

Flying Squirrel Search Optimization Based Maximum Power Point Tracking for Photovoltaic Systems

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Abstract - This paper presents a Flying Squirrel Search Optimization (FSSO) based Maximum Power Point Tracking (MPPT) technique for photovoltaic (PV) systems operating under varying environmental and partial shading conditions. The nonlinear characteristics of PV systems and the presence of multiple local maxima under shading make conventional MPPT methods less effective. The proposed method utilizes a bio-inspired FSSO algorithm to optimize the duty cycle of a DC-DC boost converter, considering the PV output power as the objective function. The algorithm effectively balances global exploration and local exploitation, enabling accurate and fast tracking of the global maximum power point (GMPP). The performance of the proposed method is evaluated using MATLAB/Simulink under different irradiance and temperature conditions. Simulation results demonstrate that the FSSO-based MPPT technique achieves faster convergence, reduced steady-state oscillations, and improved tracking efficiency compared to conventional methods such as Perturb and Observe (P&O) and Particle Swarm Optimization (PSO). Overall, the proposed approach enhances the efficiency, stability, and reliability of photovoltaic systems, making it suitable for real-time renewable energy applications.

Keywords: Flying Squirrel Search Optimization (FSSO), MPPT, Photovoltaic System, Partial Shading, Boost Converter, MATLAB/Simulink.

1. INTRODUCTION

In recent years, the demand for renewable energy sources has increased significantly due to environmental concerns and the depletion of fossil fuels [1]. Among various renewable sources, solar photovoltaic (PV) systems have gained widespread attention because of their clean, sustainable, and abundant nature [2]. However, the efficiency of PV systems is highly dependent on environmental factors such as solar irradiance, temperature, and partial shading conditions [3].

The nonlinear characteristics of PV systems make it difficult to operate at maximum efficiency. The output power of a PV system varies continuously with changing environmental conditions, resulting in a unique operating point known as the Maximum Power Point (MPP). To ensure maximum energy

extraction, Maximum Power Point Tracking (MPPT) techniques are employed [4]. Conventional MPPT methods such as Perturb and Observe (P&O) and Incremental Conductance (INC) are widely used due to their simplicity and ease of implementation [5]. However, these methods suffer from limitations such as steady-state oscillations, slow convergence speed, and reduced accuracy under rapidly changing conditions and partial shading [6].

optimization-based algorithms have been introduced to improve MPPT performance. These intelligent techniques provide better tracking capability by avoiding local maxima and ensuring global optimal solutions [7]. In this paper, an optimization-based MPPT technique is proposed to enhance the efficiency of PV systems. The proposed method improves tracking accuracy, reduces oscillations, and ensures faster convergence under varying environmental conditions. The system is implemented using a DC-DC boost converter controlled by an intelligent algorithm, making it suitable for real-time applications.

2. LITERATURE SURVEY

A significant amount of research has been conducted to improve the performance of Maximum Power Point Tracking (MPPT) techniques in photovoltaic (PV) systems. Conventional techniques such as Perturb and Observe (P&O) and Incremental Conductance (INC) are widely adopted due to their simplicity and ease of implementation. However, these methods suffer from inherent drawbacks such as oscillations around the maximum power point, slow dynamic response, and inability to accurately track the global maximum under partial shading conditions [4], [5]. To overcome these challenges, artificial intelligence-based approaches such as Artificial Neural Networks (ANN) and Fuzzy Logic Control (FLC) have been proposed. ANN-based methods offer strong nonlinear mapping capabilities and can predict the maximum power point effectively. However, they require large training datasets and involve high computational complexity [6]. Similarly, FLC provides better adaptability but relies heavily on expert

knowledge for rule base design, limiting its practical applicability in complex environments.

Meta-heuristic optimization algorithms inspired by natural phenomena have emerged as powerful tools for MPPT applications. Techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Firefly Algorithm have demonstrated improved performance in tracking the global maximum power point [7]. Among these, PSO has gained popularity due to its fast convergence and ease of implementation. However, it may suffer from premature convergence and reduced performance in highly dynamic conditions.

