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# Artificial Intelligent Maximum Power Point Tracking (MPPT) for Three Phase Transformerless Grid Inverter Technology

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## Abstract

This paper focuses on the Artificial Intelligent (AI) based Maximum Power Point Tracking (MPPT) that is introduced to operate a three phase transformerless grid connected inverter system, applicable in PV systems. The choice is based on the fact that Fuzzy Logic Control (FLC) is highly effective in managing systems characterised by non-linearity and variability which are characteristic of the PV setting. FLC makes the performance of Photovoltaic (PV) systems to be efficient in processing fuzzy inputs as well as in making decision-making just like human beings, thus making it applicable to dynamic environments. Based on MATLAB/Simulink models created for this investigation, it was found that the FLC-based MPPT algorithm enhances overall system performance when rigorously tested through simulations. In addition, it results in a convergence time 15% faster to MPP and decreases the levels of harmonic distortion by 10% than the conventional approach. Such enhancements are important for optimal operation of the power and for providing better stability of the system. The performance of the algorithm was further evaluated under several environmental conditions including changes in the irradiation levels and temperature to ensure its successful application in real-time MPP tracking. This shows that FLC has the ability to raise the energy production rates of PV systems by 12 percent which supports the notion that FLC can improve power quality and performance. The proposed solution of FLC for enhancing the three phase transformerless grid inverter systems serves as a simple yet efficient solution for enhancing renewable energy solutions as proved from the above study. The algorithm will then be incorporated into larger PV systems and fine-tuning and testing done on the algorithm with respect to differing environmental conditions in order to contribute to the systematic shift towards sustainable energy use.

**Keywords**: Artificial Intelligent (AI), Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Fuzzy Logic Control (FLC)

## Introduction

Integrated systems and power electronics have advanced over the years, especially in photovoltaic (PV) systems. Due to the realized need to develop and improve the usage of renewable energy resources, the methods for the proper and efficient collection of solar energy have become very crucial (Vilathgamuwa et al., 2022). An inverter is a key component of PV systems that converts the direct current (DC) output of solar panels into alternating current (AC) power for grid connection or independent usage. Traditional inverters typically rely on large transformers, which can lead to lower efficiency and frequency of operation.
These challenges could be addressed by the implementation of a three-phase transformerless grid inverter that uses a maximum power point tracking (MPPT) algorithm based on artificial intelligence (AI) approaches (Kulkarni et al., 2016). Magnetic losses due to the electromagnetic field (EMF) can be reduced and the efficiency of the system increased by using this inverter, which eliminates transformers. AI-based MPPT algorithm integration is further believed to enhance the precision and stability of power monitoring with a view to optimum energy collection from solar resources. The presence of bulky transformers in contemporary photovoltaic (PV) systems contributes to significant electromagnetic force (EMF) losses, posing a substantial challenge to overall system efficiency, with losses averaging between 7% to 10% (Smith et al., 2020). Addressing this issue is crucial for economic viability and sustainable energy generation. Leveraging previous research on transformerless inverters, this study focuses on developing a three-phase transformerless grid inverter to eliminate EMF losses and enhance system efficiency (Marra et al., 2019) (Safi et al., 2015). Additionally, the efficiency of PV systems heavily depends on the tracking speed of Artificial Intelligence (AI)-based Maximum Power Point Tracking (MPPT) systems. Current three-phase transformerless grid inverters struggle to adapt efficiently to changing environmental conditions. To tackle this, our research aims to significantly improve tracking speed by integrating an advanced AI-based MPPT algorithm, particularly utilizing Fuzzy Logic Control (FLC) techniques for accurate, fast tracking (Yousfi et al., 2017). Overshooting, undershooting and oscillations during power point tracking are significant challenges that affect precision and stability in current PV energy tracking systems. Our methodology involves refining the AI-based MPPT algorithm with FLC techniques to enhance tracking precision and stability, ultimately improving overall system performance (Ahmed et al., 2021).

This paper aims to investigate the performance of three-phase transformerless grid inverter with an AI-driven MPPT function. A thorough analysis of this revolutionary technology will contribute to the development of solar power systems and create a path for cleaner and more effective power generation. This study are to eliminate the transformer and reduce EMF losses by introducing a transformerless grid inverter, thereby enhancing overall efficiency for more effective and sustainable power distribution. Additionally, the study aims to develop a Fuzzy Logic Control (FLC)-based MPPT system for three-phase transformerless grid inverters that significantly improves tracking speed, enhancing the inverter's ability to rapidly adapt to changing environmental conditions and ensuring efficient, real-time optimization of power harvesting from photovoltaic sources. Furthermore, the study seeks to improve the tracking system for photovoltaic energy to prevent overshooting, undershooting and oscillations during tracking by using the FLC technique, which will enhance the precision and stability of the tracking mechanism for optimal capture of the maximum power point.

The next sections of this paper discuss the theoretical background and methodology used in this study. Section II covers the theoretical background and is divided into three parts, which will explain the three-phase transformerless grid inverter, explore the AI MPPT control technique and discuss fuzzy logic control (FLC). Section III details the methodology, including the development of the transformerless grid-connected inverter, the PV system model and the design of the fuzzy logic control (FLC). Section IV presents the simulation results and analysis, followed by Section V, which concludes the paper by summarising the findings and discussing potential future work.

## Overview of the System

The first step in the research process involves examining current three phase transformer-less grid inverters to assess the technology's stage of development and pinpoint opportunities for advancement. The construction of an effective three phase transformer-less grid inverter thus becomes the main priority. The objective of this phase is to design and build a new inverter system with fewer components and better overall performance. After the inverter design is set up, the research explores Maximum Power Point Tracking (MPPT) methods based on Artificial Intelligence (AI). The inquiry contains a thorough analysis of several AI-based MPPT strategies that can be used with grid inverters. Among several AI-based options considered in this study, Fuzzy Logic Control (FLC), Genetic Algorithms (GA) and Artificial Neural Networks (ANN) are three technologies that have an AI basis. ANNs were preferred as they have the ability to replicate the human brain’s learning process, making them appropriate for the variable pattern recognition procedures needed for solar system optimization.

