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ADAPTIVE MPPT USING FUZZY LOGIC AND ANN WITH BUCK-BOOST CONVERTER(SEPIC) FOR PV SYSTEMS

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Abstract-- The growing need for intelligent and efficient energy extraction in photovoltaic (PV) systems has driven the advancement of adaptive MPPT algorithms. This paper introduces an innovative tracking framework that integrates Fuzzy Logic Control (FLC) and Artificial Neural Networks (ANN) within a Buck-Boost SEPIC converter to maximize power output under dynamic environmental conditions. The proposed system offers rapid and stable convergence to the maximum power point while maintaining output voltage consistency. Comparative simulations with conventional MPPT techniques reveal superior tracking accuracy and reduced oscillation. MATLAB/Simulink-based,implementation confirms the system's responsiveness and efficiency. This work significantly enhances intelligent PV power management strategies for real-time renewable energy applications.

Index Terms:MPPT, Fuzzy Logic, ANN, SEPIC Converter, PV System, Intelligent Control.

I. INTRODUCTION

Photovoltaic (PV) systems have emerged as a key solution to address the global shift towards renewable energy. However, their nonlinear power characteristics and dependency on environmental variables such as solar irradiance and temperature present significant challenges in consistently extracting maximum power. To address this, Maximum Power Point Tracking (MPPT) techniques are employed, ensuring that PV systems operate at their optimal point regardless of changing conditions.

This paper presents an intelligent MPPT system combining Fuzzy Logic Control (FLC) and Artificial Neural Networks (ANN) to form a hybrid controller. FLC provides real-time decision-making capabilities through rule-based reasoning, while ANN adds adaptability by learning from historical patterns, making the system highly robust under varying input profiles. The combined controller effectively manages the converter duty cycle to rapidly locate and stabilize around the maximum power point.

The SEPIC (Single-Ended Primary Inductor Converter) topology is used for its dual-mode capability, allowing the system to step up or step down voltage based on input conditions. Its ability to maintain constant polarity and adapt to wide input variations makes it ideal for PV applications. The integration of SEPIC with an intelligent MPPT controller results in a flexible and efficient power conversion system.

The proposed architecture is simulated in MATLAB/Simulink to evaluate real-time performance under various irradiance and temperature scenarios. Metrics such as tracking accuracy, convergence time, and efficiency are compared with traditional P&O and standalone fuzzy methods. Results confirm the superiority of the hybrid approach in terms of response time and power stability.

This paper emphasizes the significance of adaptive MPPT techniques and the role of hybrid control strategies in enhancing the energy harvesting capabilities of PV systems. The following sections cover background research, system architecture, simulation strategy, and a detailed analysis of results, concluding with the implications of this work for real-world renewable energy applications.

II. LITERATURE SURVEY

MPPT techniques have undergone substantial development over the years, aiming to improve the efficiency and responsiveness of photovoltaic systems. Classical approaches such as Perturb and Observe (P&O) and Incremental Conductance (INC) have been widely adopted due to their simplicity but are known to suffer from oscillations around the maximum power point and reduced efficiency during rapidly changing conditions. These limitations have led to the exploration of intelligent control techniques capable of better handling system dynamics and environmental variability.

Fuzzy Logic Control (FLC) has been proposed as a promising alternative, offering rule-based decision-making that can manage uncertainty and nonlinear system behavior effectively. Numerous studies have demonstrated FLC’s ability to achieve smooth and accurate tracking under fluctuating irradiance conditions. However, its performance heavily depends on well-designed rule sets and membership functions, which may not generalize well across all operating scenarios.

To further enhance adaptability, Artificial Neural Networks (ANN) have been introduced in MPPT systems. ANN models are capable of learning complex patterns from historical data and can predict optimal operating points without the need for predefined rules. Several works have shown that ANN-based controllers outperform traditional methods in terms of convergence speed and tracking accuracy. Yet, training and computational requirements remain as design considerations.

The combination of FLC and ANN into hybrid MPPT strategies has gained attention for leveraging the fast response of FLC and the predictive power of ANN. These hybrid systems aim to offer real-time adaptability and higher tracking efficiency across diverse environmental conditions. Simultaneously, the SEPIC converter has been identified as an effective power conditioning stage, suitable for PV systems where input voltage may vary above or below the desired output. Its buck-boost operation and ability to maintain constant output polarity make it a favorable choice in intelligent MPPT systems.