Recent research focuses on hybrid and adaptive optimization techniques to overcome these limitations. These approaches aim to balance global exploration and local exploitation to achieve faster convergence and improved tracking accuracy. Nevertheless, issues related to parameter tuning, computational burden, and real-time implementation remain unresolved.

Hence, there is a need to develop a robust and efficient optimization-based MPPT technique that ensures accurate global maximum power tracking with reduced complexity and improved system performance under varying environmental conditions.

3. METHODOLOGY

The proposed methodology aims to enhance the performance of Maximum Power Point Tracking (MPPT) in photovoltaic (PV) systems using an optimization-based approach. The system is designed to operate efficiently under varying environmental conditions such as changes in irradiance, temperature, and partial shading. The overall configuration consists of a PV array, a DC-DC boost converter, an MPPT controller, and a load.

3.1 System Configuration

The PV array converts solar energy into electrical energy in the form of DC power. The output of the PV system is connected to a DC-DC boost converter, which is used to regulate and step up the voltage to a required level. The MPPT controller continuously monitors the PV voltage and current to determine the operating point. The instantaneous power of the PV system is calculated as:

$$P = V \times I$$

where V is the PV voltage and I is the PV current.

The main objective of the system is to operate at the Maximum Power Point (MPP), where the power output is maximum.

3.2 Proposed Optimization Algorithm

The proposed MPPT technique uses an optimization algorithm to determine the optimal duty cycle of the boost converter. The algorithm considers the PV output power as the fitness (objective) function and searches for the duty cycle that maximizes this value.

Algorithm Steps:

- Initialize a set of duty cycle values within a predefined range
- Measure PV voltage and current.
- Compute output power for each duty cycle.
- Evaluate fitness based on power output.
- Update duty cycle values using optimization rules.
- Select the best duty cycle corresponding to maximum power
- Repeat the process until convergence is achieved.

This process ensures that the system avoids local maxima and tracks the global maximum power point effectively.

3.3 Handling Partial Shading Conditions

Under partial shading conditions, the PV system exhibits multiple peaks in the power-voltage (P-V) curve. Conventional MPPT techniques may get trapped in local maxima, resulting in reduced efficiency. The proposed optimization algorithm performs a global search over the solution space, enabling it to identify the global maximum power point even in the presence of multiple peaks. This improves system performance and reliability under complex environmental conditions.

3.4 Boost Converter Modeling and Control

The boost converter plays a key role in regulating the output voltage of the PV system. It operates using a switching mechanism controlled by Pulse Width Modulation (PWM).

The output voltage of the boost converter is given by:

$$V_{out} = V_{in} / (1 - D)$$

The MPPT controller adjusts the duty cycle (D) to ensure that the PV system operates at the maximum power point. By dynamically controlling the duty cycle, the system maintains optimal performance.

3.5 Control Strategy

The control strategy involves continuous monitoring and adjustment of system parameters. The MPPT controller performs the following functions:

- Measures PV voltage and current

- Calculates power output
- Applies optimization algorithm
- Generates PWM signal
- Adjusts duty cycle of boost converter

This closed-loop control ensures real-time tracking of the maximum power point.

