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Enhancing Power Quality with Intelligent Control: Neural Network-Driven Shunt Active Power Filter for Harmonic Mitigation

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Abstract: This project addresses the issue of harmonic distortion in power systems caused by non-linear loads, such as rectifiers, induction motors, and unbalanced loads, by designing and implementing an ANN-based Shunt Active Power Filter (SAPF). Harmonics, which are voltage or current waveforms at multiples of the fundamental frequency, can severely impact power quality, leading to reduced efficiency, overheating, and potential equipment damage. The SAPF developed in this project successfully reduces the Total Harmonic Distortion (THD) in the source current from 27.36% to 4.74% by generating compensating currents that neutralize the harmonics introduced by these non-linear loads. Initially, the SAPF was based on a PI Controller, achieving a THD reduction to 4.74%. However, by replacing the PI Controller with an Artificial Neural Network (ANN) in the SAPF, the THD was further reduced to 4.68%. The design of the SAPF includes a PQ and I Compensation Calculation subsystem for determining compensating currents, a Hysteresis Controller for generating switching signals, and a PQ Measurement subsystem for monitoring power quality. Each of these components contributes to the SAPF's ability to effectively mitigate harmonics and improve overall power quality. The project demonstrates the SAPF's robustness and effectiveness in real-world applications, making it a practical solution for systems where harmonic distortion poses significant challenges.

Keywords: Harmonic Distortion, Non-Linear Loads, Power Quality, Shunt Active Power Filter (SAPF), Artificial Neural Network (ANN), Total Harmonic Distortion (THD), PI Controller, Compensating Currents, Hysteresis Controller, PQ Measurement.

I. INTRODUCTION

Power quality is a vital component of contemporary electrical systems, significantly affecting the efficiency, reliability, and longevity of electrical equipment. One of the main challenges in ensuring high power quality is harmonic distortion, which is especially common in systems with non-linear loads like rectifiers, induction motors, and unbalanced loads. Harmonics are voltage or current waveforms that appear at multiples of the fundamental frequency and can cause various negative effects, such as decreased efficiency, equipment overheating, and heightened losses in the power system.[2]

This research aims to reduce harmonic distortion by designing and implementing a Shunt Active Power Filter (SAPF) that utilizes an Artificial Neural Network (ANN). The SAPF is a sophisticated power electronic device that produces compensating currents to counteract the harmonics created by non-linear loads, thus improving overall power quality. The use of an ANN allows the SAPF to learn and enhance its harmonic mitigation capabilities by optimizing control

signals in real time.[13] This ANN-based control approach offers more accurate and efficient compensation compared to conventional methods. The effectiveness of the SAPF is evaluated based on its ability to lower the Total Harmonic Distortion (THD) in the source current, which is a crucial measure of power quality.[9] In this study, we analyzed a power system model that includes 3 - three-phase rectifiers, an unloaded induction motor, and a three-phase unbalanced load. These components are common sources of harmonics in industrial and commercial settings. The research highlights the effectiveness of the SAPF in enhancing power quality in systems impacted by harmonic distortion, proving it to be a practical and reliable solution for real-world applications where maintaining high power quality is crucial.

II. THEORITICAL FOUNDATIONS

A. *Basic Introduction of Literature Survey*

In IEEE std. 519-1992 (1993), "Power quality" can be understood from two distinct viewpoints: that of the supplier (utility) and that of the consumer (end user) of electricity. For the generator (utility), power quality pertains to its capability to produce power at a frequency of 50Hz with minimal fluctuations. In contrast, for transmission and distribution at the end user level, power quality is defined by the voltage remaining within a tolerance of 5%. [6]

B. *Harmonics*

Minh Ly Duc et al. (2024)[10] in their paper discussed that there are two key standards for managing power quality in distribution. The first is the EN 50160 standard, which outlines the grid characteristics that public distribution networks must adhere to. The second is the IEEE 519 Standard, which provides guidelines for customers to help them reduce the impact of non-linear loads on their systems.

Unstable power quality can lead to equipment malfunction or even failure, resulting in economic losses for users.[10] Distortions can create noise and disrupt power quality. Harmonic currents arise from non-linear loads connected to the distribution network, causing impedance and distortion in the supply voltage.

Sujay Madane et al. (2017)[11] mentioned in their research paper that the conventional electrified train locomotive load and the large speed train load share several similar characteristics, such as significant power, a high power factor, a low harmonic factor, and a large negative sequence factor. These factors can lead to adverse effects on the power supply system, including increased losses due to motor vibrations, which in turn raise heat levels. Additionally, this can reduce the output of the transformer and cause malfunctions in the relay system.

The electrified railway system has significantly impacted telecommunication systems, communication systems, railroad signalling, and the main supply system. This has led to several issues, including disturbances in power quality such as voltage imbalances, flickering voltages, current instability, and harmonic currents.[11] Particularly, unfavourable currents with opposite sequences and reactive power have a substantial effect on the railway system. To improve power quality, various compensation strategies are employed to address these effects.

