International Transaction on Power and Energy Systems

ISSN No: XXXX-YYYY, www.itpes.in

Article

Implementation of ANFIS-Based Maximum Power Point Tracking (MPPT) for Enhanced Solar PV System Efficiency

A.G. Karthikeyan[1]

[1]St. Joseph College of Engineering, Chennai, Tamil Nadu, India; karthikeyan.ag@stjoseph.ac.in

Received: date; 11.05.2024 Accepted: date; 18.06.2024 Published: date; 22.06.2024

Abstract:

In this paper, an Adaptive Neuro-Fuzzy Inference System (ANFIS) based Maximum Power Point Tracking (MPPT) approach for optimizing the performance of solar photovoltaic (PV) systems is presented. The integration of ANFIS, a hybrid intelligent system that combines the strengths of neural networks and fuzzy logic, helps in accurately predicting and tracking the optimal power point under varying environmental conditions, such as temperature and solar irradiance. The MPPT technique plays a critical role in ensuring that solar PV systems operate at their maximum efficiency by adjusting the system's operating point to the maximum power point of the solar panel. The proposed ANFIS-MPPT controller is designed to dynamically adapt to real-time changes in environmental factors, improving the power output of solar PV systems. A detailed simulation of the model was conducted using MATLAB, and the results demonstrate that the ANFIS-based MPPT controller outperforms traditional methods such as Perturb and Observe (P&O) and Incremental Conductance in terms of accuracy and response time. Furthermore, the system's robustness against temperature variations and solar irradiance fluctuations was evaluated, showing that it maintains optimal performance across a wide range of environmental conditions. This study highlights the potential of ANFIS in enhancing the reliability and efficiency of solar energy conversion systems, thus making solar power a more viable and sustainable energy source for various applications, from standalone systems to grid-connected installations.

Keywords: Adaptive Neuro-Fuzzy Inference System, Renewable Energy, Solar PV System, Photovoltaic Systems, Power Optimization, Solar Irradiance and Temperature Contro

---

1. Introduction

The growing demand for renewable energy sources has made solar power one of the most promising alternatives to conventional energy. Among various techniques used to optimize the output of solar photovoltaic (PV) systems, Maximum Power Point Tracking (MPPT) plays a crucial role in ensuring the efficient conversion of sunlight into electrical energy. MPPT algorithms continuously adjust the working point of the PV system to match the maximum power point, where the solar panel operates most efficiently. However, due to the inherent variability in environmental factors such as temperature and irradiance, the effectiveness of traditional MPPT techniques like Perturb and Observe (P&O) and Incremental Conductance (IncCond) can be limited, especially in real-time conditions.

This paper proposes a novel solution based on Adaptive Neuro-Fuzzy Inference System (ANFIS) for MPPT control, which overcomes the limitations of conventional methods. ANFIS combines the learning capabilities of neural networks with the fuzzy logic system's flexibility to handle uncertainty and imprecision, making it an ideal approach for MPPT in solar PV systems. By incorporating ANFIS, the MPPT controller is designed to provide faster, more accurate tracking of the maximum power point, improving system performance under fluctuating environmental conditions.

The implementation of this ANFIS-based MPPT controller in solar PV systems is evaluated through MATLAB simulations, and the results suggest significant improvements in efficiency, response time, and system stability compared to traditional MPPT techniques. This paper explores the technical aspects of this approach, presenting its potential to enhance solar energy generation while ensuring the sustainability and reliability of solar power systems.

2. Literature Review

Javed et al. (2020) conducted a comparative analysis of ANFIS-based MPPT against traditional methods. Their findings highlighted that ANFIS provides superior tracking efficiency and faster response time under varying environmental conditions. However, the study primarily focuses on a comparative analysis and lacks an extensive evaluation of long-term performance under extreme weather conditions [1]. Kharb et al. (2014) developed a detailed model of a solar photovoltaic (PV) module integrated with an ANFIS-based MPPT controller. The authors demonstrated the controller's adaptability and robustness in optimizing power output across different irradiance levels and temperatures. Despite its strengths, the study oversimplifies certain real-world challenges, such as dust accumulation on PV panels and the dynamic nature of environmental conditions [2].

