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# Shunt Active Power Filter Control Algorithms for Mitigating Harmonics: A Review

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***ABSTRACT:*** *This study provides an in-depth analysis of the control algorithms used in Shunt Active Power Filters, which are used in power systems to reduce harmonic distortion. Recent years have seen a rise in harmonic pollution due to the growth of non-linear loads, which has a negative impact on electrical equipment efficiency and power quality. By introducing compensating currents to offset harmonic components, SAPFs provide a practical solution to this issue. A systematic examination of several control systems is given in this article, together with information on their benefits, drawbacks, and most current developments. Important algorithms covered are adaptive and predictive control schemes, time-domain and frequency-domain procedures, and strategies for managing distorted and imbalanced grid circumstances. The study also discusses the difficulties and potential avenues for future research in SAPF control, including the creation of reliable, computationally effective, and grid-adaptive algorithms for integration with contemporary smart grids.*

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## I. INTRODUCTION

Maintaining adequate power quality has become more difficult as non-linear loads—such as arc furnaces, variable speed motors, and power electronic converters—become more common in contemporary power systems. These loads cause the grid to be injected with harmonic currents, which alter the voltage and current's sinusoidal waveform and have a number of negative impacts. These include higher losses in the distribution and transmission networks, equipment overheating, malfunctioning delicate electronic systems, and decreased system efficiency overall (Jain, 2018).

Shunt Active Power Filters have become a well-liked method of reducing harmonic distortion and enhancing power quality. Because SAPFs have adaptive compensation capabilities, they may successfully suppress harmonics over a wide variety of operating conditions, in contrast to passive filters, which have set compensation features and potential resonance concerns. In order to successfully cancel out the harmonic currents produced by the non-linear loads and restore the sinusoidal waveform of the grid current, SAPFs work by injecting compensating currents into the grid that are equal in magnitude but opposite in phase to those currents (Gupta & Aharwal, 2023; A. Kumar & Jain, 2022a; Singh et al., 2024).

A SAPF's efficiency is largely dependent on its control algorithm, which determines how quickly and accurately the power electronic converter generates switching signals, reference currents, and harmonic detection. Many control algorithms have been developed and put into practice over time; each has advantages and disadvantages in terms of complexity, computational load, dynamic response, and resilience to grid disruptions (R. Kumar & Bansal, 2018; Maciel et al., 2018).

The state-of-the-art control algorithms used in SAPFs for harmonic mitigation are thoroughly reviewed in this study. The organized examination of several control systems, including their underlying ideas, benefits, drawbacks, and most recent developments, is presented in this paper. The examination includes both adaptive and predictive control schemes, time-domain and frequency-domain methodologies, and strategies for managing distorted and imbalanced grid circumstances(Gupta & Aharwal, 2022; A. Kumar & Jain, 2022b, 2022c). The study also highlights the difficulties and potential avenues for future research in SAPF control, including the creation of reliable, computationally effective, and grid-adaptive algorithms that will allow for a smooth integration with contemporary smart grids (Hadi et al., 2022; Mahmoud et al., 2020).

## II. CONSTRUCTION OF SHUNT ACTIVE POWER FILTER

This section of the research paper will discuss the typical construction of a Shunt Active Power Filter, focusing on its key components and their functions.

1. **Power Electronic Converter**

A power electronic converter, usually a Voltage Source Inverter made of semiconductor switching components like Metal-Oxide Semiconductor Field-Effect Transistors or Insulated Gate Bipolar Transistors, is the central component of the SAPF. Power rating, switching frequency, and conduction losses are some of the criteria that influence the choice of switching device. By introducing the appropriate compensatory currents into the grid, the VSI functions as a controllable current source(Khatua et al., 2021; Meena & Gupta, 2018; Raj et al., 2022).

2. **DC Energy Storage**

A DC energy storage element, usually a capacitor bank, is connected to the DC side of the VSI. This capacitor bank serves two primary purposes:

*Energy Buffering*: It absorbs and releases energy during fluctuations in the AC grid and compensates for any instantaneous power mismatch between the load and the source.

*Maintaining DC Voltage*: It provides a stable DC voltage to the VSI, ensuring proper operation and control.

**3. Control System**

The control system represents the brain of the SAPF, responsible for generating the appropriate switching signals for the VSI based on the detected harmonic content. It typically comprises:

*Current Sensors*: These sensors measure the load currents and grid currents, providing the necessary information for harmonic detection.

*Digital Signal Processor or Microcontroller*: This unit executes the selected control algorithm, analyzing the measured currents, calculating the required compensating currents, and generating the PWM signals for the VSI.