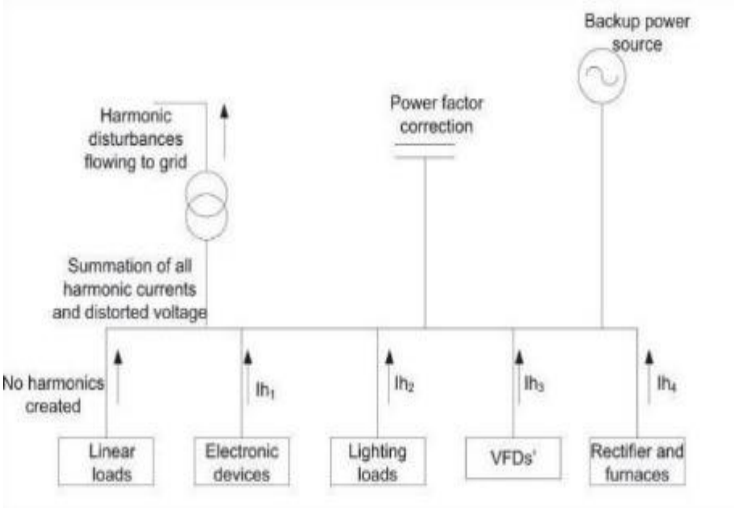


Fig. 1. The Movement of Harmonic Current in a Distribution System. [6]

Dinesh Kumar et. al.(2014)[9], Total Harmonic Distortion (THD) refers to the distortion in voltage and current waveforms and serves as a crucial metric for assessing power quality problems in transmission and distribution systems. THD indicates how much each harmonic component contributes to the overall signal. The definition of THD for both voltage and current signals is:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{40} V_h^2}}{V_{1(rms)}}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{40} I_h^2}}{I_{1(rms)}}$$

The harmonic order, denoted as h, plays a crucial role in understanding the effects of loads that generate harmonics. Such loads can adversely affect nearby sensitive equipment if they lead to significant voltage distortion. This distortion, which arises from the harmonic-producing load, is influenced by the system's impedance and the amount of harmonic current introduced.[14] When the system impedance is low, the voltage distortion is usually minor, unless harmonic resonance takes place.

C. *Harmonics Mitigation Using Filters*

A filter is an electronic device designed to isolate a specific frequency while blocking or reducing others. It achieves this through the use of components like resistors, capacitors, and inductors. Filters play a crucial role in eliminating noise and harmonics, ensuring the production of clean and stable signals.[8]

Komalika gaikwad et al (2022)[12] in their paper, Power quality issues appear as variations in voltage, current, or frequency, potentially leading to malfunctions in sensitive equipment. In this project, we are using Harmonic Filters as a mitigation technique. The IEEE 519 power harmonic standard recommends that total harmonic distortion should remain below 5%.

Passive Power Filter: S. Parthasarathy et al.(2012)[5] ,mentioned, Passive filters are commonly employed for harmonic mitigation and have long been a standard solution in power systems. These filters are made up of passive components like resistors, capacitors, and inductors, and they function without requiring an external power source. Their role is to either redirect harmonic currents away from the line or to block their flow between various sections of the system by tuning into specific frequencies.

Passive Series Filter: A series passive filter helps to minimize harmonics in systems that utilize diode rectifiers and R-L loads. It incorporates an AC line reactor along with a DC link filter to smooth out the current waveform, thereby reducing distortion. This enhancement leads to better system performance, increased efficiency, and improved reliability, resulting in a more stable power supply.[1][12]

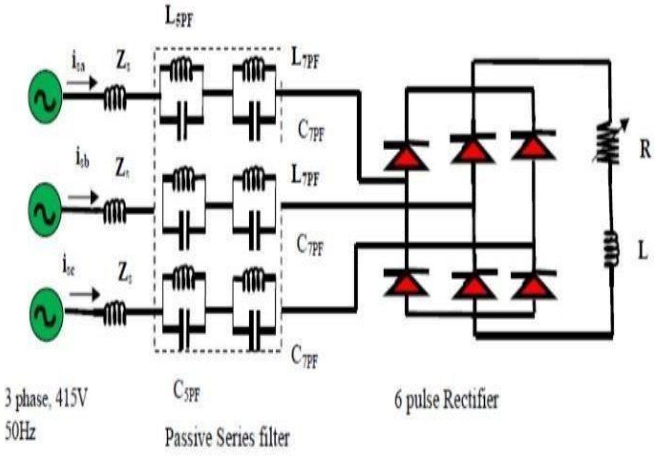


Fig. 2. Schematic diagram of a series-connected passive filter with a six-pulse rectifier [7]

Passive Shunt Filter: Harmonic filtering using passive filters is one of the oldest and most commonly employed technologies for tackling harmonic distortion in electrical systems. These filters are popular because of their straightforward design and affordability. Passive harmonic filters work by reducing harmonic currents within the distribution system. They are specifically designed to redirect harmonic currents away from the load while also improving the power factor.[2] The shunt filter is connected in parallel with the load, offering low impedance at the targeted frequency. This approach provides two main benefits: filtering and power factor correction. The advantages include decreased AC power loss and the ability to carry only a fraction of the total current.

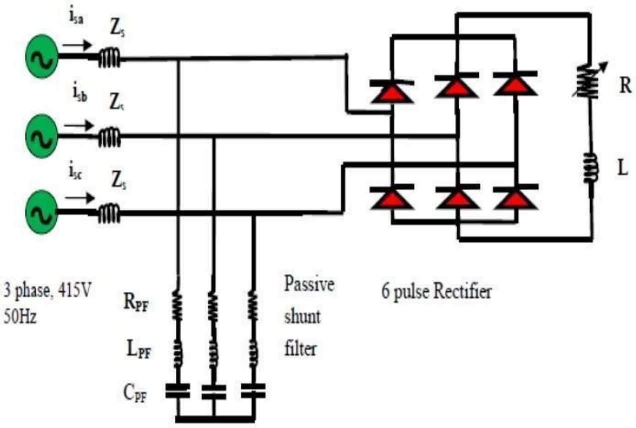


Fig. 3. Shunt filter connection with a six-pulse rectifier circuit at the input. [7]

Active Power Filter: S. Parthasarathy (2012)[5] et al, in their paper, Active Power Filters (APF) address the limitations of passive filters by utilizing a power converter to reject harmonic currents. The Shunt Active Power Filter (SAPF) is designed to not only suppress harmonic currents but also to compensate for reactive power. It functions as a current source in parallel with the nonlinear load. The control of the APF power converter is set to generate a compensation current that is equal in magnitude but opposite in direction to the harmonic current produced by the nonlinear load. Active filters incorporate an active component, like an operational amplifier, along with passive components such as resistors, capacitors, and inductors.