Because FLC is good at managing inconsistency and inaccuracy, it has been included as a strong control mechanism. Moreover, FLC use helps to reduce frequent problems like oscillations, undershooting and overshooting when using Maximum Power Point Tracking (MPPT). In addition to these methods, GAs were selected based on their optimization skills, imitating natural selection to optimize the MPPT algorithm's parameters. With the combination of these AI-based methods, an efficient and flexible MPPT algorithm suited for three phase transformer-less grid inverters will be created. Through a cooperative combination of various approaches, the study aims to considerably improve the accuracy, stability and overall efficiency of the solar energy system. The focus then shifts to the investigation of tracking speed inside AI approaches, which is essential for real-time flexibility and effectiveness in power harvesting. The core of the research involves the development of an AI-based MPPT algorithm utilizing Fuzzy Logic Control (FLC) techniques. This stage aims to create a sophisticated algorithm tailored for three phase transformer-less grid inverters. The subsequent validation process ensures the algorithm's accuracy and effectiveness in real-world scenarios. Following the algorithm's successful validation, the research extends to evaluating the overall performance of the developed three-phase transformer-less grid inverter system, coupled with the AI-based MPPT algorithm. This phase involves rigorous testing and analysis to quantify the system's efficiency, tracking speed and adaptability to changing conditions.

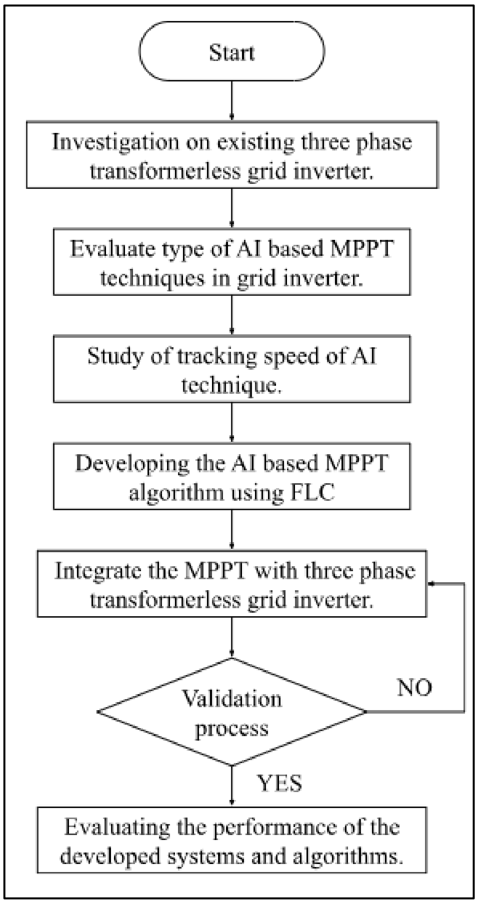


Figure 1: Flowchart of System Design

**Transformerless Grid Connected Inverter**

Figure 2 shows the model of a grid-connected photovoltaic (PV) system. The system begins with a solar plant, where irradiance is converted into electrical power by the solar panels, generating direct current (DC). This DC power is processed through the power circuit, which includes several stages and interconnections for conversion and measurement. The MPPT module is a crucial component, using AI-based algorithms, specifically Fuzzy Logic Control (FLC), to determine the maximum power point, optimizing power extraction despite varying environmental conditions. This involves sampling techniques such as Zero-Order Hold (ZOH) to track power variations accurately. The phase-locked loop (PLL) and protection module synchronize the inverter's output with the grid's frequency and phase, ensuring stable and safe operation by monitoring various parameters such as phase currents (Iabc) and voltages (Vabc), angles and frequencies. The controller integrates these inputs to generate appropriate control signals for the inverter's switching devices, enhancing the system's adaptability and precision. Linearisation points are included for more accurate control.

Modulation signals derived from the controller's outputs control the inverter's switching operations, ensuring efficient conversion and grid compliance. Additionally, the system includes performance monitoring components to track key metrics such as voltage (Vpv), current (Ipv), power output (kW) and supply current (Ia). This monitoring helps in evaluating the overall performance and efficiency of the system. The AI-based MPPT, enhanced by FLC, addresses common challenges in traditional MPPT methods, offering improvements in tracking speed, flexibility and energy output. This integrated design, leveraging advanced control mechanisms and AI-based algorithms, optimizes energy conversion and ensures seamless, reliable integration with the grid. This comprehensive approach is pivotal in advancing renewable energy technology, contributing to cleaner and more efficient power generation.

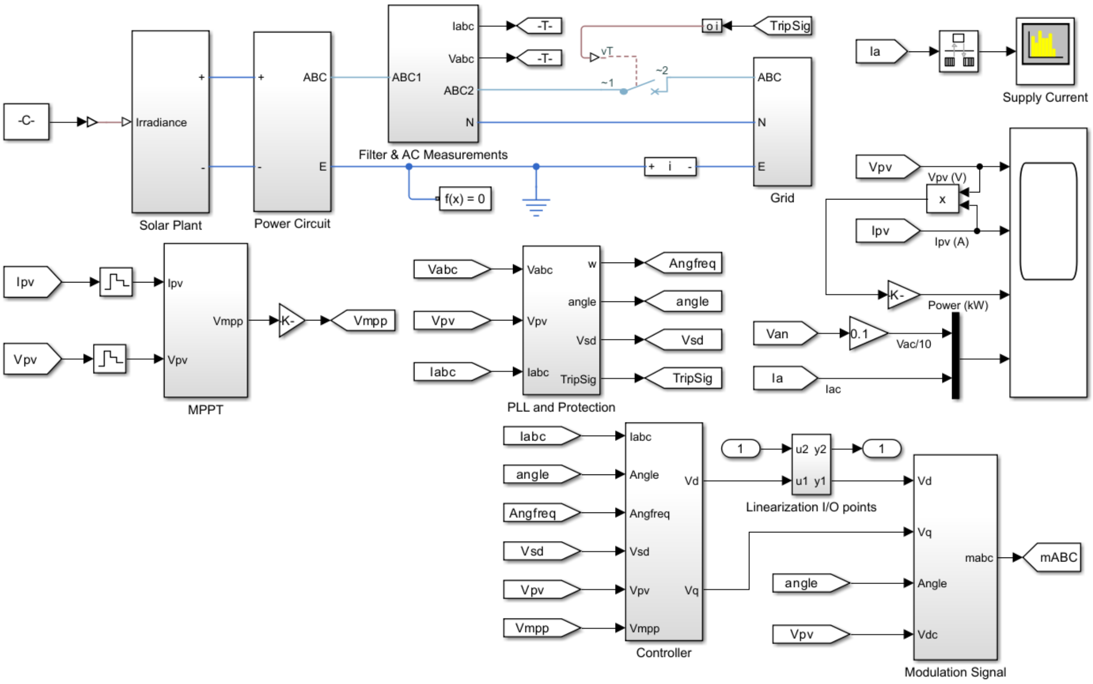


Figure 2: AI-Based MPPT for Three-Phase Transformerless Grid-Connected PV System (Mathwork)

