Design and Analysis of Distributed Generation System Based on InterLosses Conditions

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Abstract

The integration of renewable energy sources in Distributed Generation (DG) systems poses significant power quality challenges, necessitating advanced compensation techniques. This study investigates the performance of an improved An Artificial Neural Network (ANN) is used to improve the Unified Power Quality Conditioner (the UPQC) to regulate power quality in a three-phase low-voltage DG system integrating wind and solar photovoltaic (PV) energy. The proposed system, UPQC-ANN-RE, is designed to minimize Problems with power quality, including harmonics, current distortions, and voltage swings while ensuring stable grid integration. A MATLAB-based simulation is performed to evaluate different converter topologies and control strategies. Initially, a Neutral-Point-Clamped (NPC) converter with an ANN controller is analysed, followed by the replacement of the NPC converter with an H-Bridge converter to assess its impact on power quality improvement. Further enhancement is achieved by incorporating a Fuzzy Logic Controller (FLC) with the H-Bridge converter, demonstrating superior performance in mitigating harmonics and improving overall system stability. The comparative analysis highlights that the optimized converter topology, combined with intelligent control techniques, significantly enhances the dependability and efficiency of the DG system powered by renewable energy. The results confirm that the suggested strategy is successful in raising power quality metrics, lowering harmonic distortions, and guaranteeing a more reliable and effective power distribution system.
Keywords: Robotic Neural Networks (ANN), Fuzzy Logic Controller, and Unified Electrical Power Conditioner (UPQC) (FLC), Renewable Energy, Converter Topology.

1. Introduction

Increasingly, distributed generation (DG) is incorporating renewable energy sources (RES). systems has significantly transformed modern power networks. Solar Photo Voltaic (PV) and wind energy systems have emerged as viable solutions for sustainable energy generation, contributing to the decrease in greenhouse gas emissions and reliance on fossil fuels [1]. However, the integration of these renewable sources introduces several power quality challenges, including voltage fluctuations, current harmonics, frequency deviations, and transient disturbances [2]. Addressing these issues is crucial to ensuring the stable operation of DG systems and maintaining the reliability of power distribution networks. Unified Power Quality Conditioners (UPQC) are among the best ways to address power quality issues in DG systems [3]. The UPQC is a multipurpose power conditioning tool that blends shunt and series compensators to solve power quality problems caused by both current and voltage. Traditional UPQC systems rely on traditional controllers like proportional-integral (PI) and PID (proportion controllers, which often exhibit limitations in dynamic response and adaptability to non-linear loads [4]. To enhance the performance of UPQC, the implementation of artificial intelligence-based controllers, Fuzzy Logic Controllers (FLC) and Artificial Neural Networks (ANN), including has been explored in recent research [5].

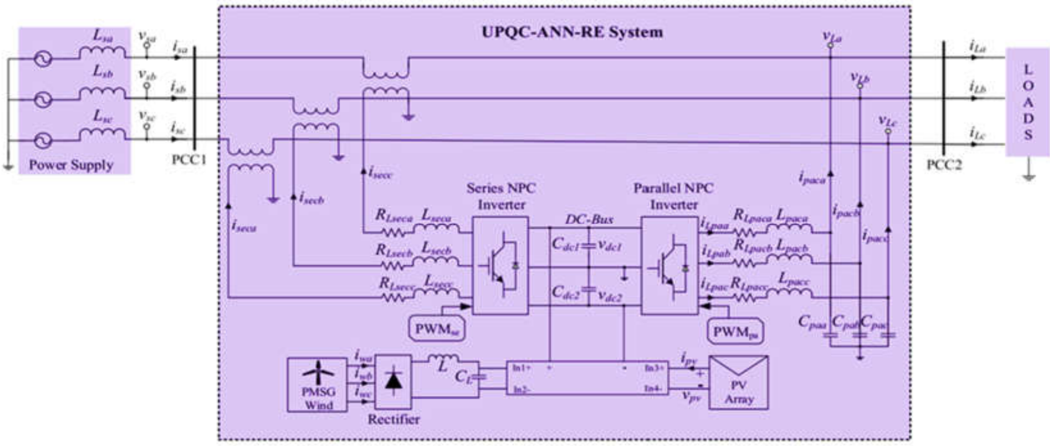


Figure 1 Block Diagram Representation of UPQC-ANN- Resystem

This study proposes an advanced UPQC system enhanced with an ANN controller, termed as UPQC-ANN-RE, to improve power quality in a three-phase low-voltage DG system incorporating solar PV and wind energy [6]. The primary objective is to minimize total harmonic distortion (THD), mitigate voltage fluctuations, and ensure a stable power supply. A MATLAB-based simulation is conducted to analyze the impact of different converter topologies and control strategies on power quality enhancement [7]. Initially, the study investigates the performance of a Neutral-Point-Clamped (NPC) converter with an ANN controller. The results indicate that while the ANN-based control improves the dynamic response of the system, the NPC converter has limitations in reducing THD effectively [8]. To address this, the NPC converter is replaced with an H-Bridge converter, which exhibits superior performance in harmonic mitigation and voltage regulation [9]. Furthermore, an additional improvement is achieved by integrating an FLC with the H-Bridge converter, which enhances system stability and reduces power quality disturbances [10].