Penumathsa Manasa et al.(2018) [4] have discussed in the paper The theory of instantaneous reactive power addresses limitations in traditional power theories for single-phase sinusoidal systems. While these conventional concepts are well understood, they fall short when dealing with nonlinear load conditions. The IRP theory, also referred to as instantaneous reactive power theory or p-q theory, utilizes the abc-αß0 transformation. It effectively compensates for harmonic power in systems with sinusoidal and unbalanced supply voltages, but struggles under conditions of unbalanced and non-sinusoidal supply voltages.

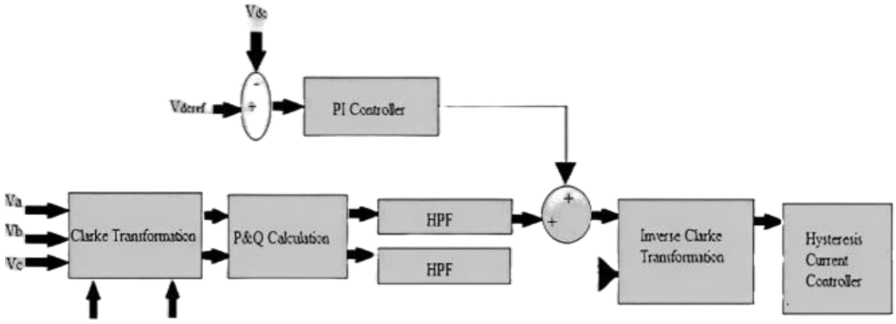


Fig. 4. Flow Chart Representation of PQ Theory. [4]

The compensation power P&Q is determined using the formulas provided below. The P and Q values encompass both fundamental and harmonic components.

The fundamental components are processed through a high-pass filter, and the losses from the parallel active power filter are included to enhance the system's efficiency.

P = (Vα * Iβ + Vβ * Iα) Q = (-Vβ * Iα + Vα * Iβ).

Series Active power filter: Zainal Salam et al, (2006)[8] The operating principle of series Active Power Filters (APF) revolves around isolating harmonics between the nonlinear load and the power source. This is achieved by injecting harmonic voltages (Vf) across the interfacing transformer. Series APFs are less prevalent than their counterpart, the shunt APF, primarily because they must manage high load currents. These high power load currents considerably raise their current rating, particularly on the secondary side of the interface transformer, leading to increased I^2R losses.

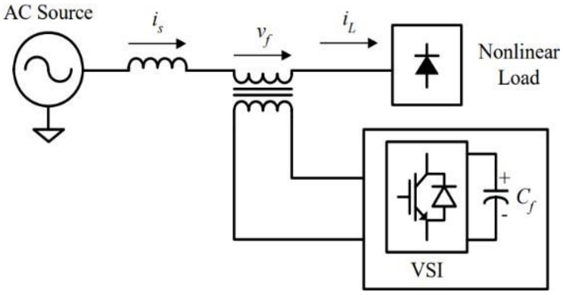


Fig. 5. Principle configuration of a Voltage Source Inverter (VSI) based series Active Power Filter (APF). [8]

Shunt Active power filter: Zainal Salam et al., (2006)[8] It includes a DC bus capacitor (C_f), a power electronic switch, and an interface inductor (L_f). The APF shunt functions as a current source, compensating for harmonic currents caused by nonlinear loads. The operation of the APF shunt involves injecting a compensation current that matches the distorted current, effectively canceling it out. This is done by "shaping" the compensation current waveform (If) with the help of voltage source inverter switches. The shape of the compensation current is determined by measuring the load current (Il) and subtracting it from a sinusoidal reference. The goal of the APF shunt is to achieve a sinusoidal current (Is) using the relationship: $Is = I_l - I_f$.

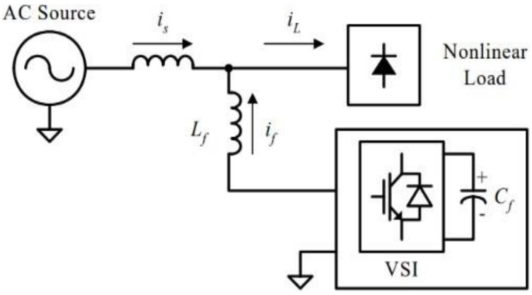


Fig. 6. The main configuration of a Voltage Source Inverter (VSI) based shunt Active Power Filter (APF). [8]

Muhammad Ossama Mahmoud et al.(2020)[3] in this paper they use The SAPF control system employs (p-q) theory to determine the optimal instantaneous current that should be injected by the SAPF to reduce source current harmonics, even when the source voltage is distorted. The SAPF provides an equal but opposite harmonic current to each phase of the supply system at the point of common coupling (PCC). For the SAPF to effectively eliminate harmonics, a pure sinusoidal source voltage input is essential. If the voltage source is distorted, the SAPF cannot operate effectively on its own and must be paired with a series active power filter to first eliminate the voltage harmonics. Once the series active power filter has cleaned the source voltage harmonics, the voltage at the PCC will be pure sinusoidal, which can then be used as the input source voltage for the SAPF.

D. *SAPF Topology*

Aliyu Sabo et al(2013)[1], in their paper mentioned, Fig 7 illustrates a single-phase active power filter (APF) system that is connected in a shunt configuration to a nonlinear load, which is the primary focus of this work. In the absence of the APF, the nonlinear current negatively impacts the source current, causing the emergence of two current components: the fundamental and harmonic components, which contaminate the entire power system. By integrating the APF, a filter current (compensation current) is generated with the same amplitude but in the opposite phase, which is then fed back into the AC network.[12] This results in the source current containing only the fundamental component.