*Gate Driver Circuit*: This circuit amplifies and isolates the PWM signals from the DSP/microcontroller, providing the necessary drive signals to the gates of the switching devices in the VSI.

**4. Filter Reactor**

A small inductance, known as the filter reactor, is connected in series with the VSI output to:

*Limit Switching Frequency Harmonics*: It attenuates the high-frequency switching components present in the injected current, preventing them from entering the grid.

*Provide a Smoothing Effect*: It smooths the output current waveform, reducing ripple and improving the overall harmonic mitigation performance.

**5. Coupling Inductor**

The SAPF is connected in parallel to the non-linear load through a coupling inductor. This inductor serves to:

*Provide a Current Path*: It allows the compensating currents from the SAPF to flow into the grid, effectively neutralizing the harmonic currents from the load.

*Isolate the SAPF*: It provides a degree of isolation between the SAPF and the grid, protecting the SAPF from voltage disturbances and transients.

**6. Optional Passive Filter**

To further reduce particular harmonics or deal with resonance problems, a passive filter may occasionally be applied in parallel to the SAPF. This hybrid strategy combines the benefits of passive and active filtering methods.

An outline of the general construction of a SAPF has been given in this section. The load's power rating, the harmonic spectrum that needs to be reduced, and the intended performance characteristics all influence the particular design and ratings of each component(Gali et al., 2017).

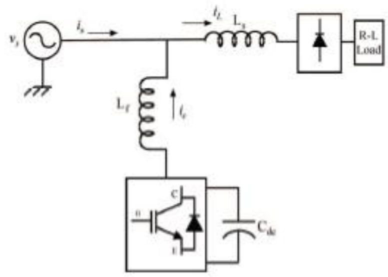

**Fig. 1 Single Line Diagram of SAPF**

## III. WORKING PRINCIPLE & CONTROL TECHNIQUES OF SAPF

This section delves into the fundamental working principle of SAPFs and explores various control techniques employed to achieve effective harmonic mitigation.

### III.A Working Principle

A SAPF's main goal is to provide compensatory currents into the grid at the Point of Common Coupling in order to neutralize the harmonic currents that are produced by non-linear loads. By utilizing the superposition principle, this is accomplished.

Harmonic Current Detection: Using current sensors, the SAPF continuously keeps an eye on the load currents. In order to locate and extract the harmonic components that are present, the control system examines these currents.

Reference Current Generation: The control system creates reference compensating currents that are equal in magnitude to the harmonic components but opposite in phase based on the detected harmonic currents.

PWM Signal Generation: To create switching signals for the VSI, the control system uses a pulse width modulation technique. By regulating the semiconductor devices' switching, these signals effectively shape the SAPF's output current.

Current Injection: Using the coupling inductor as a conduit, the VSI injects the compensatory currents into the grid while being powered by the PWM signals. These currents essentially cancel out the load's harmonic currents because they are 180 degrees out of phase with them.

Resultant Current: The total of the load current and the compensatory current is the net current that the PCC sends into the grid. This resulting current can be controlled to almost become sinusoidal, which lowers the THD and enhances power quality.

### III.B Control Techniques

Numerous control techniques have been developed for SAPFs, each with its own advantages and limitations. Some of the prominent control strategies include:

III.B.1 Time-Domain Control

Hysteresis Current Control: This simple and robust method compares the actual compensating current with the reference current within a hysteresis band. Switching actions are triggered to maintain the current error within the defined band.

Deadbeat Control: This technique aims to force the compensating current to track the reference current within a single sampling period, resulting in fast dynamic response but potentially higher switching frequency.

Repetitive Control: This method is particularly effective in tracking periodic signals like harmonics. It learns the repetitive nature of the disturbance and generates a compensating signal with the same periodicity.

III.B 2 Frequency-Domain Control

Instantaneous Reactive Power Theory (p-q Theory): This widely used technique decomposes the load currents into active, reactive, and harmonic components. The SAPF is controlled to compensate for the reactive and harmonic components, ensuring near-unity power factor operation.

Discrete Fourier Transform: This method analyzes the load current waveform in the frequency domain to identify and quantify the individual harmonic components. The SAPF is then controlled to inject compensating currents at the specific harmonic frequencies.

III.B 3 Adaptive and Predictive Control

Adaptive Control: These techniques adjust the controller parameters online based on the changing system dynamics, making them suitable for handling variations in load and grid conditions.

Model Predictive Control: This advanced control strategy predicts the future behavior of the system over a finite horizon and optimizes the control actions to achieve the desired performance.

III.B 4 Other Techniques

Sliding Mode Control: This robust control technique offers good disturbance rejection capabilities and insensitivity to parameter variations.

