, 500 W/m<sup>2</sup>):** In this scenario, partial shading affects only one PV module while the remaining modules receive full irradiance. The system exhibits ripples and oscillations with less reliable performance under this light partial shading condition.



**Fig7. PSA results — Static Partial Shading (1000, 1000, 1000, 500) W/m<sup>2</sup>.**

**Fig 8 PSA results — Static Partial Shading (1000, 950, 700, 650) W/m<sup>2</sup>:Case 4 – Static Partial Shading (1000, 950, 700, 650 W/m<sup>2</sup>):** This case represents a relatively uniform partial shading scenario closer to practical urban operating conditions. The irradiance variation among modules is moderate and evenly distributed. The controller maintains reduced ripple in voltage and power, ensuring reliable energy extraction and precise stable tracking even where small differences between local and global peaks exist.



**Case 5 – Dynamic Partial Shading:** Partial shading is introduced to represent rapidly changing environmental conditions such as moving clouds or temporary obstacles. The irradiance levels vary over time, resulting in continuous changes in the PV array output characteristics. The GWO- INC MPPT method effectively adapts to varying irradiance and continuously searches for the GMPP. The controller quickly adjusts the DC-DC converter duty cycle to minimize power losses during transitions. Although temporary transients appear in waveforms during irradiance changes, the system rapidly stabilizes once the new operating point is identified.

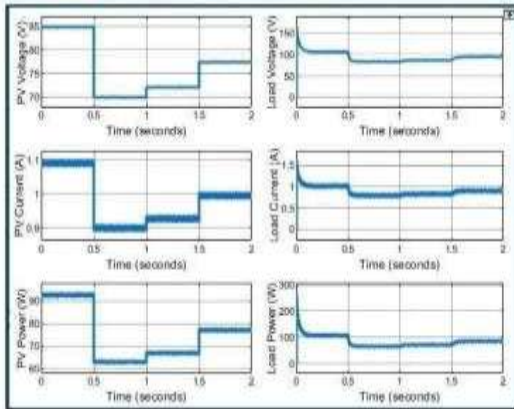


Fig. 11. GWO-INC results under dynamic partial shading conditions.

## VII. CONCLUSION

This paper presents an improved Maximum Power Point Tracking approach for solar photovoltaic systems operating under partial shading conditions. The base method employs the Projectile Search Algorithm (PSA), a novel physics-inspired metaheuristic that uses projectile motion principles to effectively locate the global maximum power point. PSA demonstrates fast convergence, low computational complexity, and reliable tracking performance under various static and dynamic partial shading conditions.

The proposed GWO-INC method combines the global search power of Grey Wolf Optimization with the precise local tracking of the Incremental Conductance method, enhancing tracking capability by accurately locating the GMPP with superior convergence and stable operation even under varying irradiance levels.

The GWO-INC controller significantly reduces power and voltage ripple during steady-state operation, resulting in smoother output characteristics compared to the base PSA method. Simulation results under four static partial shading conditions and one dynamic shading condition validate the effectiveness of both methods. The GWO-INC method consistently shows faster settling time, reduced steady-state oscillations, and higher power extraction efficiency across all tested conditions, making it a robust and practical solution for real-world solar energy applications.

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