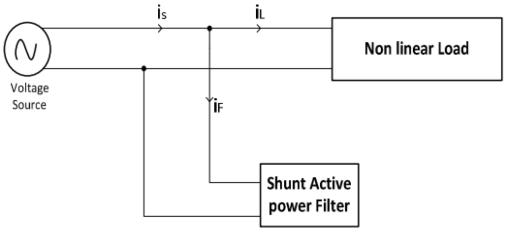


Fig. 7. Fig of APF [1]

E. *Artificial Neural Network (ANN)*

Seema Agrawal et. al. [2016] [14] presents an approach using Artificial Neural Networks (ANN) to enhance phase-locking mechanisms, which are critical for maintaining accurate signal alignment in power quality management. This approach leverages the Widrow-Hoff rule to minimize the average square error between actual and estimated signals, ensuring that the system operates with high precision. In Shunt Active Power Filters (SAPF), ANN generates a unit template that helps the filter quickly detect and respond to changes in load current, effectively compensating for current harmonics and thereby improving power quality. ANN's capability for self-learning and parallel computation makes it particularly suited for dynamic applications where conditions can change rapidly.

Muzammil Iqbal et. al. (2021)[13], mentioned that the ANN algorithm is used to model the complex relationships between the input and output of the system. The feedforward propagation back-propagation based ANN control is used in their work for voltage regulation and harmonic detection. In an Artificial Neural Network (ANN) architecture, hidden layers are positioned between the input and output layers. ANNs have the unique ability to improve their responses by learning from experience and adjusting to changes in the system.

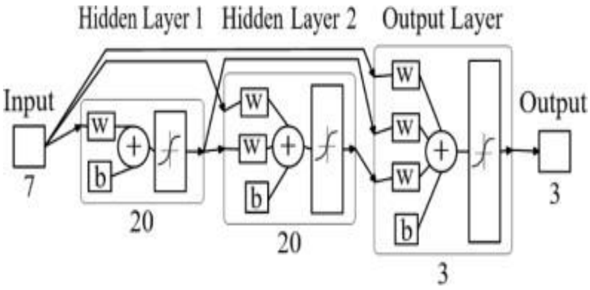


Fig. 8. ANN for harmonic detection in SAPF. [13]

For effective compensation in Active Power Filters (APFs), it's essential to quickly and accurately detect distorted signals, process reference signals properly, and ensure dynamic controller behaviour. Traditional controllers often face challenges with dynamic, non-linear loads, while controllers based on Artificial Neural Networks (ANNs) provide rapid responses and stability over a broad operational range.

III. PROBLEM IDENTIFICATION

In power systems, harmonic distortion caused by non-linear loads such as rectifiers, induction motors, and unbalanced loads presents a significant challenge to maintaining power quality. These loads introduce harmonics—multiples of the fundamental frequency—leading to issues like increased losses, equipment overheating, and reduced system efficiency. Additionally, harmonics can disrupt communication lines and protective devices, stressing critical infrastructure. The problem identification phase of this research highlights the impact of these harmonics on power systems and emphasizes the need for effective solutions, such as the Shunt Active Power Filter (SAPF), to mitigate these adverse effects and improve power quality.

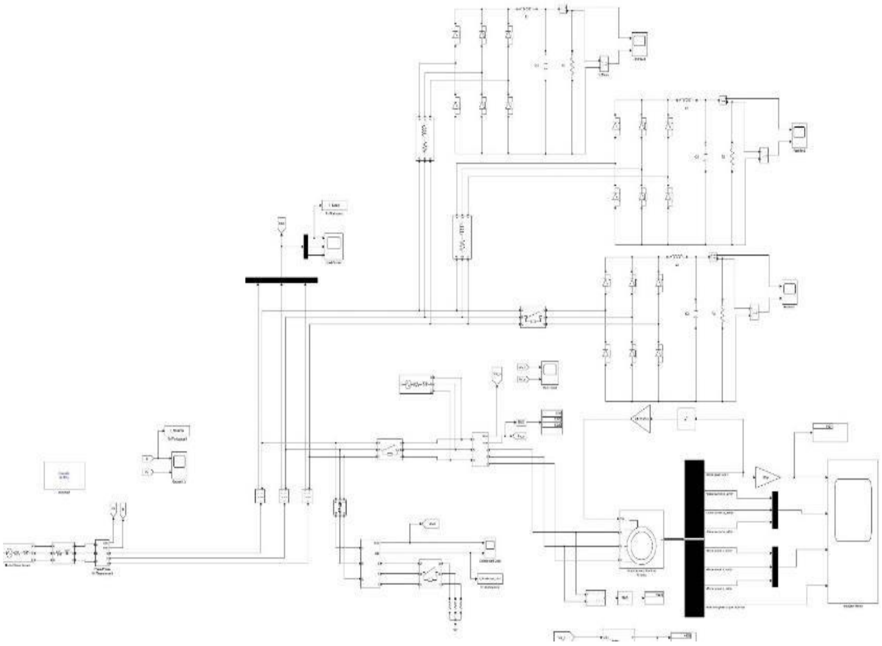


Fig. 9. Simulation Design of Power System Excluding SAPF.

The simultaneous presence of harmonics, unbalanced loads, and potential resonance conditions creates a complex environment that poses significant challenges to the stability, efficiency, and reliability of the system.

In this section, we have systematically identified and analyzed the key problems within the power system model, focusing on the interactions between the three-phase rectifier, unloaded induction motor, and three- phase unbalanced load. Each of these components introduces unique challenges, particularly concerning harmonic generation, voltage and current imbalance, and potential resonance conditions. Understanding these issues is essential for developing effective strategies to improve power quality and ensure system stability.