The key contribution of this research resides in the comparison of various converter topologies and intelligent control techniques in improving power quality in DG systems [11]. By optimizing the converter structure and employing advanced control strategies, the proposed UPQC-ANN-RE system demonstrates significant improvements in voltage and current waveforms, reducing harmonics and enhancing the reliability of renewable energy-based power distribution [12][15].

2. LITERATURE SURVEY

The integration of renewable energy sources into power distribution systems has gained significant attention in recent years. Researchers have extensively studied various methods to enhance power quality and ensure stable grid operation [16]. One of the primary challenges associated with RES integration is the increased level of harmonics and voltage fluctuations caused by intermittent power generation from PV and wind energy sources [17]. It is commonly known that the Universal Power Quality Compressor (UPQC) is a useful tool for addressing power quality problems in distributed generation systems. Several studies have explored the application of UPQC in compensating for voltage sags, swells, and current harmonics in power networks [18]. Traditional UPQC implementations primarily utilize PI and PID controllers for voltage and current regulation. However, these conventional controllers often exhibit slow response times and are less effective in handling non-linear loads [19].

To address these limitations, artificial intelligence-based controllers, power quality applications, such as Fuzzy Logic Controllers (FLC) and Artificial Neural Networks (ANN). ANN controllers have demonstrated superior adaptability and learning capabilities, making them suitable for dynamic power quality compensation [20]. Researchers have shown that ANN-based UPQC systems significantly improve transient response and harmonic reduction compared to traditional PI controllers [21]. Fuzzy Logic Controllers (FLC) have also been extensively investigated for their robustness in handling non-linearities in power systems. Studies indicate that FLC-based UPQC systems outperform conventional controllers in terms of voltage stability and harmonic suppression [22]. The combination of ANN and FLC in UPQC systems has been proposed as a hybrid approach to achieving optimal power quality enhancement in DG networks [23].

In addition to control strategies, converter topologies are essential to the operation of UPQC systems. The neutral-point-clamped (NPC) converter has been commonly used in multi-level UPQC applications due to its ability to provide better voltage control [24]. However, recent studies suggest that the H-Bridge converter exhibits improved harmonic mitigation capabilities and dynamic response compared to NPC converters [25]. The combination of ANN and FLC with H-Bridge converters has shown promising results in reducing THD and enhancing system stability [26]. Furthermore, MATLAB-based simulations have been widely employed to analyze the effectiveness of various UPQC configurations and control strategies. Simulation results from previous research indicate that intelligent control techniques and optimized converter topologies significantly contribute to improved power quality in renewable energy-based DG systems [27].

New developments in control systems and power electronics have paved the way for the development of more efficient and intelligent UPQC systems. The ongoing research in this domain continues to focus on enhancing the adaptability and robustness of UPQC controllers to meet the growing demand for stable and high-quality power distribution in modern smart grids [28]. In conclusion, the literature survey highlights the importance of advanced control techniques and optimized converter topologies in improving power quality in DG systems. The proposed UPQC-ANN-RE system builds upon existing research by integrating ANN and FLC controllers with an H-Bridge converter to achieve superior power quality performance [29-30].

3. ANN BASED UPQC

Unified Power Quality Conditioner (UPQC) Performance is measured in terms of accuracy and precision in removing harmonic components from distorted current waveforms. The best way to eliminate harmonic components Performance of shunt active power filters is determined by the accuracy and precision with which harmonic components are eliminated from distorted current waveforms. Shunt power filter management algorithm development is based on the best performance for eliminating harmonic elements from the current or voltage waveform. Usually, a traditional PI controller is employed to regulate voltage. However, a shunt active electrical filter management algorithm was developed as a result of its limitations, including the time form to the current or voltage waveform. A traditional PI controller is usually used to regulate voltage. However, due to problems such the inability to enhance the the system's rapid reaction and the time-consuming and challenging process of identifying PI parameters, an ANN, or Artificial Neural Network, supervisor has been incorporated in this k. Due to the controller's significant difficulty in recognizing PI parameters and other limitations, such as its incapacity to enhance the system's transient responsiveness, an Artificial Neural Network (ANN) operator has been implemented in this study. This is because of the controller's high speed of recognition, learning ability, and adaptability to any system. A mathematical model that draws inspiration from biological neural networks is called an Artificial Neural Network (ANN). quickness of recognition, capacity for learning, and system adaptability. An artificial neural network and biological neural networks serve as the basis for this mathematical model.

