JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

COMPARATIVE ANALYSIS OF SHUNT ACTIVE POWER FILTERS UTILIZING PI CONTROLLER, FUZZY LOGIC CONTROLLER, AND ARTIFICIAL NEURAL NETWORK.

Arsh Khan*, Kamran Ali, Vinita**, Khushi Lal****

*PhD Scholar, Electrical Engineering Department, C.V. Raman University, Kota, Bilaspur (C.G.), India

**B.Tech student, Department of Electrical & Electronics Engineering, GEC Raipur, Raipur (C.G.), India

ABSTRACT

This project addresses the issue of harmonic distortion in power systems because of harmonics generating devices, such as rectifiers, induction motors, and unbalanced loads, by designing and implementing a Shunt Active Power Filter (SAPF) using advanced control strategies. Harmonics refer to voltage or current waveforms that occur at multiples of the fundamental frequency, and can significantly degrade power quality, leading to reduced efficiency, overheating, and equipment damage. The study involves a comparative analysis of three control techniques for the SAPF: a Proportional-Integral (PI) Controller, a Fuzzy Logic Controller (FLC), and an Artificial Neural Network (ANN)-based controller. The SAPF demonstrated notable Total Harmonic Distortion (THD) reductions, with the PI Controller achieving 5.76%, the FLC-based SAPF improving to 5.19%, and the ANN-based SAPF delivering the best performance at 4.74%. The SAPF design integrates subsystems such as PQ and I Compensation Calculation for determining compensating currents, a Hysteresis Controller for generating switching signals, and a PQ Measurement subsystem for monitoring power quality. These components enable effective harmonic mitigation and improved overall power quality. The ANN-based SAPF's adaptive learning capability and real-time optimization establish it as a superior and practical solution for real-world applications requiring high power quality, highlighting the potential of intelligent control strategies in addressing complex power system challenges.

Keywords - *Harmonic distortion, Shunt Active Power Filter (SAPF), Total Harmonic Distortion (THD), Proportional-Integral (PI) Controller, Fuzzy Logic Controller (FLC), Artificial Neural Network (ANN), non-linear loads, power quality, compensating currents, hysteresis controller, PQ and I Compensation Calculation, PQ Measurement subsystem, adaptive control, real-time optimization, intelligent control strategies.*

INTRODUCTION

Power quality plays a vital role in today's electrical systems, significantly affecting the efficiency, reliability, and longevity of electrical equipment. A major challenge in ensuring high power quality is harmonic distortion, which is especially common in systems that include non-linear loads like rectifiers, induction motors, and unbalanced loads. [6] Harmonics are voltage or current waveforms that appear at multiples of the fundamental frequency. They can cause various negative effects, such as decreased efficiency, equipment overheating, and higher losses in the power system. [2]

This research focuses on mitigating harmonic distortion through the design and implementation of a Shunt Active Power Filter (SAPF) using advanced control strategies. The SAPF is a power electronic device designed to generate compensating currents that neutralize harmonics introduced by non-linear loads, thereby enhancing overall power quality.

The study undertakes a comparative analysis of three control techniques for the SAPF: the conventional Proportional-Integral (PI) controller, a Fuzzy Logic Controller (FLC), and an Artificial Neural Network (ANN)-based controller. Among these, the ANN-based SAPF demonstrated the highest effectiveness in mitigating harmonic distortion. The ANN's adaptive learning capabilities enable it to optimize control signals in real time, providing more precise and efficient compensation compared to traditional methods.

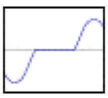
The effectiveness of the SAPF was evaluated based on its ability to reduce the Total Harmonic Distortion (THD) in the source current—a critical metric of power quality. A power system model comprising three-phase rectifiers, an unloaded induction motor, and a three-phase unbalanced load was analyzed. These components represent typical sources of harmonics in industrial and commercial environments.

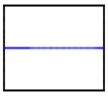
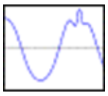
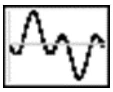
This research highlights the superiority of the ANN-based SAPF in improving power quality over PI and FLC-based methods. The ANN-based approach provides a robust, adaptive solution for real-world applications where maintaining high power quality is essential. The findings underscore the potential of intelligent control strategies in addressing complex power system challenges effectively.

LITERATURE SURVEY

FACTORS AFFECTING POWER QUALITY:

Since the 1980s, various industries have increasingly adopted power electronic devices for a range of applications. These applications include uninterrupted power supplies (UPS), variable frequency drives (VFDs), and switch-mode power supplies (SMPS). However, these semiconductor devices can cause distortion in sinusoidal currents. This distortion leads to harmonic currents passing through system impedance, which in turn generates voltage harmonics. The table below outlines the most common power quality issues.

1. Very short interruptions 	**Description**: A complete loss of electrical supply lasting from a few milliseconds to one or two seconds. **Causes**: Primarily caused by the opening and automatic reclosure of protection devices to isolate a faulty section of the network. Common fault causes include insulation failure, lightning strikes, and insulator flashovers. **Consequences**: This can lead to the tripping of protection devices, loss of information, and malfunctioning of data processing equipment. Sensitive equipment, such as adjustable speed drives (ASDs), PCs, and PLCs, may shut down if they are not equipped to handle this situation.[3]

2. Long interruptions 	**Description**: A complete interruption of electrical supply lasting longer than 1 to 2 seconds. **Causes**: This can result from equipment failure in the power system network, storms, objects like trees or cars striking lines or poles, fire, human error, or poor coordination or failure of protection devices.[3] **Consequences**: The stoppage of all equipment.
3. Voltage spike 	**Description**: A voltage spike is a rapid change in voltage, lasting from a few microseconds to a few milliseconds. **Causes**: Common causes include lightning strikes, the switching of power lines or capacitors for power factor correction, and the discharge of large loads. **Consequences**: The results can be severe. Components, especially electronic ones, may get damaged. Insulation materials can also fail. This may lead to data processing mistakes or even data loss, along with electromagnetic interference.[3]
4. Voltage swell 	**Description**: A rapid fluctuation in voltage lasting from several microseconds to a few milliseconds, with variations that can reach thousands of volts, even at low voltage levels. **Causes**: These fluctuations can be caused by lightning, switching of lines or power factor correction capacitors, and the disconnection of heavy loads. **Consequences**: Potential destruction of components, particularly electronic ones, damage to insulation materials, data processing errors or data loss, and electromagnetic interference.[3]
5. Harmonic Distortion 	**Description**: Harmonic distortion happens when voltage or current waveforms take on non-sinusoidal shapes. This occurs because the waveform is made up of various sine waves that differ in magnitude and phase. The frequencies of these waves are multiples of the power-system frequency. **Causes**: Traditional sources include electric machines operating above the knee of their magnetization curve (which means they reach magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors. In today's world, non-linear loads such as power electronics equipment—like adjustable speed drives (ASDs), switched mode power supplies, data processing gear, and energy-efficient lighting—also contribute to this issue.[3] **Consequences**: This can lead to several problems such as an increased chance of resonance, overload in neutral conductors within three-phase systems, overheating of cables and equipment, reduced efficiency in electric machines, and interference with communication systems. It may also cause errors in readings from average measurement metres and unintended tripping of thermal protections.[3]

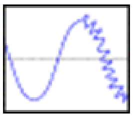
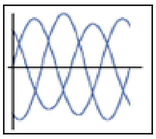
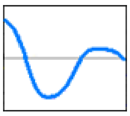
6. Voltage Fluctuation 	**Overview**: Voltage or current waveforms do not always follow a smooth, sinusoidal shape. Instead, they look different. This irregular shape comes from adding various sine waves. These waves have different sizes and phases. Their frequency is a multiple of the power system frequency.[10] **Origins**: Common sources of these variations include electric machines that run above a specific point known as the "knee" of the magnetization curve[10] (which is when magnetic saturation occurs). Other sources are arc furnaces, welding machines, rectifiers, and DC brushed motors. Nowadays, newer sources like non-linear loads also play a big role. Some examples are adjustable speed drives (ASDs), switched-mode power supplies, equipment for data processing, and energy-efficient lighting.[3]
7. Noise 	High-frequency signals often sit on top of the regular power system's waveform. **Origins**: These extra signals usually come from electromagnetic interference. This is often due to Hertzian waves like microwaves, TV broadcasts, and radiation emitted by welding machines, arc furnaces, & different electronic gadgets. Sometimes, improper grounding leads to this interference too.[3] **Impacts**: The presence of noise can cause problems for sensitive electronic devices. While these disturbances generally aren't harmful, they can lead to issues like data loss or errors during data processing.[3]
8. Voltage Unbalance 	**Description**: A voltage variation in a three-phase system where the three voltage magnitudes or the phase angle differences between them are unequal. **Causes**: This can occur due to large single-phase loads, such as induction furnaces or traction loads, or from incorrect distribution of single-phase loads across the three phases of the system, which may also result from a fault.[3] **Consequences**: Unbalanced systems create a negative sequence that is detrimental to all three-phase loads, with three-phase induction machines being the most affected.[3]
9. Voltage Sag (or dip) 	**Description**: A reduction in the normal voltage level, ranging between 10% and 90% of the nominal RMS voltage at the power frequency, lasting from 0.5 cycles to 1 minute. **Causes**: This can be caused by faults in the transmission or distribution network, often on parallel feeders, faults within a consumer's installation, the connection of heavy loads, or the start-up of large motors.[3] **Consequences**: This voltage drop can lead to the malfunction of information technology equipment, especially microprocessor-based control systems like PCs, PLCs, and ASDs, potentially causing process stoppages. It can also result in the tripping of contactors and electromechanical relays, as well as disconnection and reduced efficiency in electric rotating machines.[3][11]

Table 1. Most common power Quality affects. [3]

HARMONICS:

S. Parthasarathy et al. (2012) [6] identified harmonics as a leading issue related to power quality. Non-linear loads, such as converters, inverters, and choppers, lead to this problem. These types of loads create harmonic currents. These currents are then injected into the supply system, which ultimately decreases overall efficiency.

