



# Design and Performance Analysis of a Solar MPPT System for DC Pump Motor Fishing Units

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**ABSTRACT:** The steady increase in fossil fuel costs and the lack of dependable grid access in many coastal and inland fishing regions have created a strong demand for alternative energy sources. Renewable energy, particularly solar power, offers a practical solution for operating essential equipment in remote fisheries. This study examines the design and performance of a solar photovoltaic (PV) powered DC pump system integrated with a Maximum Power Point Tracking (MPPT) control strategy to enhance energy utilization efficiency.

The proposed system is intended to support key fisheries activities such as water pumping, aeration, and circulation, which are vital for maintaining aquatic environments and handling operations. The overall configuration includes a PV array, a DC-DC boost converter, an MPPT controller, and a DC motor-driven pump. To ensure optimal power extraction from the PV array under changing weather conditions, the Incremental Conductance (INC) algorithm is employed. This method continuously evaluates voltage and current variations to identify and maintain operation at the maximum power point, even when solar irradiance and temperature fluctuate.

The complete system is modeled and simulated using MATLAB/Simulink to assess its dynamic behavior and steady-state performance. Simulation results indicate that the MPPT-controlled system achieves faster tracking of the maximum power point with minimal oscillations compared to conventional control techniques. The boost converter effectively regulates the output voltage, supplying stable and sufficient power to the DC pump motor. As a result, the pump operates reliably under varying environmental conditions, ensuring uninterrupted performance for fisheries-related tasks.



The findings demonstrate that a solar PV system equipped with an MPPT-based control scheme provides an efficient, environmentally friendly, and economically viable solution for small-scale fisheries. By reducing reliance on diesel or grid electricity, the system lowers operational expenses and supports sustainable practices in isolated and off-grid locations. Overall, the proposed configuration shows strong potential for practical deployment in fisheries where clean and dependable energy is essential.

**KEYWORDS:** Solar photovoltaic system, DC pump motor, fishing applications, maximum power point tracking, INC algorithm, DC boost converter, renewable energy system, off-grid power supply, energy-efficient pumping.

## I. INTRODUCTION

Photovoltaic (PV) systems frequently operate under non-uniform environmental conditions. Factors such as passing clouds, nearby buildings, trees, and other physical obstructions can cause partial shading across the PV array. When this occurs, the power–voltage (P–V) characteristic of the array no longer exhibits a single peak; instead, multiple local maxima appear. Under such circumstances, many traditional Maximum Power Point Tracking (MPPT) methods are prone to settling at a local peak rather than identifying the true Global Maximum Power Point (GMPP). This leads to suboptimal energy extraction and a noticeable drop in overall system efficiency.

To address this limitation, a hybrid MPPT strategy can be employed by integrating different optimization techniques. In the proposed method, Particle Swarm Optimization (PSO) is utilized to search the entire operating range of the PV system and locate the global maximum power point under partial shading conditions. PSO, inspired by the collective behavior of swarms, enables effective global exploration and reduces the risk of convergence to local maxima.

Once the vicinity of the global peak is identified, a fine-tuning mechanism is applied to improve tracking precision and system stability. A fuzzy logic controller enhances the dynamic response by adjusting control actions based on real-time variations in voltage and current. In addition, the Perturb and Observe (P&O) technique can be incorporated for steady-state refinement, ensuring minimal oscillations around the operating point. By combining global search capability with intelligent control and local adjustment, the hybrid MPPT approach improves tracking speed, accuracy, and robustness. As a result, the PV system maintains higher efficiency even under complex shading and rapidly changing environmental conditions, making it more suitable for practical applications where consistent energy output is critical [1].

This study presents an improved Maximum Power Point Tracking (MPPT) method that integrates a fuzzy immune control mechanism with the conventional Perturb and Observe (P&O) technique. The primary objective of the proposed method is to enhance the adaptability and efficiency of photovoltaic (PV) systems by automatically adjusting controller parameters according to operating conditions. Conventional P&O-based MPPT methods are widely used due to their simplicity; however, they tend to produce steady-state oscillations around the maximum power point. These oscillations cause power fluctuations, which in turn reduce overall energy conversion efficiency. To overcome this drawback, the proposed hybrid strategy incorporates fuzzy logic with an immune-inspired control concept. This combination enables intelligent decision-making and adaptive behavior, leading to smoother and more stable power tracking.