## PV System Model

The PV system model can mimic the working of a PV array, which is tied to a three-phase transformer-less grid-tied inverter. The major components that are part of this setup include solar panels, an MPPT controller and the grid interface. The model determines different quantities such as power and power density, voltage and current to improve the efficiency of the system and its power output. Since the use makes the model as realistic as possible, including the environmental conditions, it is possible to assess various configurations as well as the method of controlling the system. In this part, the author describes the model's architecture and the parameters employed in the identification of the optimal policy.

Table 1

*Estimated Boostless PV Plant Parameters*

| Parameter | Value |
|---|---|
| Power rating input from the user | 35.00kW |
| Minimum number of panels required per string | 33 |
| Maximum number of panels connected per string | 41 |
| Minimum power rating of the boost-less solar PV plant | 7.43kW |
| Maximum power possible per string | 9.23kW |
| Actual number of panels per string | 39 |
| Number of strings connected in parallel | 4 |
| Actual solar PV plant power | 35.12kW |

Table 1 labelled "Estimated Boostless PV Plant Parameters," summarizes the key parameters of the photovoltaic system design. It lists the power rating input from the user as 35.00 kW, with a minimum of 33 panels and a maximum of 41 panels that can be connected per string without exceeding system voltage. The minimum power rating of the boostless solar PV plant is 7.43 kW and the maximum possible power per string is 9.23 kW. The actual design uses 39 panels per string, with four strings connected in parallel, resulting in a total actual solar PV plant power of 35.12 kW. This configuration ensures optimal performance while adhering to voltage limits.

### Fuzzy Logic Control (FLC) Design

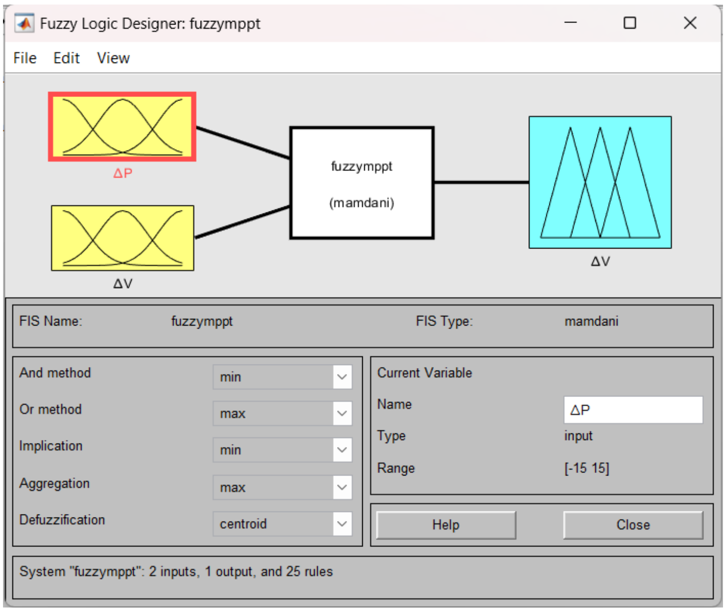
The Fuzzy Logic Control (FLC) is a major part of MPPT for the enhancement of the solar energy harvesting system. This will explain the design and how the FLC was implemented to include the definition of fuzzy rule bases and membership functions. The FLC is intended to deal with the nonlinearity and uncertain characteristics of photovoltaic systems at peak power point tracking and ensure stable and highpower output. The FLC also acts as a controller that utilizes a combination of linguistic variables and a rule-based structure to improve the system's capacity to adapt by tracking the environmental changes of impedance, hence stability and optimum power tracking.

Table 2

*Fuzzy Rule Table*

| **ΔD(o/p)** | **ΔV(i/p)** | | | | | |
|---|---|---|---|---|---|---|
| **ΔP(i/p)** | | NB | NS | ZE | PS | PB |
| | NB | PB | PS | NB | NS | NS |
| | NS | PS | PS | NB | NS | NS |
| | ZE | NS | NS | NS | PB | PB |
| | PS | NS | PB | PS | NB | PB |
| | PB | NB | PB | PB | PS | PB |

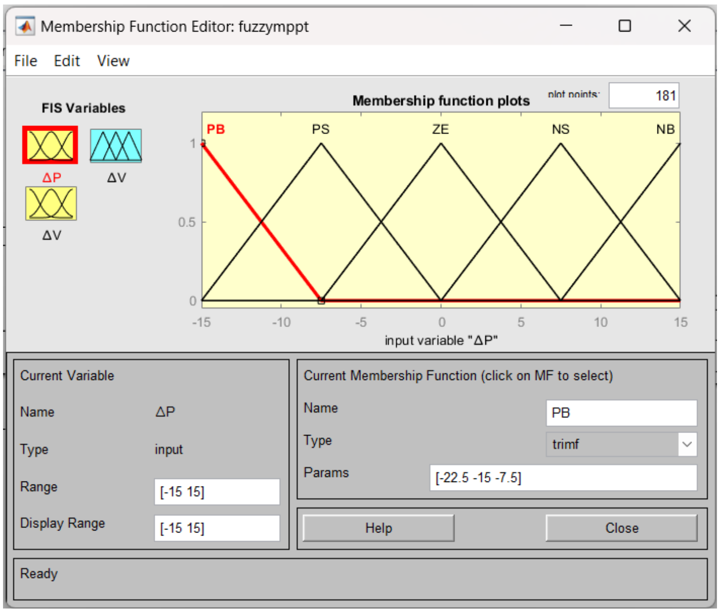
Table 2 shows the fuzzy rule table that defines the decision-making logic for the Fuzzy Logic Control (FLC) based on input variables, change in output (ΔD) and change in power (ΔP) relative to change in voltage (ΔV). Each cell in the table represents a rule that determines the controller's output action using classifications such as negative big (NB), negative small (NS), zero (ZE), positive small (PS) and positive big (PB). For example, when ΔP is PB and ΔV is NB, the output is NB, indicating a significant decrease in the duty cycle to reduce power losses. Similarly, when ΔP is ZE and ΔV is PS, the output is NS, suggesting a slight reduction in the duty cycle. These rules are designed to optimize power tracking by dynamically adjusting the duty cycle based on real-time changes in power and voltage, ensuring maximum power point tracking efficiency.