Electric power produced by a generating side ideally consists of a perfect sinusoidal waveform However, in real-world situations, it's tough to achieve that ideal condition at the user end. Many factors come into play here. For, transformers & rotating machinery can alter the currents—this is known as harmonic current. These deviations can differ from the pure sine wave form. As a result, the supply voltage might be distorted. This distortion often depends on the source impedance & the strength of the harmonic current.

Arsh Khan et al. (2024)[2] indicate that the harmonics in a system are often evaluated using Total Harmonic Distortion (THD) measurements. *"THD is defined as a metric that quantifies the distortion or irregularities in the voltage or current waveform of a power system caused by the presence of harmonics."*

The formula provided below is used to determine the THD of a system.

$$\frac{\sqrt[2]{\sum_{N=2}^{\infty} V_N^2}}{V_{1(rms)}}$$

HARMONICS MITIGATION USING FILTERS:

A filter is an electronic apparatus that isolates specific frequencies while blocking or reducing others through the use of resistors, capacitors, inductors, and various other electronic components. Filters are employed to eliminate noise, harmonics, and to generate clean, stable signals.

Zainal Salam et al. (2006)[10] mention in their study on harmonic distortion in power distribution systems that there are two main strategies for minimizing harmonic distortion. The first strategy involves passive filtering, while the second entails active powering. The simplest and most conventional way to reduce harmonic distortion is through passive filtering. Standard passive filters consist of inductors, capacitors, and resistors that are arranged and fine-tuned to control sound.

Passive Power Filter:

S. Parthasarathy et al. (2012)[6] noted that passive filters are commonly utilized for mitigating harmonics and have been a conventional remedy in power systems. These filters are made up of passive elements like resistors, capacitors, and inductors, and they function independently of an external power supply. Their role is either to redirect harmonic currents away from the line or to inhibit their movement between different system sections by adjusting to particular frequencies.

Active Power Filter:

S. Parthasarathy (2012)[6] and colleagues, in their study, indicate that Active Power Filters (APF) overcome the shortcomings of passive filters by using a power converter to remove harmonic currents. A Shunt Active Power Filter (SAPF) is specifically designed to reduce harmonic currents while also providing reactive power compensation. The SAPF functions as a current source in conjunction with the nonlinear load. The power converter within the APF is controlled to produce a compensation current that matches the magnitude of the harmonic current generated by the nonlinear load but flows in the opposite direction. Active filters use an active component, such as an operational amplifier, along with passive components like resistors, capacitors, and inductors.

Penumathsa Manasa et al. (2018)[5] discuss the instantaneous reactive power theory in their paper. The established traditional power theories for single-phase sinusoidal systems have been well documented, but these principles cannot be adequately addressed in the context of nonlinear loads. The instantaneous reactive power (IRP) theory, also referred to as p-q theory, relies on the abc-αß0 transformation. It effectively compensates for harmonic power in both sinusoidal and unbalanced supply voltage systems but performs poorly under conditions of unbalanced and non-sinusoidal supply voltages.

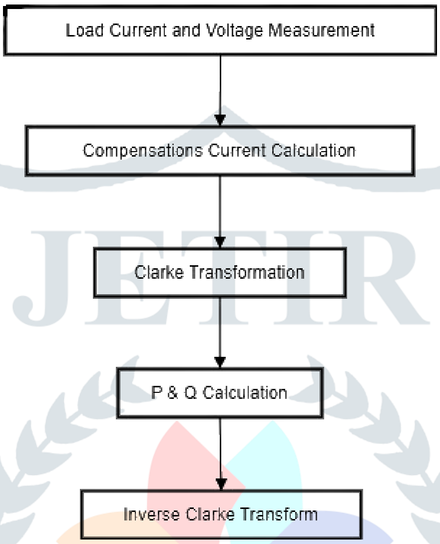


Fig 1. Flow Chart Representation of PQ theory [5]

Series Active power filter:

Zainal Salam et al. (2006)[10] stated that The operational principle of a series Active Power Filter (APF) is based on the separation of harmonics between the nonlinear load and the power source. This is accomplished by injecting harmonic voltages (V_f) through the interfacing transformer. Series APFs are not as commonly used as their counterpart, the shunt APF. This is mainly due to the fact that series APFs must handle high load currents. The increased power load currents significantly raise their current rating, especially on the secondary side of the interface transformer, which consequently leads to higher I^2R losses.

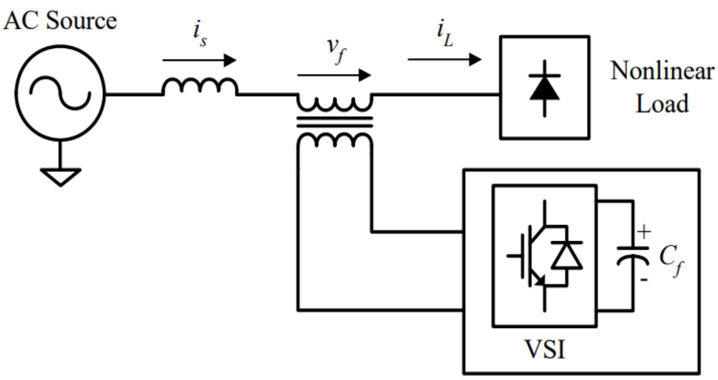


Fig 2. The main configuration of a Voltage Source Inverter (VSI) based series Active Power Filter (APF). [10]

Shunt Active power filter:

Zainal Salam et al. (2006)[10] describe The system consists of a capacitor on the DC bus (C_f), a power electronic switch, and an interface inductor (L_f). The shunt Active Power Filter (APF) acts as a current source, compensating for the harmonic currents produced by nonlinear loads. The APF shunt works by injecting a compensation current that replicates the distorted current, effectively cancelling it out. This is done by "shaping" the compensation current waveform (I_f) using voltage source inverter switches. The compensation current shape is determined by measuring the load current (I_l) and subtracting it from a sinusoidal reference. The objective of the APF shunt is to produce a sinusoidal current (I_s) based on the relationship: $Is = I_l – I_f$.

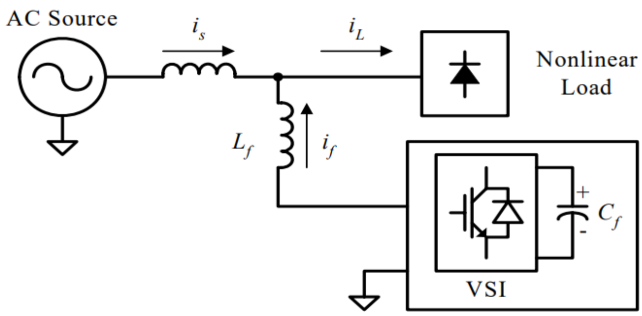


Fig 3. The main configuration of a Voltage Source Inverter (VSI) based shunt Active Power Filter (APF). [10]

In their paper, Muhammad Ossama Mahmoud et al. (2020)[4] describe how The SAPF control system employs (p-q) theory to identify the optimal instantaneous current that should be injected by the SAPF to reduce source current harmonics, even when the source voltage is affected by harmonics. The SAPF injects a harmonic current that matches the magnitude but is opposite in phase to the current in each phase of the supply system at the point of common coupling (PCC). For the SAPF to effectively eliminate harmonics, it is crucial to have a purely sinusoidal input source voltage signal. If the source voltage is distorted, the SAPF cannot function effectively on its own and needs to be combined with a series active power filter to first eliminate the harmonic distortions from the source voltage. After the series active power filter has removed the harmonic distortions, the voltage at the PCC becomes purely sinusoidal, which can then serve as the input source voltage signal for the SAPF.

