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A Comprehensive Analysis on Shunt Active Power Filters for Power Quality Enhancement Using SRF Control Method

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Abstract
The primary demand of the modern-day energy networks is to cope up with the power quality demands of the power grid facilities, this can be achieved by designing the effective power filters which reduces voltage and current harmonics. The following article is a comparative study on Instantaneous quadrature power theory and proposed SRF control algorithm to derive the compensation currents of shunt active power filter (SAPF) which enhance the power condition of the system. In order to monitor the DC-link voltage a proportional–integral (PI) controller is preferred. By adopting MATLAB/Simulink platform the SAPF is designed for stable non-linear loads. The triggering pulses are generated by hysteresis current control technique to regulate the turn on and off of the voltage source inverter (VSI) switches. The simulation results demonstrate that the total harmonic distortion can be minimized relatively to a lower value by implementing the proposed current control algorithm.
Keywords: Shunt active power filter (SAPF), Instantaneous quadrature power theory (P-Q Theory), I-Cos ψ control algorithm, proportional-Integral (P-I) controller.

I. INTRODUCTION

POWER electronics-based devices/equipments are a major key component of today's modern power processing, at the transmission as well as the distribution level because of the numerous advantages offered by them. These devices, equipments, nonlinear load including saturated transformers, arc furnaces and semiconductor switches and so on, draw non-sinusoidal currents from the utility. Therefore, a typical power distribution system has to deal with harmonics and reactive power support [1]. The presence of harmonics and reactive power in the grid is harmful, because it will cause additional power losses and malfunctions of the grid components [2]. Conventionally, passive filters consisting of tuned L-C components have been widely used to suppress harmonics because of their low initial cost and high efficiency. However, passive filters have many disadvantages, such as large size, mistuning, instability and resonance with load and utility impedances [3]. Active Power Filters have become an alternative solution for controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power and/or voltage control at high voltage distribution level [4]. Active power filters such as shunt APFs, series APFs, hybrid APFs, unified power quality conditioner (UPQC) and other combinations have made it possible to mitigate some of the major power quality problems [1]. APF system can be divided into two sections as given in Fig. 1. The control unit and the power circuit and the control unit consist of reference signal generation, gate signal generation, and capacitor voltage balance control and voltage/current measurement. Power circuit of APF is generally comprised of energy storage unit, DC/AC converter, harmonic filter and system protection.

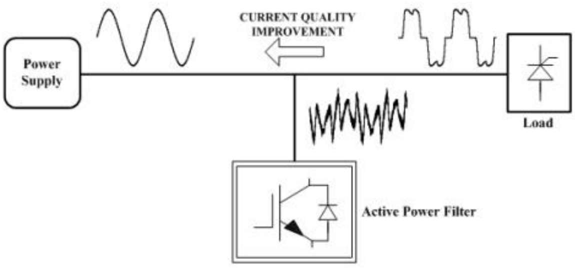

Fig. 1 Fundamental representation of APF

The findings of the comprehensive literature survey summarize the available studies related with the control unit and the power circuit of the APF.

II. POWER QUALITY PROBLEMS

The private and industrialised appliance of all the service companies across the globe [1-2] uses balanced or unbalanced non-linear electric gadgets which dependence on power electronic switches for its operation. The contamination of electrical energy distribution network is worst at employment stage due to non-linear loads like, variable speed and variable frequency drives, voltage controllers, electronic gadgets such as computers, printers, televisions, servers and telecom systems all of the which uses SMPS power conversion technologies. This results in the energy quality issues, e.g., harmonic overrefinement, voltage instability, unbalanced current, hissing noise [3]. The power loss in low-voltage distribution systems is due to harmonic distortion, poor power factor, electric heat dissipation, insulation hazards, tampering problems in communication systems and electric power system failure [4,5]. Hence, mitigation of energy quality problems has turned into a matter of discussion for the producers as well the consumers [6]. With the intention to pertain the direct inoculation of harmonic currents in to the energy grid, the Institute of Electrical and Electronics Engineering-Standards Association(“IEEE-SA”) superscribe that the total harmonic distortion (THD) of an electric power system, the IEEE criterion should be less than 5% [7,9]. The literature review reveals the most adequate technology to mitigate harmonic distortions is power filters. Consistently, to enhance the power condition at the power stations, series and shunt passive power filters are used. Since, non-linear loads in industrial firms are connected to a rigid energy system, it is demanding to model a passive filter to mitigate current harmonic disfigure. Above all, the passive filter has its innate flaw like its extensive size, reverberance with load impedance or supply impedance, unpredictability and inflexible [10]. To prevail the typical filter’s drawbacks active power filters (APFs) which includes voltage source inverters (VSIs) are put forward as a substitute. APFs owns several features, including a rapid dynamic response, flexibility and predominant filtering accuracy, qualifying it as a fitting solution for power quality problems [11]. The current harmonics and quadrature power sensing methods, along with the compensation control algorithm defines the harmonic reduction competence capability of the shunt active power filter [12-14].

