

# Harmonic Reduction in Microgrid Using APF with Fuzzy Controller

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**Abstract:-** This study proposes a method to minimize harmonic distortion in microgrids by using an Active Power Filter (APF) governed by a fuzzy logic controller. The integration of renewable energy sources and nonlinear loads introduces significant power quality challenges, especially harmonics. To overcome these issues, a fuzzy-based control technique is applied to improve the APF performance. The controller adapts effectively to changing system conditions and load variations. It generates appropriate compensating signals to suppress harmonic currents and enhance voltage and current waveforms. The approach aims to keep Total Harmonic Distortion (THD) within recommended limits.

The results indicate improved system performance and stability. The proposed solution contributes to efficient and reliable microgrid operation.

**Keywords:** - APF, Fuzzy controller, THD, etc.

## 1. Introduction

Microgrids are increasingly recognized as an effective framework for integrating distributed energy resources such as solar and wind into electrical power systems [1]. They enhance system dependability, operational flexibility, and environmental sustainability by functioning in both interconnected and isolated modes [2]. Despite these advantages, the widespread use of power electronic converters and nonlinear loads introduces power quality concerns, especially harmonic distortion [3]. These harmonics can lead to overheating, additional losses, and improper operation of sensitive devices [4]. Active Power Filters (APFs) have become a preferred solution for harmonic mitigation due to their ability to provide dynamic and precise compensation [5]. Unlike passive filtering methods, APFs can effectively respond to varying system conditions and suppress unwanted harmonics [6]. However, their performance is strongly influenced by the design of the control algorithm [7]. Conventional proportional–integral (PI) controllers often face challenges in handling nonlinearities and rapid load changes [8]. To overcome these limitations, intelligent control approaches such as fuzzy logic controllers (FLCs) have been widely explored [9]. FLCs are advantageous because they do not rely on exact mathematical models and are capable of managing system uncertainties and nonlinear behavior [10]. They offer improved dynamic response and robustness compared to traditional controllers [11]. The combination of fuzzy logic control with APFs significantly enhances harmonic compensation in microgrid systems [12]. This method effectively reduces Total Harmonic Distortion (THD) and improves the quality of voltage and current waveforms under different operating conditions [13]. Additionally, it provides better adaptability to fluctuations in renewable energy generation and load demand [14]. This work investigates the use of a fuzzy logic-based APF for mitigating harmonics in microgrids. The proposed approach aims to achieve superior power quality and ensure stable and efficient operation of the microgrid under dynamic conditions [15].

## 2. Objectives

The objective of this work is to develop a fuzzy logic controller (FLC)-based Active Power Filter (APF) for effective harmonic mitigation in microgrid systems. The proposed approach aims to reduce Total Harmonic Distortion (THD) and enhance voltage and current waveform quality under varying operating conditions. It also

seeks to improve the dynamic response and robustness of the APF compared to conventional control methods. Furthermore, the system is designed to ensure stable, reliable, and efficient microgrid operation in the presence of renewable energy fluctuations and nonlinear loads.

## II. System Description

The proposed system aims to mitigate harmonic distortion in a microgrid using a shunt Active Power Filter (APF) controlled by a Fuzzy Logic Controller (FLC). The overall configuration consists of distributed generation sources, nonlinear loads, a point of common coupling (PCC), and the APF unit.

A microgrid integrates renewable energy sources such as solar photovoltaic and wind energy through power electronic interfaces. Although these sources improve sustainability, they introduce harmonics due to switching operations and nonlinear characteristics. Additionally, nonlinear loads such as rectifiers and adjustable speed drives can further reduce power quality by introducing harmonic currents into the electrical system.

To overcome these challenges, a shunt APF is placed parallel to the nonlinear load at the PCC. The APF works by generating compensation currents that suppress the harmonic content in the load current. This process helps the source current maintain an almost sinusoidal shape, which significantly enhances power quality.

### A. System Configuration

The microgrid system consists of distributed energy resources, a nonlinear load, and a shunt APF interconnected at the PCC. The APF primarily contains a Voltage Source Inverter (VSI), a DC-link capacitor, and a fuzzy logic-based control system. The VSI produces the compensating currents needed for harmonic mitigation, whereas the DC-link capacitor helps maintain a stable voltage for effective inverter performance. The control system analyzes system parameters and produces the switching pulses required to operate the inverter.

### B. Operating Principle of APF

The APF functions by continuously sensing the load current and identifying its harmonic components. A reference compensating current is then determined using an appropriate control approach, such as instantaneous power (p-q) theory or synchronous reference frame (SRF) theory.

The APF generates a compensating current that has the same magnitude but an opposite phase to the harmonic component present in the load current. By injecting this current into the system, harmonic distortion is effectively neutralized, allowing the supply current to remain nearly sinusoidal and aligned in phase with the supply voltage.

### C. Fuzzy Logic Controller

The fuzzy logic controller significantly improves the performance of the APF by removing the requirement for an exact mathematical model and by efficiently managing nonlinearities and uncertainties within the system.