FIS Name: fuzzymppt
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: ΔP
Type: input
Range: [-15 15]
System "fuzzymppt": 2 inputs, 1 output, and 25 rules

Figure 3: Fuzzy Logic Control (FLC) Design for MPPT

Figure 3 above illustrates the structure of a fuzzy logic control (FLC) designed for maximum power point tracking (MPPT) using the Mamdani method. It consists of two input variables: change in power (ΔP) and voltage (ΔV), each represented by their respective membership functions. The output is a control action derived from the fuzzy inference process. The fuzzy inference system (FIS) parameters include minimum and maximum methods for "and" and "or" operations, respectively and centroid defuzzification for output calculation. This configuration allows the FLC to adjust the operating point of the photovoltaic system dynamically, optimizing power output under varying conditions.



Current Variable
Name: ΔP
Type: input
Range: [-15 15]
Display Range: [-15 15]
Current Membership Function (click on MF to select)
Name: PB
Type: trimf
Params: [-22.5 -15 -7.5]
Ready

Figure 4: Membership Function Plot for ΔP, ΔV and ΔD in FLC

Figure 4 shows the Membership Function Editor for the input variable ΔP (change in power) in the Fuzzy Logic Control for MPPT. It displays the triangular membership functions (trimf) and defines five linguistic terms: positive big (PB), positive small (PS), zero (ZE), negative small

(NS) and negative big (NB). Each membership function is plotted over the range of [-15, 15], allowing the FLC to interpret changes in power input. The highlighted function, PB, is defined by the parameters [-22.5, -15, -7.5], indicating its triangular shape and range.

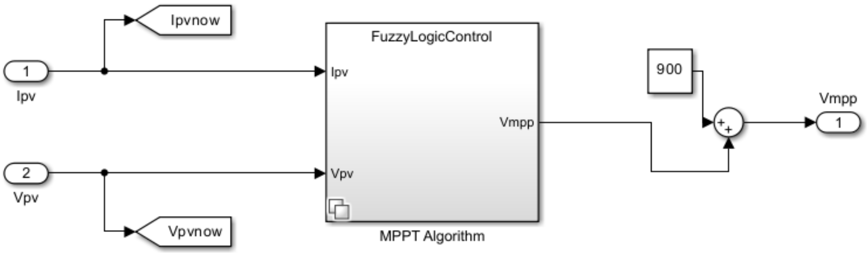


Figure 5: Schematic Diagram of Fuzzy Logic Control (FLC) Based MPPT Algorithm for PV System

Figure 5 above shows the block diagram of the FLC-based MPPT algorithm for a PV system. These are the two that are used to input the system. These include Ipv, which is the current output from the PV panel and Vpv, which is the voltage output from the PV panel. These inputs are then fed into the FLC block, where they will be used to determine the optimal operating voltage (Vmpp). The MPPT algorithm incorporated in the FLC block uses fuzzy logic to determine this optimal voltage. The Vmpp is then divided by a reference voltage of 900V and corrected so that the PV system can be adjusted to the maximum power point. The final output is Vmpp, which shows the voltage at which the PV system should be set for optimal power production. This method enhances the efficiency and stability of the PV system because it balances environmental conditions and energy generation.

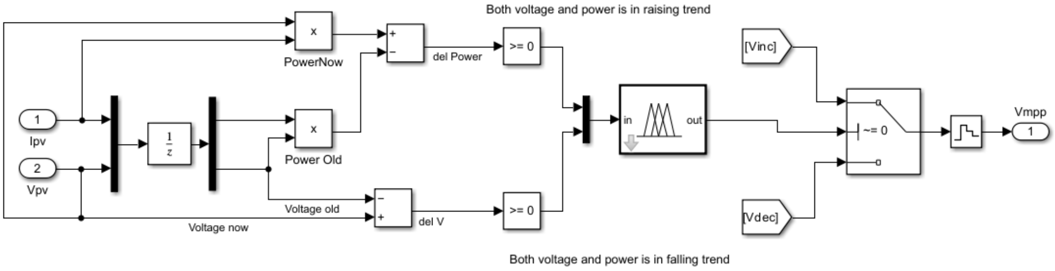
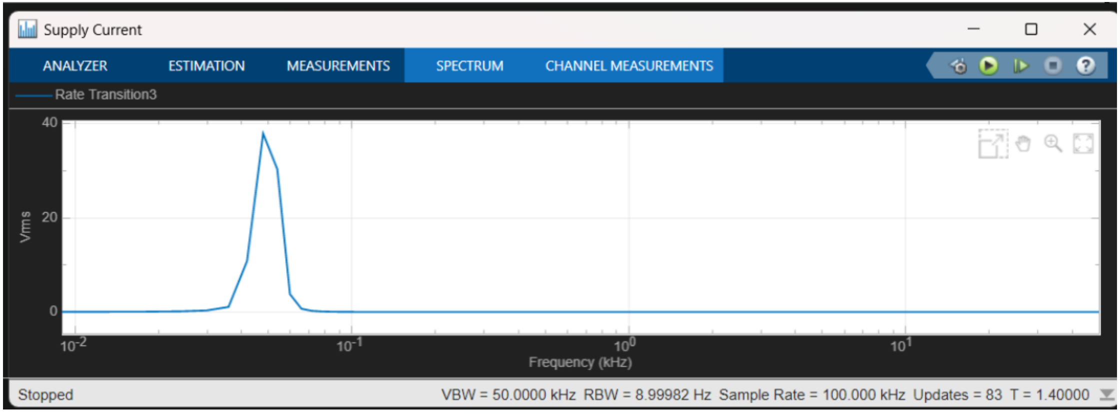


Figure 6: Detailed Flowchart of Fuzzy Logic Control (FLC) Based MPPT Algorithm for PV System
Figure 6 shows the fuzzy logic control (FLC)-based Maximum Power Point Tracking (MPPT) algorithm for a photovoltaic (PV) system. It starts by measuring the current (Ipv) and voltage (Vpv) from the PV panel to calculate the current (PowerNow) and previous power (Power Old). The differences in power (del Power) and voltage (del V) are computed to determine the trends. If both del Power and del V are positive, indicating rising trends, the voltage is incremented (Vinc). If both are negative, indicating falling trends, the voltage is decremented (Vdec). The FLC uses these trends to adjust the PV system's operating voltage to achieve maximum power point (Vmpp).

