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ANFIS-Based Asymmetric Selective Harmonic Current Mitigation in Active Power Filters Using Enhanced PWM Techniques

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ABSTRACT

The growing use of power electronic equipment, driven by increasing energy demand, has intensified issues related to harmonic distortion and poor power quality in electrical systems. Active Power Filters (APFs) have proven effective in mitigating such distortions, and this study introduces an advanced approach using Adaptive Neuro-Fuzzy Inference Systems (ANFIS) to enhance Pulse Width Modulation (PWM) control within APFs. The proposed ANFIS-based method efficiently handles asymmetric selective harmonic current mitigation by combining the adaptive learning capability of neural networks with the decision-making flexibility of fuzzy logic. The developed model is implemented in MATLAB to evaluate its performance. Simulation results demonstrate that the proposed ANFIS-based technique significantly improves power quality by reducing total harmonic distortion (THD) from 3.59% to 0.15%. Furthermore, the system achieves voltage outputs of 300 V at a 5-level inverter and 500 V at a 7-level inverter, with corresponding current values of 6 A and 10 A, respectively. Compared with conventional Artificial Neural Network (ANN)-based approaches, the proposed method achieves superior accuracy, stability, and harmonic suppression. These findings highlight ANFIS as a reliable and intelligent control solution for advanced power electronic applications, promoting improved efficiency and system dependability in modern power networks.

KEYWORDS: *ANFIS, ANN, Fuzzy, Asymmetric, Harmonic, PWM, Active, Power Filters, APFs.*

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I. INTRODUCTION

The rise of nonlinear loads in modern power systems has heightened concerns about harmonic distortions. Harmonics, which are multiples of the fundamental frequency, can lead to serious problems such as equipment overheating, increased energy losses, and the malfunctioning of sensitive devices. Consequently, effective harmonic mitigation has become essential for maintaining power quality. Active Power Filters (APFs) have proven to be a reliable solution, actively compensating for harmonic currents and improving the overall power supply quality. Among the various strategies for harmonic mitigation, Pulse Width Modulation (PWM) techniques have been particularly successful. PWM adjusts the width of pulses in switching signals to control voltage and current waveforms, ultimately managing the power delivered to the load. Asymmetric selective harmonic mitigation PWM stands out as an effective method due to its ability to target specific harmonic components, offering a tailored solution for harmonic reduction.

The development of multi-level inverters has also transformed power electronics. These inverters generate multiple voltage levels, helping to reduce total harmonic distortion (THD) in output waveforms. The 7-level inverter, in particular, strikes an ideal balance between performance and complexity, making it a preferred option for high-performance APFs. Despite these advancements in inverter technology and PWM strategies, achieving optimal harmonic mitigation remains challenging. This is where intelligent control systems like Adaptive Neuro-Fuzzy Inference Systems (ANFIS) become valuable. ANFIS merges neural networks' learning capabilities with fuzzy logic's reasoning, creating a robust framework for complex control tasks. Its adaptability allows it to manage the nonlinearities and uncertainties in power systems, making it well-suited for controlling APFs.

This paper explores the application of ANFIS for asymmetric selective harmonic current mitigation in 7-level inverters used in APFs. The main goal is to harness ANFIS's adaptive and intelligent control capabilities to enhance APF performance. The proposed approach involves designing an ANFIS-based controller that can dynamically adjust the 7-level inverter's switching signals, specifically targeting harmonic components for mitigation.

The subsequent sections provide an in-depth exploration of the theoretical background, system design, and implementation of the proposed method. The theoretical background discusses the basics of harmonic distortions, PWM techniques, and multi-level inverters. The system design section outlines the structure and operation of the 7-level inverter and explains how ANFIS is integrated into the control loop. Implementation details include the simulation setup, parameter optimization, and performance evaluation.

Simulation results confirm the effectiveness of the ANFIS-based controller in reducing harmonic distortions, showing significant improvements in power quality metrics compared to traditional methods. Moreover, a comparative analysis with other control techniques demonstrates ANFIS's advantages in adaptability, precision, and computational efficiency. The integration of ANFIS for asymmetric selective harmonic current mitigation in 7-level inverters offers a promising solution for improving APF performance. This approach not only enhances power quality but also lays the groundwork for future research in intelligent control systems for power electronics.