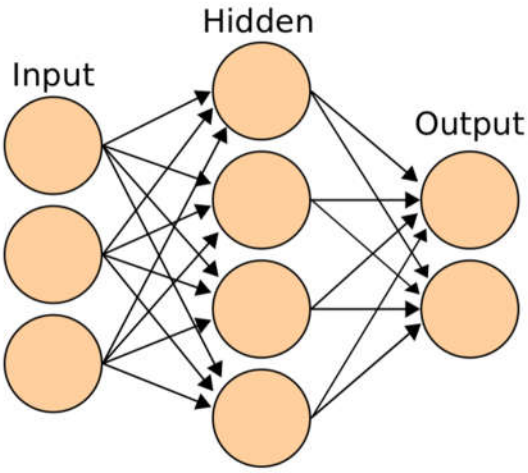


Figure 2 Structure of ANN

A network of interconnected artificial neurons that use the connectionist method to compute information makes up an artificial neural network. It shares two characteristics with the brain: The connectionist method is used to compute information using a network of interconnected artificial neurons that make up an artificial neural network. akin to the cerebral cortex in two aspects: (i) The network collects information through the learning process. (i) The network collects the data through the learning process. (ii) The data is stored using interneuron connection (ii) Interneurons' connection strengths are used to store the data. For the "n" and "n-1" intervals, the extensive link voltage data acquired using the conventional method is available in the MATLAB workspace. Following that, this data is used to train the ANN Controller. The MATLAB environment contains the vast amount of DC-link voltage data for the "n" and "n intervals obtained via the traditional method. After that, the ANN Controller is trained that has been retrieved. The layers of input and output have a fixed number of neurons to process the information. Seven secret terations and six validation checks are carried out at each stage to lessen the possibility of errors. The number of cells in the input and output layers is fundamentally fixed in order to process the information. At every training session, seven concealed layers of 1000 iterations and six validation checks are carried out to lessen the possibility of errors. For the Series Active Power Source (S-APF), the timely and highly accurate identification of disruptive signals and the speedy processing of reference signals are prerequisites for the desired compensation.

Integrating dispersed generation systems with renewable energy sources presents challenges in maintaining power quality, necessitating advanced compensation techniques. This study explores the performance of an Unified Power Quality Conditioners (UPQC) tuned using Artificial Neural Networks (ANN) can improve power quality in a three-phase low-voltage DG system incorporating solar Photo Voltaic (PV) and wind energy. The proposed system, UPQC-ANN-RE, is designed to minimize total harmonic distortion and improve voltage stability while ensuring stable grid integration. A MATLAB-based simulation is conducted to analyze different converter topologies and controllers.

Initially, the system employs an NPC converter with an ANN controller to regulate power quality. However, this configuration results in significant harmonic distortions in both source voltage and load current. To enhance the performance, the NPC converter is replaced with an H-Bridge converter while maintaining the ANN controller. This modification leads to a noticeable improvement in power quality by reducing voltage and current harmonics. To further optimize performance, the ANN controller is substituted with a Fuzzy Logic Controller (FLC) while keeping the H-Bridge converter. This final configuration demonstrates superior performance with minimal harmonic distortion and improved system stability.

The core functionality of the proposed system revolves around the UPQC, which consists of series and shunt compensators. The series compensator mitigates voltage distortions by injecting an appropriate compensating voltage, ensuring a balanced and stable supply. The shunt compensator counteracts current distortions by supplying or absorbing reactive power, thereby improving power factor and mitigating load-related harmonics. The integration of an ANN-based controller enhances the dynamic response of the UPQC, allowing for real-time adjustments and better adaptation to fluctuating power conditions. However, when the ANN controller is replaced with an FLC, the system achieves even greater precision in harmonic mitigation and power quality enhancement.

The outcomes of the simulation confirm that the suggested system by demonstrating significant improvements in power quality parameters. The comparative analysis between different converter and controller configurations highlights the superior performance of the H-Bridge converter with an FLC. The system not only reduces harmonic distortions but also ensures efficient energy utilization, making it a viable solution for integrating renewable energy sources into distribution networks. By leveraging intelligent control strategies and optimized converter topologies, the UPQC-ANN-RE system proves to be a reliable and effective approach to mitigating power quality issues in distributed generation systems.

4. SIMULATION RESULTS AND ANALYSIS

The simulation results for the proposed in a distributed generation (DG) system powered by renewable energy, the single power quality conditioner (UPQC) were analyzed using MATLAB. The study primarily focused on the performance comparison of different converter topologies and control strategies in mitigating power quality issues. Source voltage, source current, load voltage, and load current Total Harmonic Distortion (THD) values were recorded for different configurations, demonstrating the effectiveness of the proposed approach

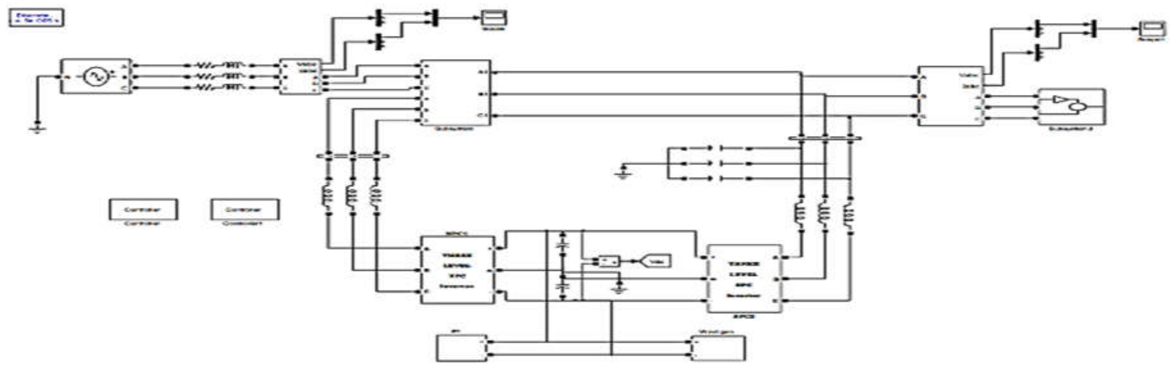


Figure 3 Proposed system simulation circuit

4.1. NPC Converter with ANN Controller

Initially, the system was implemented with a Neutral Point Clamped (NPC) converter controlled by an Artificial Neural Network (ANN). The performance parameters obtained from the simulation revealed that the NPC converter with ANN resulted in a source voltage THD of 3.93%, source current THD of 5.36%, load voltage THD of 3.93%, and load current THD of 27.04%.