The FLC uses the error and the variation in error between the reference current and the actual current as its input variables. Using these inputs, the controller evaluates a predefined set of linguistic rules to produce an appropriate control response.

The fuzzy control process mainly involves three steps: fuzzification, rule processing, and defuzzification. The resulting output is then applied to the PWM generator to create switching signals that regulate the operation of the VSI.

### D. Pulse Width Modulation Technique

The Pulse Width Modulation (PWM) method is employed to generate gating signals for the inverter switches. In this process, the control signal from the fuzzy controller is compared with a high-frequency carrier waveform to create the required switching pulses.

This method ensures accurate tracking of the reference current and reduces switching losses, thereby improving system efficiency.

### E. DC-Link Voltage Control

The DC-link capacitor voltage is regulated at a constant value to guarantee reliable operation of the VSI. A dedicated voltage control loop is used to stabilize the capacitor voltage by compensating for system losses and preserving the overall energy balance.

### F. Harmonic Compensation Mechanism

The harmonic compensation process involves several steps. First, the distorted load current is measured and analyzed to extract harmonic components. Next, a reference compensating current is generated. The fuzzy logic controller processes the error signals and produces appropriate control actions. Finally, the VSI injects the compensating current into the system.

As a result, harmonic distortion is significantly reduced, and the source current attains a nearly sinusoidal waveform with lower Total Harmonic Distortion (THD).

### G. Modes of Operation

The proposed system is capable of functioning in both grid-connected and islanded operating modes. During grid-connected operation, the APF improves power quality at the PCC while remaining synchronized with the utility grid. Under islanded conditions, the microgrid operates independently, and the APF maintains stable voltage and current performance.

### H. Advantages of Proposed System

The proposed fuzzy logic-controlled APF offers several advantages, including improved harmonic compensation, fast dynamic response, robustness against parameter variations, and reduced THD. It also enhances system reliability and efficiency without requiring an exact mathematical model.

## III. Control Mechanism

The linear control method used in an active power filter (APF) relies on a closed-loop negative feedback system, as illustrated in Figure 1. In this technique, the actual compensating current  $i_f$  is continuously measured and compared with the reference current  $i_{ref}$ . The difference between these currents produces an error signal, which is then processed by an error amplifier to obtain a suitable control signal.

The generated control signal is fed into a pulse width modulation (PWM) block, where it is compared with a high-frequency triangular or sawtooth carrier waveform. This comparison produces switching pulses that drive the power electronic switches of the APF. In linear control approaches, the switching frequency is determined by the carrier waveform and remains constant throughout operation.

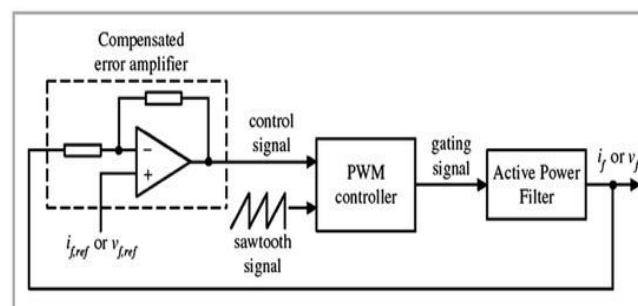


Fig 1: Linear control technique diagram

As depicted in Figure 2, the switching signal is turned ON when the control signal exceeds the carrier waveform and turned OFF when the carrier waveform becomes greater than the control signal. This modulation technique ensures accurate switching operation and effective tracking of the reference current. The errors are controlled as below,

$$e(t) = V_{dc,ref} - V_{dc}(t)$$

$$u(t) = K_p e(t) + K_i \int e(t) dt$$

The use of a constant switching frequency in linear control enhances system predictability, ensures stable operation, and improves harmonic compensation performance, thereby minimizing distortion in the supply current.