On running this simulation, we get the following waveforms of source current and source voltage-

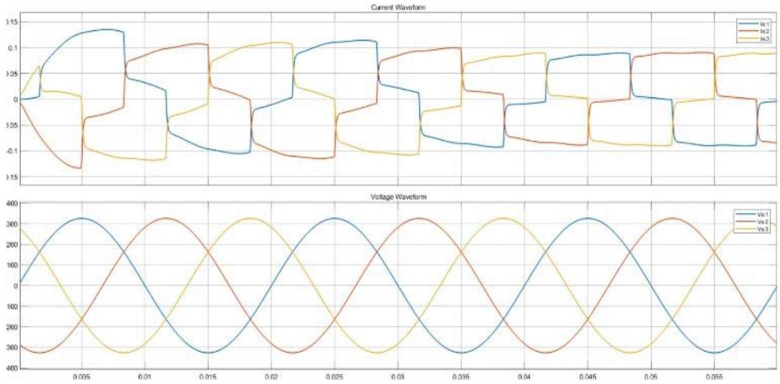
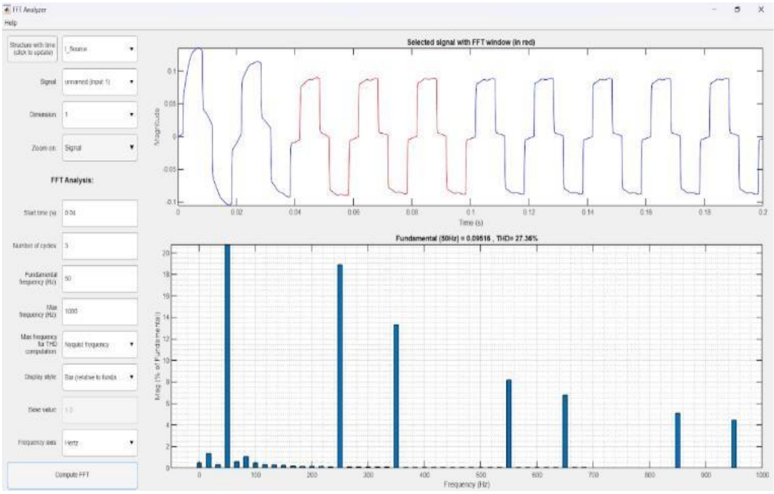


Fig. 10. Distorted waveform of source current due to harmonics.

While performing FFT analysis of this simulation diagram we get the following results-



Structure with time (click to update): I_Source
Signal: unnamed (input 1)
Dimension: 1
Zoom on: Signal
FFT Analysis:
Start time (s): 0.04
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to funda
Base value: 1.0
Frequency axis: Hertz

Fig. 11. Isource waveform and %THD

The simulation results reveal that the Total Harmonic Distortion (THD) in the power system, without the implementation of the Shunt Active Power Filter (SAPF), is 27.36%. This high level of distortion is primarily attributed to the presence of non-linear loads, rectifier in this case, which introduce significant harmonic currents into the system. The excessive THD not only impacts the efficiency of the power system but also poses a risk to the longevity and reliability of electrical equipment. This underscores the critical need for an effective harmonic mitigation strategy. Consequently, the use of an Active Power Filter becomes essential to reduce THD and enhance overall power quality, as will be explored in the proposed methodology section.

IV. PROPOSED METHODOLOGY

In this research, the proposed methodology focuses on designing and implementing an ANN based Shunt Active Power Filter (SAPF) to mitigate harmonic distortion in a power system influenced by non-linear loads. The SAPF operates by generating compensating currents that neutralize the harmonics produced by these loads, thereby reducing the Total Harmonic Distortion (THD) and improving overall power quality.

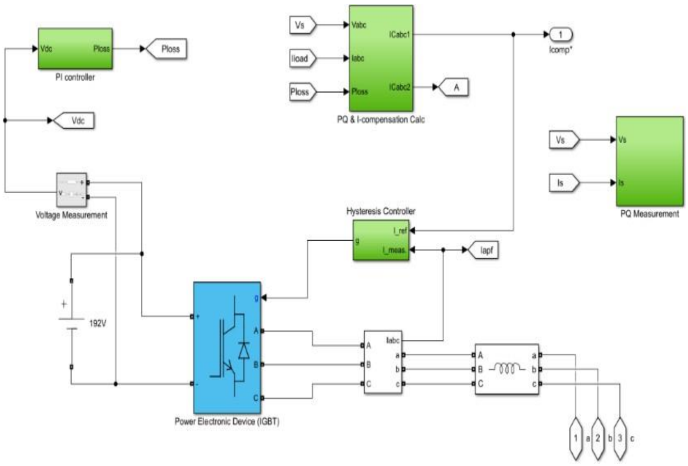


Fig. 12. Connections inside SAPF Block

The methodology centers on key components: the PI Controller, PQ and I Compensation Calculation block, Hysteresis Controller, and PQ Measurement block.

The PI Controller regulates the DC link voltage to ensure stable SAPF operation, while the PQ and I Compensation Calculation block uses PQ theory and Clarke's transformation to determine compensating currents in the α-β reference frame. The Hysteresis Controller generates switching signals for accurate injection of these currents, and the PQ Measurement subsystem monitors power quality, offering real-time feedback on THD reduction.

This methodology effectively improves power quality by mitigating harmonic distortion, highlighting the role of advanced control strategies and power theories.

A. *Clarke's Voltage Transformation*

The three-phase voltage (V_{abc}) is transformed into two-phase voltages (V_{α}, V_{β}), which are easier to work with in the context of power calculations.

