



e-ISSN: 2278-8875

p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 15, Issue 1, January 2026

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.807

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✉ ijareeie@gmail.com

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Review Paper Reduction of Harmonic Distortion in Microgrid using Artificial Neural Network (ANN) And Shunt Active Power Filter (SAPF) Techniques

Snehal Dadasaheb Gaikwad, Dr. P. V. Paratwar

Department of Electrical Engineering, Dattakala College of Engineering, Savitribai Phule Pune University (SPPU),
Pune, India

ABSTRACT: The increasing penetration of nonlinear loads and renewable energy sources in microgrids has led to significant power quality issues, particularly harmonic distortion in voltage and current waveforms. These harmonics result in equipment overheating, increased power losses, malfunction of sensitive devices, and non-compliance with power quality standards such as IEEE-519. Conventional harmonic mitigation techniques, including passive filters and traditional controllers for Shunt Active Power Filters (SAPFs), suffer from limited adaptability under dynamic operating conditions. This project presents an intelligent harmonic mitigation approach using an Artificial Neural Network (ANN)-based controlled Shunt Active Power Filter for microgrid applications. The proposed system employs an ANN controller to generate accurate compensating current references in real time, enabling effective suppression of harmonics under varying nonlinear load and renewable energy conditions. The ANN enhances the dynamic response and robustness of the SAPF compared to conventional controllers such as PI or proportional-resonant controllers. The microgrid system, including nonlinear loads and SAPF with ANN control, is modeled and simulated using MATLAB/Simulink. Performance evaluation is carried out in terms of Total Harmonic Distortion (THD), transient response, and waveform quality. Simulation results demonstrate a significant reduction in current and voltage THD to within IEEE-519 permissible limits, thereby improving overall power quality and system reliability. The proposed ANN-SAPF approach proves to be an effective and adaptive solution for harmonic distortion reduction in modern microgrid systems.

KEYWORDS: Microgrid, Harmonic Distortion, Shunt Active Power Filter (SAPF), Artificial Neural Network (ANN), Power Quality, Total Harmonic Distortion (THD), Nonlinear Loads, IEEE-519 Standards.

I. INTRODUCTION

Background: The modern electrical power system is undergoing a major transformation due to the increasing integration of distributed energy resources (DERs) such as solar photovoltaic systems, wind energy conversion systems, and battery energy storage. Microgrids have emerged as an effective solution to integrate these renewable sources while improving reliability, flexibility, and energy efficiency. A microgrid is a localized group of interconnected loads and distributed generation sources that can operate in both grid-connected and islanded modes. While microgrids offer several advantages, they also introduce significant power quality challenges, among which harmonic distortion is one of the most critical.

Harmonic Distortion in Microgrids: Harmonic distortion arises primarily due to the extensive use of nonlinear loads and power electronic converters in microgrids. Devices such as inverters, rectifiers, variable frequency drives, switched-mode power supplies, and electric vehicle chargers draw non-sinusoidal currents from the supply, resulting in distorted voltage and current waveforms. Harmonics are frequency components that are integer multiples of the fundamental frequency and can propagate throughout the microgrid, adversely affecting both generation and load-side equipment. Excessive harmonic distortion leads to several operational problems including overheating of transformers and motors, increased losses in conductors, malfunction of protection devices, interference with communication systems, and reduced lifespan of electrical equipment. Additionally, high levels of Total Harmonic Distortion (THD) can cause resonance conditions and voltage instability, which may compromise the overall reliability of the microgrid. To ensure acceptable power quality, standards such as IEEE-519 specify permissible limits for harmonic distortion in power systems.



Conventional Harmonic Mitigation Techniques: Traditional harmonic mitigation methods include passive filters and conventional control strategies for active filters. Passive filters, although simple and cost-effective, suffer from drawbacks such as fixed compensation characteristics, large size, tuning issues, and potential resonance with the grid impedance. Shunt Active Power Filters (SAPFs) have been widely adopted as an effective alternative due to their ability to dynamically inject compensating currents and suppress harmonics in real time. However, the performance of SAPFs heavily depends on the control strategy used for reference current generation and inverter switching. Conventional controllers such as Proportional-Integral (PI), hysteresis, and proportional-resonant (PR) controllers perform adequately under steady-state conditions but exhibit limitations under rapidly changing load conditions and system uncertainties. These controllers require precise mathematical models and parameter tuning, making them less effective in highly nonlinear and dynamic microgrid environments.