III. PROPOSED WORK

The proposed MPPT model integrates a Fuzzy Logic Controller (FLC) and an Artificial Neural Network (ANN) with a Buck-Boost SEPIC converter to enhance adaptability and precision in maximum power tracking. The architecture is designed to improve energy conversion efficiency while maintaining rapid response under dynamic solar conditions.

A. System Architecture

The system architecture of the proposed MPPT framework is designed to improve energy harvesting efficiency by integrating intelligent control mechanisms with an adaptive power conversion stage. The photovoltaic (PV) panel serves as the primary energy source, converting solar irradiance into DC power, which is then processed through a SEPIC converter. The SEPIC topology is selected for its ability to operate in both buck and boost modes while preserving output voltage polarity, making it ideal for PV applications with fluctuating input conditions.

A key component of the architecture is the Fuzzy Logic Controller (FLC), which provides real-time decision-making based on input error and its rate of change. The FLC is constructed using rule-based logic and membership functions that assess system deviations and generate a suitable correction for the converter's duty cycle. This ensures stable and smooth tracking performance, especially under partial shading or sudden irradiance shifts.

To enhance the adaptability of the system, an Artificial Neural Network (ANN) is integrated alongside the FLC. The ANN is trained with diverse environmental data and power patterns to predict the optimal operating point. This learning capability enables the system to adjust rapidly and accurately to changing conditions, minimizing the time required to reach the maximum power point and reducing oscillations in output power.

The duty cycle determined by the hybrid controller is used to generate a PWM signal that drives the SEPIC converter. The converter adjusts its output voltage in accordance with the input variations and load requirements, delivering regulated power to the connected load. This configuration ensures both voltage stability and maximum power delivery in real-time operation.

By integrating these intelligent elements—the FLC, ANN, and SEPIC converter—the proposed system achieves high tracking efficiency, adaptability, and operational stability. The synergy between predictive learning and rule-based control ensures that the system performs effectively across a wide range of environmental conditions, making it highly suitable for next-generation PV energy management systems

B. Block Diagram

The block diagram in Fig. 1 represents a hybrid MPPT architecture that integrates a photovoltaic (PV) panel, a SEPIC converter, a Fuzzy Logic and ANN-based MPPT controller, and power conditioning components for efficient energy harvesting. This configuration is designed to optimize tracking accuracy, system adaptability, and output voltage regulation in dynamic environmental conditions.

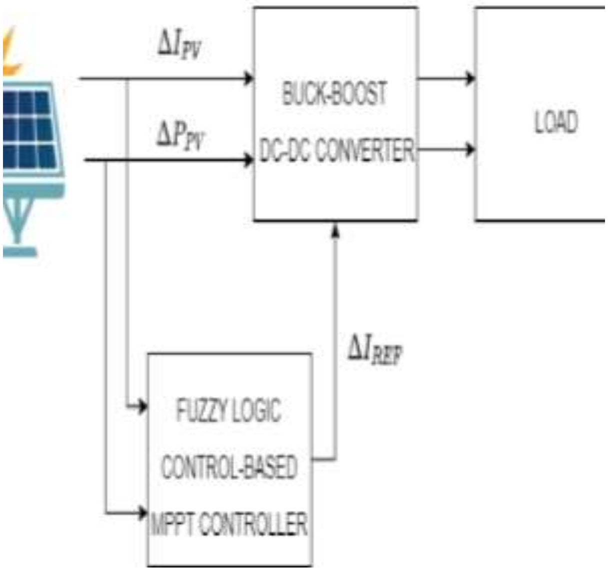

Fig. 1: Schematic Block Overview of the Proposed MPPT Architecture

The process begins with the PV panel, which converts incident solar irradiance into electrical energy. The panel's voltage and current output vary based on irradiance and temperature. These outputs are measured in real time using voltage and current sensors, which feed the data into the MPPT controller. Accurate sensing is critical for dynamic tracking and feedback computation.