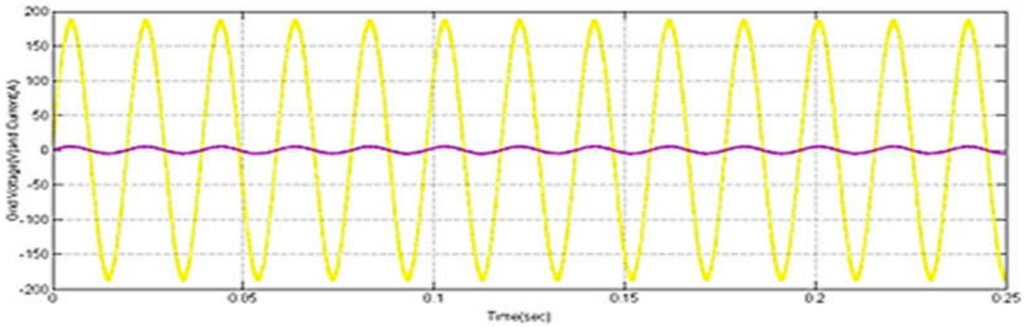


Figure 4 Simulated results

The NPC converter, being a multilevel topology, offers better voltage sharing among semiconductor switches, leading to improved voltage waveform quality. However, despite its advantages, the observed THD values indicate the presence of considerable harmonic distortion, particularly in the load current. The reason for this is the switching behaviour of the converter and the inability of the ANN controller to fully compensate for the harmonics in the system.

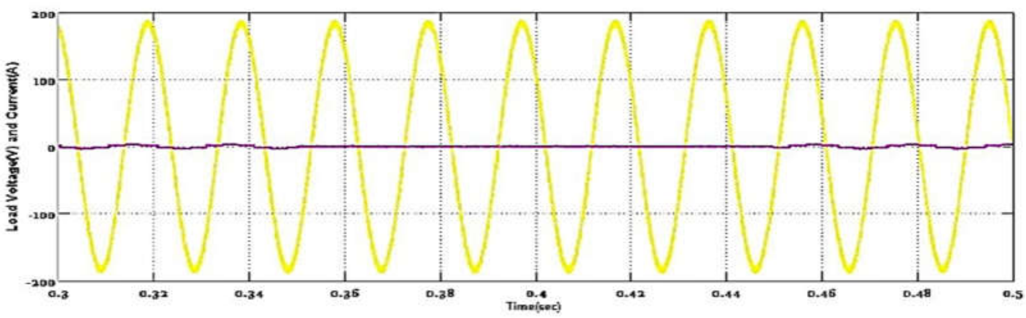


Figure 5 Simulated results Figure 5 Simulated results

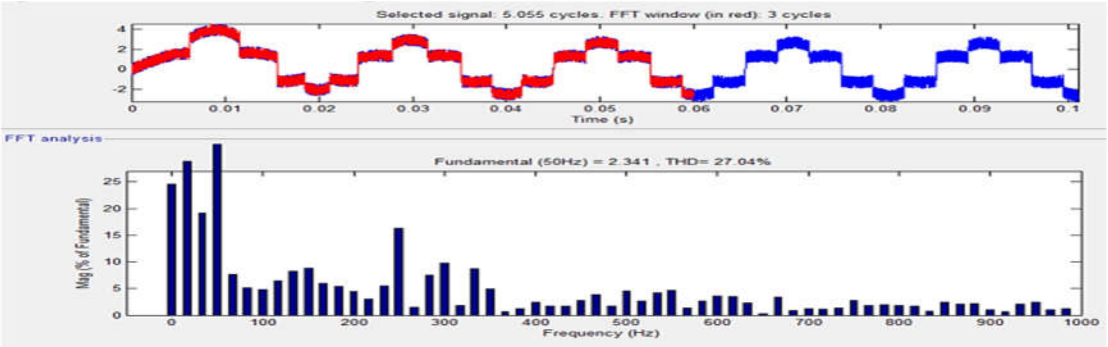
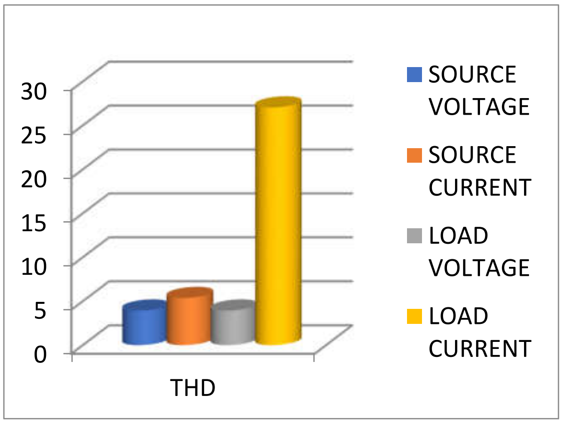


Figure 6 Load Current THD

The high load current THD signifies that nonlinear loads in the system generate substantial harmonic components that are not adequately mitigated. The ANN controller provides better adaptability and learning capability compared to traditional PI controllers, but the effectiveness is limited due to the inherent design constraints of the NPC converter. The imbalance in voltage levels within the NPC structure may also contribute to the increased harmonic content, necessitating further improvements.