Fuzzy Logic Control: This method utilizes fuzzy logic rules to handle the non-linearity and uncertainty associated with power systems.

The choice of control technique depends on factors like the desired performance, complexity, computational burden, and robustness requirements. Recent research has focused on developing hybrid control schemes that combine the advantages of multiple techniques to achieve optimal performance under various operating conditions.

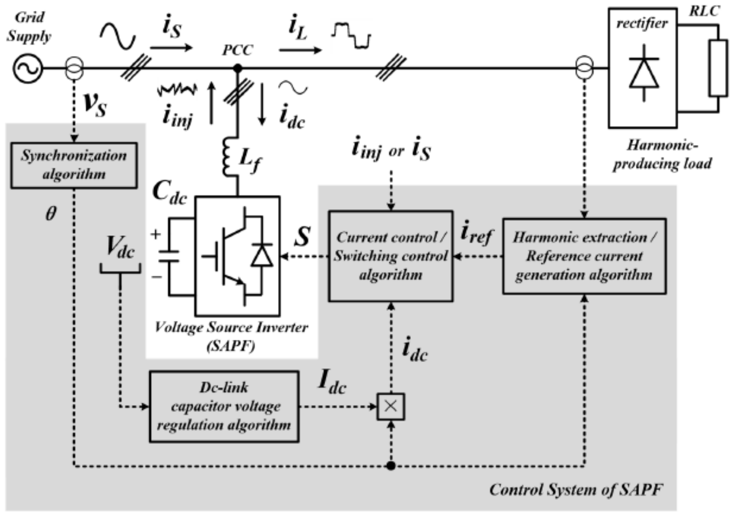


**Fig. 2 Typical circuit configuration for a shunt active power filter (SAPF) with control algorithms based on an inverter.**

## IV. SHUNT APF CLASSIFICATION USING CONTROL TECHNIQUES

Given the diverse range of control techniques applicable to Shunt Active Power Filters, categorizing them systematically aids in understanding their strengths and limitations for specific applications. This section presents a classification of SAPFs based on the underlying control strategies employed.

### IV.A Time-Domain Control Based SAPFs

This category encompasses SAPFs that operate directly on the instantaneous values of currents and voltages in the time domain.

**Hysteresis Band Current Control:** These SAPFs utilize a simple yet effective control strategy where the actual compensating current is compared to the reference current within a predefined hysteresis band. Switching actions are triggered to maintain the current error within this band. While simple to implement, the variable switching frequency can lead to higher losses and acoustic noise.

**Deadbeat Control:** This technique aims for fast dynamic response by forcing the compensating current to track the reference current within a single sampling period. However, this requires accurate system modeling and can lead to high switching frequencies, increasing switching losses.

**Repetitive Control:** Ideal for periodic disturbances like harmonics, this method learns the repetitive pattern of the unwanted signal and generates a compensating signal with the same periodicity. This results in excellent steady-state harmonic mitigation but can be sensitive to grid frequency variations.

### IV.B Frequency-Domain Control Based SAPFs

These SAPFs rely on frequency-domain analysis of the current waveforms to identify and mitigate harmonics.

**Instantaneous Reactive Power Theory (p-q Theory):** This widely adopted technique decomposes the load currents into active, reactive, and harmonic components using Clarke and Park transformations. The SAPF then compensates for the reactive and harmonic components, leading to near-unity power factor operation. However, it can be sensitive to unbalanced and distorted grid voltage.

**Discrete Fourier Transform Based Control:** This method analyzes the load current waveform in the frequency domain using DFT to identify and quantify individual harmonic components. The SAPF then injects compensating currents at those specific harmonic frequencies. While accurate in steady-state, its dynamic response can be slower due to the computational burden of DFT calculations.

### IV.C Adaptive and Intelligent Control Based SAPFs

This category includes SAPFs that adapt to changing system dynamics and uncertainties.

**Adaptive Control:** These SAPFs adjust their controller parameters online based on real-time system identification or estimation techniques. This makes them suitable for handling variations in load and grid conditions, improving robustness. However, the design and implementation of adaptive algorithms can be complex.

**Model Predictive Control:** This advanced technique predicts the future behavior of the system over a finite horizon and optimizes the control actions to achieve desired performance while satisfying system constraints. While offering superior performance, MPC requires significant computational resources and accurate system models.

**Fuzzy Logic Control:** Utilizing fuzzy logic rules, these SAPFs handle the non-linearity and uncertainty inherent in power systems. FLC offers flexibility and can incorporate expert knowledge, but its performance relies heavily on the design of the fuzzy rule base.