Fuzzy Logic Controller

Abderrahmen Benyamina et al., (2023)[1] in their research paper mentioned that control by fuzzy logic is considered among the intelligent and robust techniques, hence it is used in many applications like control of electrical machines, power electronic converters and active filters. The main advantage of a fuzzy controller is that it doesn't need a model of the controlled system; it can operate easily with inaccurate signals, and can treat non linearity.

The structure of fuzzy controller basically comprises of three modules which are -

1. Fuzzification
2. Fuzzy interference
3. De-fuzzification

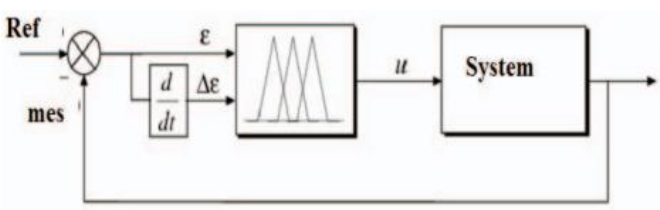


Figure 4. Control principle of the active filter by a fuzzy controller [1]

The main drawback of using fuzzy controllers is that, a real time implementation of fuzzy logic requires a powerful processor, many solutions are proposed to reduce fuzzy logic complexity, neural network is one of them.

Artificial Neural Network

Seema Agrawal et. al. [2016] [8] 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 minimise 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.

Several advanced ANN structures have been developed to address different challenges in power quality management. These include:

1. Adaptive Neuro-Fuzzy Inference System (ANFIS): combines neural networks with fuzzy logic for enhanced decision-making

2. Radial-Basis-Function Neural Network (RBFNN): excels in pattern recognition

3. Adaptive Linear Neuron (ADALINE): valuable for linear modelling

4. Recurrent Neural Network (RNN): handles sequences of data

5. Feed-Forward Multilayer Neural Network (MNN): known for its effectiveness in a range of tasks requiring a clear data flow.

Among these, Feed-Forward MNN and ADALINE are particularly popular for their efficiency in extracting harmonic currents in Active Power Filters (APFs).

To demonstrate the effectiveness of the proposed ANN-based control system, simulations were conducted using MATLAB/Simulink, a widely-used tool for modelling and analysing electrical systems. These simulations validate the proposed approach and highlight its potential to significantly enhance power quality in practical applications.

PROBLEM IDENTIFICATION

In electrical power systems, harmonic distortion caused by non-linear loads such as rectifiers, induction motors, and unbalanced loads presents a significant challenge for ensuring power quality. These loads produce harmonics, which are multiples of the fundamental frequency, leading to issues like higher power losses, overheating of equipment, and reduced system efficiency. Furthermore, harmonics can interfere with communication lines and protective devices, putting critical infrastructure under stress. The problem identification phase of this study underscores the effects of these harmonics on power systems and highlights the necessity for effective solutions, such as the Shunt Active Power Filter (SAPF), to alleviate these negative impacts and enhance power quality.

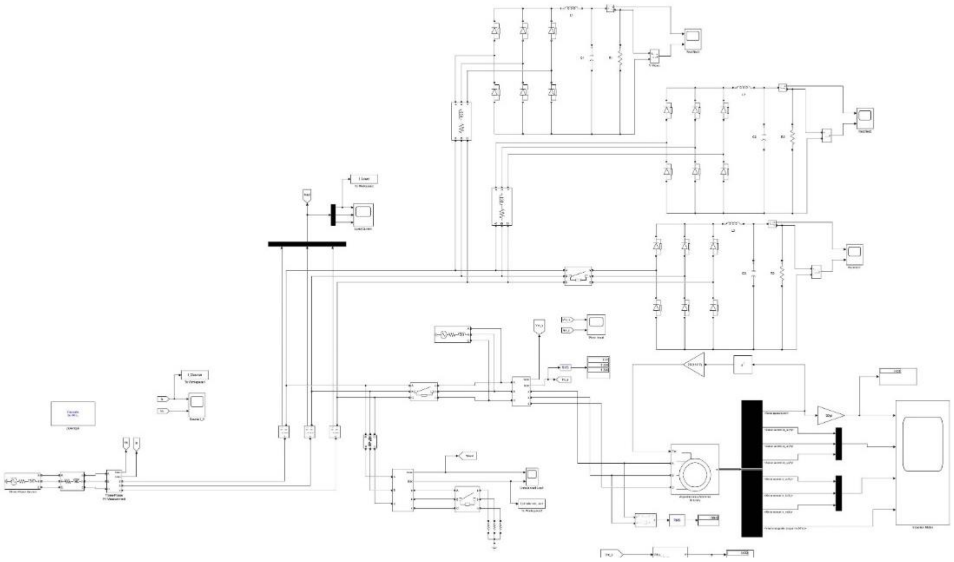


Fig 5. Simulation Design of Power System without SAPF

The simultaneous occurrence of harmonics, unbalanced loads, and possible resonance conditions creates a complicated situation that presents considerable challenges to the system's stability, efficiency, and reliability. In this section, we have methodically identified and examined the primary issues within the power system model, concentrating on the interactions among the three-phase rectifier, an unloaded induction motor, and a three-phase unbalanced load. Each of these elements contributes distinct challenges, especially regarding harmonic generation, voltage and current imbalances, and possible resonance conditions. Grasping these problems is crucial for devising effective strategies to enhance power quality and maintain system stability. Upon conducting this simulation, we obtained the following waveforms for the source current and source voltage—

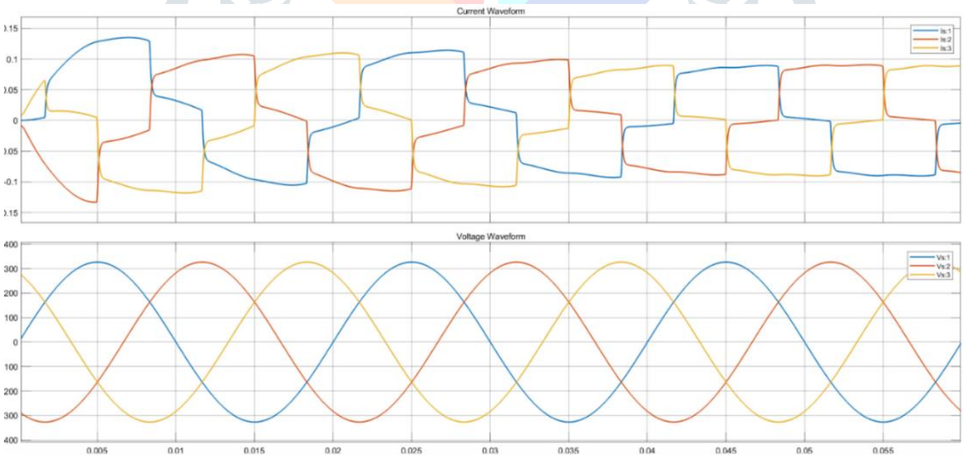


Fig 6. Distorted waveform of source current due to harmonics.

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

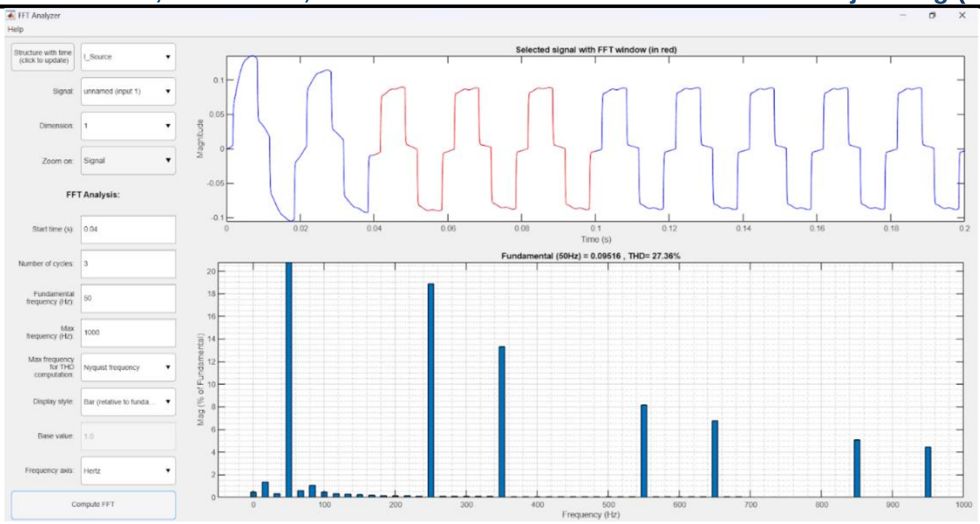


Fig 7. I_{source} waveform and %THD

The simulation results show that the Total Harmonic Distortion (THD) in the power system, before implementing the Shunt Active Power Filter (SAPF), is at 27.36%. This high level of distortion is primarily caused by the presence of non-linear loads, specifically the rectifier, which injects considerable harmonic currents into the system. The high THD not only affects the power system's efficiency but also threatens the durability and dependability of electrical devices. This highlights the urgent necessity for an effective strategy to mitigate harmonics. Therefore, implementing an Active Power Filter is crucial for minimizing THD and improving overall power quality, which will be discussed in the proposed methodology section.