Program used for this Clarke Voltage Transformation is - function [x,y] = VCT(u,v,w)

```
%#em1

x = sqrt(2/3) * (u - (0.5 * v) - (0.5 * w));

y = sqrt(2) * (0 + (0.5 * v) - (0.5 * w));
```

$$\begin{bmatrix} \boldsymbol{v_{\alpha}} \\ \boldsymbol{v_{\beta}} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

B. *Clarke's Current Transformation*

Similarly, the three-phase current (Iabc) is transformed into two-phase currents (I_{alpha}, I_{beta}), representing the load currents in the transformed reference frame.

Program for Clarke Current Transformation is - function [x,y] = ICT(u,v,w)

```
%#em1
```

```
x = sqrt(2/3) * (u - (0.5 * v) - (0.5 * w));

y = sqrt(2) * (0 + (0.5 * v) - (0.5 * w));
```

$$\begin{bmatrix} \boldsymbol{I_1} \\ \boldsymbol{I_2} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

These transformed voltages and currents are crucial for the subsequent steps in the PQ and I Compensation Calculation process.

C. *Program for PQ calculation block*

```
function [P,Q,Valpha,Vbeta] = PQ(x1,x2,y1,y2)

%#em1

P = (x1 * y1) + (x2 * y2);

Q = (x2 * y1) - (x1 * y2);

Valpha = x1; V

beta = x2;
```

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_1 & V_2 \\ -V_2 & V_1 \end{bmatrix} \begin{bmatrix} \boldsymbol{I_1} \\ \boldsymbol{I_2} \end{bmatrix}$$

D. *Program for alpha-beta current block*

```
function [Ic1,Ic2] = ICOM(Posc,q,V1,V2)

%#em1

Ic1 = (-1/(V1^2) + (V2^2)) * ((Posc * V1) + (q * V2));

Ic2 = (-1/(V1^2) + (V2^2)) * ((Posc * V2) - (q * V1));
```

$$\begin{bmatrix} I_{C1} \\ I_{C2} \end{bmatrix} = -\frac{1}{V_1^2 + V_2^2} \begin{bmatrix} V_1 & V_2 \\ V_2 & -V_1 \end{bmatrix} \begin{bmatrix} P_{OSC} \\ q \end{bmatrix}$$

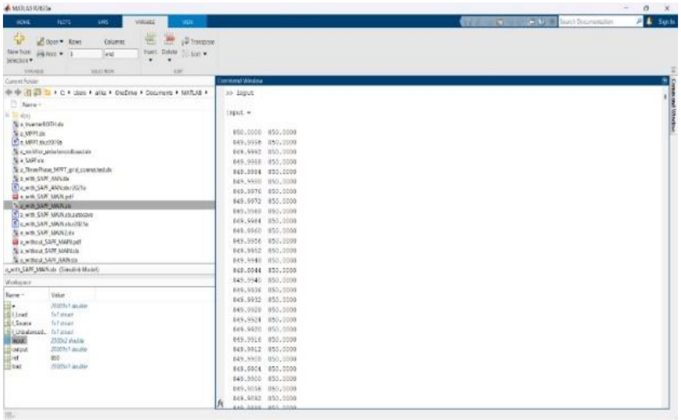
E. *Program for compensating current*

```
function [ICa, ICb, ICc] = ICal(Ic1, Ic2)

%#em1

 ICa = sqrt(2/3) * Ic1;

 ICb = sqrt(2/3) * ((-0.5 * Ic1) + (sqrt(3) / 2 * Ic2));

ICc = sqrt(2/3) * ((-0.5 * Ic1) - (sqrt(3) / 2 * Ic2));
```

$$\begin{bmatrix} I_{Ca} \\ I_{Cb} \\ I_{Cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{C1} \\ I_{C2} \end{bmatrix}$$

This MATLAB function computes the compensating currents for a three-phase system using the inputs Ic1 and Ic2, which represent the outputs of Clarke's transformation in the α-β frame. It employs trigonometric relationships to transform these α-β components back into the three-phase currents ICa, ICb, and ICc, ensuring that the compensating currents are correctly distributed among the three phases. The scaling factor $\frac{\sqrt{2}}{3}$ ensures that the calculated currents have the right amplitude.

To train the ANN, we first gather the input matrix using the previous values from the PI controller. These values are essential since the ANN will operate based on them. The input matrix has two columns: the first column contains the error values, and the second column includes the reference values.



```
>> input

input =
```

Fig. 13. Input matrix for training an artificial neural network (ANN).

Now *“nftool”* command is entered in the command window and this opens the neural fitting application.

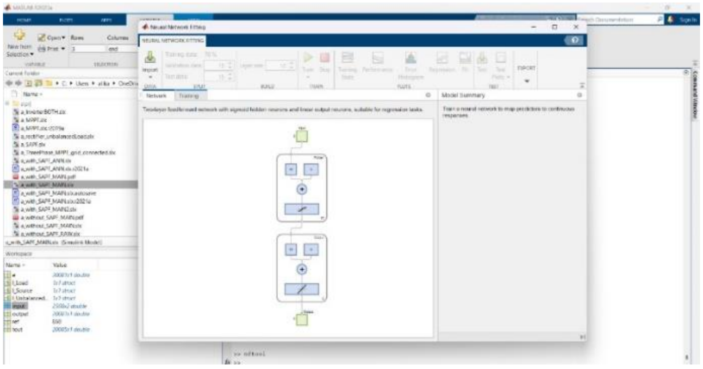
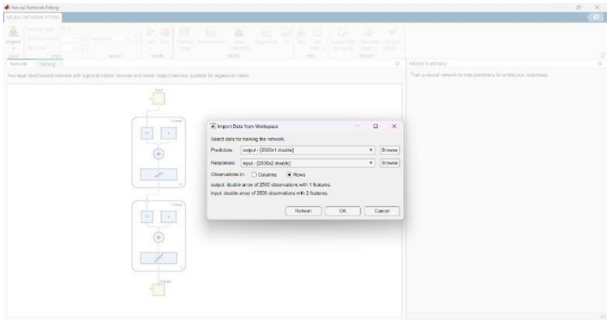


Fig. 14. nftool application.l

In a neural network fitting application, input and output values are used to train the Neural Network. The network learns to associate the input with the output based on these values. A higher regression value suggests improved training performance, indicating that the network has successfully grasped the relationship between inputs and outputs.