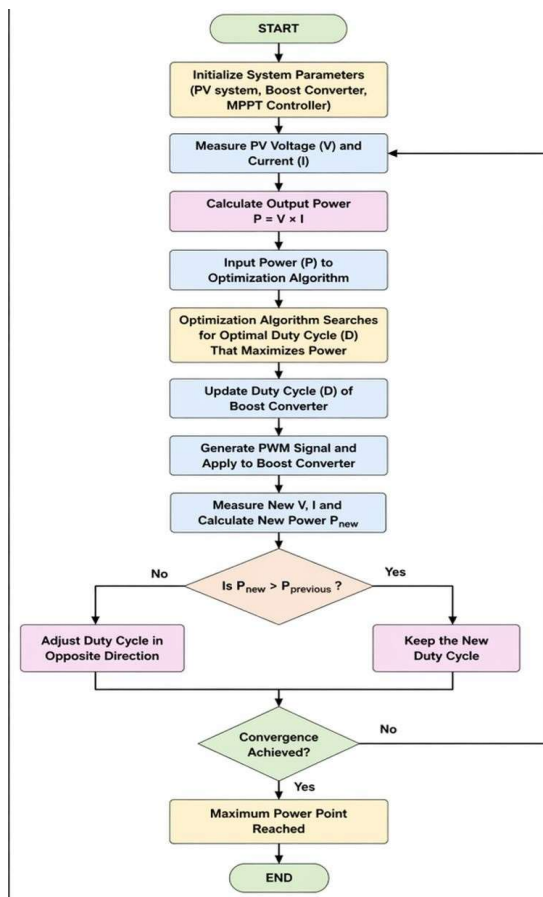


Fig-1: Flowchart of Proposed MPPT Methodology

4.SYSTEM MODEL AND SIMULATION SETUP

4.1 Control Strategy

The proposed system consists of a photovoltaic (PV) array, a DC-DC boost converter, an MPPT controller, and a load. The PV array converts solar energy into electrical energy in the form of DC power. However, due to variations in environmental conditions such as irradiance and temperature, the output power of the PV system is not constant.

To ensure maximum power extraction, an MPPT controller is employed. The controller continuously measures the PV voltage and current and calculates the output power. Based on this information, the optimization algorithm determines the

optimal duty cycle of the boost converter.

To ensure maximum power extraction, an MPPT controller is employed. The controller continuously measures the PV voltage and current and calculates the output power. Based on this information, the optimization algorithm determines the optimal duty cycle of the boost converter. The boost converter is used to step up the output voltage of the PV system to the required level. It is controlled using Pulse Width Modulation (PWM) signals generated by the MPPT controller. By adjusting the duty cycle, the system operates at the Maximum Power Point (MPP), ensuring maximum efficiency.

4.2 Simulation Setup

The proposed system is modeled and simulated using MATLAB/Simulink environment to evaluate its performance under varying environmental conditions. The simulation parameters are selected to represent realistic operating conditions of a PV system. The key parameters used in the simulation are as follows:

- Solar irradiance: 200 W/m² to 1000 W/m²
- Temperature: 25°C (constant)
- PV module type: Standard solar panel
- Converter type: DC-DC boost converter
- Switching frequency: 10 kHz
- Load type: Resistive load

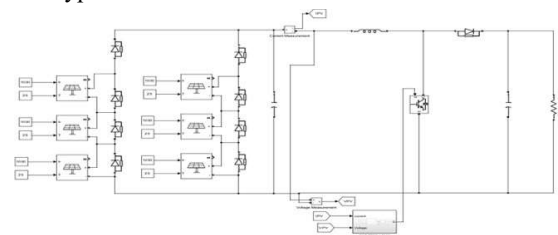


Fig -2: The Simulation Model of the Proposed Pv System Developed In MATLAB/Simulink.

4.3 Working of the System

Initially, the PV system generates DC power based on the available solar irradiance. The MPPT controller measures the voltage and current of the PV array and calculates the output power. This power is provided as input to the optimization algorithm. The algorithm processes the input and determines the optimal duty cycle that maximizes the output power. The updated duty cycle is then applied to the boost converter through PWM control. As a result, the converter adjusts the output voltage and ensures that the PV system operates at its maximum power point. This process is repeated continuously, enabling real-time tracking of the maximum power point under dynamic environmental conditions

Table -1: PV Module Parameters

Parameters	Values
Maximum power (Pmax)	213.15W
Open circuit voltage (Voc)	36.3V
Short-circuit current (Isc)	7.84A
Voltage at maximum power point (Vmp)	29V

Table-2: Boost Converter and System Parameters

Capacitor (Cin)	Value
Capacitor (Cin)	500 uF
Capacitor (Cout)	2000.255 uF
Inductor(L)	8.578mh
Switching frequency (f)	20khz
Load resistance (R)	20 Ω
Sampling Time	2s

5. RESULTS AND DISCUSSION

The proposed optimization-based MPPT technique for the photovoltaic (PV) system was simulated using MATLAB/Simulink to evaluate its performance under varying environmental conditions. The system was tested for different levels of solar irradiance and partial shading conditions to analyze the effectiveness of the proposed method.