PROPOSED METHODOLOGY

This study focuses on the design and implementation of a Shunt Active Power Filter (SAPF) that uses Artificial Neural Networks (ANN), alongside another SAPF that employs Fuzzy Logic Control, to tackle harmonic distortion in power systems influenced by non-linear loads. A comparison of these two methods is carried out to determine which one is more effective and suitable. The SAPF works by generating compensating currents that counterbalance the harmonics produced by non-linear loads, thereby reducing Total Harmonic Distortion (THD) and improving overall power quality.

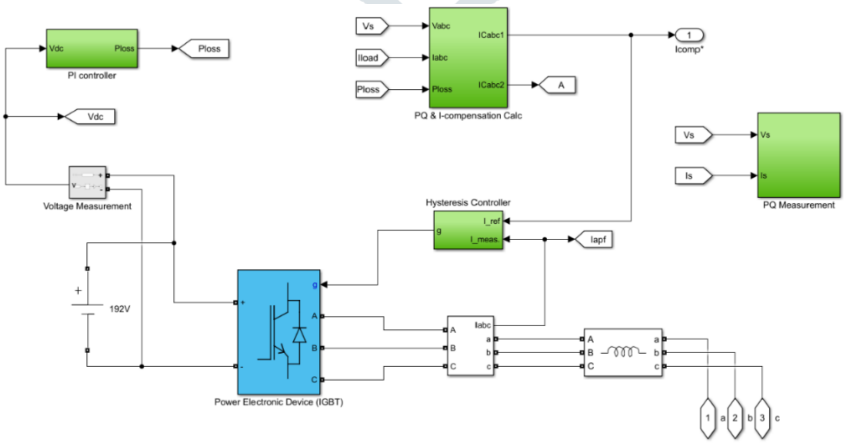


Fig 8. Connections inside SAPF Block

The approach is based on several essential elements: the PI Controller, the PQ and I Compensation Calculation block, the Hysteresis Controller, and the PQ Measurement block.

- The PI Controller regulates the DC link voltage to maintain stable operation of the SAPF.
- The PQ and I Compensation Calculation block computes compensating currents using PQ theory, relying on instantaneous power in the α-β reference frame, with Clarke's transformation being used to convert abc signals for easier analysis.
- The Hysteresis Controller produces switching signals that ensure accurate injection of compensating currents.
- The PQ Measurement subsystem tracks power quality, supplying real-time feedback on the reduction of THD.

CLARKE VOLTAGE TRANSFORMATION:	**CLARKE CURRENT TRANSFORMATION:**

The three-phase voltage (Vabc) is transformed into two-phase voltages (Valpha, Vbeta), 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);
	Similarly, the three-phase current (Iabc) is transformed into two-phase currents (Ialpha, Ibeta), 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);

PROGRAM FOR PQ CALCULATION BLOCK IS -	**PROGRAM USED FOR ALPHA BETA CURRENT BLOCK IS -**
function [P,Q,Valpha,Vbeta] = PQ(x1,x2,y1,y2) %#em1 P = (x1 * y1) + (x2 * y2); Q = (x2 * y1) - (x1 * y2); Valpha = x1; Vbeta = x2;	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));
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));	

Table 3. Clarke and Inverse Clarke Transformation

This MATLAB function determines the compensating currents for a three-phase system using Ic1 and Ic2, which represent the outputs from Clarke's transformation in the α-β domain. The function employs trigonometric relationships to transform these α-β components back into the three-phase currents ICa, ICb, and ICc, thereby ensuring an accurate allocation of the compensating currents among the three phases. The scaling factor $\frac{\sqrt{2}}{3}$ represents that the calculated currents maintain the correct amplitude.

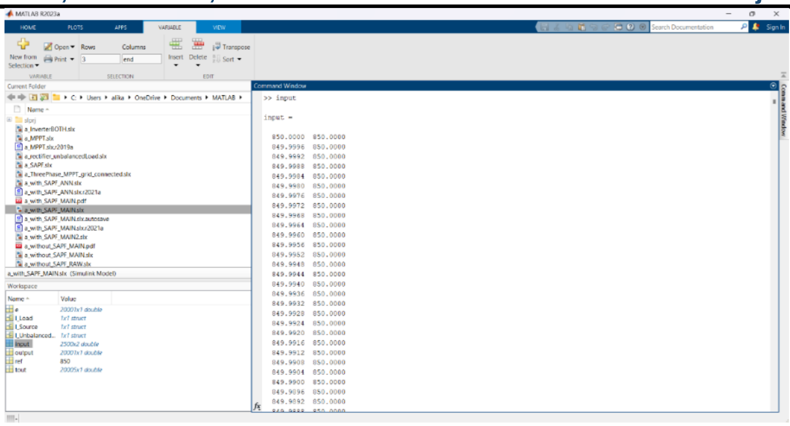


Fig 9. Input matrix for training of ANN

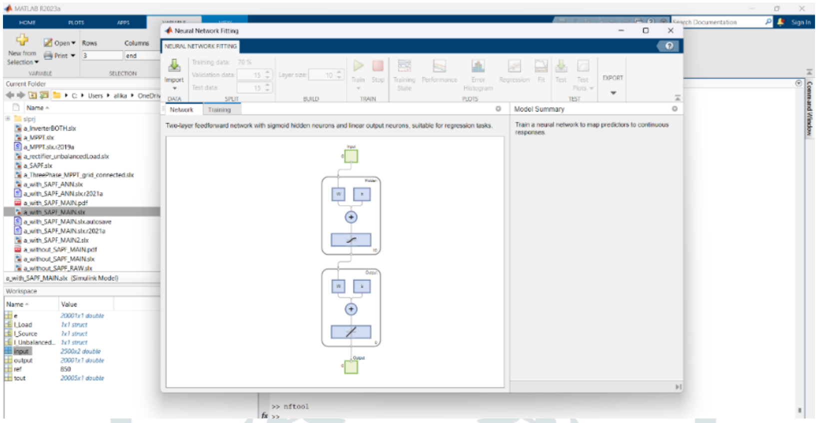


Fig 10. nftool application

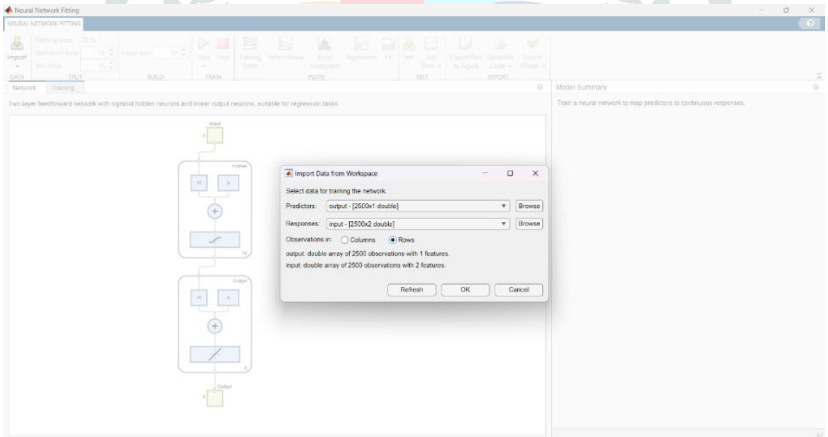


Fig 11. Uploading the target and input values in nftool

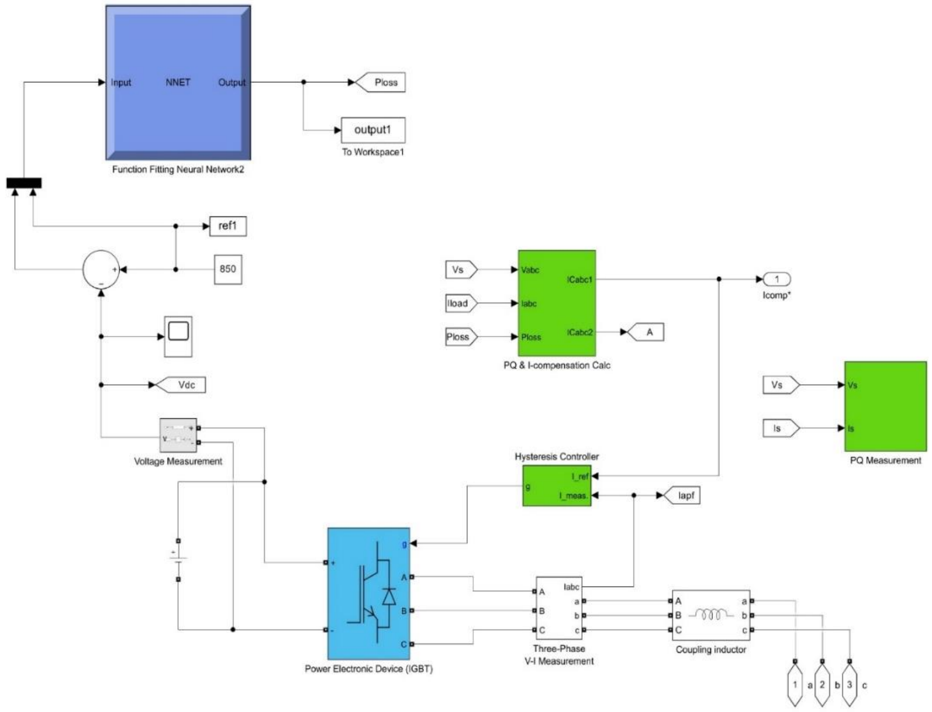


Fig 12. Simulink diagram of ANN based SAPF.