III. PARAMETERS

Electric systems and grids are complex dynamic systems. These systems suffer usually from unexpected or sudden changes of the currents and voltages. These changes are due mainly to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervener into the grid [31]. With the increasing use of power semiconductors in the most of industrial and domestic procedures, the electric grids are polluted with different harmonic currents and voltages. These harmonics affect the normal function of the most of the grid connected devices; in addition to considerable economic losses. Many classic and modern solutions have been proposed in the literary for the harmonic problems. In this chapter, the harmonic problem as one of the most common power quality problems will be presented. The different modern and traditional solutions will then be discussed.

Power Systems Distortion and Problems

In power systems, different voltage and current problems can be faced. The main voltage problems can be summarized in short duration variations, voltage interruption, frequency variation, voltage dips, and harmonics. Harmonics represent the main problem of currents of power systems.

Voltage Dips (Sags)

The voltage dips are periodic perturbations. They appear as a natural effect of the switching of the transistors. They are due also to the start of big loads like motors. Lifts, lights, heaters…etc. this phenomena causes bad functioning of the protection equipment's.

Harmonics

Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of loads produces currents and voltages with frequencies that are integer multiples of the 50 or 60 Hz fundamental frequency. These frequencies components are a form of Most encountered power system problems. a) Voltage swells. b) Voltage sags. c) Voltage interruption. d) Frequency variation. e) Voltage unbalance. f) Harmonics. Harmonics are familiar to the musicians as the overtones from an instrument. They are the integer multiples of the instrument's fundamental or natural frequency that are produced by a series of standing waves of higher and higher order. Electrical pollution known as harmonic distortion. There are two types of harmonics that can be encountered in a power system.

IV. RESEARCH MOTIVATION

Active power filters are adaptable and flexible answer for voltage quality issues. Improvement of technologies gave to ac induction machine drive and, specifically, acknowledgment of quick electronic switches has built up the utilization of active filters for harmonic and power factor compensation. A few works on active filter controllers dependent on synchronous reference outline transformation are carried out. Shunt active filters utilizing traditional control strategies have effectively been utilized to make up for basic power quality issues like current harmonics, reactive power and load imbalance. Shunt active power filters are normally carried out with pulse-width modulated voltage source inverters. In this sort of uses, the pwm-vsi works as a current controlled voltage source and compensates current harmonics by soaking-in equal however inverse harmonic compensating current. An extremely important topic for shunt active filter design is the selection of a compensating strategy,thatis,the method for testing the reference compensating current. Different current control ways of were proposed for shunt active filter. Hysteresis current control method is the most popular one in terms of quick current controllability, versatility and easy implementation.

V. POWER-QUALITY THEORY (P-Q THEORY)

Electric power quality is the degree to which the voltage, frequency, and waveform of a power supply system conform to established specifications. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady a.c. frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave). In general, it is useful to consider power quality as the compatibility between what comes out of an electric outlet and the load that is plugged into it. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power. The electric power industry comprises electricity generation (AC power), electric power transmission and ultimately electric power distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load.

VI. PROPOSED METHODOLOGY

The Synchronous Reference Frame (SRF) method is a control technique used in electrical power systems to improve power quality by accurately identifying and compensating unwanted harmonic and reactive components of current or voltage. It works by transforming the three-phase system quantities into a rotating reference frame that rotates in synchronism with the supply voltage.