Intelligent Control Using Artificial Neural Networks: Artificial Neural Networks (ANNs) have gained significant attention in power system applications due to their ability to learn complex nonlinear relationships, adapt to changing system conditions, and provide fast and accurate control responses. Unlike conventional controllers, ANN-based controllers do not require an exact mathematical model of the system and can be trained using input-output data to predict optimal control actions. In the context of harmonic mitigation, ANN controllers can be employed to generate accurate compensating current references for SAPFs by learning harmonic patterns under various load conditions. This intelligent control approach enhances the adaptability, robustness, and dynamic performance of SAPFs, enabling effective harmonic suppression even under fluctuating renewable energy generation and nonlinear load variations.

Motivation and Contribution of the Present Work: Motivated by the limitations of conventional harmonic mitigation techniques, this project focuses on the integration of an ANN-based controller with a Shunt Active Power Filter for reducing harmonic distortion in microgrids. The proposed approach aims to achieve superior THD reduction, faster transient response, and improved power quality compliance compared to traditional control methods. The main contribution of this work lies in the development and simulation of an intelligent ANN-SAPF system capable of adaptive harmonic compensation under dynamic microgrid operating conditions. The effectiveness of the proposed method is validated through simulation studies using MATLAB/Simulink, demonstrating significant improvement in power quality and compliance with IEEE-519 standards.

II. LITERATURE SURVEY

1) Adaptive Artificial Neural Network Control for SAPF

Title: Adaptive artificial neural network based control strategy for shunt active power filter

Source: IEEE Conference Publication (2025)

Summary: Proposes an adaptive ANN controller for SAPF reference current generation to improve harmonics mitigation and dynamic response compared to fixed control strategies. Demonstrated enhanced compensation under varying nonlinear loading conditions.

2) Neural Networks based Shunt Hybrid Active Power Filter (ANN & ANFIS)

Title: Neural Networks based Shunt Hybrid Active Power Filter for Harmonic Elimination

Authors: Iqbal et al., IEEE Access

Summary: Compares multiple neural architectures (ANN, ANFIS, RNN) for reference estimation and DC-link control in hybrid APFs, with RNN showing best performance in THD reduction and stability.

3) ANN-SOGI Based SAPF for Harmonics

Title: ANN-SOGI-based Shunt Active Power Filter for Harmonic Mitigation

Published: International Journal of Electrical and Electronics Research (2023)

Summary: Integrates ANN with a Second Order Generalized Integrator to generate reference currents for SAPF under PV integration, improving harmonic suppression and offering fast dynamic tracking.

4) Simulation & Real Implementation of SAPF with ANN

Title: Simulation and real time implementation of shunt active power filter using adaptive neural network topology

Published in: Electric Power Systems Research (2024)

Summary: Combines IRP theory with ANN (ADALINE) to extract fundamental waveform components and control SAPF switching. Includes hardware validation showing improved THD under nonlinear loads.



5) IEEE 3rd Int. Conf. SAPF using Instantaneous PQ

Title: Implementation of Instantaneous PQ Theory to Improve Power Quality by Shunt Active Power Filter for Non-Linear Loads

Conference: IEEE 3rd Int. Conf. on Electrical Power and Energy Systems (ICEPES) (2024)

Summary: Uses instantaneous active/reactive power (PQ) theory to extract harmonic components for SAPF control, demonstrating effective THD mitigation that complements ANN approaches.

6) Microgrid Challenges Review Including Control Methods

Title: A comprehensive review of microgrid challenges...control strategies

Journal: Journal of Electrical Systems and Information Technology (2024)

Summary: Reviews a wide range of microgrid control techniques including conventional, advanced and intelligent approaches (e.g., neural networks) and identifies gaps in adaptive harmonic mitigation.

7) AI & Optimization Techniques for Power Quality

Title: AI-Driven Optimization Techniques for Power Quality Improvement

Source: Engineering in Sustainable Energy Systems (2025)

Summary: Surveys modern AI methods (including ANN) applied to active filter parameter tuning and harmonic prediction, emphasizing adaptive and machine-learning strategies for real-time systems.

8) Deep Learning-Based Harmonic Compensation in SAPF

Title: Deep Learning-Based Dynamic Harmonic Compensation in Three-Phase Systems Using DNN-Controlled Shunt Active Power Filter

Publication: ResearchGate (Nov 2025)

Summary: Extends ANN control to deep-network architectures (DNN) for dynamic, real-time harmonic compensation with improved tracking and robustness over traditional ANN approaches.