Parameter	THD
Source voltage	3.93
Source current	5.36
Load voltage	3.93
Load current	27.04

Table1.THD value of NPC Bridge converter



Graph1.THD value of NPC converter

4.2. H-Bridge Converter with ANN Controller

To improve system performance, the NPC converter was replaced with an H-Bridge converter while retaining the ANN controller. The results from the MATLAB simulation showed a notable reduction in harmonic distortion: the source voltage THD dropped to 2.22%, source current THD to 4.24%, load voltage THD to 2.22%, and load current THD to 23.80%.

The H-Bridge converter provides a more flexible and efficient voltage conversion mechanism compared to the NPC topology. The reduction in source voltage THD indicates improved quality of the voltage at the common coupling point, which enhances grid stability. Similarly, the lower source current THD suggests reduced harmonic injection into the utility grid, preventing potential resonance and power quality issues.

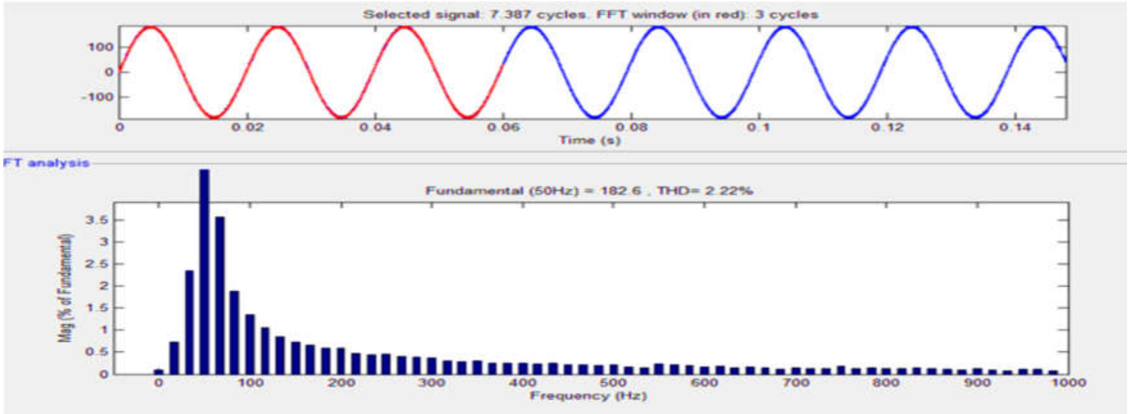


Fig7.Source voltage THD

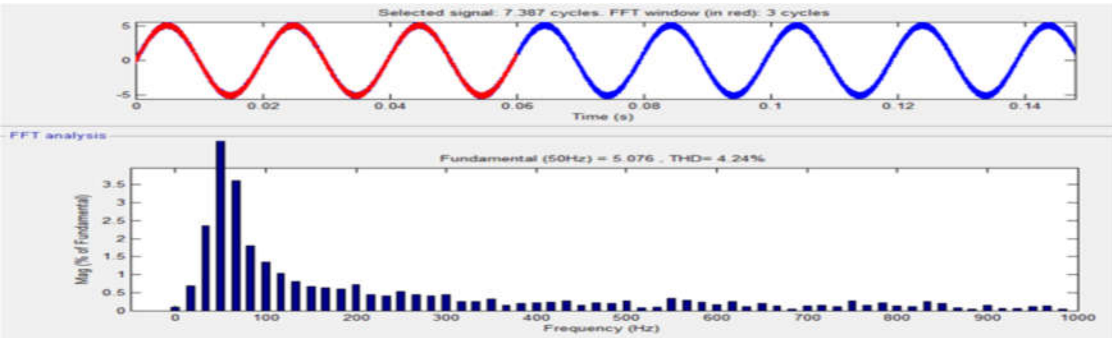


Fig8.Source Current THD

The load voltage THD also witnessed a significant decline, implying that the voltage supplied to the connected loads is now cleaner and less affected by distortions. However, the load current THD, although reduced, remained relatively high. This suggests that while the H-Bridge converter improves the system's harmonic mitigation capability, the ANN controller alone is insufficient to achieve optimal performance. The controller's training data and response time may contribute to residual harmonics, indicating the need for a more robust control strategy.

Overall, this observation highlights the advantages of using an H-Bridge converter over an NPC converter, particularly in reducing voltage harmonics. However, the remaining harmonic distortion in load current suggests further enhancements are needed to achieve optimal performance.