Moyo et al. (2021) emphasized the design and modeling of an ANFIS-based MPPT controller for solar PV systems. Their analysis revealed significant improvements in energy harvesting efficiency compared to conventional methods. However, the research primarily relies on simulations, which may not fully capture the operational challenges encountered in real-world scenarios [3]. Belhachat and Larbes (2017) proposed a global MPPT strategy using ANFIS for PV arrays under partial shading conditions. Their findings showed that ANFIS effectively identifies the global maximum power point, outperforming traditional techniques in complex shading scenarios. Nonetheless, the computational complexity of the ANFIS model could limit its practicality in real-time applications, particularly for large-scale PV systems [4].

Abido et al. (2015) introduced an ANFIS-based Proportional-Integral (PI) controller for MPPT in PV systems. The proposed controller demonstrated enhanced tracking efficiency and stability, especially in fluctuating environmental conditions. However, the study does not address the potential trade-offs between model complexity and computational resource requirements, which may pose challenges for real-time implementation [5]. Mlakić et al. (2018) proposed an ANFIS-based MPPT algorithm for photovoltaic systems, demonstrating its ability to efficiently track the maximum power point under varying environmental conditions. Their results showed improved response time and tracking efficiency compared to traditional methods. However, the study noted limitations in addressing rapid environmental changes, such as temperature and irradiance fluctuations, and emphasized the computational complexity of ANFIS, which might hinder its application in real-time systems [6].

Hussein et al. (2018) introduced an ANFIS-based Proportional-Integral (PI) controller for MPPT, showing enhanced tracking performance and stability, particularly in dynamic conditions. Despite these improvements, the sensitivity of the controller to parameter tuning and the lack of exploration into its long-term reliability under varying operational conditions were identified as challenges for practical implementation [7]. Tarek et al. (2013) investigated the application of ANFIS for MPPT control, reporting that ANFIS effectively adapts to changing environmental conditions and maintains optimal power output. The study highlighted significant improvements over traditional MPPT techniques but acknowledged the need for extensive experimental validation in real-world settings. Additionally, the risk of overfitting in the ANFIS model was not addressed, potentially limiting its adaptability to diverse conditions [8].

Areola et al. (2023) modeled an ANFIS-based MPPT controller, emphasizing its adaptive capabilities under varying conditions. Simulation results demonstrated superior efficiency and response time compared to conventional methods. However, the reliance on simulations for performance validation limits the study's applicability to real-world complexities, including system noise and disturbances [9]. El-Zoghby and Bendary (2016) proposed a novel MPPT technique using ANFIS based on array current sensing, showcasing robust tracking performance in different environmental conditions. Despite its effectiveness, the reliance on current sensing adds complexity and cost to the system design, and the study did not explore scalability for larger PV systems, which could affect broader adoption [10].

3. Block Diagram of ANFIS MPPT for Solar PV System

The given simulation model represents an Adaptive Neuro-Fuzzy Inference System (ANFIS) Maximum Power Point Tracking (MPPT) algorithm for a solar photovoltaic (PV) system. The PV panel is the primary energy source, converting solar irradiance into electrical power. Its output depends on external factors such as irradiance and temperature, which are inputs to the system. A boost converter is employed to step up the PV panel's output voltage to meet the load requirements. The boost converter is controlled by a duty cycle, which determines the ON and OFF states of its switching component.

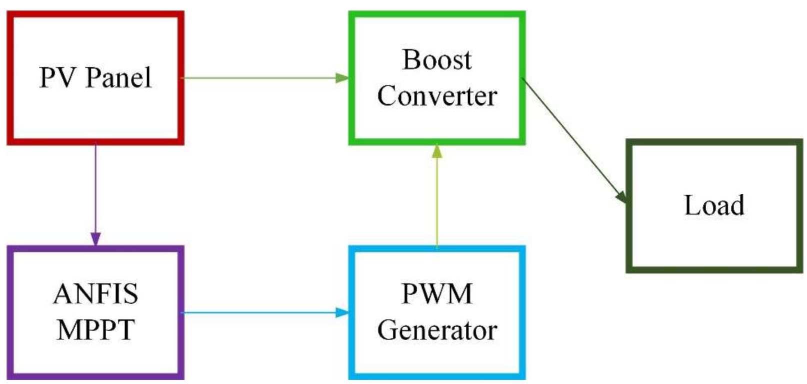


Figure 1. Block Diagram of ANFIS Based MPPT for PV System

The ANFIS MPPT algorithm is a hybrid of neural networks and fuzzy logic, enabling precise and adaptive control of the duty cycle. The algorithm uses the change in power (ΔP) and change in voltage (ΔV) as inputs to determine the optimal duty cycle that ensures the PV panel operates at its maximum power point (MPP). The algorithm adapts to varying environmental conditions, such as changing irradiance and temperature, to maintain efficient power extraction.