The controller design is developed through a structured process. Initially, a nonlinear mathematical model of the PV generator is formulated to represent its electrical characteristics accurately. The current–voltage (I–V) relationship is then linearized around standard test conditions to simplify control analysis and implementation. Based on this model, a complete renewable energy conversion system is constructed, where the fuzzy immune controller is embedded within the MPPT framework.

To further enhance performance, genetic algorithms are employed to optimize controller parameters. This optimization process ensures precise estimation of the reference PV voltage determined through the modified P&O method. By carefully regulating the duty cycle of the DC–DC converter, the system achieves stable operation with reduced ripple and minimized power oscillations.

Overall, the proposed fuzzy immune P&O-based MPPT technique offers improved tracking accuracy, faster dynamic response, and enhanced stability. It provides a practical and efficient solution for maximizing energy extraction from PV systems under varying environmental conditions [1-2]



To improve the energy conversion efficiency of solar photovoltaic (PV) systems, a modified Perturb and Observe (P&O)-based Maximum Power Point Tracking (MPPT) technique is proposed. The central idea of this method is to reduce unnecessary searching across the entire power-voltage (P-V) curve and instead concentrate the tracking process near the most probable maximum power region.

In this approach, the PV array's voltage-power characteristics are segmented into four distinct operating regions using an estimation of the open-circuit voltage. By identifying these regions, the controller can predict where the maximum power point (MPP) is most likely to occur. Rather than applying small perturbations throughout the full voltage range, the algorithm performs detailed and fine tracking only within a narrow band—approximately ten percent of the voltage range—surrounding the anticipated peak. Outside this targeted region, a larger fixed step size is used to move the operating point quickly toward the expected maximum zone. This reduces tracking time and enhances dynamic response, especially during sudden changes in irradiance. Once the operating point enters the vicinity of the maximum power region, the method transitions to an adaptive adjustment mechanism similar to that used in conventional P&O techniques. The step size is gradually reduced to minimize steady-state oscillations and improve output stability. By combining fast coarse searching with refined local tracking, the modified P&O algorithm achieves quicker convergence and reduced power fluctuations. As a result, the PV system operates closer to its true maximum power point with improved efficiency and smoother performance under varying environmental conditions [2-3].

A significant issue in building-integrated photovoltaic (BIPV) installations is ensuring that the maximum available power is consistently harvested from the solar modules. The structural configuration of the PV system greatly influences how efficiently the generated energy is captured and delivered to the load or grid. System architecture determines how modules interact electrically and how well the system adapts to variations in environmental conditions.

In conventional central inverter setups, several PV modules are connected in series and/or parallel to a single inverter. While this arrangement simplifies system design and reduces installation cost, it makes the entire array vulnerable to partial shading. When one or more modules receive less sunlight due to shadows from nearby structures, trees, or architectural elements, their output current decreases. Because series-connected modules must carry the same current, the performance of the entire string is limited by the weakest module.

This mismatch among modules results in power losses and a noticeable drop in overall efficiency. Consequently, partial shading can significantly affect energy yield in BIPV systems that rely on centralized inverter configurations. Addressing this limitation requires improved system designs or advanced control strategies that can mitigate mismatch effects and enhance power extraction under non-uniform operating conditions [4]. Maximum Power Point Tracking (MPPT) plays a crucial role in renewable energy conversion systems, including solar photovoltaic arrays, wind turbines, and marine energy devices. Its purpose is to ensure that the energy source operates at its optimal point so that the highest possible power is delivered despite variations in environmental conditions such as sunlight intensity, wind speed, or water flow.

Among the commonly adopted MPPT methods, Perturb and Observe (P&O) and Incremental Conductance (INC) are widely preferred because of their straightforward structure and ease of practical implementation. These techniques rely on measuring changes in voltage and current to determine the direction in which the operating point should move in order to reach the maximum power region.