II. PROPOSED METHODOLOGY

The flow chart is explained followings-

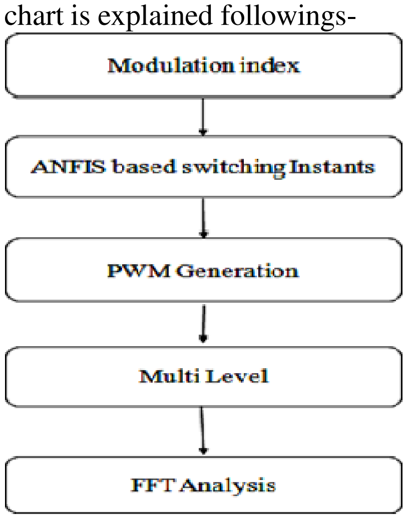

Figure 1: Flow chart

The proposed methodology for asymmetric selective harmonic current mitigation using ANFIS in a 7-level inverter integrated into Active Power Filters (APFs) follows the flowchart shown in the image. The key steps in this methodology are outlined below:

1. Modulation Index Calculation

The process begins with the determination of the modulation index, which is a critical parameter in PWM control. The modulation index, defined as the ratio of the reference signal amplitude to the carrier signal amplitude, directly influences the inverter's output voltage and the harmonic content. The appropriate modulation index is calculated based on the desired output voltage and the specific requirements for harmonic mitigation.

2. ANFIS-Based Switching Instants

Once the modulation index is determined, it is used as an input to the Adaptive Neuro-Fuzzy Inference System (ANFIS). The ANFIS model is trained to generate precise switching instants for the inverter's power switches. This involves the following sub-steps:

- **Training Data Collection:** Data on switching instants corresponding to various modulation indices and harmonic profiles is collected through simulations or experimental setups.
- **ANFIS Model Training:** The collected data is used to train the ANFIS model. The training process involves adjusting the membership functions and rule base to minimize the error between the predicted and actual switching instants.
- **Switching Instant Prediction:** After training, the ANFIS model can accurately predict the switching instants required for the given modulation index to achieve optimal harmonic mitigation.

3. PWM Generation

The predicted switching instants from the ANFIS model are then used to generate the PWM signals. This involves the following steps:

- **Carrier Signal Generation:** A high-frequency triangular or sawtooth carrier signal is generated.
- **Comparison with Reference Signal:** The predicted switching instants determine the points at which the reference signal crosses the carrier signal. This comparison produces the PWM signal, which dictates the on-off states of the power switches in the inverter.

4. Multi-Level Inverter Operation

The generated PWM signals are fed to the 7-level inverter. The 7-level inverter uses these signals to control the power switches, producing a multi-level output voltage waveform. The multi-level structure helps in reducing the harmonic content in the output by approximating a sinusoidal waveform more closely compared to conventional two-level inverters.

5. FFT Analysis

The final step involves the analysis of the inverter's output using Fast Fourier Transform (FFT) to evaluate the harmonic content. This step includes:

- **Harmonic Analysis:** The FFT is performed on the output voltage waveform to decompose it into its harmonic components.
- **Total Harmonic Distortion (THD) Calculation:** The THD, which is a measure of the overall harmonic distortion in the waveform, is calculated from the FFT results.
- **Performance Evaluation:** The effectiveness of the ANFIS-based control in reducing specific harmonic components and the overall THD is assessed. The results are compared with those obtained from conventional PWM strategies to demonstrate the advantages of the proposed methodology.

By following this structured approach, the proposed methodology aims to achieve efficient and precise harmonic mitigation in APFs, leveraging the adaptive and intelligent control capabilities of ANFIS combined with the benefits of multi-level inverter technology.