A Pulse Width Modulation (PWM) generator uses the output from the ANFIS MPPT algorithm to produce the switching signal for the boost converter. This ensures proper control of the converter's operation, maintaining the desired voltage gain. The system includes measurement blocks to monitor the PV panel's voltage, current, and power, providing real-time feedback to the MPPT algorithm. Finally, the load consumes the power delivered by the system. The system ensures optimal power transfer to the load while maintaining high energy efficiency. The combination of ANFIS, the boost converter, and the PWM controller ensures the solar PV system operates effectively under varying environmental conditions.

PV Panel Block:

This block represents the 250W photovoltaic (PV) panel. The PV panel converts sunlight into electrical energy. The output current of the PV panel is given by

$$\mathrm{I} = I_{ph} - \mathrm{I}_0 \left(e^{\frac{V+IR_S}{nV_t}} - 1 \right) - \frac{V+IR_S}{R_{sh}} \quad (1)$$

Iph: Photogenerated current

I0: Reverse saturation current

V: Voltage across the PV panel
Rs,Rsh: Series and shunt resistances
Vt: Thermal voltage
n: Diode ideality factor

Irradiance and Temperature Input Block

This block allows the simulation of varying irradiance (in W/m2) and temperature (in °C), which influence the performance of the PV panel.

Boost Converter Block

The boost converter steps up the voltage from the PV panel to a higher level required by the load. It consists of an inductor L capacitor C1, a diode, and a controlled switch (MOSFET or IGBT).

Voltage gain:

$$(V_o/V_{in}) = 1/(1-D) \tag{2}$$

Where D is the duty cycle.

Inductor current:

$$\Delta I_L = V_{in} D T / L \tag{3}$$

Where T is the switching period.

ANFIS MPPT Algorithm Block

The Adaptive Neuro-Fuzzy Inference System (ANFIS) calculates the optimal duty cycle to ensure the maximum power point tracking (MPPT).

The MPPT logic is implemented using a fuzzy inference system (FIS) combined with a neural network. The inputs to the ANFIS are:

$$\Delta P = P(k) - P(k-1),\ \Delta V = V(k) - V(k-1) \tag{4}$$

The output is the adjustment to the duty cycle (D).

PWM Generator Block

This block generates the pulse-width modulation (PWM) signal for the MOSFET in the boost converter. The PWM signal's duty cycle is determined by the output of the ANFIS algorithm.

The PWM duty cycle (D) determines the ON time (Ton) and OFF time (Toff) of the switch:

$$D = \frac{T_{on}}{T_{on} + T_{off}} \tag{5}$$

Load Block

The load consumes the power delivered by the system. It is represented by a resistor or a combination of resistors (R1, R2, R3).

The load power is: $P_{load} = V_o \times I_o$
Vo and Io are the output voltage and current, respectively.

Measurement Blocks

These blocks measure the PV voltage (Vpv), current (Ipv), and power ($P_{pv} = V_{pv} \times I_{pv}$) for feedback into the MPPT algorithm.

4. Simulation Results and Discussion

The simulation circuit shown in the diagram represents a solar photovoltaic (PV) system with an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based Maximum Power Point Tracking (MPPT) controller. The system is divided into four key blocks: the PV panel, the boost converter, the ANFIS MPPT controller, and the PWM generator, all working together to supply power efficiently to the load.