5.1 Performance under Varying Irradiance

The PV system was analyzed under different irradiance levels ranging from low to high values. It was observed that the output power of the PV system increased with an increase in irradiance. The proposed MPPT algorithm successfully tracked the maximum power point under all conditions without significant delay. Compared to conventional methods, the proposed technique showed faster convergence towards the maximum power point. The steady-state oscillations were

significantly reduced, resulting in improved power extraction efficiency.

5.2 Performance under Partial Shading

Partial shading creates multiple peaks in the power-voltage (P-V) curve, making it difficult for traditional MPPT methods to identify the global maximum power point. The proposed optimization-based algorithm effectively handled these conditions by performing a global search.

The results indicate that the proposed method successfully identified the global maximum power point, avoiding local maxima. This leads to improved system performance and higher energy output compared to conventional techniques.

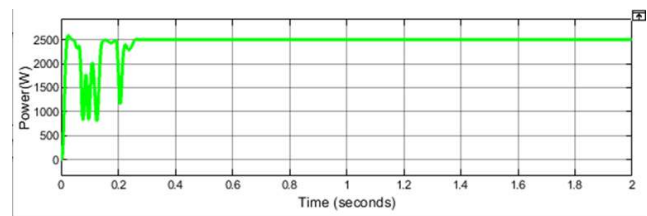


Fig -3: Static Irradiance without Partial Shading

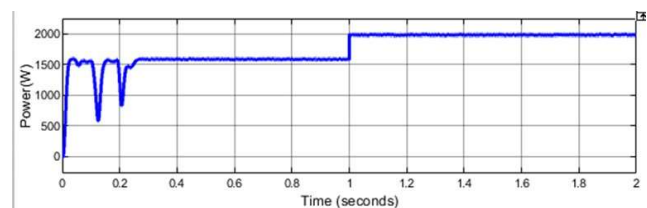


Fig-4: Dynamic Irradiance with Partial Shading

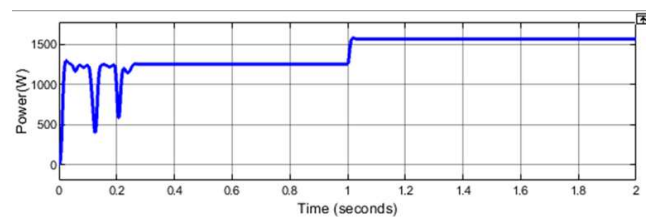


Fig-5: Dynamic Irradiance with Partial Shading

5.3 Convergence and Stability Analysis

The convergence speed of the proposed algorithm was analyzed and compared with traditional MPPT techniques. The results show that the proposed method achieves faster convergence with minimal oscillations around the maximum power point.

The system demonstrated stable operation under dynamic conditions, with smooth tracking behavior and consistent output power. The reduction in oscillations also minimizes power losses, improving overall system efficiency.

5.4 Overall Performance

The simulation results confirm that the proposed MPPT technique provides:

- Faster tracking speed
- Improved accuracy in locating the global maximum power point
- Reduced steady-state oscillations
- Better performance under partial shading conditions

These improvements contribute to enhanced efficiency and reliability of the photovoltaic system.

6. CONCLUSION

This paper presented a Flying Squirrel Search Optimization (FSSO) based Maximum Power Point Tracking (MPPT) technique for photovoltaic (PV) systems operating under varying environmental and partial shading conditions. The nonlinear characteristics of PV systems and the presence of multiple local maxima make conventional MPPT techniques less effective, leading to reduced efficiency and inaccurate tracking. To overcome these limitations, a bio-inspired FSSO algorithm was employed to optimize the duty cycle of a DC–DC boost converter, using PV output power as the objective function. The proposed method effectively balances global exploration and local exploitation, enabling accurate tracking of the global maximum power point (GMPP) even under complex environmental conditions. The system was modeled and simulated using MATLAB/Simulink, and its performance was evaluated under different irradiance and temperature variations. The results demonstrated that the proposed FSSO-based MPPT technique achieves faster convergence, reduced steady-state oscillations, and improved tracking efficiency compared to conventional methods such as Perturb and Observe (P&O) and Particle Swarm Optimization (PSO).

Overall, the proposed approach enhances the efficiency, stability, and reliability of photovoltaic systems. It provides a promising solution for real-time renewable energy applications. Future work can focus on hardware implementation and experimental validation to further improve system performance and practical applicability.

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