Despite their simplicity, both methods face a fundamental challenge in choosing an appropriate perturbation step size. If a large step size is selected, the system can respond quickly to environmental changes and reach the vicinity of the maximum power point faster. However, this often results in noticeable oscillations around the optimum point, causing power fluctuations and energy loss. On the other hand, using a small step size reduces steady-state oscillations and improves stability, but it slows down the convergence process, especially under rapidly changing conditions.

This trade-off between tracking speed and steady-state accuracy remains one of the primary limitations of conventional MPPT techniques, motivating the development of improved or adaptive control strategies [3-5]

## II. PROPOSED SYSTEM

The solar panel under consideration has a rated peak output of about 259.9 W when tested under standard test conditions (STC). It is constructed with 60 photovoltaic cells, a configuration commonly found in medium-capacity modules used for residential rooftops and small industrial installations.

The open-circuit voltage ( $V_{oc}$ ) of the module is 38.3 V, representing the terminal voltage when the panel is not connected to any load. The short-circuit current ( $I_{sc}$ ) is 8.96 A, which corresponds to the maximum current delivered when the output terminals are directly shorted. These two parameters define the extreme operating limits of the module. At the maximum power point (MPP), the module delivers its highest rated power. Under this condition, the operating voltage is approximately 30.4 V and the corresponding current is about 8.55 A. These values represent the optimal combination of voltage and current required to extract maximum energy from the panel.

Temperature has a noticeable influence on the electrical performance of the module. The open-circuit voltage decreases as temperature rises, with a temperature coefficient of about 0.323% per degree Celsius. In contrast, the short-circuit current shows a slight positive temperature dependence, increasing by roughly 0.015% per degree Celsius. These characteristics highlight the importance of proper thermal management and maximum power point tracking to maintain efficient operation under varying environmental conditions.

### Block Diagram

The proposed system is composed of a photovoltaic (PV) module, an MPPT controller, a PWM generation unit, a DC–DC converter, and the connected load. The PV panel serves as the primary energy source, converting incident solar radiation into electrical power. Since solar irradiance and temperature vary throughout the day, the output voltage and current of the panel continuously change. As a result, the panel does not naturally operate at its maximum power point under all conditions.

To achieve optimal energy extraction, the instantaneous voltage and current of the PV module are continuously sensed and supplied to the MPPT controller. Based on these input signals, the MPPT algorithm determines the operating point at which the panel can deliver maximum power. This calculated reference is then used to control the power conversion stage.

The controller's output is translated into a Pulse Width Modulation (PWM) signal. The PWM unit generates appropriate switching pulses that regulate the duty cycle of the DC–DC converter. By adjusting the duty ratio, the converter modifies the effective input impedance seen by the PV panel, thereby forcing it to operate near its maximum power point.

The DC–DC converter consequently regulates the voltage and current supplied to the load. Through continuous duty cycle adjustment, the system maintains stable and efficient power transfer. The conditioned output ensures reliable performance of the load device while maximizing the overall efficiency of the solar energy conversion process and show Fig.2

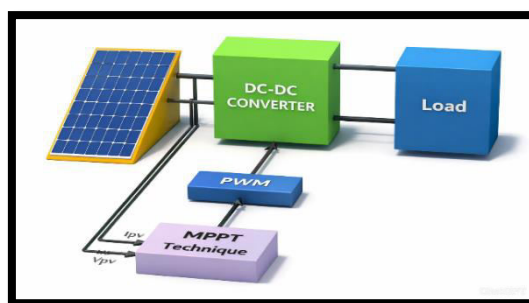


Fig.2 Block Diagram

### Boost converter

A boost converter is a DC–DC power conversion device designed to raise a lower input voltage to a higher output voltage. It is commonly employed in solar photovoltaic (PV) systems, particularly in applications that incorporate Maximum Power Point Tracking (MPPT). In such systems, the converter plays a key role in adjusting the electrical operating conditions of the PV panel so that maximum available power can be extracted.

The basic configuration of a boost converter includes an inductor, a controlled semiconductor switch (typically a MOSFET or IGBT), a diode, and an output capacitor. Its operation is based on energy storage and transfer principles.