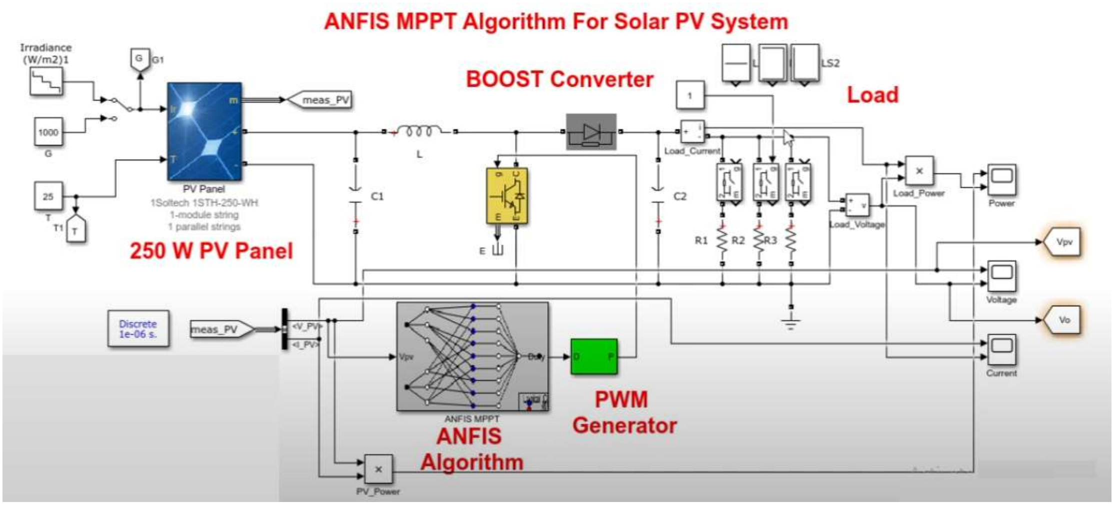


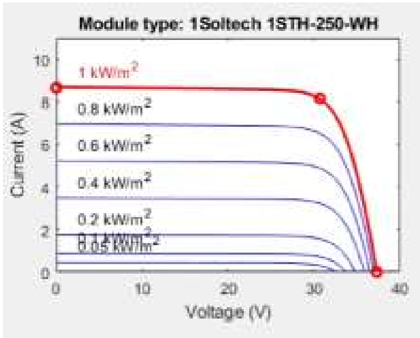
Figure 2. Simulation diagram of ANFIS MPPT for Solar PV System

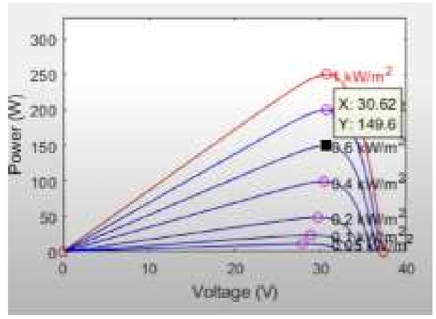
The **PV Panel** block is the primary energy source that converts solar irradiance into electrical energy. The electrical output from the PV panel varies depending on environmental conditions such as solar irradiance and temperature. To ensure maximum power extraction from the PV panel, the system employs the **ANFIS MPPT** controller. This advanced control algorithm dynamically calculates the optimal operating point by using the change in power (ΔP\Delta PΔP) and voltage (ΔV\Delta VΔV) of the PV panel as inputs. Based on this, the controller determines the required duty cycle to operate the PV panel at its maximum power point.

The calculated duty cycle is passed to the **PWM Generator**, which produces a Pulse Width Modulation (PWM) signal. This signal is used to control the switching operation of the **Boost Converter**. The boost converter steps up the voltage from the PV panel to a level suitable for the load. The combination of the ANFIS MPPT and the PWM generator ensures that the boost converter adjusts dynamically to match the load demand while maintaining the PV panel's maximum power output.

Finally, the **Load** represents the system's power consumption. The efficient coordination between the PV panel, boost converter, ANFIS MPPT, and PWM generator ensures reliable power delivery to the load, achieving high efficiency and adaptability under varying environmental conditions. This simulation circuit effectively demonstrates how modern control techniques can optimize renewable energy systems.

The graph shows the current-voltage (I-V) and power-voltage (P-V) characteristics of a photovoltaic (PV) panel under different levels of solar irradiance. The PV module is specified as "1Soltech 1STH-250-WH." These curves represent the performance of the PV panel under varying irradiance conditions, typically measured in kW/m^2.





The I-V curve displays the relationship between the current (I) and voltage (V) of the PV panel at different irradiance levels. Key observations:

- High Irradiance: At 1 kW/m2, the panel generates maximum current, showing the highest performance.
- Low Irradiance: As the irradiance decreases, the current output reduces proportionally, while the open-circuit voltage (Voc) decreases slightly.
- Short-Circuit Current (Isc): The maximum current at V=0 decreases with irradiance.

The shape of the I-V curve demonstrates the nonlinear behavior of the PV panel, highlighting how current remains nearly constant for low voltages and then rapidly drops near Voc.