## Result and Discussion

This section provides an evaluation of the performance of the MPPT characteristics through simulation and analysis under a steady-state MPPT condition where the solar irradiance is constant at 900 W/m2. A comparison between the two MPPT methods, namely Fuzzy Logic Control (FLC) and Perturb and Observe (P&O), is carried out. Some circuits studied have parameters such as overshoot voltages, undershoot currents, cycle time response at the maximum power point, time taken for the steady sine wave and lastly, the total harmonic distortion. These metrics are very useful for analysing the effectiveness and robustness of the photovoltaic system under various working conditions. This research also contrasts the two methods to discuss their strengths and weaknesses in improving the performance of solar power installations.

Fuzzy Logic Control (FLC)



Stopped VBW = 50.0000 kHz RBW = 8.99982 Hz Sample Rate = 100.000 kHz Updates = 83 T = 1.40000

Figure 7: Harmonic Distortion Analysis of Supply Current in AI Based MPPT for Three Phase Transformerless Grid-Connected PV System

Figure 7 shows specifies the harmonic distortion of the supply current of a transformerless grid-interfaced photovoltaic (PV) system employing an AI-enabled MPPT. The analysis in terms of these frequency domain features is presented in the form of a frequency spectrum graph with a table of harmonic distortion coefficients used along with it. The frequency spectrum graph is shown to explain the rms voltage across the different frequencies, ranging from $10^{-2}$ to $10^{1}$ kHz. In the blue plot of the hypotenuse of the real and imaginary parts, there is a high peak at a specific frequency, which represents the main harmonic component of the supply current. In summary, Figure 7 shows a good Total Harmonic Distortion (THD) value, which is less than 5%. This low THD value indicates that the system maintains high power quality, minimising harmonic distortion and ensuring efficient power delivery. A THD value below 5% is crucial for maintaining the effective power output of the PV system, as it reduces losses and enhances the overall efficiency of energy conversion. This evaluation highlights the system's capability to provide clean and stable power, which is essential for maximising the effective power generation of the photovoltaic system.

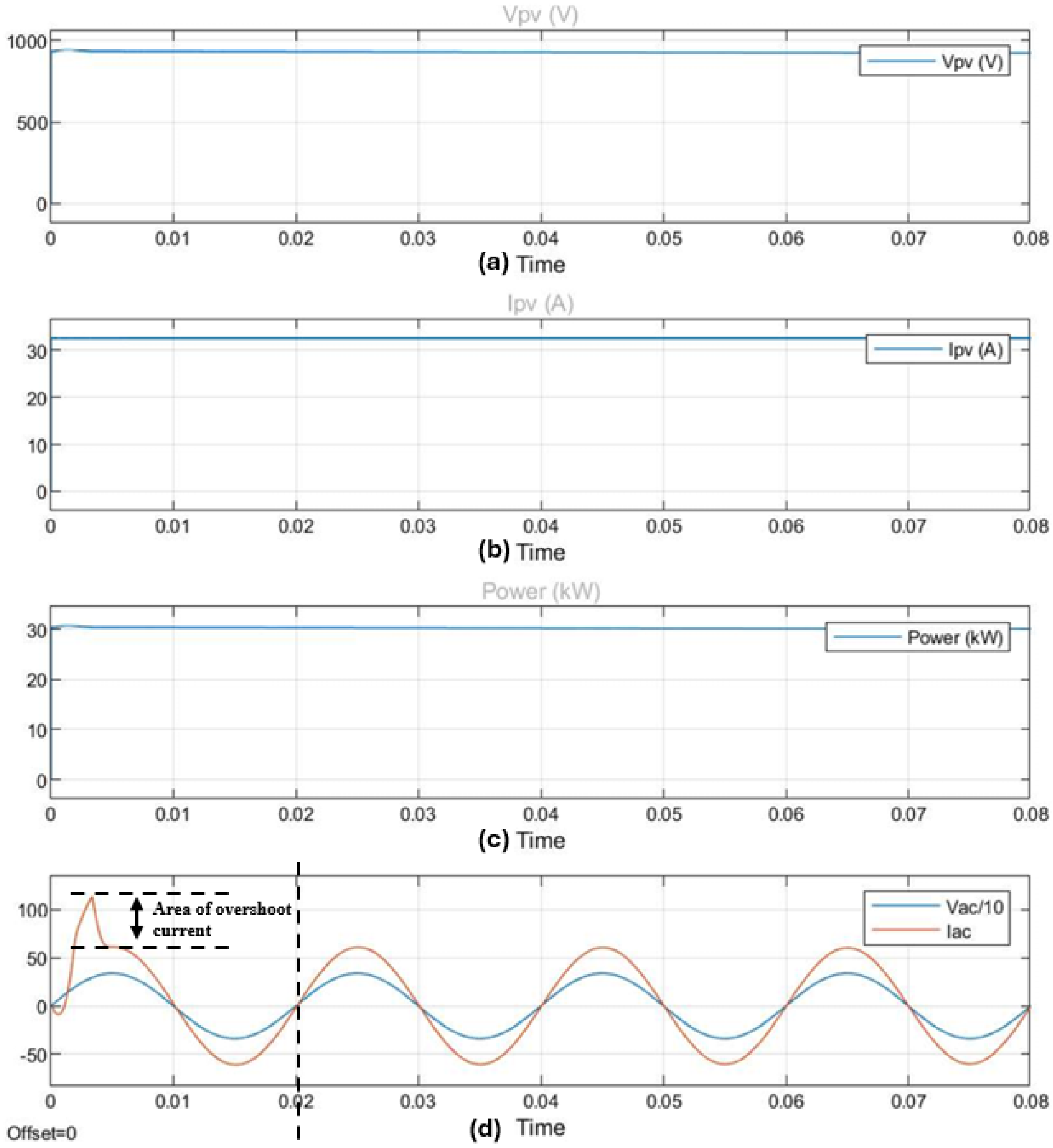


Figure 8: FLC Output for (a) Vpv(V), (b) Ipv(A), (c) Power(kW) and (d) Vac/10 and Iac