In this method, the three-phase currents are converted into two components—direct (d-axis) and quadrature (q-axis)—that represent the active and reactive power parts of the system. A Phase-Locked Loop (PLL) keeps the reference frame aligned with the fundamental frequency of the source.

The SRF controller then separates the fundamental (useful) components from the harmonic and reactive (unwanted) components using filters. The unwanted parts are used to generate compensating signals for the Shunt Active Power Filter (SAPF), which injects equal and opposite currents into the line.

Power Quality Improvement:

By using the SRF method, the system can:

- Eliminate current harmonics caused by nonlinear loads,
- Compensate reactive power,
- Achieve unity power factor,

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- Reduce current distortion, and
- Maintain sinusoidal source currents and balanced operation.

Steps of the SRF Method
Step 1: Measure System Quantities
Measure the three-phase source voltages and load currents at the Point of Common Coupling (PCC).
These signals are used to detect harmonics and determine compensation needs.
Step 2: Generate Reference Angle using PLL
A Phase-Locked Loop (PLL) is used to synchronize with the supply voltage.
The PLL provides a continuously updated phase angle of the grid voltage.
This ensures that the control system always aligns with the fundamental frequency.
Step 3: Transform Currents to Rotating Reference Frame
The measured three-phase load currents are transformed into a rotating reference frame (d–q–0 frame) using the PLL angle.
In this frame:
The d-axis component represents the active current (real power).
The q-axis component represents the reactive and harmonic current.
Step 4: Extract Fundamental Components
Use a Low-Pass Filter (LPF) to separate the fundamental DC components (representing real and reactive power) from the AC components (representing harmonics).
The harmonic parts are identified for compensation.
Step 5: Generate Reference Compensation Currents
Based on the filtering results:
The unwanted harmonic and reactive parts are selected to be cancelled.
These components are used to generate the reference compensating currents that the active filter must inject.
Step 6: Convert Back to Three-Phase System
The reference compensation currents (in the d–q frame) are transformed back into the three-phase (a–b–c) system.
These become the target currents for the inverter to produce.
Step 7: Control the Inverter (SAPF)
The Shunt Active Power Filter inverter uses a current control technique such as:
Hysteresis current control, or
Sinusoidal PWM control.
The inverter injects equal and opposite currents to the harmonics and reactive components.
Step 8: Inject Compensating Currents
The SAPF injects these compensating currents into the line.
This action cancels out harmonic distortion and reactive power drawn by the nonlinear load.
Step 9: Improve Power Quality
As a result:
The source current becomes purely sinusoidal,

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The power factor approaches unity, and
The Total Harmonic Distortion (THD) of the supply current is significantly reduced.

VII. RESULT AND SIMULATION

The given diagram represents a Simulink model of a Shunt Active Power Filter (SAPF) using a Hysteresis Current Control technique for power quality improvement in a three-phase system. The main objective of this system is to compensate for current harmonics and reactive power caused by nonlinear loads.

In summary, this model demonstrates how a Shunt Active Power Filter dynamically compensates for harmonic and reactive components using a VSI, hysteresis control, and PI-based DC-link voltage regulation, thereby ensuring improved power quality and maintaining sinusoidal source currents at unity power factor.

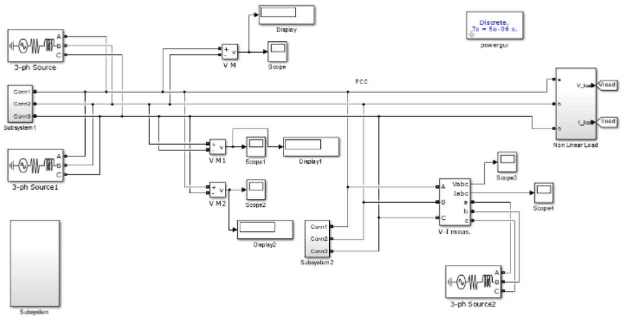

Fig.2.Simulink Model.