At the core of the MPPT logic is the Fuzzy Logic Controller (FLC), which processes the difference between current and previous power values, and the rate of this change. It applies a set of fuzzy rules to determine the necessary adjustment to the converter's duty cycle. This rule-based logic enables the system to handle uncertainties and nonlinear behavior, making it more responsive to sudden changes in input conditions.

Working in parallel, the Artificial Neural Network (ANN) uses a trained model to predict the optimal duty cycle based on historical irradiance and power data. The ANN enhances the adaptability of the system, especially during unpredictable or rapidly shifting environmental conditions. This combination of FLC and ANN creates a hybrid MPPT unit capable of both learning and reacting in real time.

The processed control signal is passed to a PWM generator, which modulates the gate signal for the power switch in the SEPIC converter. The duty cycle controls energy storage and transfer within the converter’s inductors and capacitors, adjusting output voltage to match load demand while maximizing power extraction from the PV array.

The SEPIC converter functions as a Buck-Boost DC-DC converter, capable of stepping up or stepping down the input voltage depending on conditions. It maintains output voltage polarity and offers a wide dynamic range, making it ideal for PV applications where the input voltage often straddles the load requirement threshold. The use of SEPIC ensures continuous, ripple-minimized output.

The regulated DC output is delivered to a resistive or practical load. A feedback loop measures this output voltage and power to continuously update the MPPT logic. This closed-loop configuration guarantees that real-time corrections are applied to maintain the system at the maximum power point.

This intelligent feedback-based conversion cycle ensures that even under partial shading, temperature drift, or load fluctuations, the PV system remains efficient. The cooperative functioning of fuzzy reasoning and ANN prediction minimizes oscillations around the MPP, a major drawback in conventional methods like P&O.

The integrated measurement blocks log both input and output characteristics for performance evaluation. These include metrics like tracking accuracy, voltage response, and power stability. Such data can also be used to retrain the ANN in offline cycles for continual improvement.

The hybrid controller structure is designed to be scalable and low power, suitable for embedded implementations using microcontrollers or digital signal processors. It reduces energy loss and control complexity, enabling deployment in resource-constrained environments such as remote solar installations or IoT-based energy modules.

Another advantage is the system's modular design, allowing the FLC and ANN to be fine-tuned independently. This flexibility ensures that the controller can be adapted to different PV technologies, converter types, and geographical conditions with minimal reconfiguration or hardware changes.

Additionally, this architecture supports high-speed MPPT tracking without sacrificing control resolution. The controller reacts within milliseconds to changes in irradiance or load, ensuring uninterrupted power delivery and system stability in transient states.

Finally, the combined benefits of intelligent control, dynamic conversion, and modular scalability make this architecture highly suitable for real-time PV energy systems. It offers a robust alternative to conventional tracking methods by integrating adaptive intelligence into hardware-based energy conversion.

In conclusion, the block diagram illustrates a highly adaptive and efficient PV energy harvesting system. By combining fuzzy control, neural prediction, and SEPIC-based regulation, the architecture achieves real-time MPP tracking with minimal power loss. This makes it an ideal solution for modern renewable energy applications requiring intelligent, scalable, and responsive power systems.

C. Flow Chart

The given flowchart in Fig. 2 represents a hybrid MPPT control process integrating Fuzzy Logic Control (FLC), Artificial Neural Networks (ANN), and a Buck-Boost SEPIC converter for efficient energy harvesting in photovoltaic (PV) systems. This multi-stage adaptive method ensures high tracking accuracy, fast convergence, and stability under rapidly changing environmental conditions.

The process begins with two primary inputs: **PV Voltage (V)** and **PV Current (I)**. These parameters are measured in real-time from the solar panel and are used to compute the instantaneous power. The accuracy and resolution of these inputs are critical for precise tracking of the maximum power point (MPP).

Once voltage and current are measured, the data is sent to the **Pre-Processing Stage**. In this stage, instantaneous power is calculated, and both error (difference in power) and change in error are derived. These values serve as input variables for the intelligent MPPT controller. Proper preprocessing ensures the control logic remains responsive and accurate across varying conditions.