Import Data from Workspace

Select data for training the network.

Predictors: output - [2500x1 double]

Responses: input - [2500x2 double]

Observations in: ○ Columns ● Rows

output: double array of 2500 observations with 1 features.

input: double array of 2500 observations with 2 features.

Fig. 15. Uploading the target and input values in nftool

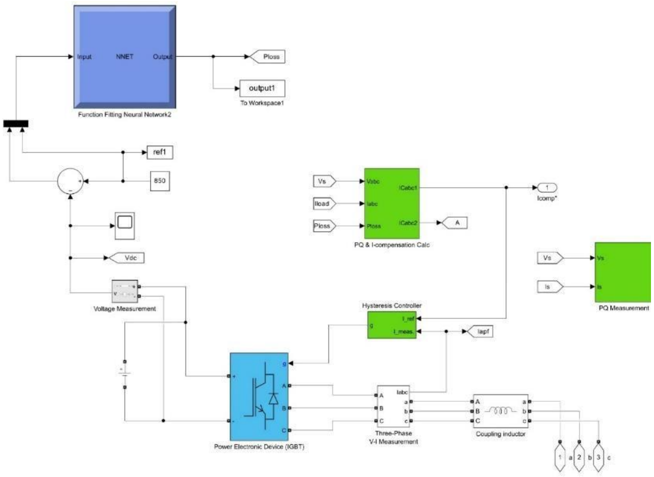
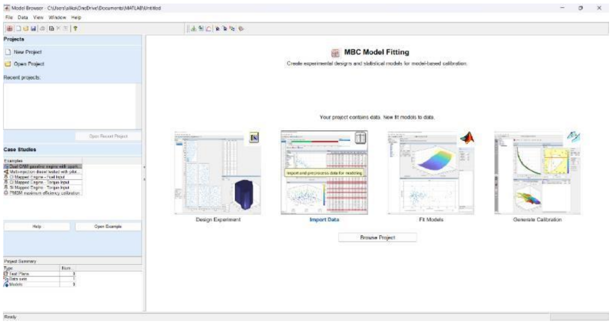


Fig. 16. Simulink diagram of ANN based SAPF.

Model-based calibration in MATLAB is used to optimize and fine-tune system parameters by creating a mathematical model of the system. It helps simulate different scenarios, test system behavior, and adjust the parameters to achieve the best performance without needing physical prototypes, saving time and resources.



Model Browser - C:\Users\alika\OneDrive\Documents\MATLAB\Untitled

MBC Model Fitting

Create experimental designs and statistical models for model-based calibration.

Your project contains data. Now fit models to data.

Import and preprocess data for modeling

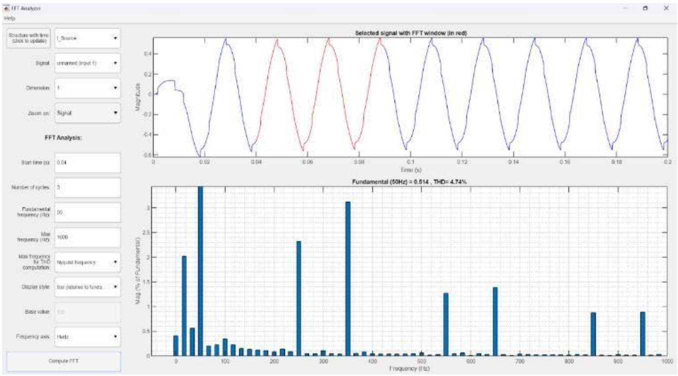
Ready

Fig. 17. MBC Model Fitting application.

V. RESULT

After implementing the ANN-based SAPF in the power system, there was a significant reduction in the THD of the source current. The SAPF was designed to inject compensating currents that effectively counteract the harmonic components in the system, leading to an overall improvement in power quality.

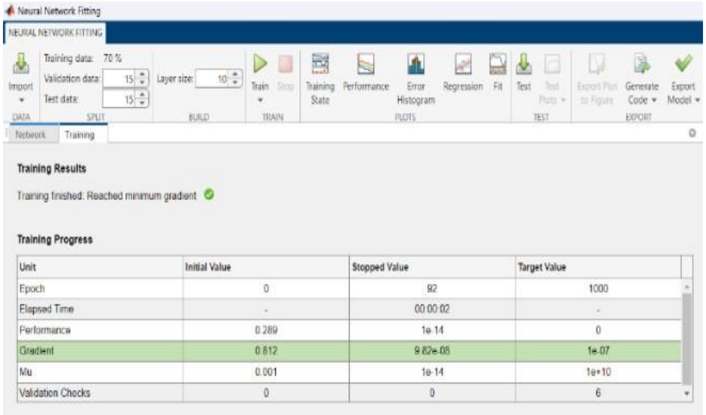
Reduced THD in Isource: With the SAPF operational, the total harmonic distortion (THD) in the source current (Isource) decreased to 4.74%. This notable reduction in THD demonstrates the SAPF's effectiveness in reducing harmonics and maintaining the power system within acceptable limits. The waveform below illustrates the harmonic content of the source current following the implementation of the SAPF.