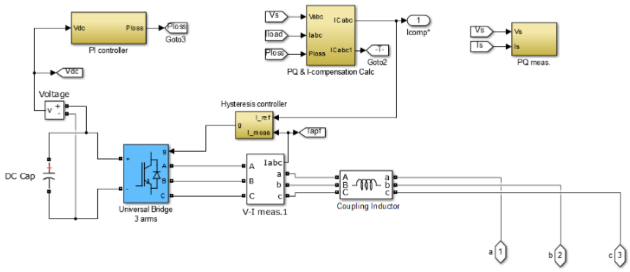

Fig.3. Shunt active power filters.

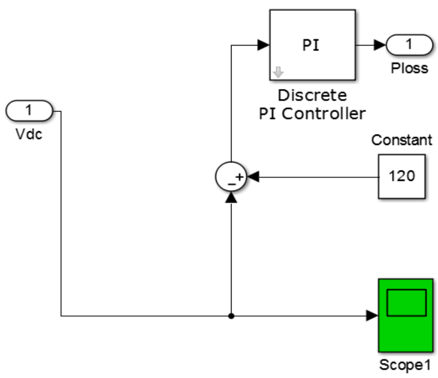

Fig.4.PI controller.

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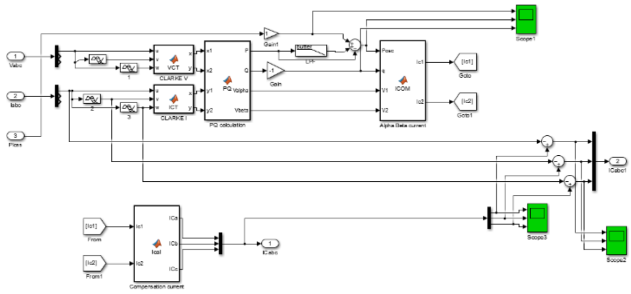

Fig.5 Transforms.

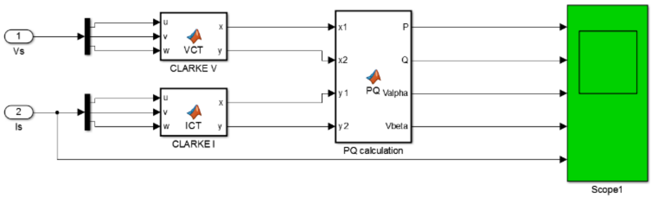

Fig.6 PQ Calculation.

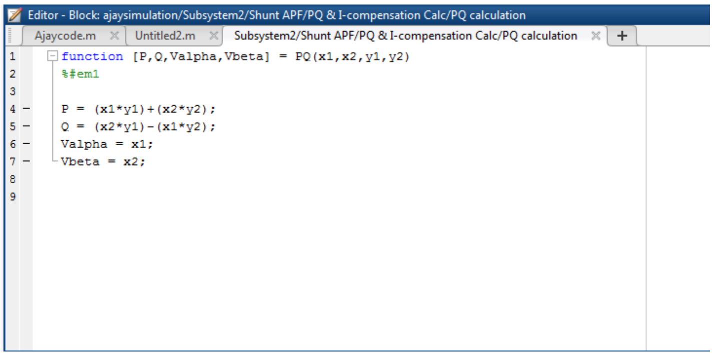

Fig.7 Script.