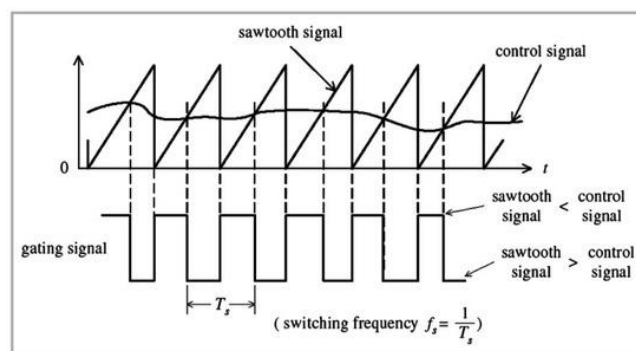


Fig.2 : Gating signal generation by linear controller

#### IV. Test System and Result Analysis

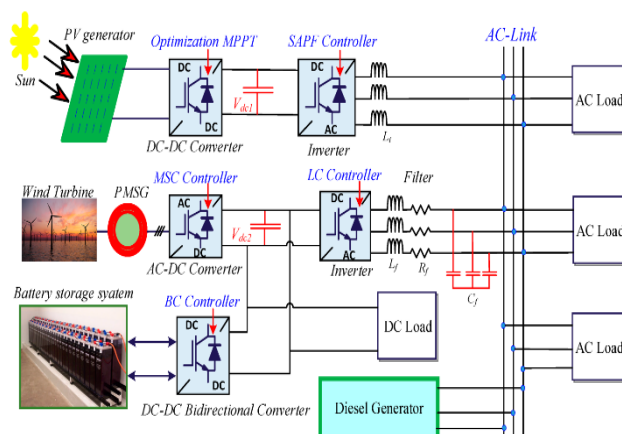
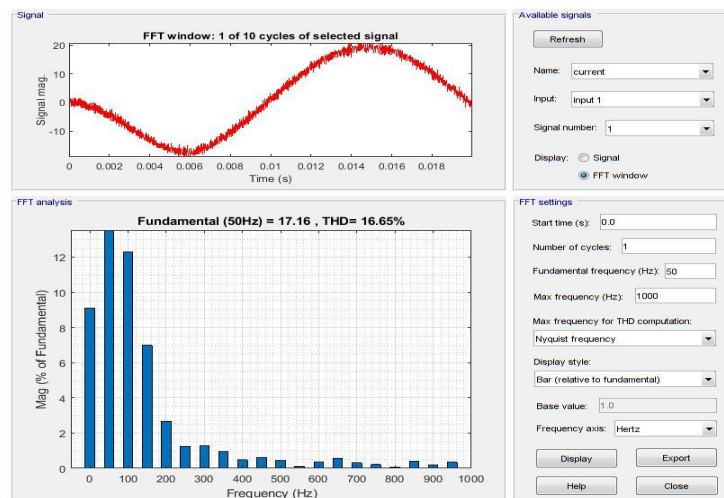


Fig.3 : Test system

The simulation analysis is performed under normal operating conditions to assess the effectiveness of the proposed system. A three-phase supply of 415 V with a frequency of 50 Hz is used as the input source. To create harmonic distortion, the nonlinear load is represented by a diode rectifier connected to an RL load. The converter switching devices operate at a switching frequency of 10 kHz, enabling efficient control and minimizing ripple effects.

A DC-link voltage of 700 V is maintained to ensure stable operation of the active power filter. Furthermore, the filter inductance is chosen within the range of 2–5 mH to provide effective current smoothing and improved harmonic compensation.



**Fig. 4 : FFT analysis without APF and Fuzzy**

The effectiveness of the proposed microgrid system is examined through comprehensive simulation and harmonic analysis under various operating conditions. System performance is evaluated based on waveform characteristics, harmonic distortion, and Total Harmonic Distortion (THD).

Initially, the system operates without any compensation, and the source current waveform exhibits significant distortion because of the nonlinear loads connected to the network. FFT analysis of this condition indicates a THD value of nearly 16.6%, reflecting poor power quality performance.

To enhance the system behavior, a conventional Active Power Filter (APF) is introduced. With the APF in operation, the harmonic components in the source current are noticeably reduced, resulting in a cleaner and more stable waveform. The corresponding FFT results show that the THD decreases to approximately 10%. Although this represents a considerable improvement in harmonic suppression, the distortion level is still higher than the recommended standard limits.

Further improvement is obtained by integrating a fuzzy logic controller with the APF system. The fuzzy-based APF offers superior adaptability and faster dynamic response under changing load conditions. Consequently, the source current waveform becomes almost sinusoidal with very low distortion. FFT analysis verifies that the THD is reduced to nearly 4%, demonstrating a significant enhancement in power quality.

A comparative study of the harmonic spectra shows that lower-order harmonics are effectively minimized using the proposed approach. The noticeable reduction in harmonic amplitudes across various orders confirms the efficiency of the fuzzy logic control technique. Moreover, the obtained THD values are evaluated against the limits defined in IEEE 519 standards. The analysis indicates that the THD achieved with the fuzzy-controlled APF remains within the acceptable limit of 5%, thereby satisfying standard power quality requirements.

Overall, the simulation outcomes confirm that the proposed system successfully mitigates harmonic distortion and improves power quality in microgrid applications. Compared with the conventional APF method, the fuzzy logic-based APF demonstrates better performance, making it a dependable and effective solution for modern electrical power systems.

## V. Conclusion

The proposed fuzzy logic-based Active Power Filter successfully minimizes harmonic distortion in the microgrid system. Simulation outcomes demonstrate that the Total Harmonic Distortion (THD) is reduced from 16.6% to nearly 4%, thereby meeting the limits specified in IEEE 519 standards. In addition, the proposed approach enhances waveform quality, improves system stability, and delivers better overall power performance under nonlinear load conditions.

For future developments, the proposed technique can be implemented in real-time hardware environments and evaluated under varying renewable energy operating conditions. The use of advanced intelligent control methods, such as adaptive or hybrid control strategies, may provide further performance improvements. Moreover, integration with smart grid technologies and optimization approaches can be investigated to achieve greater system efficiency and reliability.

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