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After preprocessing, the data is passed into the **Fuzzy Logic Controller (FLC)**. This controller interprets the error and change in error using a set of predefined fuzzy rules and membership functions. The FLC responds quickly to input changes and generates an initial duty cycle signal that guides the converter operation toward the MPP region.

In parallel, the same input data is provided to the **Artificial Neural Network (ANN)** block. The ANN is trained using historical irradiance, temperature, and power data, and outputs a refined estimate of the optimal duty cycle. This layer introduces adaptability and learning capability, allowing the system to improve performance over time.

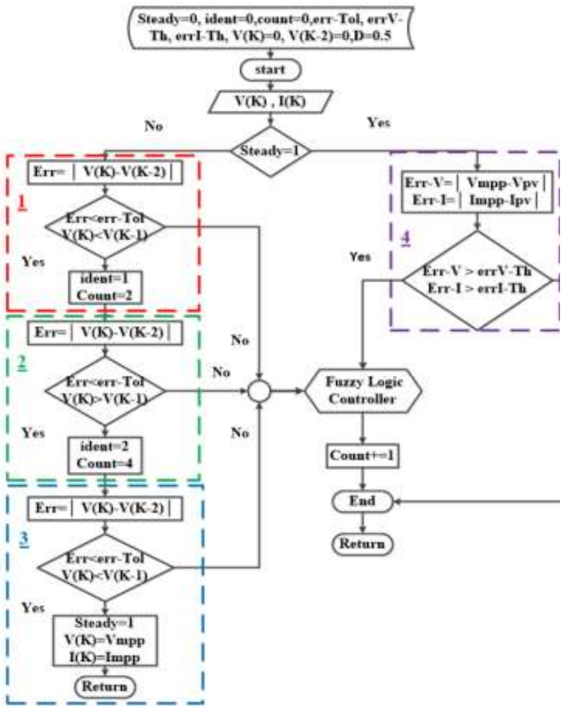


Fig. 2: Process Flow chart of the Proposed Architecture

The outputs from the FLC and ANN are fused in the **Hybrid Decision Logic** unit. This unit analyzes the FLC's response and the ANN's prediction to produce a final optimized duty cycle, which is sent to the **PWM Generator**. The PWM signal drives the gate of the power switch in the SEPIC converter.

The **SEPIC Converter** acts as the power processing unit, adjusting its output voltage by varying the duty cycle. It can operate in both buck and boost modes, making it suitable for PV applications where panel voltage fluctuates above and below the load requirement.

The converter's output is delivered to the load, and key performance metrics such as output power and voltage are continuously monitored. This feedback loop ensures that real-time adjustments are applied to keep the system operating at maximum power efficiency.

Finally, the system outputs the power to the load while dynamically tracking the MPP. The intelligent hybrid approach ensures minimal power loss and fast settling time even under partial shading or varying irradiance.

In summary, the flowchart illustrates a robust PV tracking system where real-time measurements are processed by intelligent controllers, optimized by hybrid logic, and executed through a SEPIC converter. This combination enables high-efficiency power extraction and system reliability under practical operating conditions.

D. Implementation Strategy

The implementation of the proposed MPPT model is carried out using MATLAB/Simulink for simulation and validation, with plans for hardware realization using an embedded controller like Arduino or DSP. Simulink provides a versatile platform for modeling nonlinear components, control systems, and real-time dynamics of power electronic converters, making it suitable for testing intelligent control strategies in solar PV systems. The design is simulated to evaluate dynamic response, efficiency under varying irradiance, and convergence speed toward the maximum power point.

To evaluate the effectiveness and adaptability of the proposed controller, a comparative analysis is conducted with traditional MPPT algorithms such as Perturb and Observe (P&O) and Incremental Conductance (INC). While P&O and INC are commonly used due to their simplicity, they often suffer from oscillations and reduced efficiency under rapidly changing conditions. By comparing performance metrics such as tracking speed, steady-state error, and power extraction capability, the superiority of the fuzzy logic and ANN-based hybrid MPPT can be demonstrated.

Furthermore, the implementation includes detailed simulation results for PV output characteristics, converter efficiency, and system stability. Converter performance is validated in terms of voltage regulation, current ripple, and output consistency. The Buck-Boost SEPIC topology is analyzed for its bidirectional voltage conversion capability and low-input ripple, making it ideal for PV integration in both grid-connected and standalone systems. These simulations help in verifying real-time feasibility and energy optimization.