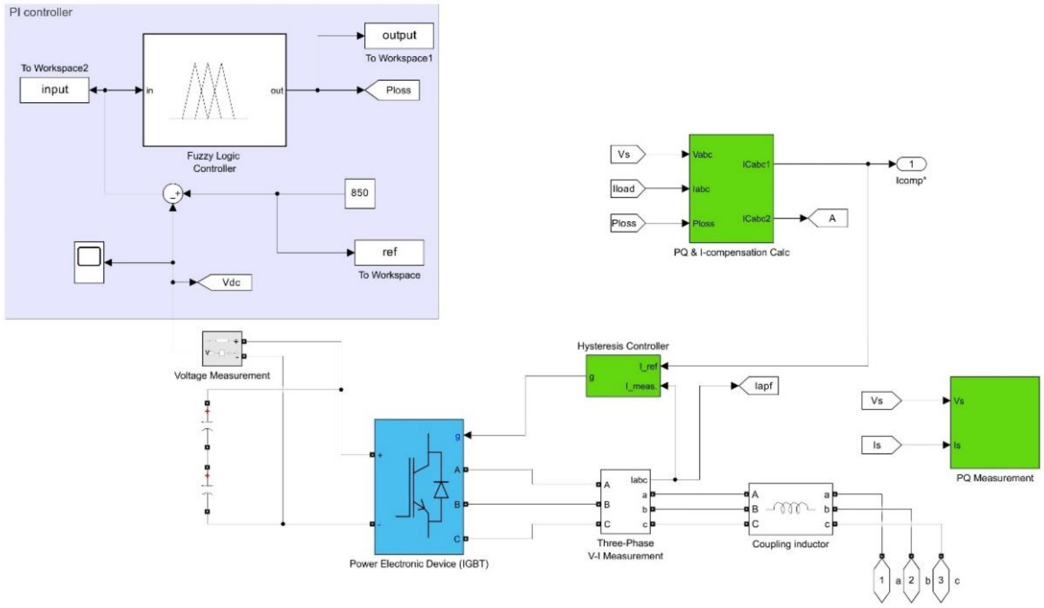


Fig 13. Simulink diagram of a Fuzzy Logic Controller (FLC) for a Shunt Active Power Filter (SAPF).

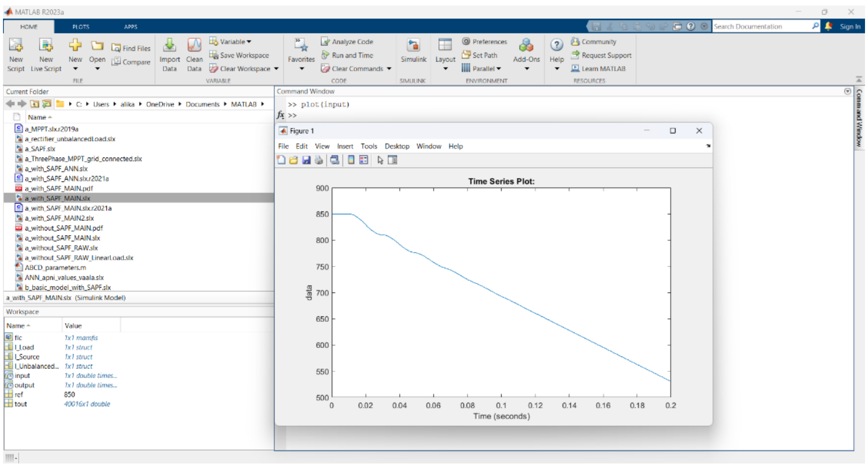


Fig 14. Input curve obtained for getting input values to be fed in Fuzzy Logic Controller

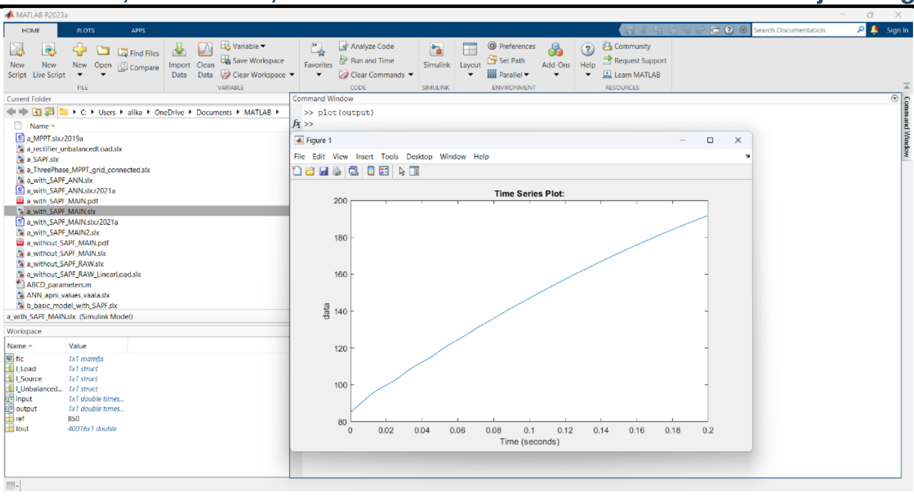


Fig 15. Output curve obtained for getting output values to be fed in Fuzzy Logic Controller