9) Hybrid Control Method for MG Power Quality

Title: A hybrid control approach to improve power quality in microgrid systems

Journal: Hybrid Intelligent Systems (2025)

Summary: Combines several intelligent control layers (adaptive + harmonic damping) for microgrid voltage and harmonic compensation; complements ANN-based SAPF control.

10) Optimization of SAPF Design for Harmonic & Reactive Power

Title: An optimized shunt active power filter using the golden Jackal optimizer for power quality improvement

Journal: Scientific Reports (2025)

Summary: Applies AI optimization (Golden Jackal optimizer) to SAPF control parameters and design for combined harmonic and reactive power mitigation, achieving significant THD reduction under dynamic loads.

III. PROPOSED SYSTEM

The proposed system aims to reduce harmonic distortion in a microgrid by integrating an Artificial Neural Network (ANN)-based controller with a Shunt Active Power Filter (SAPF). The microgrid consists of distributed generation sources, nonlinear loads, and a three-phase distribution network. Due to the presence of power electronic converters and nonlinear loads, the system experiences significant harmonic distortion in current and voltage waveforms. The proposed ANN-SAPF system actively compensates for these harmonics to improve overall power quality.

Architecture of the Proposed System

The proposed system comprises the following main components:

1. Microgrid with nonlinear loads
2. Shunt Active Power Filter (SAPF)
3. Voltage Source Inverter (VSI)
4. DC-link capacitor
5. ANN-based control unit
6. Current and voltage sensing units



The SAPF is connected in parallel with the nonlinear load at the point of common coupling (PCC). It injects compensating currents that are equal in magnitude and opposite in phase to the harmonic currents generated by the load, thereby ensuring that the source currents remain nearly sinusoidal.

ANN-Based Control Strategy

The ANN controller is the core of the proposed system. It is designed to generate accurate reference compensating currents for the SAPF in real time. The ANN is trained using input data such as load current, source current, and voltage signals to learn the nonlinear relationship between harmonic components and required compensation currents.

Unlike conventional PI or PR controllers, the ANN controller does not rely on precise mathematical modeling of the system. It adapts dynamically to changes in load conditions and renewable energy fluctuations, providing faster response and improved harmonic suppression. The trained ANN outputs reference currents that guide the switching of the VSI in the SAPF.

Shunt Active Power Filter Operation

The SAPF operates by sensing the distorted load currents and generating compensating currents through the VSI. A suitable modulation technique, such as Pulse Width Modulation (PWM), is used to control the inverter switches. The DC-link capacitor maintains a constant DC voltage, which is regulated by the ANN controller to ensure proper operation of the SAPF.

By injecting compensating currents at the PCC, the SAPF cancels harmonic and reactive current components, forcing the source currents to become sinusoidal and in phase with the source voltage. This results in reduced Total Harmonic Distortion (THD) and improved power factor.

Advantages of the Proposed System

The proposed ANN-based SAPF system offers several advantages:

- Adaptive harmonic compensation under dynamic load conditions
- Improved THD reduction compared to conventional controllers
- Faster transient response and enhanced system stability
- Robust performance without requiring an exact mathematical model
- Compliance with IEEE-519 power quality standards