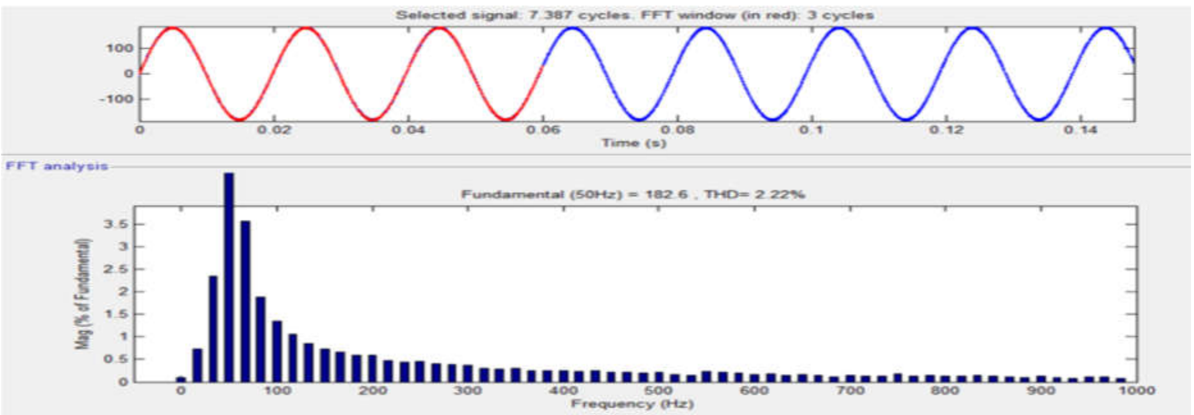


Fig9.Load voltage THD

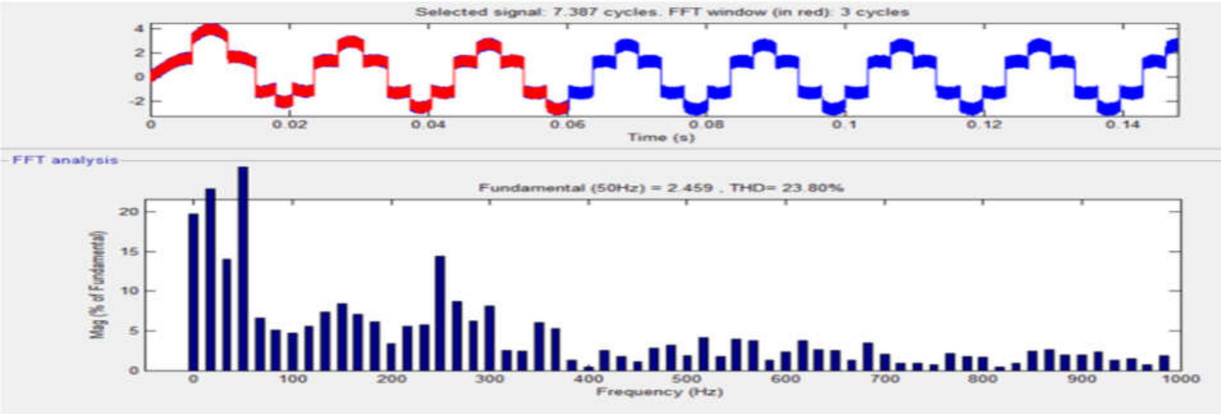
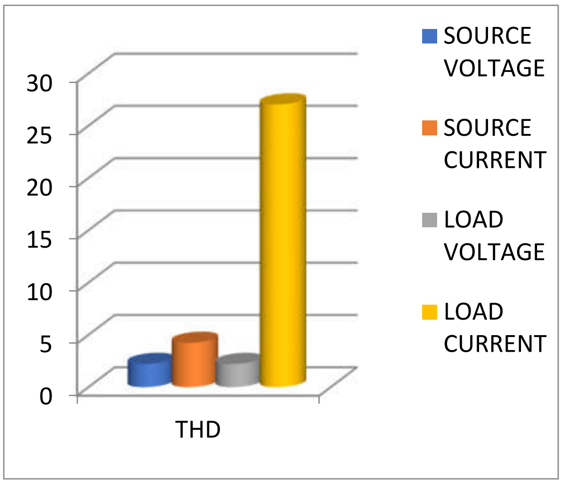


Fig10.Load voltage THD

Parameter	THD
Source voltage	*2.22*
Source current	*4.24*
Load voltage	*2.22*
Load current	*23.80*

Table2. THD values of H Bridge converter



Graph2. THD values of H Bridge converter

4.3. Fuzzy Logic Controller (FLC)

The H-Bridge converter was retained in the final simulation configuration, but a Fuzzy Logic Controller (FLC) was used in place of the ANN controller. The results demonstrated the best performance among the tested configurations, with a source voltage THD of 0.92%, source current THD of 2.98%, load voltage THD of 1.01%, and load current THD of 17.79%.

The adoption of FLC significantly enhanced harmonic suppression across all parameters. The source voltage THD reached its lowest value, indicating highly stable voltage conditions at the grid interface. This improvement is attributed to the FLC's superior decision-making capability in handling nonlinearities and disturbances in the system. Unlike ANN, which relies on training data, FLC uses a rule-based approach that adapts dynamically to changing operating conditions, resulting in improved harmonic mitigation.