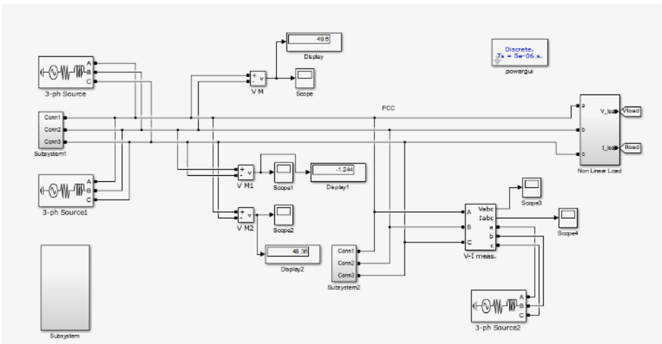

Fig.8 Simulation

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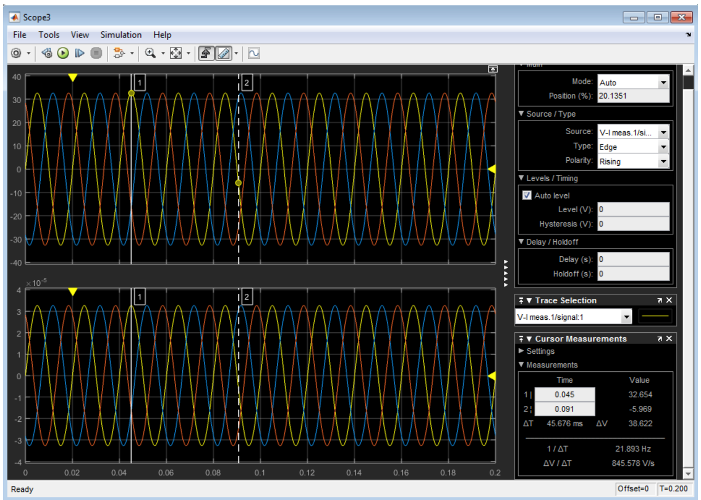

Fig.9 Load across Outputs

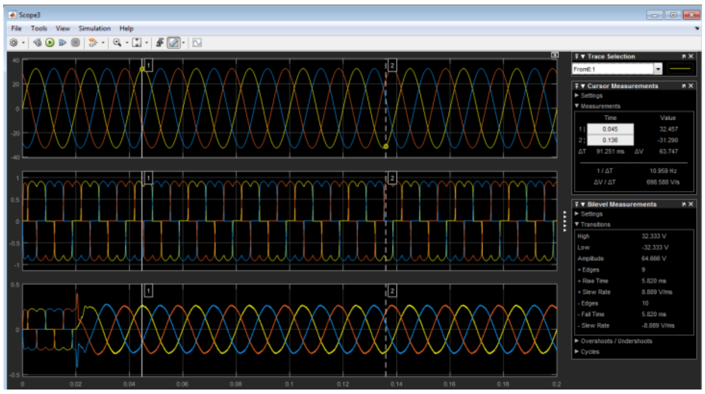

Fig.10 Filter across Outputs.

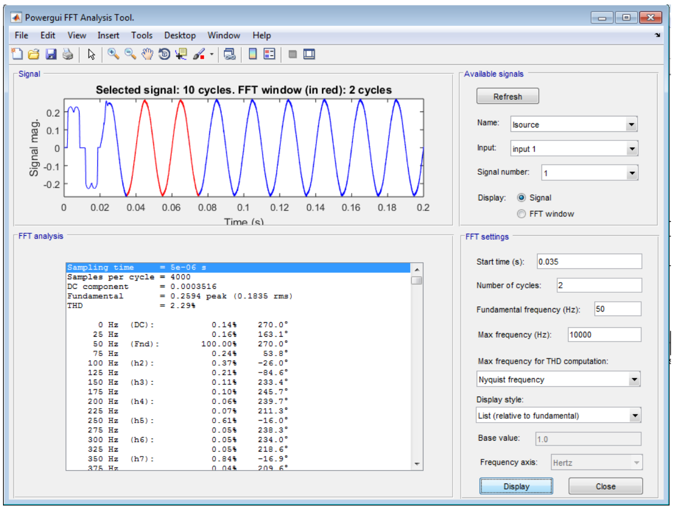

Fig.11 THD variation.