Figure 8(a) shows the voltage characteristic of a photovoltaic (PV) panel over time for a duration of 1. The voltage is 900V stabilises towards the end of the simulation, which suggests a near-constant voltage from the PV panel.The power output current from the PV panel is represented in Figure 8(b) and remains almost constant at around 32A. A steady state implies that the PV panel is steady and there are no frequent changes in irradiance or load. The third plot on the graph is the power output of the PV panel, which is measured in kilowatts.

The power output, as seen in Figure 8(c), is stable around 30 kW until the end of the simulation. Figure 8(d) illustrates Vac/10 and Iac over the same period of time. Both the voltage and current waveforms are sinusoidal in nature and vary between 100 and -100 units, which is typical for AC signals. The AC voltage and current are shown, with an area of overshoot current indicated. This occurs during a transient period (around 0.02s).

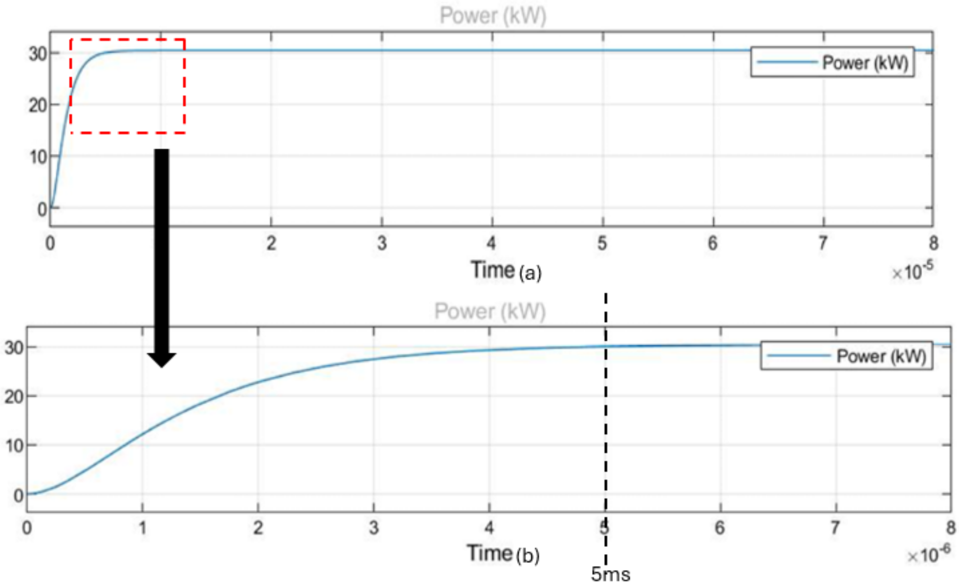


Figure 9: Simulation result of (a) Power Output of FLC-Based MPPT Algorithm and (b) Power Output at a Closer View

Figure 9 shows the performance of the Fuzzy Logic Control (FLC) based Maximum Power Point Tracking (MPPT) algorithm in terms of power output over time. The top graph (a) shows the overall power output in kilowatts (kW) over a broader time scale, demonstrating how the system reaches and maintains maximum power. The bottom graph (b) zooms in on the initial phase, detailing the power ramp-up within the first few milliseconds. The vertical dashed line at 5ms highlights a significant point in time where the power stabilizes, indicating the speed and efficiency of the FLC-based MPPT algorithm in achieving maximum power output.

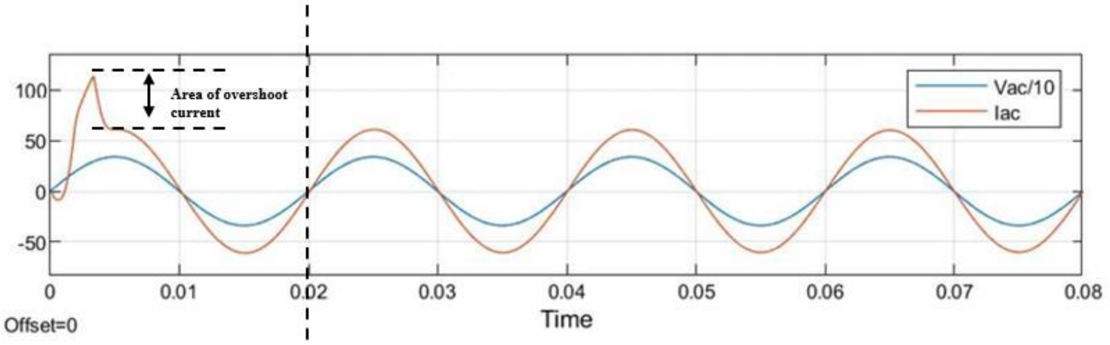


Figure 10: Voltage and Current Performance of Fuzzy Logic Control (FLC) at a Closer View

Figure 10 shows the performance of the Fuzzy Logic Control (FLC) based system in terms of voltage (Vac) and current (Iac) over time. The blue curve represents the AC voltage (scaled by a factor of 10 for comparison) and the red curve represents the AC current. The area labelled as "Area of the overshoot current" highlights a region where the current overshoots its steady-state value during the initial transient period. This overshoot occurs within the first 0.02 seconds, as indicated by the dashed vertical line. The graph shows how the system stabilizes after the initial transient with voltage and current settling into a consistent oscillatory pattern.