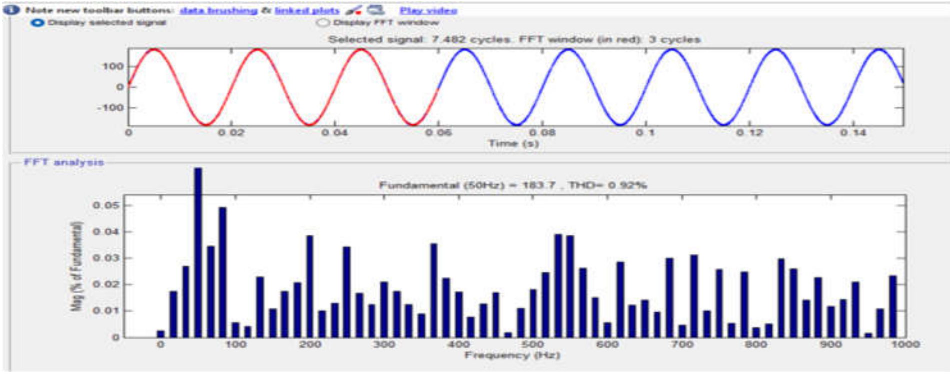


Fig11.Source voltage THD

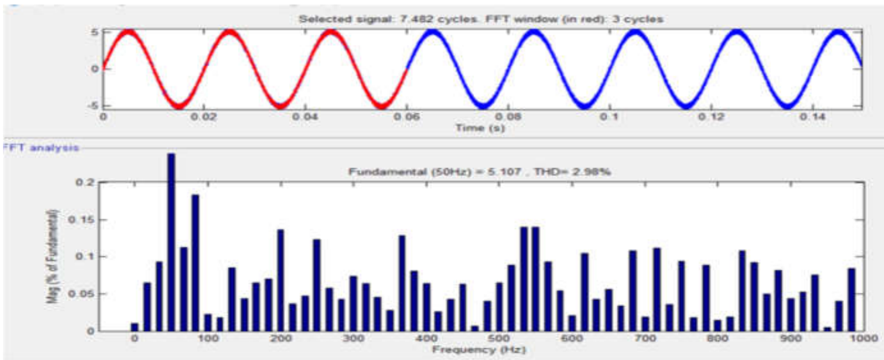


Fig12.Source voltage THD

The substantial reduction in source current THD indicates that the FLC is more effective in regulating current distortions, ensuring minimal harmonic infusion into the grid. This is essential for adhering to grid standards and norms. reducing potential issues related to power quality regulations. The load voltage THD showed a remarkable decrease, suggesting enhanced voltage stability and minimal distortion in the power supplied to the loads. The significant improvement in load current THD further validates the effectiveness of the H-Bridge converter combined with FLC in reducing harmonics. The reduction in load current harmonics implies smoother operation of connected loads, improved efficiency, and minimized overheating and losses in electrical components.