When the switch is turned on, current flows through the inductor, allowing it to store energy in its magnetic field. During this period, the diode remains reverse-biased, and the load is supported by the charge stored in the output capacitor. When the switch is turned off, the inductor releases its stored energy. This energy flows through the diode to the output side, combining with the input supply and producing a higher output voltage.

The relationship between input and output voltage is governed by the duty cycle of the switching signal. By varying the duty cycle through a Pulse Width Modulation (PWM) control scheme, the output voltage can be regulated effectively. In MPPT-based solar systems, this controllability allows the converter to adjust the PV panel's operating voltage, ensuring that it remains at or near the maximum power point despite fluctuations in sunlight intensity and temperature. Boost converters are widely favored in solar energy applications due to their straightforward design, good efficiency, and capability to deliver a stable and elevated output voltage. These characteristics make them well suited for supplying power to loads such as DC motors and other DC-operated equipment, as illustrated in Figure 3.

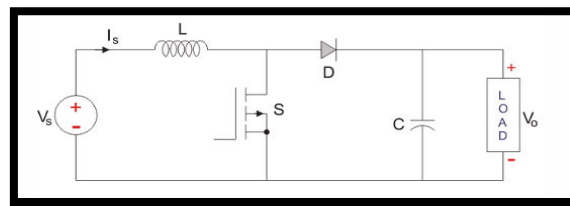


Fig.3 Boost Converter

**DC Pump**

In the proposed solar MPPT-based fishing system, a 48 V DC pump motor serves as the main load. This voltage level is well suited for medium-scale photovoltaic installations and is particularly advantageous in standalone applications. Operating at 48 V allows lower current flow for a given power level, which reduces conduction losses in cables and switching devices while maintaining a safe operating range. Within the system configuration, the DC pump is supplied by a solar PV array through a DC-DC boost converter governed by an MPPT control scheme. The MPPT unit continuously monitors the panel's electrical parameters and adjusts the operating point to obtain maximum available power under varying sunlight and temperature conditions. The boost converter then steps up and regulates the voltage to meet the requirements of the 48 V motor, ensuring consistent and dependable performance even when environmental conditions fluctuate.

This type of DC pump is well suited for fisheries-related operations such as water circulation in tanks, aeration for maintaining dissolved oxygen levels, transporting live fish, and small-scale water transfer tasks. Its straightforward design, minimal maintenance needs, and strong starting torque make it reliable for outdoor and remote applications where consistent operation is critical. Integrating a 48 V DC pump motor with a solar PV system equipped with MPPT control results in improved overall efficiency and sustainability. The arrangement decreases reliance on fuel-powered generators, cuts operational expenses, and offers an environmentally responsible energy solution for small fishing units, especially in coastal or off-grid regions. The system configuration is illustrated in Figure 4.



Fig.4 DC Pump



### Incremental Conductance (INC)

The Incremental Conductance (INC) technique is a commonly adopted Maximum Power Point Tracking (MPPT) method in solar photovoltaic (PV) systems. Its purpose is to keep the PV array operating at the maximum power point (MPP) despite variations in sunlight intensity and cell temperature. Since these environmental factors continuously influence the voltage–current characteristics of a solar panel, an effective tracking strategy is essential to maintain optimal energy extraction.

The operating principle of the INC method relies on the behavior of the power–voltage (P–V) curve. At the maximum power point, the slope of the P–V curve becomes zero. In analytical terms, this occurs when the derivative of power with respect to voltage equals zero. By expressing power as the product of voltage and current, this condition leads to a relationship where the incremental conductance ( $\Delta I/\Delta V$ ) is equal in magnitude and opposite in sign to the instantaneous conductance ( $I/V$ ).