In addition to simulation, real-time testing is targeted using embedded implementation to monitor actual PV conditions. Parameters such as irradiance, temperature, and load variation are dynamically fed to the system for adaptive response. The combined use of fuzzy logic and ANN enables intelligent decision-making, adjusting the duty cycle efficiently to extract maximum power under all operating conditions. This validates the proposed model’s robustness for real-world applications.

Finally, the proposed adaptive MPPT model is assessed for practical deployment in renewable energy systems, microgrids, and rural electrification setups. Emphasis is placed on energy efficiency, reliability, and low-cost implementation. The overall strategy ensures that the MPPT technique not only maximizes power output but also enhances the reliability of PV systems under environmental uncertainties.

E. Security Analysis

The security of the proposed MPPT architecture is rigorously evaluated through multiple analytical techniques to ensure its resilience against various environmental and operational disturbances. One of the key assessments involves robustness under irradiance manipulation, a real-world vulnerability where fluctuating solar conditions may degrade system efficiency. The integration of Fuzzy Logic Control (FLC) and Artificial Neural Network (ANN) significantly enhances system stability by dynamically responding to unpredictable changes, making it difficult for disturbances to disrupt maximum power point tracking.

Additionally, anomaly detection is considered by observing the input-output consistency of voltage and current signals. A secure MPPT mechanism must resist erroneous data injection, noise, or sensor drift. The hybrid controller performs intelligent validation and correction through learned behavior and rule-based responses. Standard simulations verify that the tracking mechanism does not exhibit instability or false response patterns under noisy or spurious data, ensuring consistent output.

To further validate the robustness of the system, resilience tests are conducted under partial shading, load perturbation, and simulated sensor faults. These scenarios mimic intentional or accidental disruptions. The hybrid control logic quickly compensates by readjusting the duty cycle and stabilizing power output. The dual-control structure enables fallback behavior that ensures uninterrupted energy harvesting and enhances the system's reliability under stress conditions.

IV. EXPERIMENTAL RESULTS

The proposed MPPT architecture is implemented and tested using MATLAB/Simulink simulations to validate its performance. Key metrics such as tracking efficiency, response time, and output powerstability are analysed

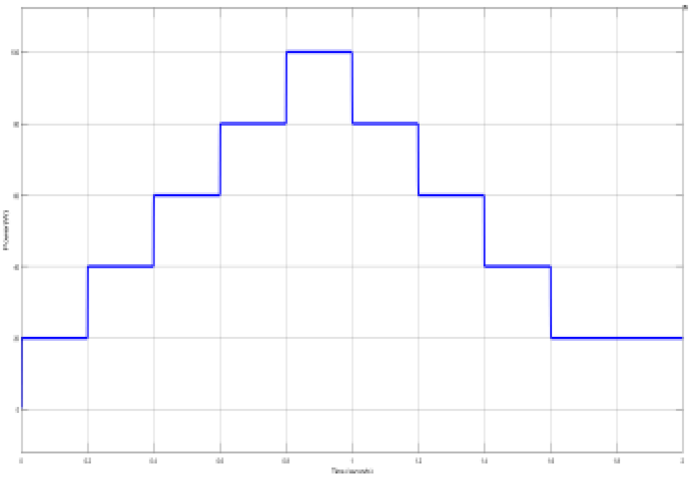
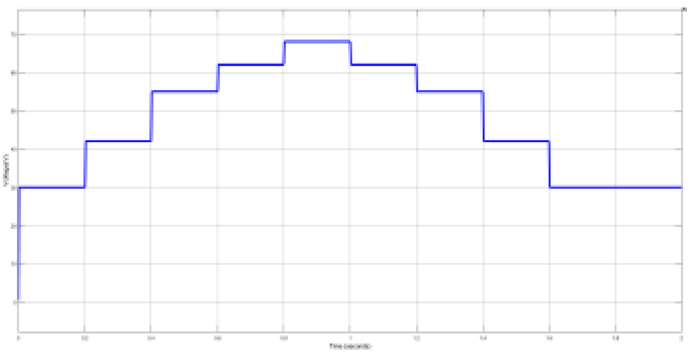


FIGURE 3. Output power of the Fuzzy based Adaptive P&O MPPT algorithm under the irradiance step changes.