III. SIMULATION RESULTS

The simulation is performed using the MATLAB software-

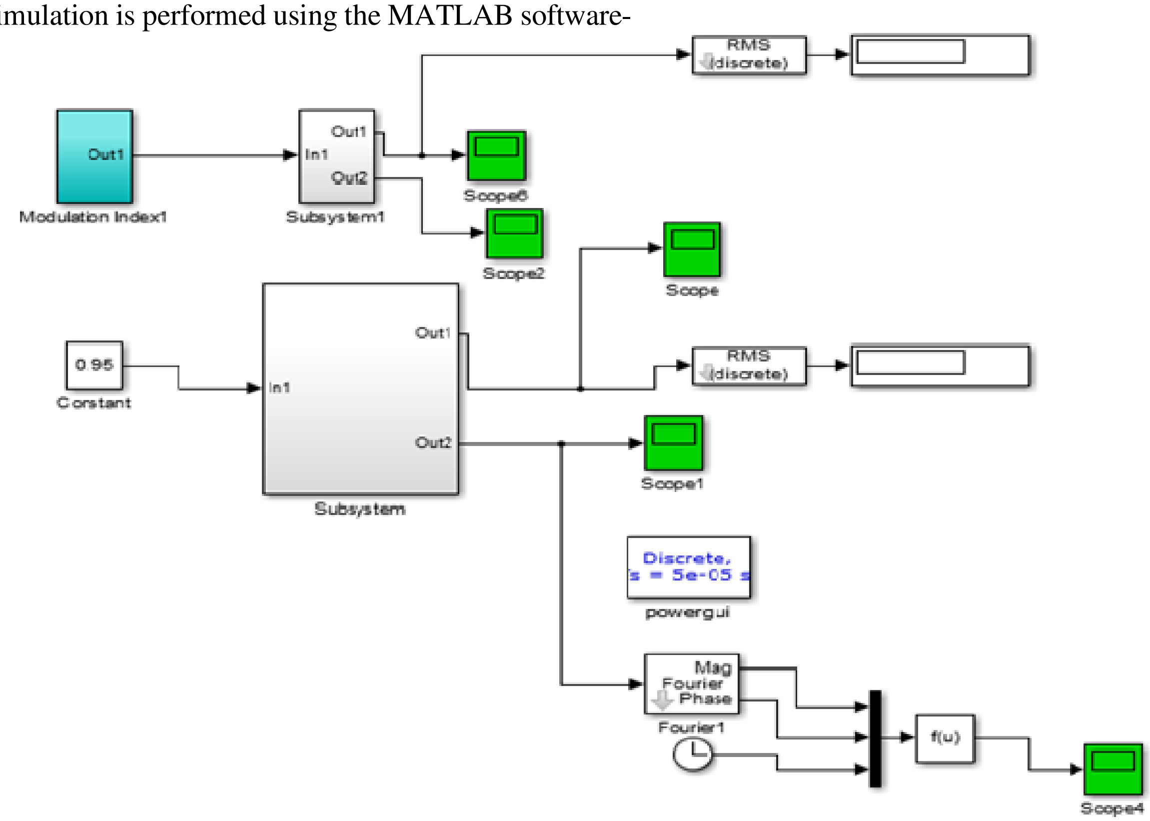

Figure 2: Proposed Model

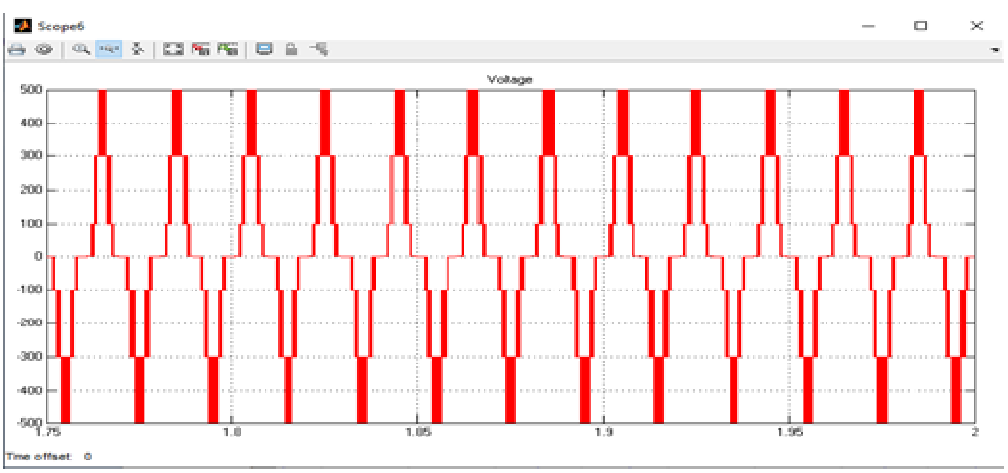

Figure 3: Output Voltage

Figure 3 shows the output waveform. A 7-level multi-level inverter in an Active Power Filter (APF) is designed to generate an output voltage with multiple discrete voltage levels.