In practical implementation, the controller continuously measures small changes in current and voltage and compares the ratio  $\Delta I/\Delta V$  with  $-I/V$ . If the incremental conductance is greater than the negative instantaneous conductance, the operating point lies on the left side of the MPP, and the system increases the operating voltage. If it is smaller, the operating point is on the right side, and the voltage is decreased. When both quantities are equal, the system recognizes that the maximum power point has been reached and maintains the current operating condition. A key strength of the INC method is its ability to identify the correct direction toward the MPP without relying solely on periodic perturbations. This reduces steady-state oscillations and enhances tracking accuracy, especially during rapid changes in irradiance. As a result, the system achieves improved efficiency and faster dynamic response compared to simpler MPPT approaches.

### III. RESULT AND DISCUSSION

The designed solar MPPT system intended for the DC pump motor fishing unit was developed and evaluated through simulation under a range of operating conditions. The modeled setup included a photovoltaic (PV) array, a DC–DC boost converter, an Incremental Conductance (INC)–based MPPT controller, and a 48 V DC pump motor acting as the load. The primary aim was to examine how effectively the MPPT algorithm could maximize power extraction from the PV array while ensuring steady motor performance during changes in solar irradiance.

The simulation results presented in Figure 5 demonstrate that the INC control strategy effectively identifies and maintains operation at the maximum power point. When irradiance levels vary, the controller promptly modifies the duty cycle of the boost converter to adapt to the new electrical conditions. This rapid adjustment allows the PV array to remain near its optimal operating region, thereby minimizing energy loss and enhancing overall efficiency. The boost converter plays a critical role in stabilizing the voltage supplied to the 48 V DC pump motor. Although the PV output fluctuates with sunlight intensity, the converter regulates the output voltage to prevent abrupt changes at the motor terminals. Consequently, the pump runs smoothly, with minimal variations in speed and torque.

The system’s dynamic behavior confirms that the INC-based MPPT approach provides quick convergence to the maximum power point while keeping steady-state oscillations low. In comparison with basic fixed-duty or less advanced control techniques, the proposed configuration achieves superior power utilization and improved voltage regulation, making it suitable for reliable operation in solar-powered fishing applications.

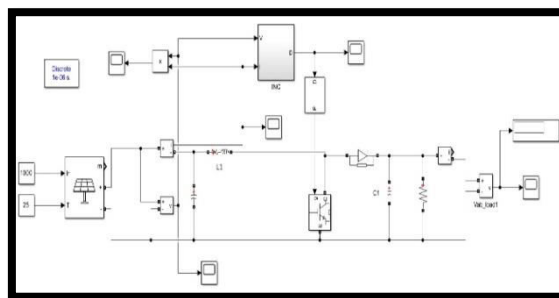


Fig.5 Proposed Simulation Diagram

The graph presents the variation of the solar panel output voltage over a time span of two seconds. At the beginning of the simulation, the voltage shows a pronounced transient response accompanied by noticeable oscillations. This initial fluctuation is typical during system start-up, when the MPPT controller begins searching for the optimal operating point of the photovoltaic array.

As time progresses, the magnitude of these oscillations decreases steadily. The controller adjusts the operating voltage, and the system moves closer to the maximum power region. After the short transient interval, the output voltage stabilizes within the range of approximately 30–31 V, which corresponds to the expected maximum power point voltage of the panel.

The minor, periodic ripples that remain after stabilization are mainly caused by the high-frequency switching of the DC–DC boost converter and the continuous fine-tuning action of the MPPT algorithm. These small variations are normal in power electronic systems and do not significantly affect performance.

The quick reduction of oscillations and the steady voltage level indicate that the MPPT controller responds efficiently and converges rapidly to the maximum power point. The stable operation observed after the transient phase confirms that the system maintains effective energy extraction under the simulated conditions, as illustrated in Figure 6.