Structure with time (click to update): I_Source
Signal: unnamed (input 1)
Dimension: 1
Zoom on: Signal
FFT Analysis:
Start time (s): 0.04
Number of cycles: 3
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to funda...
Base value: 1.0
Frequency axis: Hertz

Fig. 18. I$_{source}$ waveform and THD with SAPF

The results obtained after training the artificial neural network (ANN) are as follows:



Training data: 70 %
Validation data: 15
Test data: 15
Layer size: 10

Training Results

Training finished: Reached minimum gradient ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	92	1000
Elapsed Time	-	00:00:02	-
Performance	0.289	1e-14	0
Gradient	0.812	9.82e-08	1e-07
Mu	0.001	1e-14	1e+10
Validation Checks	0	0	6

Fig. 19. ANN Training Results including Epoch, Performance and gradient.

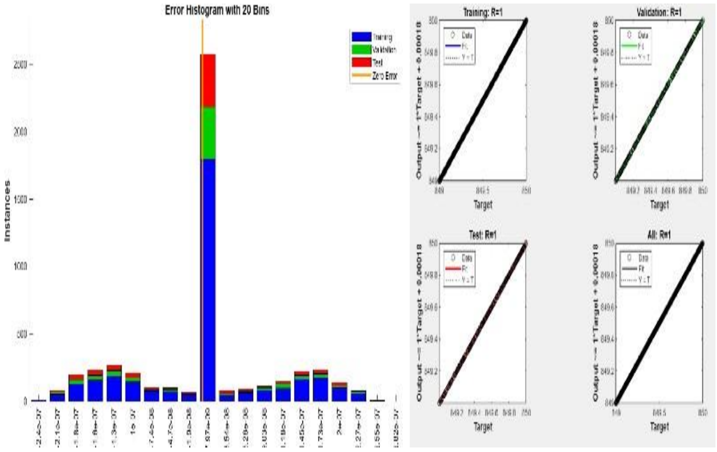
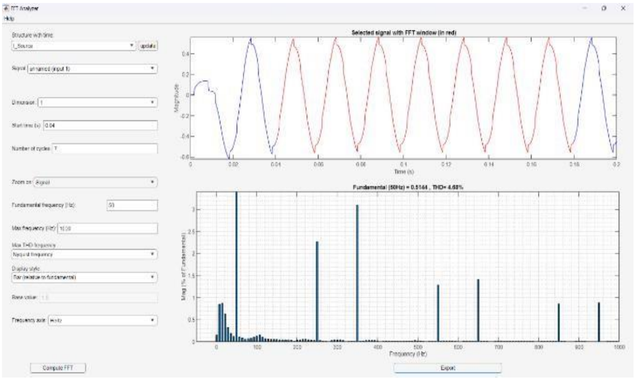


Fig. 20. Histogram & Regression Plot



Structure with time: I_Source
Signal: unnamed (input 1)
Dimension: 1
Start time (s): 0.04
Number of cycles: 7
Zoom on: Signal
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max THD frequency: Nyquist frequency
Display style: Bar (relative to fundamental)
Frequency axis: Hertz

Fig. 21. Isource waveform and THD with ANN based SAPF

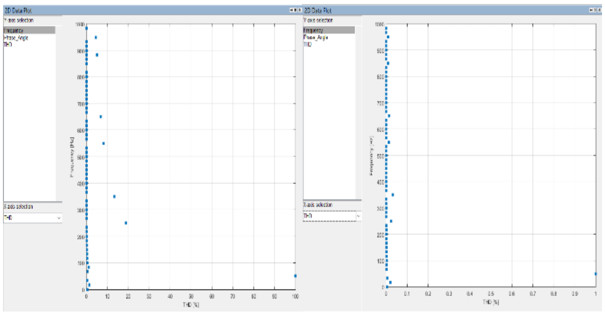


Fig. 22. 2D graph showing relation between Frequency and THD without SAPF and with SAPF respectively.

At a frequency of 50 Hz, the Total Harmonic Distortion (THD) percentage is at its peak compared to other frequency levels, showing that the 3rd harmonic is the most prominent among the harmonic multiples. As the frequency rises, the impact of higher-order harmonics diminishes, which is consistent with the usual behavior of harmonics in power systems.

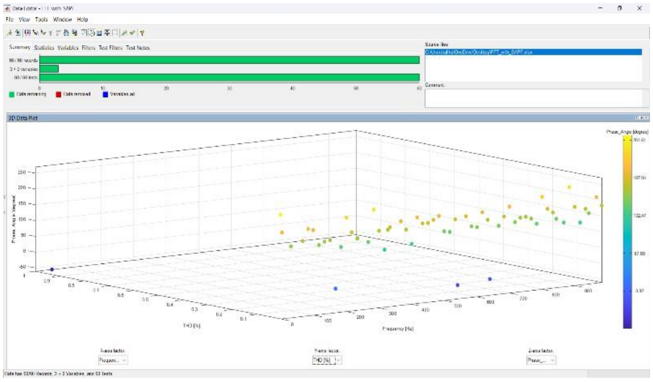


Fig. 23. 3D graph showing relation between Frequency, THD and phase angle of SAPF connected model.

VI. CONCLUSION

The research effectively showcases the design and implementation of an ANN-based Shunt Active Power Filter (SAPF) aimed at reducing harmonic distortion in power systems that utilize non-linear loads. Initially, the SAPF equipped with a PI controller managed to lower the Total Harmonic Distortion (THD) from 27.36% to 4.74%. By substituting the PI controller with an ANN, the THD was further improved to 4.68%. In line with IEEE 519 standards, which suggest maintaining a THD below 6% for systems connected to the public grid, the ANN-based SAPF significantly enhances power quality. These findings highlight the essential role of advanced filtering methods, like the ANN-integrated SAPF, in ensuring optimal power quality and supporting dependable system performance.

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