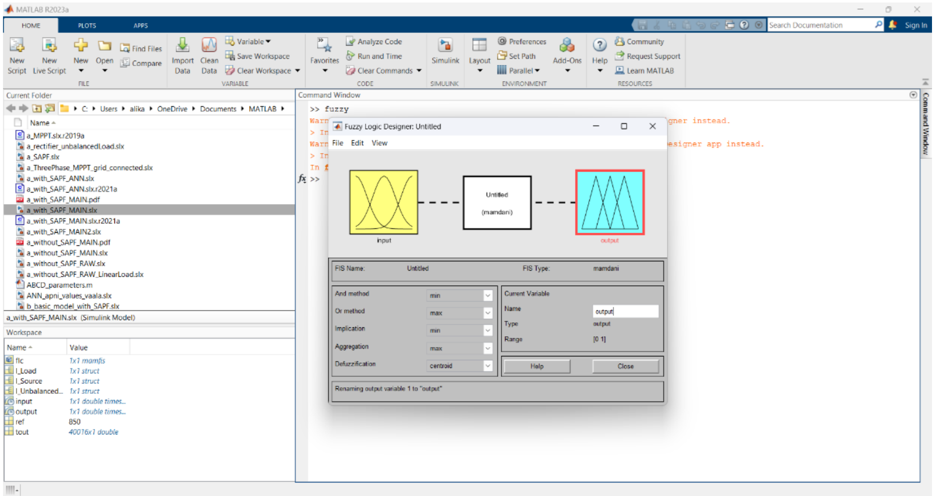


Fig 16. Fuzzy Logic Controller (FLC) Application

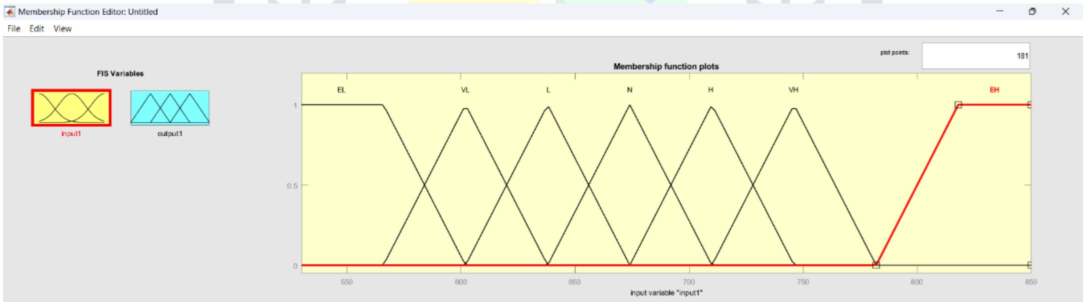


Fig 17. Input membership function graph

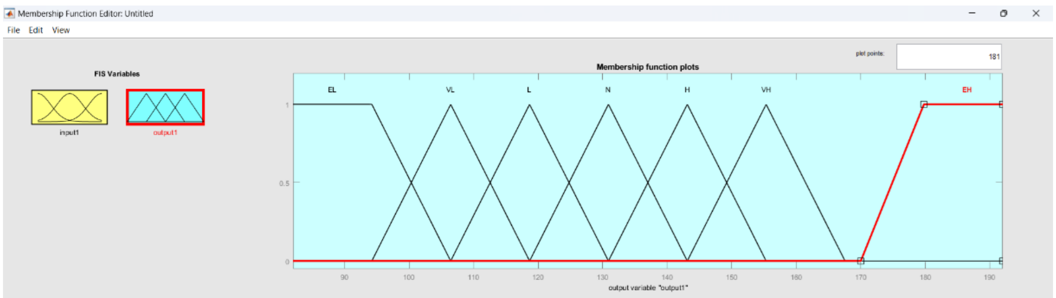


Fig 18. Output membership function graph

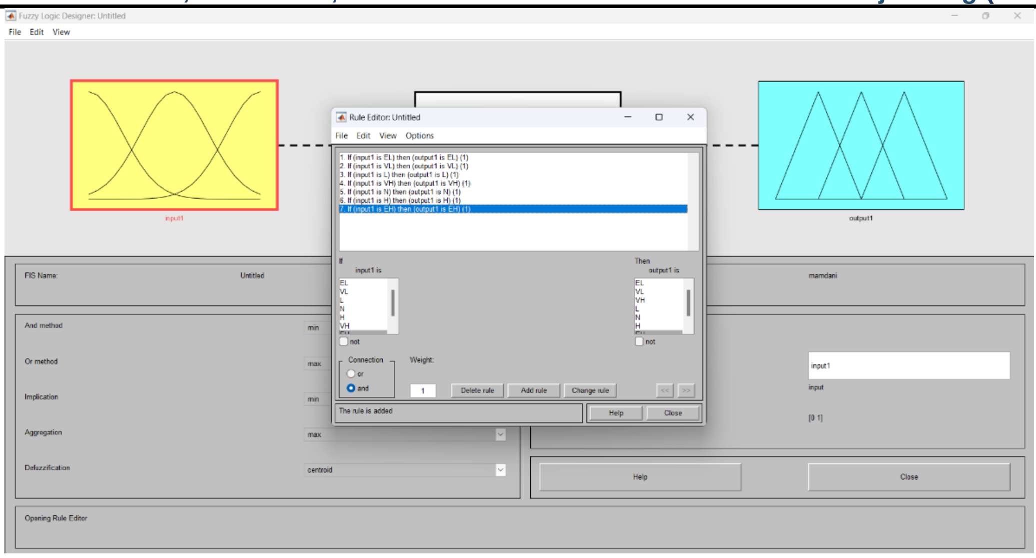


Fig 19. Feeding Instructions to FLC

Model-based calibration in MATLAB allows for the optimization and refinement of system parameters through the development of a mathematical representation of the system. It enables the simulation of various scenarios, examination of system performance, and adjustment of parameters to attain optimal performance without the necessity of physical prototypes, thereby conserving time and resources.

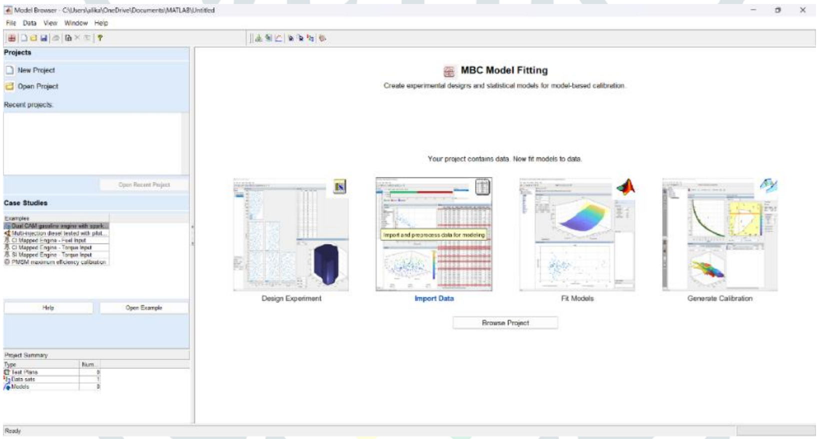


Fig 20. MBC Model Fitting application.

RESULT

The SAPF was created to inject compensating currents that effectively neutralize the harmonic components in the system, which in turn improves overall power quality. At first, the use of a conventional SAPF led to some improvement in the Total Harmonic Distortion (THD) within the system. The addition of a Fuzzy Logic Controller to the SAPF further reduced the THD. However, the ANN-based SAPF surpassed both methods, achieving a more substantial reduction in THD and proving to be more effective in enhancing power quality.

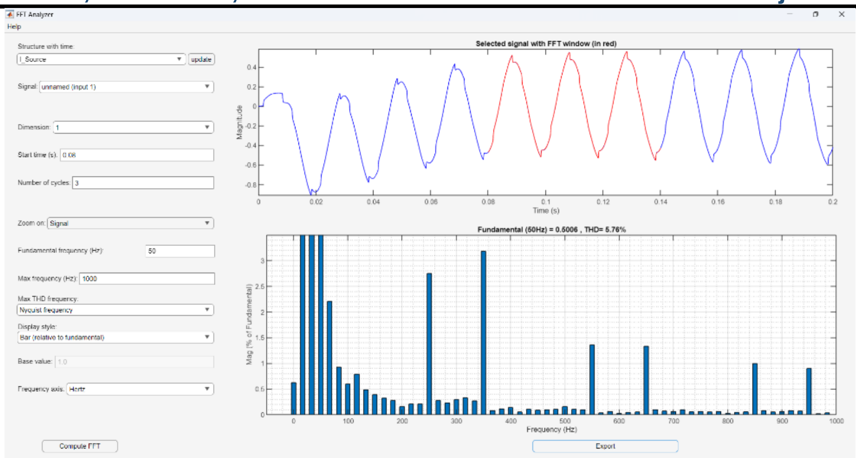


Fig 21. I_{source} waveform and THD with SAPF

The results obtained after training of ANN are as follows:

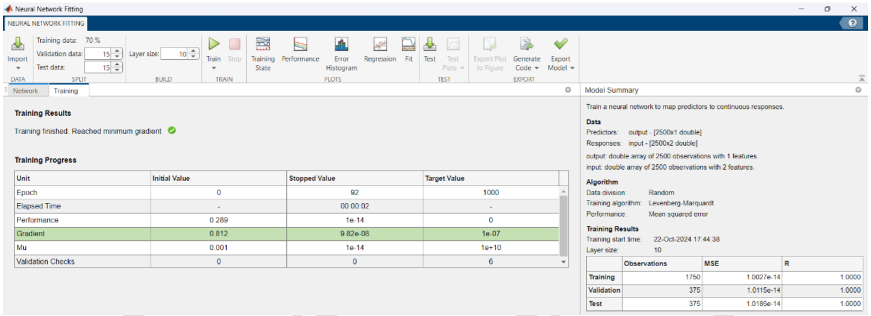


Fig 22.ANN Training Results including Epoch, Performance and gradient.