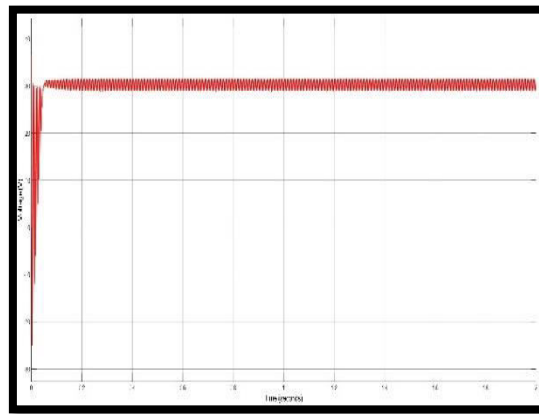
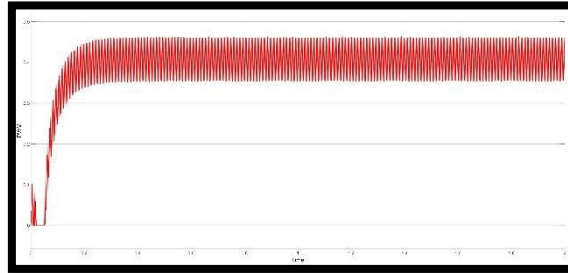


Fig.6 Solar Panel Voltage graph

The PWM waveform represents the switching activity of the DC–DC converter throughout system operation. At the start of the graph, a brief transient phase is visible, during which the duty cycle increases from an initially low value. This behavior reflects the controller's response as it adjusts the operating conditions to drive the system toward the desired set point.

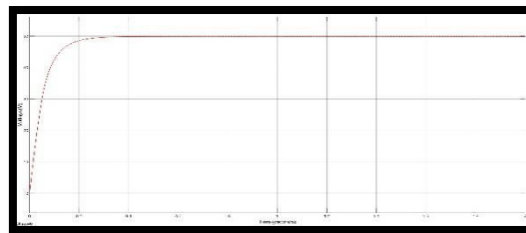
Once the transient interval passes, the waveform becomes regular and periodic. The switching pulses display consistent amplitude and frequency, indicating that the control algorithm has achieved steady-state operation. This stable pulse pattern confirms that the converter is being properly regulated and that the system is effectively maintaining the intended operating point.

In the steady region, the nearly constant pulse width demonstrates that the duty cycle has been successfully tuned according to the prevailing input and load requirements. The lack of significant fluctuations or irregular switching events further suggests that the control mechanism is functioning reliably with minimal tracking error. The observed behavior, as illustrated in Figure 7, highlights the stability and proper performance of the PWM-controlled converter within the overall system.



**Fig.7 PWM Generator waveform**

The DC pump output graph depicts the motor's response immediately after power is supplied. At the beginning of the waveform, the output increases rapidly from zero, reflecting the starting phase of the motor. This sharp rise corresponds to the development of speed and torque as the converter delivers the required voltage and current to the pump. Following this brief transient interval, the output settles into a steady operating region. In this phase, the motor output remains nearly constant, indicating that the desired operating conditions have been reached and are being maintained by the control system. The lack of significant oscillations or irregular variations demonstrates that the regulation mechanism is functioning effectively. The short rise time highlights the ability of the control strategy to provide adequate starting torque and a fast dynamic response. Meanwhile, the stable steady-state portion of the curve confirms that the system can sustain consistent motor performance under the applied load. Such stable behavior is essential in pumping applications, where uniform flow rate and pressure are critical for reliable operation, as illustrated in Figure 8.



**Fig.8 DC Pump Voltage graph**

## IV. CONCLUSION

The designed solar-powered DC pump system demonstrates effective energy conversion and reliable motor operation under varying conditions. By integrating a maximum power point tracking technique, the system is able to extract the highest possible power from the solar panel and deliver it efficiently to the DC pump motor. This improves overall performance and ensures better utilization of the available solar energy. The use of the incremental conductance method enables accurate tracking of the maximum power point, even when solar irradiance and temperature change. The boost converter helps in regulating the voltage level and maintaining a steady supply to the pump motor. As a result, the motor starts smoothly, reaches its operating speed quickly, and maintains stable output during continuous operation. The simulation results confirm that the system provides fast response, stable voltage, and consistent motor performance. The PWM control ensures proper switching action, while the DC pump output shows minimal fluctuations in the steady-state region. These characteristics indicate that the proposed system is suitable for practical applications such as small fishing units or remote water pumping setups. Overall, the solar MPPT-based DC pump system offers an efficient, reliable, and environmentally friendly solution for standalone pumping applications. The design can help reduce dependence on conventional energy sources and support sustainable operation in off-grid locations.

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