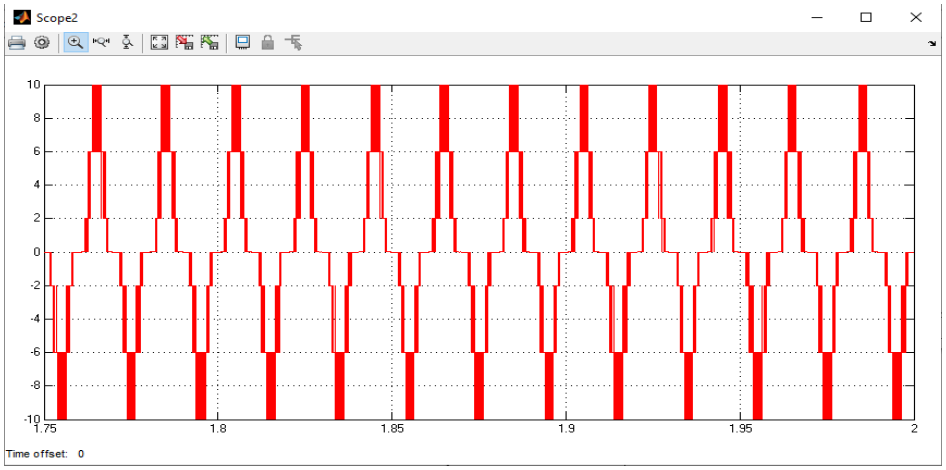

Figure 4: Output Current

Figure 4 is showing the output current. The output current of a 7-level multi-level inverter in an Active Power Filter (APF) is a crucial parameter, especially when considering its role in mitigating harmonics and improving the power quality of an electrical system.

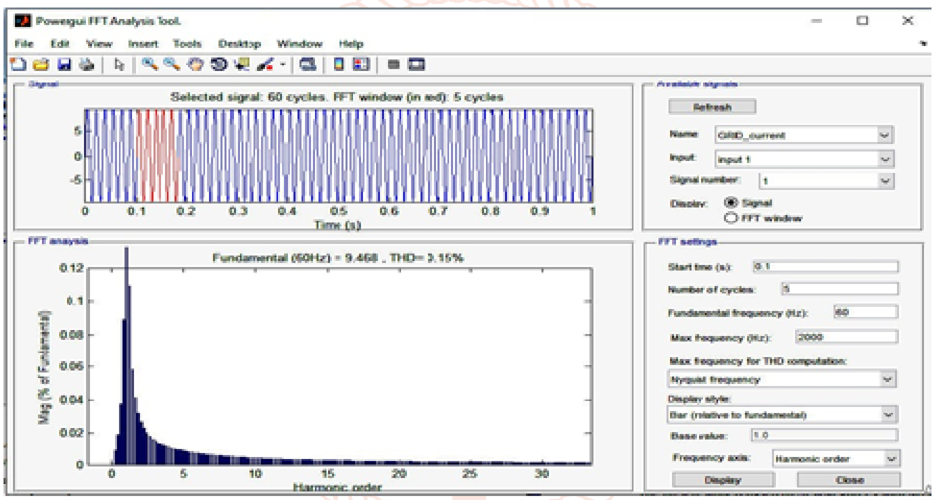

Figure 5: Total Harmonic Distortion (THD)

Figure 5 present Total Harmonic Distortion (THD) which is a measure of the harmonic content present in a signal compared to its fundamental frequency.

Table 1: Result Comparison

Sr. No.	Parameters	Previous Work	Present Work
1	Technique	ANN	ANFIS
2	Voltage	200V	500V
3	Current	Not Mentioned	10A
4	THD	3.59%	0.15%

IV. CONCLUSION

This study demonstrates the effectiveness of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) for enhancing Pulse Width Modulation (PWM) in Active Power Filters (APFs) aimed at mitigating asymmetric harmonic distortions. By integrating neural network learning with fuzzy logic reasoning, the proposed system achieves adaptive, precise, and efficient control of harmonic currents, significantly improving overall power quality.

Simulation analysis conducted in MATLAB validates the performance of the proposed model. The ANFIS-based control strategy achieves a remarkable reduction in total harmonic distortion from 3.59% to 0.15%, along with output voltages of 300 V and 500 V at 5-level and 7-level configurations, respectively. The associated current values of 6 A and 10 A further confirm the improved efficiency and stability of the system.

Compared to traditional Artificial Neural Network-based methods, the proposed ANFIS approach delivers faster convergence, enhanced adaptability, and superior harmonic mitigation performance. The results establish ANFIS as a promising control strategy for modern power systems, ensuring high reliability, improved power factor, and minimal harmonic interference.

Future research can explore the integration of real-time hardware-in-the-loop (HIL) testing, renewable energy sources, and advanced optimization algorithms to further strengthen the robustness and scalability of ANFIS-controlled APFs in diverse industrial and grid-connected applications.

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