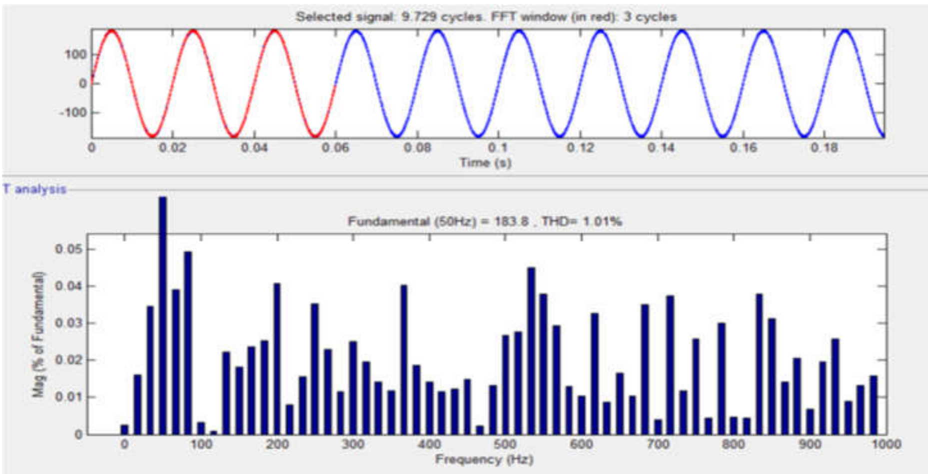


Fig13.Load voltage THD

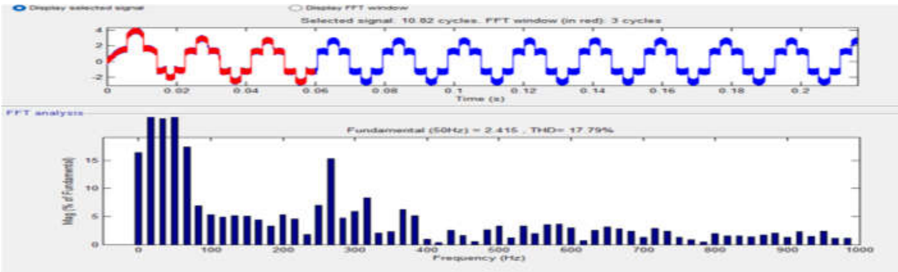


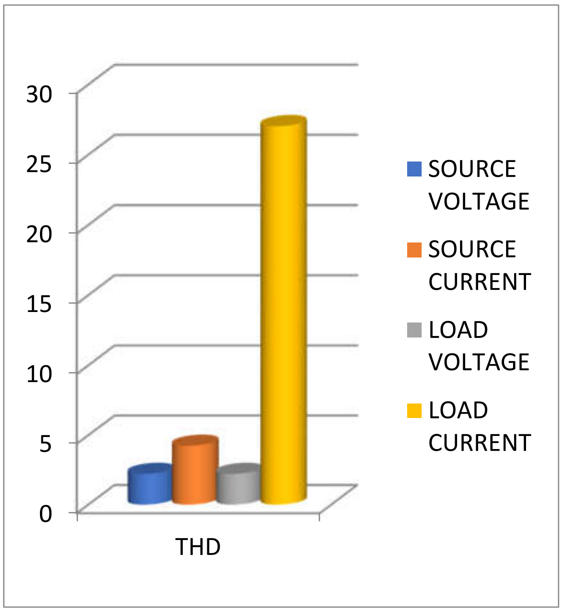
Fig14.Load voltage THD

While ANN provides better performance than conventional PI controllers, the NPC converter's limitations in balancing voltage levels result in higher harmonic distortion, particularly in load current. The H-Bridge converter significantly improves system performance by lowering source voltage and current THD values. However, ANN's performance is still constrained in mitigating load current harmonics effectively. The best performance is observed with the combination of the H-Bridge converter and FLC. This setup achieves the lowest THD values across all parameters, ensuring superior power quality and stable integration with the grid. The study conclusively demonstrates that the choice of converter topology and control strategy plays an essential part of improving power quality in DG systems powered by renewable energy. The transition from NPC to H-Bridge converter results in significant performance gains, and replacing ANN with FLC further enhances harmonic mitigation. The lowest THD values are achieved with the H-Bridge converter and FLC, proving it to be the most effective configuration for maintaining voltage stability and reducing current distortions.

Future research can explore additional improvements by integrating hybrid control strategies that combine the advantages of ANN and FLC. Real-time hardware implementation and experimental validation of the proposed system can further verify its practical applicability. Moreover, adaptive fuzzy systems and machine learning-based predictive controllers ca n be investigated to enhance the system's dynamic response under varying grid conditions .By adopting the optimal configuration of the H-Bridge converter with FLC, power quality in renewable energy-based DG systems can be significantly enhanced, ensuring stable and efficient operation with minimal harmonics. This study provides valuable insights into power quality optimization, paving the way for more reliable and sustainable integration of renewable energy sources into modern electrical grids.

Parameter	**THD**
Source voltage	0.92
Source current	2.98
Load voltage	1.01
Load current	17.79

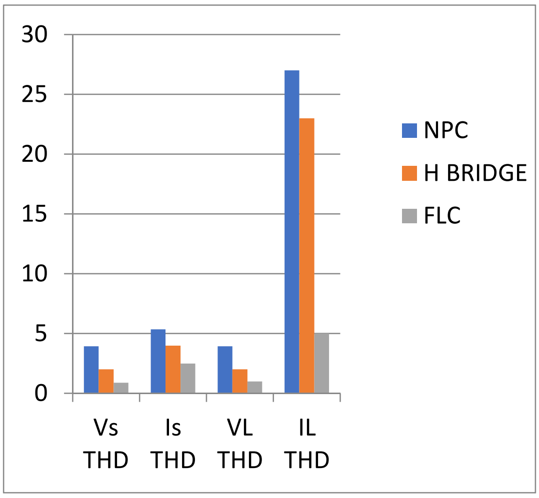
Table3. THD value of FLC



Graph 3 THD values of FLC Converter

Converter	THD Source voltage	THD Source current	THD Load voltage	THD Load current
NPC converter	3.93	5.36	3.93	27.04
H-bridge converter	2.22	4.24	2.22	23.80
Fuggy converter	0.92	2.98	1.01	17.79

Table 4 Total THD values



Graph 4 Comparision of THD

5. CONCLUSION

This study presents an advanced power quality enhancement approach for renewable energy-based Distributed Generation (DG) systems using an improved Unified Power Quality Conditioner (UPQC). The proposed system, UPQC-ANN-RE, integrates solar PhotoVoltaic (PV) and wind energy sources while utilizing intelligent control strategies, including an essential part of improving power quality in DG systems powered by renewable energy. (FLC). The research evaluates different converter topologies and its effect on power quality, with a particular emphasis on lowering THD and improving voltage stability. A comprehensive MATLAB-based simulation is conducted to analyze the performance of various configurations. The study initially implements a Neutral Point Clamped (NPC) converter with an ANN controller, followed by the substitution of the NPC converter with an H-Bridge converter, demonstrating a noticeable improvement in power quality. Further enhancement is achieved by integrating an FLC with the H-Bridge converter, resulting in a more stable and efficient system with minimized harmonics. The comparative analysis confirms that the H-Bridge converter with FLC outperforms other configurations in terms of harmonic suppression, voltage regulation, and overall system efficiency. The findings validate that the combination of an optimized converter topology and intelligent control techniques significantly enhances the reliability of renewable energy-based DG systems. The proposed system effectively mitigates power quality problems such current distortions and voltage swings, guaranteeing a more steady incorporation of renewable energy sources into the electrical system. Future research can explore hybrid control strategies, adaptive tuning techniques, and real-time hardware implementation to further optimize the system's performance. Overall, this study provides a robust framework for improving power quality in modern DG systems, promoting the sustainable and efficient utilization of renewable energy. efficient system with minimized harmonics. The comparative analysis confirms that the H-Bridge converter with FLC outperforms other configurations in terms of harmonic suppression, voltage regulation, and overall system efficiency. The findings validate that the combination of an optimized converter topology and intelligent control techniques significantly enhances the reliability of renewable energy-based DG systems. The proposed system effectively mitigates power quality problems such current distortions and voltage swings, guaranteeing a more steady incorporation of renewable energy sources into the electrical system. Future research can explore hybrid control strategies, adaptive tuning techniques, and real-time hardware implementation to further optimize the system's performance. Overall, this study provides a robust framework for improving power quality in modern DG systems, promoting the sustainable and efficient utilization of renewable energy.

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