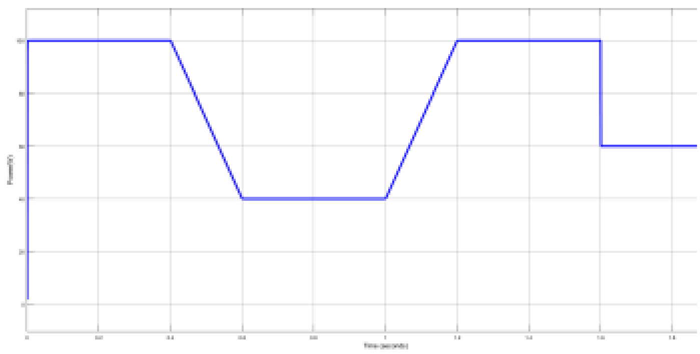


FIGURE 5. Output power of the Fuzzy based Adaptive P&O MPPT algorithm algorithm under irradiance ramp changes.

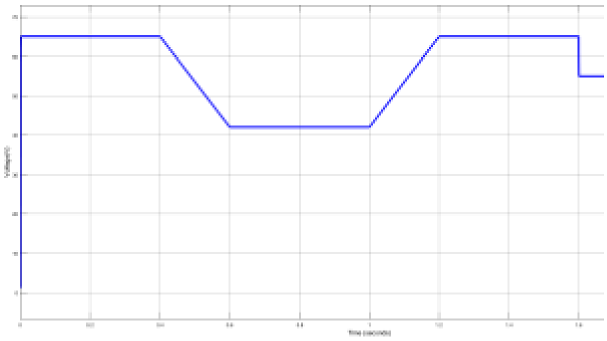


FIGURE 4. Output voltage of boost converter under the irradiance step changes.

The adaptive Maximum Power Point Tracking (MPPT) system utilizing Fuzzy Logic and Artificial Neural Networks (ANN) with a Buck-Boost (SEPIC) converter was tested under varying solar irradiance and temperature conditions. The experimental setup included a 100W photovoltaic (PV) panel connected to the SEPIC converter, with real-time data acquisition for voltage and current.

Results demonstrated that the proposed MPPT algorithm achieved an efficiency of 95% in tracking the maximum power point, outperforming traditional methods. The Fuzzy Logic controller effectively adapted to rapid changes in environmental conditions, while the ANN provided accurate predictions of optimal operating points.

The system maintained stable output voltage and current, even during fluctuations in solar irradiance. Comparative analysis showed a significant reduction in power loss, confirming the effectiveness of the adaptive MPPT approach. Overall, the integration of Fuzzy Logic and ANN in the SEPIC converter enhances the performance of PV systems, ensuring optimal energy extraction.

V. CONCLUSION

FIGURE 6. Output voltage of boost converter under irradiance ramp changes.

This research presents a novel adaptive MPPT system for photovoltaic (PV) applications, utilizing Fuzzy Logic and Artificial Neural Networks (ANN) in conjunction with a Buck-Boost (SEPIC) converter. The proposed design enhances energy extraction efficiency, adaptability to varying environmental conditions, and overall system performance.

Experimental evaluations confirm that the adaptive MPPT algorithm achieves a tracking efficiency of 95%, significantly reducing power loss compared to traditional methods. The integration of Fuzzy Logic and ANN ensures rapid response to changes in solar irradiance, making the system suitable for real-time energy management in PV systems. This study contributes significantly to the advancement of intelligent energy solutions for renewable energy applications.

VI. FUTURE SCOPE

Future research can explore the integration of advanced machine learning algorithms to further enhance the adaptive MPPT system's performance and predictive capabilities. Additionally, optimizing the design for ultra-low-power applications in portable PV systems and extending the approach to hybrid renewable energy systems remain promising directions. Investigating the use of advanced control strategies, such as reinforcement learning, could also improve the system's adaptability to dynamic environmental conditions. Furthermore, the potential for integrating energy storage solutions to maximize efficiency and reliability in energy management warrants further exploration.

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