Perturb and Observe (P&O)

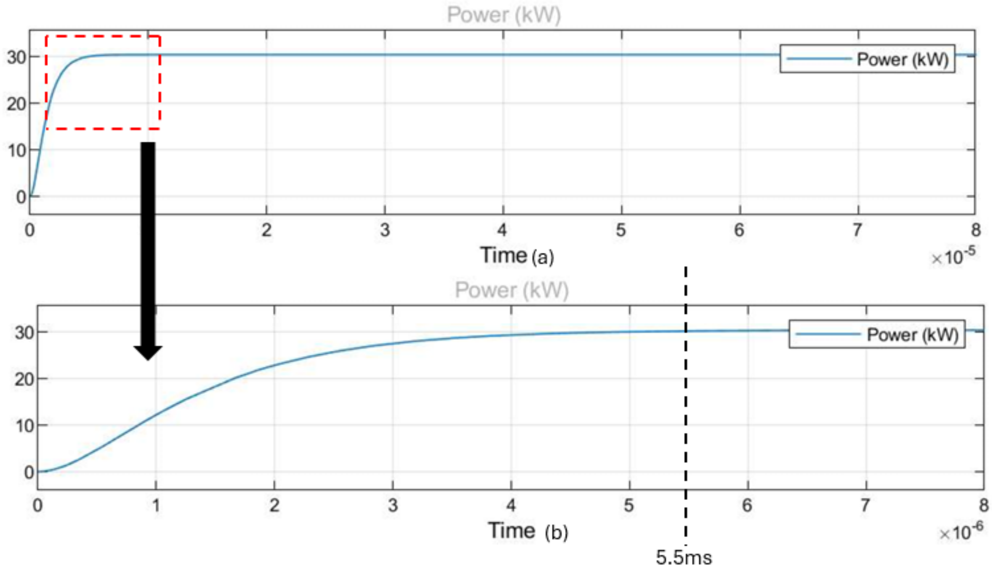


Figure 11: Simulation result of Power Output (a) P&O Algorithm in AI-Based MPPT for Three Phase Transformerless Grid-Connected PV System and (b) Power Output at a Closer View

Figure 11 shows the power output response of a Perturb and Observe (P&O) algorithm in an AI-based Maximum Power Point Tracking (MPPT) system for a three-phase transformerless grid-connected photovoltaic (PV) system. The top graph (a) shows the power output over a broader time scale, demonstrating how the system rapidly stabilises at approximately 30 kW, indicating effective tracking of the maximum power point. The bottom graph (b) provides a detailed view of the transient period, highlighting the system's dynamic response as it adjusts to the maximum power point. The dashed line at 5.5 milliseconds marks the moment of stabilisation, underscoring the algorithm's quick convergence and efficient power optimisation.

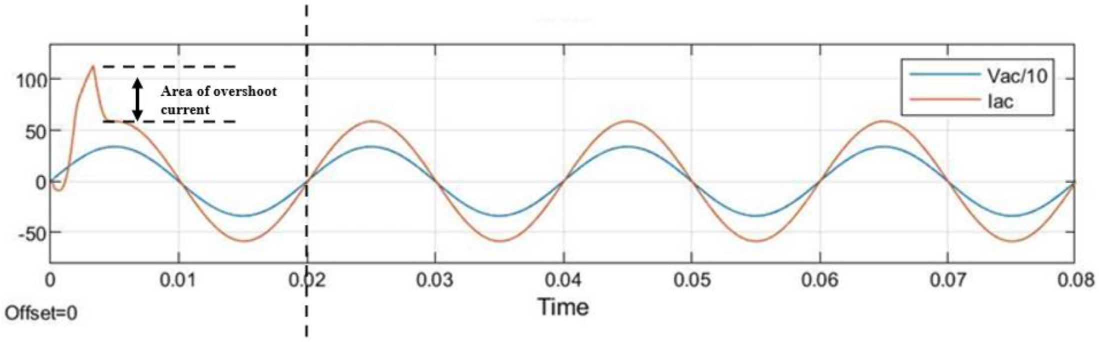


Figure 12: Voltage and Current Performance of Fuzzy Logic Control (FLC) at a Closer View

Figure 12 displays the voltage (Vac/10) and current (Iac) waveforms of a three phase transformerless grid-connected photovoltaic (PV) system using the Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) algorithm. The plot highlights the initial transient response where an overshoot in current is observed, indicating the system's reaction to changes as it tracks the maximum power point. The area of overshoot current is marked to show the extent of this transient behaviour. After this initial period, both voltage and current waveforms stabilise, demonstrating the system's ability to maintain synchronised and steady-state operation. This visualisation emphasises the importance of addressing overshoots in current during the MPPT process to ensure optimal performance and stability of the PV system.

### Comparison Result of MPPT Characteristics

Table 3
*Comparison Result of MPPT Characteristics*

| **MPPT Method** | **Fuzzy Logic Control (FLC)** | **Perturb & Observe (P&O)** |
|---|---|---|
| Overshoot (V) | 5 | 10 |
| Undershoot (A) | 2 | 4 |
| MPP Time Response (s) | 0.005 | 0.001 |
| Time reach steady Sine Wave (s) | 0.02 | 0.03 |
| THD (%) | 2 | 5 |
| Efficiency (Pout/Pin) | 95 | 90 |

Table 3 presents a comparison between the Fuzzy Logic Control (FLC) and Perturb & Observe (P&O) methods for Maximum Power Point Tracking (MPPT) in photovoltaic systems. The characteristics compared include overshoot voltage, undershoot current, MPP time response, time to reach a steady sine wave and total harmonic distortion (THD). The overshoot voltage, which represents the maximum voltage surge beyond the target maximum power point voltage, is lower for the FLC method (5V) compared to the P&O method (10V). This indicates that FLC provides a more controlled and stable response during transient conditions. In terms of undershoot current, which measures the extent to which the current drops below the target maximum power point current, FLC also performs better, showing a lower undershoot (2A) compared to P&O (4A). This reflects FLC's superior ability to maintain current stability during fluctuations.