### IV.D Hybrid Control Based SAPFs

Recognizing the strengths and limitations of individual control techniques, researchers have explored combining them to leverage their advantages. These hybrid control schemes aim to achieve optimal performance under various operating conditions. For instance, combining the fast response of deadbeat control with the harmonic-specific mitigation of DFT-based control can lead to a highly effective SAPF.

This classification provides a structured overview of SAPFs based on their control techniques. The choice of the most suitable control strategy depends on factors like the desired performance, complexity, cost, and specific application requirements. As research progresses, we can expect further advancements in control algorithms, leading to more robust, efficient, and intelligent SAPFs for modern power systems(Hoon et al., 2017, 2019).

**TABLE. 1 Comparison based on application of Shunt APF**

| Ref | Topology used | 1ϕ or 3ϕ | Control Technique | Compensation Parameters | Neutral Current Compensation | Shoot through Problem | Complexity of circuit | Complexity of control algorithm | Power Level | Applications |
|---|---|---|---|---|---|---|---|---|---|---|
| | VSI | Both | pq, Energy balanced theory, DC link | Voltage & Current | No | Yes | Less | Less | Low & Medium | Diode bridge rectifier / Converter based IMD |
| | CSI | Both | SHE, PWM | Current | No | Yes | Less | Less | Low & Medium | Large industrial drives / AC loads |
| | Split | 3ϕ | pq, SRF, | Voltage & | Yes | Yes | Medium | Medium | Low & | Computer/Commerc |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | capac itor | | EPLL | Current | | | | | Medium | ial appliances |
| | MLI topol ogy | Both | pq, SRF, ISCT | Voltage & Current | Yes | Yes | High | High | High | Traction Applications |

## V. Implementation and Practical Challenges of Shunt Active Power Filters

While Shunt Active Power Filters offer a promising solution for harmonic mitigation and power quality enhancement, their practical implementation presents various challenges. This section delves into the key aspects of SAPF implementation and discusses the practical challenges encountered in real-world applications.

### V.A Implementation Considerations

Power circuit design of power circuit in a SAPF typically comprises a Voltage Source Inverter, DC-link capacitor, coupling inductor, and filter components. Selecting appropriate components with suitable ratings and characteristics is crucial for efficient and reliable operation. Factors like switching frequency, voltage and current ratings, thermal management, and protection need careful consideration. The control system forms the heart of a SAPF, dictating its performance and effectiveness. Choosing the appropriate control algorithm, designing the control loop parameters, and implementing the control logic on a suitable hardware platform are critical steps. Real-time processing capabilities, communication interfaces, and protection mechanisms are essential for robust control.

Accurate measurement of grid currents and voltages is crucial for effective harmonic detection and compensation. Selecting sensors with appropriate accuracy, bandwidth, and dynamic range is essential. Proper placement of sensors to minimize noise and interference is also critical. For the SAPF to inject compensating currents effectively, it needs to be synchronized with the grid voltage. This requires accurate phase angle detection and synchronization techniques to ensure the injected currents are in phase opposition to the harmonic components.

### V.B Practical Challenges

The performance of SAPFs can be sensitive to variations in grid impedance, which can affect the accuracy of harmonic current injection. Adaptive control techniques and robust design considerations are necessary to mitigate the impact of grid impedance variations. In practical scenarios, grid voltages are often unbalanced and distorted, which can degrade the performance of SAPFs. Control algorithms need to be robust to these non-ideal grid conditions to ensure effective harmonic compensation.

The switching actions of the VSI in a SAPF result in switching losses, which can reduce overall efficiency. Selecting appropriate switching devices, employing advanced modulation techniques, and optimizing switching frequencies are crucial for maximizing efficiency. The implementation of SAPFs involves sophisticated power electronic converters, control systems, and sensors, leading to higher costs compared to passive filters. The complexity of control algorithms and the need for specialized expertise can also pose challenges.

### V.C Future Directions

Addressing these practical challenges is crucial for wider adoption of SAPFs. Research efforts are focused on developing:

*Robust and Adaptive Control Algorithms:* Advanced control techniques that can handle grid impedance variations, unbalanced voltages, and distorted waveforms are being explored.

*Multilevel Inverter Topologies:* Employing multilevel inverters can reduce voltage stress on switching devices, lower switching losses, and improve harmonic performance.

*Advanced Filtering Techniques:* Hybrid filters combining active and passive elements are being investigated to achieve a balance between performance and cost.

*Integration with Smart Grid Technologies:* Integrating SAPFs with smart grid functionalities like real-time monitoring, communication, and control can enhance their effectiveness and enable grid-level optimization.