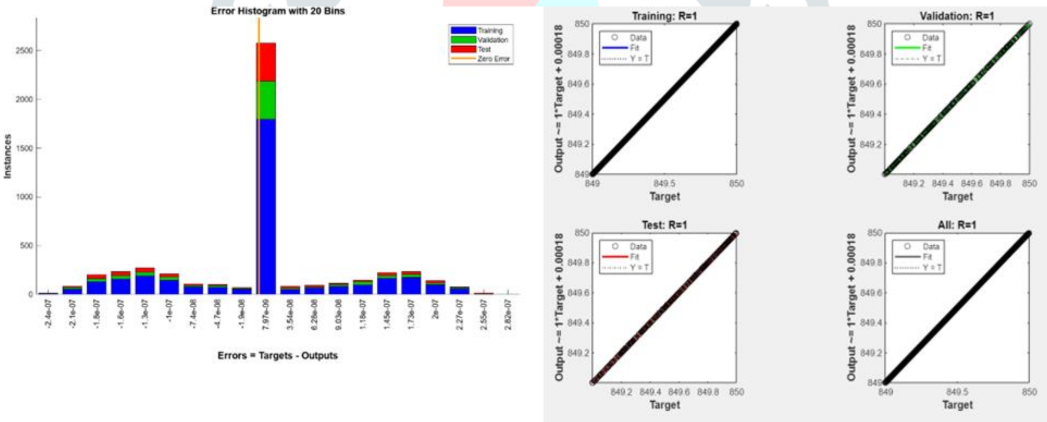


Fig 23. Histogram Plot & Regression Plot

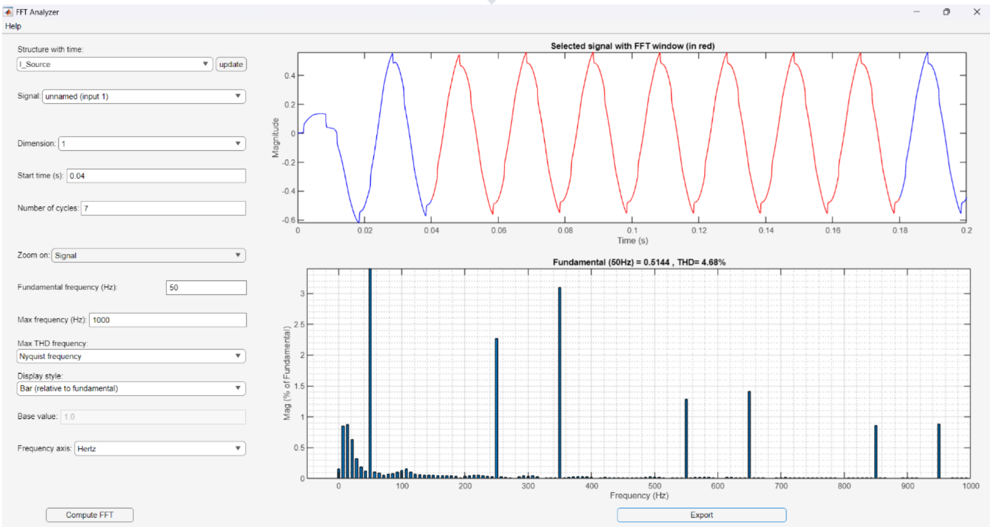


Fig 24. I_{source} waveform and THD with ANN based SAPF

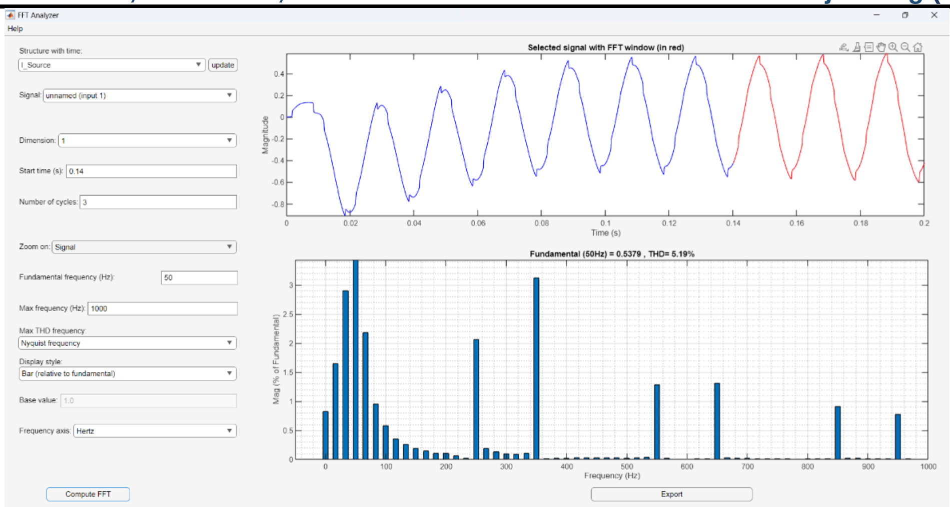


Fig 25. I_{source} waveform and THD with FLC based SAPF

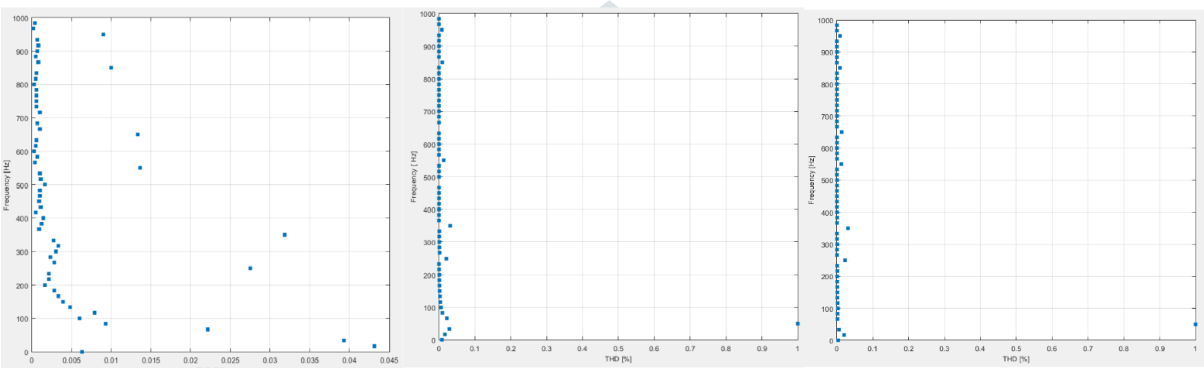


Fig 26. 2-D graph plot of Frequency v/s THD with PI controller based SAPF, FLC based SAPF and ANN based SAPF respectively.

At a frequency of 50 Hz, the percentage Total Harmonic Distortion (THD) is highest compared to other frequency levels, indicating that the 3rd harmonic is the most significant among the harmonic multiples. As the frequency increases, the contribution of higher-order harmonics decreases, which aligns with the typical behaviour of harmonics in power systems.

Methodology used	PI controller based (conventional)	Fuzzy Inference System (FIS) based	Artificial Neural Network (ANN) based
%THD	*5.76%*	*5.19%*	*4.74%*

Table 4 . Results obtained in different techniques

From the above-mentioned analysis, we observed the numerical data comparison. Now, for the signal data comparison, we will examine the outputs using the Data Inspector application in MATLAB/Simulink.

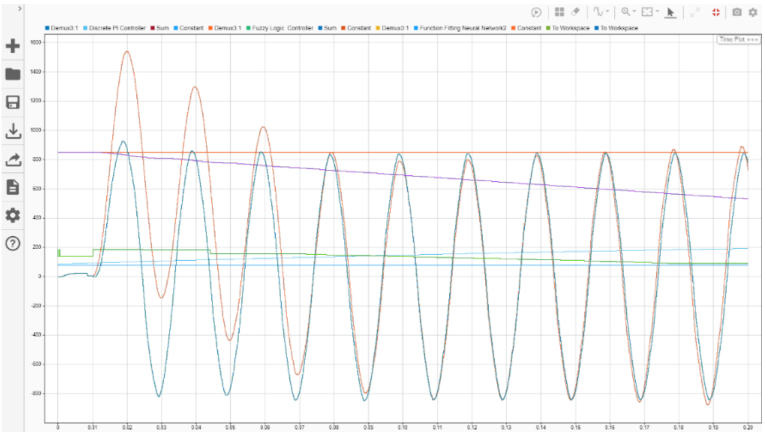


Fig 27. Plot of different signals in one plane

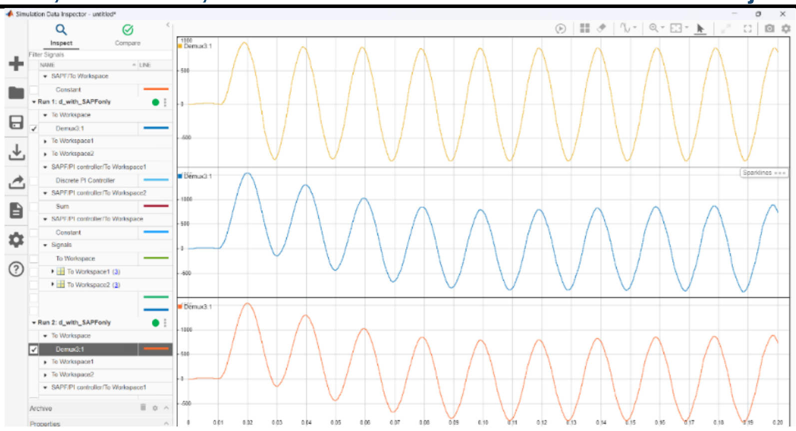


Fig 28. Plot of current waveforms in PI, FLC and ANN based SAPF respectively.

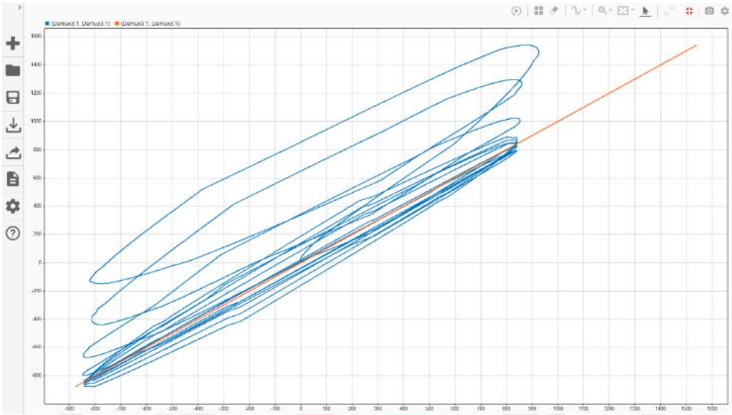


Fig 29. Circular plot of PI, FLC and ANN based SAPF.