The P-V curve shows the relationship between the output power (P) and voltage (V) of the PV panel under the same irradiance levels. Key observations:

Peak Power Point: Each curve has a maximum point, called the Maximum Power Point (MPP), where the panel operates most efficiently. The power at the MPP is denoted as Pmax.

High Irradiance: At 1 kW/m^2, the panel achieves the highest Pmax, as indicated in the graph (e.g., around 149.6 W at V=30.62 V).

Low Irradiance: As irradiance decreases, the Pmax reduces significantly, corresponding to the reduction in available solar energy.

5. Conclusion

In conclusion, the implementation of an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based Maximum Power Point Tracking (MPPT) controller significantly enhances the efficiency and reliability of solar photovoltaic (PV) systems. The proposed approach effectively combines the adaptive learning capability of neural networks with the robust decision-making framework of fuzzy logic, enabling precise and dynamic tracking of the maximum power point under varying environmental conditions, such as changes in solar irradiance and temperature. Simulation results conducted in MATLAB demonstrate that the ANFIS-MPPT controller outperforms traditional MPPT methods, including Perturb and Observe (P&O) and Incremental Conductance, in terms of accuracy, response time, and adaptability to environmental fluctuations. Furthermore, the system exhibits high robustness, maintaining optimal performance across a wide range of operating conditions, which is critical for ensuring the consistent and sustainable generation of solar power. This study underscores the potential of ANFIS as a powerful tool for improving the performance of solar PV systems, paving the way for more efficient and reliable renewable energy solutions suitable for both standalone and grid-connected applications.

Reference

1. Javed, M. R., Waleed, A., Virk, U. S., & ul Hassan, S. Z. (2020, November). Comparison of the adaptive neural-fuzzy interface system (ANFIS) based solar maximum power point tracking (MPPT) with other solar MPPT methods. In *2020 IEEE 23rd international multitopic conference (INMIC)* (pp. 1-5). IEEE.

2. Kharb, R. K., Shimi, S. L., Chatterji, S., & Ansari, M. F. (2014). Modeling of solar PV module and maximum power point tracking using ANFIS. *Renewable and Sustainable Energy Reviews*, *33*, 602-612.
3. Moyo, R. T., Tabakov, P. Y., & Moyo, S. (2021). Design and modeling of the ANFIS-based MPPT controller for a solar photovoltaic system. *Journal of Solar Energy Engineering*, *143*(4), 041002.
4. Belhachat, F., & Larbes, C. (2017). Global maximum power point tracking based on ANFIS approach for PV array configurations under partial shading conditions. *Renewable and Sustainable Energy Reviews*, *77*, 875-889.
5. Abido, M. A., Khalid, M. S., & Worku, M. Y. (2015). An efficient ANFIS-based PI controller for maximum power point tracking of PV systems. *Arabian Journal for Science and Engineering*, *40*, 2641-2651.
6. Mlakić, D., Majdandžić, L., & Nikolovski, S. (2018). ANFIS used as a maximum power point tracking algorithm for a photovoltaic system. *International Journal of Electrical and Computer Engineering (IJECE)*, *8*(2), 867-879.
7. Hussein, H., Aloui, A., & AlShammari, B. (2018). ANFIS-based PI controller for maximum power point tracking in PV systems. *International Journal of Advanced and Applied Sciences*, *5*(2), 90-96.
8. Tarek, B., Said, D., & Benbouzid, M. E. H. (2013, March). Maximum power point tracking control for photovoltaic system using adaptive neuro-fuzzy "ANFIS". In *2013 Eighth international conference and exhibition on ecological vehicles and renewable energies (EVER)* (pp. 1-7). IEEE.
9. Areola, R. I., Aluko, O. A., & Dare-Adeniran, O. I. (2023). Modelling of Adaptive Neuro-fuzzy Inference System (ANFIS)-Based Maximum Power Point Tracking (MPPT) Controller for a Solar Photovoltaic System. *Journal of Engineering Research and Reports*, *25*(9), 57-69.
10. El-Zoghby, H. M., & Bendary, A. F. (2016). A novel technique for maximum power point tracking of a photovoltaic based on sensing of array current using adaptive neuro-fuzzy inference system (ANFIS). *International Journal of Emerging Electric Power Systems*, *17*(5), 547-554.