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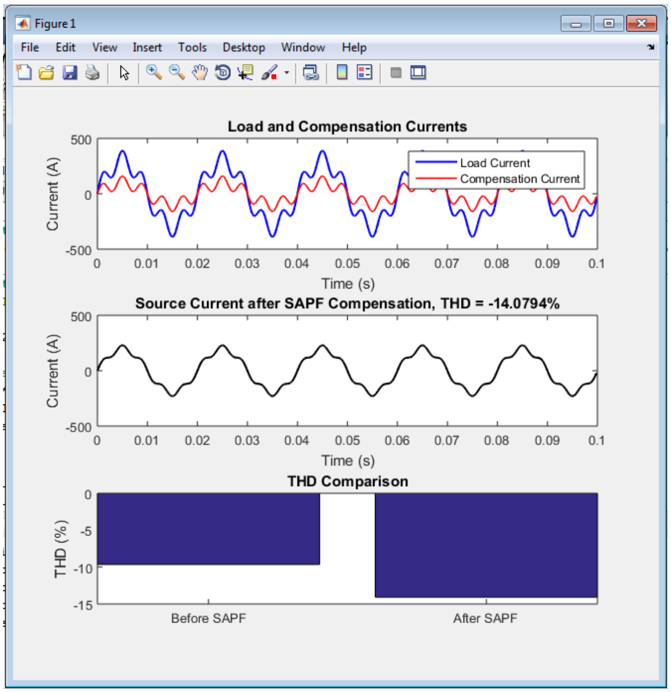

Fig.12 Optimize THD for Custom Inputs.

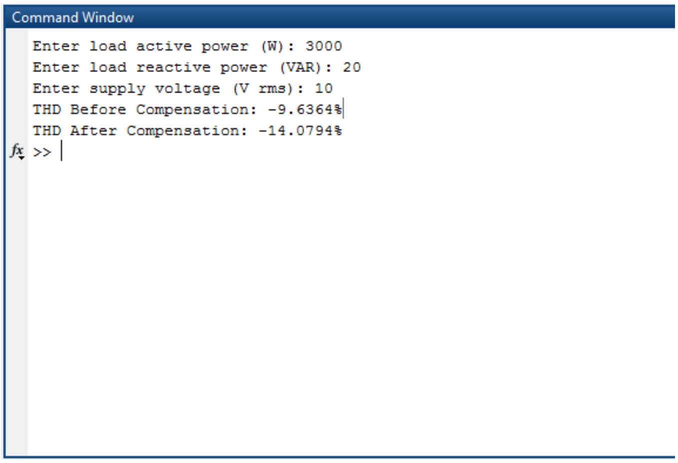

Fig.13 Command Window Outputs.

TABLE 1. Comparison between previous and proposed Work

Parameter	Previous [16]	Proposed
THD%	24.80	2.294

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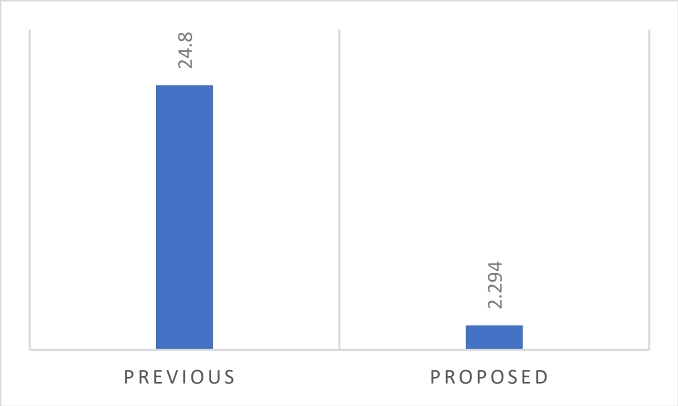

Fig.14 Comparison between previous and proposed Work

VIII. CONCLUSION

The study demonstrates the effectiveness of the Synchronous Reference Frame (SRF) method in enhancing power quality by mitigating current harmonics and improving the overall THD (Total Harmonic Distortion) in the electrical system. By implementing the SRF-based Shunt Active Power Filter, the compensation current closely follows the harmonic components of the nonlinear load, resulting in significant reduction of THD at the source side.

Simulation results with variable load and power conditions show that the SAPF can adapt dynamically, maintaining near-sinusoidal source currents even under fluctuating loads. Comparative analysis of before and after compensation currents confirms that the SRF method provides precise harmonic extraction, effective reactive power compensation, and improved system efficiency.

This research validates that the SRF-based SAPF is a reliable and efficient solution for power quality enhancement in industrial and residential networks with nonlinear loads. Further work can extend this approach to three-phase unbalanced systems, integration with renewable energy sources, and real-time hardware implementation for practical deployment.

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