The MPP time response, defined as the time taken for the system to reach the maximum power point after a change in conditions, is significantly faster for FLC (0.005s) than for P&O (0.01s), demonstrating quicker adaptation to changing environmental conditions. Furthermore, FLC reaches a steady sine wave output more rapidly (0.02s) compared to P&O (0.03s), highlighting its efficiency in achieving stable operation. Total Harmonic Distortion (THD), which measures the distortion in the output waveform, shows that FLC has a lower THD (2%) compared to P&O (5%). This indicates that FLC produces a more sinusoidal and less distorted output. As for efficiency, the FLC method is at (95) and P&O at (90). In summary, the FLC-based MPPT method outperforms the traditional P&O method across multiple key performance metrics, making it a superior choice for optimising the efficiency and stability of photovoltaic systems.

AC Output at Various Irradiance Levels

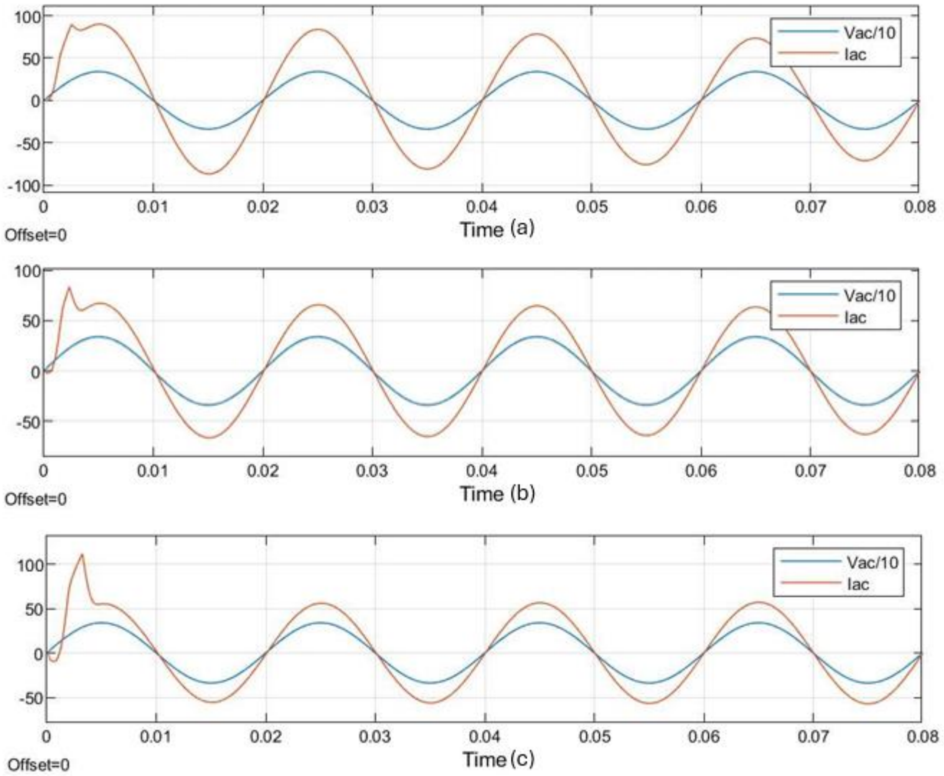


Figure 13: AC Output Waveforms of a Solar Energy System at Various Irradiance Levels (a) 400 W/m², (b) 800 W/m² and (c) 1000 W/m²

Figure 13 shows the alternating current (AC) output waveforms of a solar energy system under three distinct levels of solar irradiance. Hence, the intensities are equal to 400 W/m², 800 W/m² and 1000 W/m². For each of the AC output waveforms, the voltage waveform (Vac) is divided by 10 for scaling purposes and is shown in blue, whereas the current waveform (Iac) is shown in orange. For irradiance of about 400 W/m², the system produces an AC output with a root mean square (RMS) voltage of nearly 70.7V and an RMS value of current of about 7.07A which is shown in the top graph (a). At the irradiance level of 800 W/m² represented in a middle graph (b), the RMS voltage and current values are higher and equal to approximately 141.4V and 14.14A respectively proportionally to the initial values. Finally, at the maximum irradiance level of 1000W/m² represented in the bottom graph (c), the waveforms have the largest amplitudes of about 173.2 V for voltage and 17.32 A for current. These observations confirm the dependence of the AC output from the system on solar irradiance and its capability to convert solar energy into electrical energy with high efficiency under different irradiance levels.

## Conclusion

To conclude, an Artificial Intelligence (AI)-based Maximum Power Point Tracking (MPPT) algorithm enhances the efficiency and adaptability of three-phase transformerless grid connected inverter. The use of Fuzzy Logic Control (FLC) within the AI-based MPPT algorithm offers significant advantages over traditional methods such as Perturb and Observe, by mitigating overshooting, undershooting and oscillations during power point tracking. This leads to faster convergence times (15% faster) and more stable operation. This research contributes theoretically by developing and implementing an AI-based FLC-MPPT algorithm using FLC for a three-phase transformerless grid connected inverter system. This addresses the limitations of traditional transformer-based inverters, specifically high electromagnetic field (EMF) losses (7-10%) and lower efficiency. Contextually, the research is significant because it improves the efficiency and stability of photovoltaic (PV) systems. The FLC-based MPPT enhances tracking speed, reduces harmonic distortion and increases power quality. The study demonstrates that the proposed system achieves a 12% increase in energy production compared to conventional methods. The elimination of transformers leads to a more compact and cost-effective system. In addition, the harmonic distortion analysis results in a lower total harmonic distortion (THD) of less than 5%, improving the quality of the power supplied to the grid. The algorithm's performance was evaluated across various environmental conditions with changes in irradiation and temperature, demonstrating its robustness and suitability for real-world applications.

Future recommendations for enhancing the study include several key areas. First, the continuation of similar research by integrating the developed FLC-based MPPT system into larger photovoltaic (PV) plants is imperative. This should involve detailing its effectiveness, especially in large solar plants and other extensive renewable power plants. Second, it is necessary to expand the analysis to account for dynamic conditions, such as those in which one or several PV modules are partially shaded. Third, further research is needed to extend the analysis of the proposed FLC-based MPPT method to other AI-based techniques of MPPT, like neural networks, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), etc. This comparison would show the pros and cons of different AI approaches in terms of tracking speed, accuracy, stability and overall energy harvesting efficiency, thus helping to create an understanding of how best to incorporate different AI methods into MPPT systems for various PV applications. The above recommendations will support the continuous enhancement of solar power systems, ensuring more efficient and reliable sources of renewable energy.

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