Fig 30. Plot of ANN, PI controller and FLC signals.

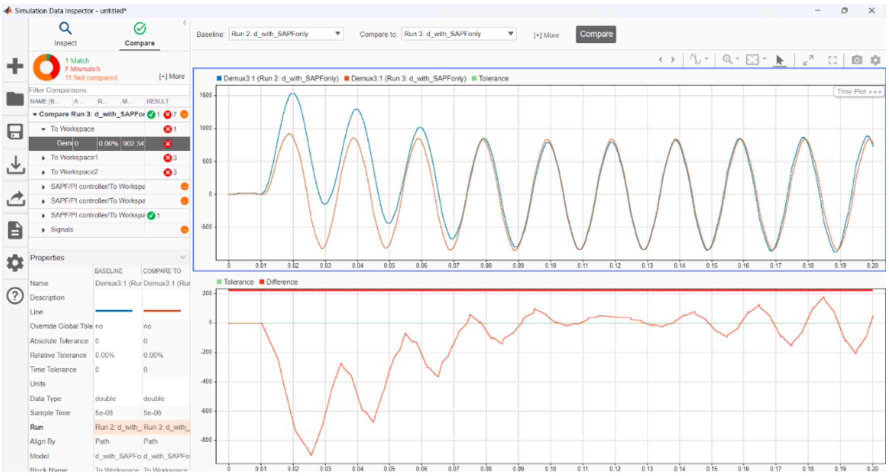


Fig 31. Comparison between FLC and ANN based SAPF methodolgies.

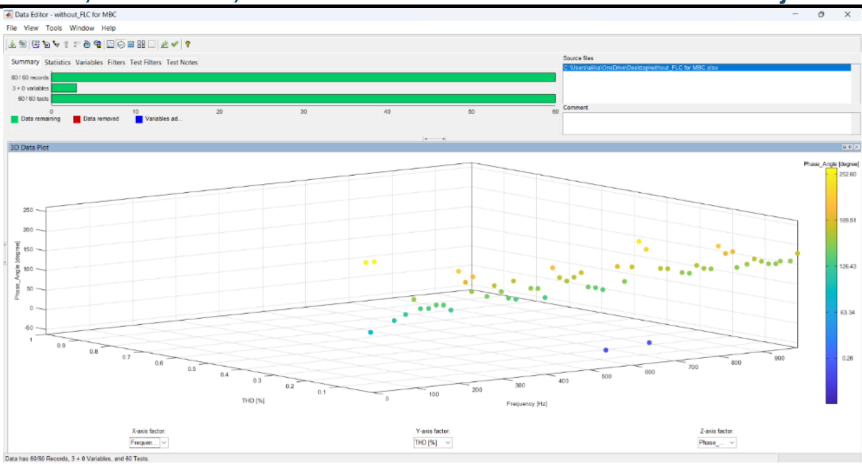


Fig 32. MBC 3-D plot using PI controller based SAPF

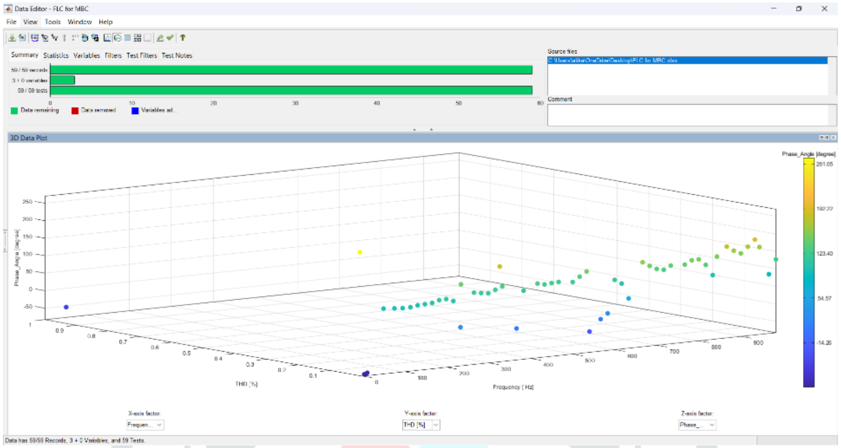


Fig 33. MBC 3-D plot using Fuzzy Logic controller based SAPF

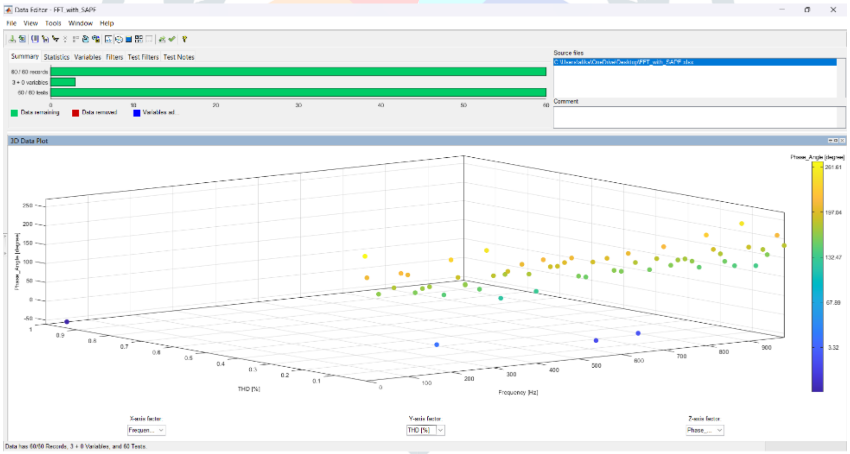


Fig 34. MBC 3-D plot using Artificial Neural Network based SAPF

CONCLUSION

This research demonstrates the effectiveness of advanced control strategies for mitigating harmonic distortion in power systems with non-linear loads. A comparative analysis of control techniques in a Shunt Active Power Filter (SAPF) showed that the PI controller reduced the Total Harmonic Distortion (THD) from 27.36% to 5.76%, while the Fuzzy Logic Controller (FLC) further improved it to 5.19%. The ANN-based SAPF achieved the best performance, reducing THD to 4.68%, satisfying IEEE 519 standards for power quality.

These results highlight the progression from traditional PI control to intelligent methods like FLC and ANN, with the ANN-based SAPF offering superior adaptability and performance under dynamic conditions. This research underscores the importance of intelligent filtering techniques in improving power quality and ensuring efficient, reliable system performance.

REFERENCES

[1] Abderrahmen Benyamina, Samir Moulahoum, Ilhami Colak, Ramazan Bayindir "Hybrid Fuzzy Logic-Artificial Neural Network Controller for Shunt Active Power Filter", 5th International Conference on Renewable Energy Research and Applications.

[2] Arsh Khan, Shashwat Dhurandhar, Rupendra Patel, Mayank Nagwanshi, Rose Mary Tirkey "Power Quality Analysis And Improvement Using Shunt Active Power Filter With Neural Network & Machine Learning", 2024 JETIR April 2024, Volume 11, Issue 4 www.jetir.org(ISSN-2349-5162).

[3] De Almeida A., Moreira L., Delgado J., "Power quality problems and new solutions", ISR – Department of Electrical and Computer Engineering University of Coimbra, Pólo II, Renewable Energy and Power Quality Journal.

[4] Muhammad Ossama Mahmoud, Wael Mamdouh, Hamdy Khalil "Source current harmonic mitigation of distorted voltage source by using shunt active power filter", International Journal of Electrical and Computer Engineering (IJECE) .

[5] Penumathsa Manasa, K. Narasimha Rao, D. Bala Bhaskar "Mitigation Of Harmonics Using Shunt Active Power Filter In The Distribution System" © 2018 JETIR July 2018, Volume 5, Issue 7 www.jetir.org (ISSN-2349-5162)

[6] S. Parthasarathy, Dr . V. Rajasekaran "Harmonic Mitigation in a Rectifier System Using Hybrid Power Filter ",2012 International Conference on Computing, Electronics and Electrical Technologies [ICCEET] .

[7] Sharma Yatharth, R Vijay Mohan "Capacitor Banks and Its Effect on Power System with High Harmonics Loads", 2018 3rd International Conference for Convergence in Technology (I2CT).

[8] Seema Agrawal, Prakash Kumar , D. K. Palwalia "Artificial Neural Network based Three Phase Shunt Active Power Filter".

[9] Zainal Salam ,Tan Perng Cheng and Awang Jusoh "Harmonics Mitigation Using Active Power Filter: A Technological Review" Department of Energy Conversion, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor, Malaysia. Corresponding author: zainals@fke.utm.my (Z.Salam).

[10] Alfaris, Faris Ebrahem. "Modular Static Transmission and Distribution controller of Distributed Renewable Energy Resources.", North Carolina State University, 2020.

[11] Ferreira, Fernando Jose Teixeira Estevao "Strategies to Improve the performance of Three-phase Induction motor driven systems", Universidad de Coimbra (Portugal), 2022.