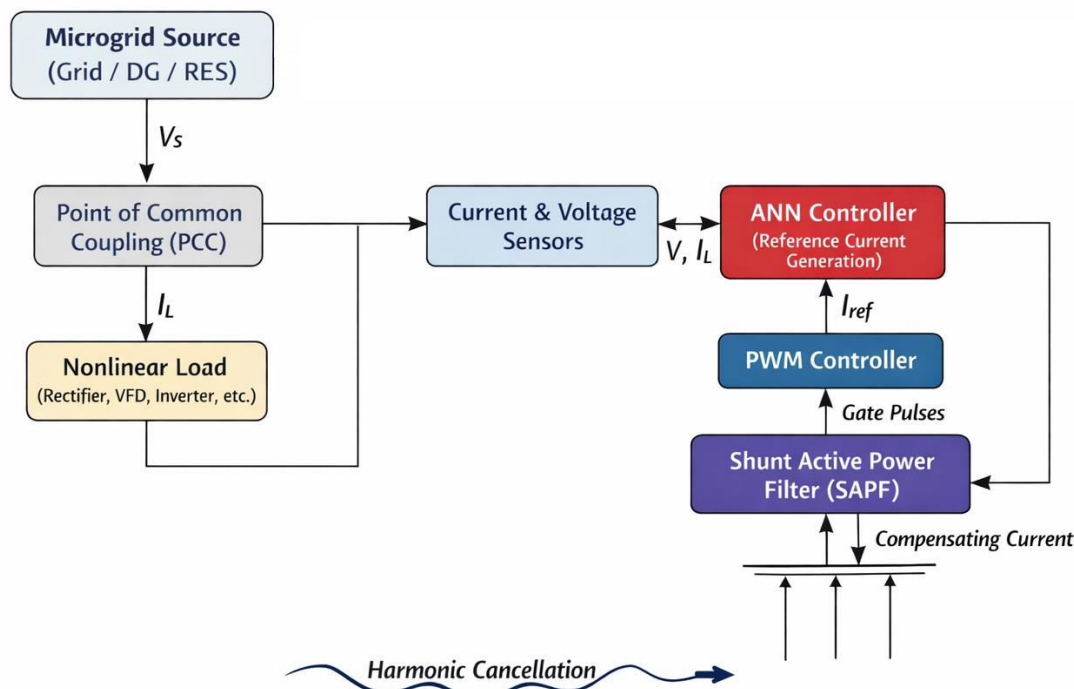


Fig.1. Proposed System



Description

1. Microgrid Source: The microgrid source consists of the utility grid and/or distributed energy resources such as solar PV, wind systems, and battery storage. It supplies power to both linear and nonlinear loads connected at the Point of Common Coupling (PCC).

2. Nonlinear Load: Nonlinear loads such as rectifiers, inverters, variable frequency drives, and power electronic converters draw non-sinusoidal current from the source. These loads are the primary cause of harmonic distortion in the microgrid.

3. Point of Common Coupling (PCC) : The PCC is the connection point where the source, nonlinear load, and Shunt Active Power Filter are interconnected. Harmonic compensation is performed at this point to ensure sinusoidal source current.

4. Current and Voltage Sensors: Sensors continuously measure source current, load current, and voltage signals. These measured signals are provided as inputs to the ANN controller for harmonic detection and compensation.

5. ANN Controller: The Artificial Neural Network acts as an intelligent controller that:

- Learns nonlinear relationships between distorted load currents and required compensating currents
- Generates accurate reference compensating currents in real time
- Adapts dynamically to changing load and operating conditions

Unlike conventional controllers, ANN does not require an exact mathematical model.

6. PWM Controller: The Pulse Width Modulation (PWM) controller converts the ANN-generated reference signals into appropriate gate pulses for the Voltage Source Inverter.

7. Voltage Source Inverter (VSI): The VSI is the power electronic interface of the SAPF. It generates compensating currents based on the PWM gate pulses and draws energy from the DC-link capacitor.

8. Shunt Active Power Filter (SAPF): The SAPF injects compensating currents equal in magnitude and opposite in phase to the harmonic currents produced by the nonlinear load. This results in:

- Cancellation of harmonics
- Sinusoidal source current
- Improved power factor
- Reduced Total Harmonic Distortion (THD)

Outcome of the Proposed System

- Effective harmonic mitigation
- THD reduced within IEEE-519 limits (<5%)
- Improved power quality and system reliability
- Adaptive performance under dynamic microgrid conditions

IV. CONCLUSION

This paper presented an intelligent harmonic mitigation approach for microgrid systems using an Artificial Neural Network (ANN)-based Shunt Active Power Filter (SAPF). The increasing use of nonlinear loads and power electronic converters in modern microgrids significantly degrades power quality by introducing harmonic distortion. Conventional harmonic mitigation techniques, although effective under steady-state conditions, lack adaptability and fail to provide optimal performance under dynamic operating scenarios. The proposed ANN-controlled SAPF system effectively addresses these challenges by providing adaptive and real-time harmonic compensation without relying on an exact mathematical model of the system. By learning the nonlinear relationship between distorted load currents and compensating currents, the ANN controller enhances the dynamic response and robustness of the SAPF. The system actively injects compensating currents at the Point of Common Coupling (PCC), resulting in nearly sinusoidal source currents and improved power factor. Simulation studies carried out using MATLAB/Simulink demonstrate that the proposed approach significantly reduces Total Harmonic Distortion (THD) in both current and voltage waveforms. The achieved THD values comply with IEEE-519 standards, confirming the effectiveness of the ANN-SAPF system in improving power quality. Compared to conventional controllers, the proposed system exhibits faster transient response,



superior harmonic suppression, and better adaptability to varying load and operating conditions. Overall, the ANN-based SAPF proves to be a reliable and efficient solution for harmonic distortion reduction in microgrids. The proposed methodology enhances system stability, efficiency, and reliability, making it highly suitable for modern and future power systems with high penetration of renewable energy sources.

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