By overcoming these implementation challenges and pursuing ongoing research efforts, SAPFs can play a pivotal role in ensuring high power quality in modern power systems with increasing penetration of non-linear loads.

## VI. Conclusion

This study provided a thorough analysis of the shunt active power filter, which can be used to raise PQ in grid-side and utility systems alike. Table 1 displays a full comparison of the many aspects of shunt APF and discusses and highlights the various concerns with various topologies, control approaches, and PWM algorithms. This work has addressed the various advanced processors, their potential for use in the development of shunt APF, and the future research scope in this field.

## REFRENCES

[1]. Gali, V., Gupta, N., & Gupta, R. A. (2017). Mitigation of power quality problems using shunt active power filters: A comprehensive review. Proceedings of the 2017 12th IEEE Conference on Industrial Electronics and Applications, ICIEA 2017, 2018-Febru, 1100–1105. https://doi.org/10.1109/ICIEA.2017.8283004

[2]. Gupta, C., & Aharwal, V. K. (2022). Optimizing the performance of Triple Input DC-DC converter in an Integrated System. Journal of Integrated SCIENCE & TECHNOLOGY, 10(3), 215–220.

[3]. Gupta, C., & Aharwal, V. K. (2023). Design and simulation of Multi-Input Converter for Renewable energy sources. Journal of Integrated SCIENCE & TECHNOLOGY, 11(3), 1–7.

[4]. Hadi, A., Thjeel, E., & Nahar, A. (2022). A Review of Control Technique Applied in Shunt Active Power Filter (SAPF). Engineering and Technology Journal, 40(8), 140–149. https://doi.org/10.30684/etj.v40i8.2116

[5]. Hoon, Y., Radzi, M. A. M., Hassan, M. K., & Mailah, N. F. (2017). Control algorithms of shunt active power filter for harmonics mitigation: A review. Energies, 10(12). https://doi.org/10.3390/en10122038

[6]. Hoon, Y., Radzi, M. A. M., Zainuri, M. A. A. M., & Zawawi, M. A. M. (2019). Shunt active power filter: A review on phase synchronization control techniques. Electronics (Switzerland), 8(7), 1–20. https://doi.org/10.3390/electronics8070791

[7]. Jain, S. (2018). Control strategies of shunt active power filter. In Modeling and Control of Power Electronics Converter System for Power Quality Improvements. Elsevier Inc. https://doi.org/10.1016/B978-0-12-814568-5.00002-8

[8]. Khatua, B. B., Gupta, C., & Kumar, A. (2021). Harmonic Investigation Analysis of Cascade H Bridge Multilevel Inverter with Conventional Inverter using PSIM. 04(03), 9–14.

[9]. Kumar, A., & Jain, S. (2022a). Critical Analysis on Multilevel Inverter Designs for. 14(3). https://doi.org/10.18090/samriddhi.v14i03.22

[10]. Kumar, A., & Jain, S. (2022b). Multilevel Inverter with Predictive Control for Renewable Energy Smart Grid Applications. International Journal of Electrical and Electronics Research, 10(3), 501–507. https://doi.org/10.37391/IJEER.100317

[11]. Kumar, A., & Jain, S. (2022c). Predictive Switching Control for Multilevel Inverter using CNN-LSTM for Voltage Regulation. 11, 1–9.

[12]. Kumar, R., & Bansal, H. O. (2018). Shunt active power filter: Current status of control techniques and its integration to renewable energy sources. Sustainable Cities and Society, 42, 574–592. https://doi.org/10.1016/j.scs.2018.07.002

[13]. Maciel, L. F. A., Morales, J. L. M., Gaona, D. C., & Pimentel, J. G. M. (2018). A study of a three-phase four-wire shunt active power filter for harmonics mitigation. 2018 IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2018, 1, 1–6. https://doi.org/10.1109/ROPEC.2018.8661416

[14]. Mahmoud, M. O., Mamdouh, W., & Khalil, H. (2020). Source current harmonic mitigation of distorted voltage source by using shunt active power filter. International Journal of Electrical and Computer Engineering, 10(4), 3967–3977. https://doi.org/10.11591/ijece.v10i4.pp3967-3977

[15]. Meena, V., & Gupta, C. (2018). A Review of Design , Development , Control and Applications of DC − DC Converters. 2581, 28–33.

[16]. Raj, A., Kumar, A., & Gupta, C. (2022). Shunt Active Filters : A Review on Control Techniques II . Shunt Active Power Filter. 05(02), 78–81.

[17]. Singh, C. B., Kumar, A., Gupta, C., Cience, S., Echnology, T., & Dc, D. C. (2024). Comparative performance evaluation of multi level inverter for power quality improvement. 12(2), 1–7.