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Mitigation Of Grid Current Harmonics By Using Anfis Based Shunt Active Power Filter

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Abstract:
More applications are using non-linear power electronic equipment, which distorts the current distribution system and creates significant Power-Quality (PQ) issues. These sophisticated non-linear power electronics, such as rectifiers and switch-mode power supplies, cause reactive power issues and harmonic current distortions that deteriorate the purity of source waveforms at the distribution system's common coupling/feeding point (PCC). Modern power systems must be designed with dependable power filters that reduce voltage and current harmonics in order to satisfy utility grid power quality standards.

This project discusses a thorough, methodical approach to designing a shunt active power filter (SAPF) for improving power quality. The DC-link voltage is controlled by an ANFIS controller. The extraction of the reference current makes use of the instantaneous reactive power theory. Based on PQ theory, the best Shunt Active Power Filter has been created for PQ improvement; this is the technologically and commercially ideal equipment. MATLAB/Simulink is used to generate and simulate the detailed SAPF for balanced nonlinear loads.

***Key Word**: Power Quality (PQ), Common Coupling Point(PCC), Shunt Active Power Filter(SAPF), Adaptive Neuro-Fuzzy Inference System (ANFIS).*

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I. Introduction

Power electronic switches are the foundation of nonlinear electric appliances, which are extensively employed in both residential and commercial applications across the globe [1,2]. Power quality issues such harmonic distortion, voltage fluctuation, and noise are caused by nonlinear loads like arc furnaces, variable frequency drives (VFDs), and personal computers [3-5]. Power losses, electric device heating, insulation failures and the communication system interference, in the worst situations, electric power systems failures are all caused by harmonic distortion in low-voltage distribution systems[6]. As a result, fixing power quality issues has emerged as a crucial concern for both the utility and the consumer [7-8]. This standard specifies that the total harmonic distortion (THD) cannot be greater than 5%. Power filters are thus utilised in order to adhere to the 5% restriction [9]. Power filters are readily available, effective technologies that are frequently employed to stop the spread of harmonic distortion. Typically, passive power filters in series and shunt configurations are connected to the distribution network in order to enhance power quality [10]. Designing a passive power filter that can successfully remove harmonic current distortion in industrial nonlinear loads connected to a stiff power source is difficult, tough[11]. Additionally, the passive filter is connected to intrinsic flaws include its massive bulk, resonance with utility or load impedance, unpredictability and rigidity [12–14]. On the other hand, passive filters have been substituted by active power filters (APFs) that use voltage source inverters (VSIs) in order to overcome the classic filters limitations.

APFs are a great way to address power quality issues because of their many advantages, which include flexibility, quick dynamic response, and accurate progressive filtering [15]. The current harmonics, reactive power sensing technique, compensation control algorithm, and other factors primarily dictate the harmonic mitigation capability of the shunt active power filter [16–17]. The instantaneous reactive power theory (P-Q theory) is commonly used to compare the various reference compensation current control systems. The following steps are taken in order to finish the donations listed above: Section II provides ANN based SAPF, Fuzzy tuned PI based SAPF, ANFIS based SAPF.

Shunt Active Power Filter:

The most widely used kind of active filter is SAPF. A SAPF converter can be single-phase or three-phase, and it can be a voltage source or current source inverter. With a 180° phase shift, this filter functions as a current source, injecting the harmonic components of the load. Its controller forces a power electronic converter to accurately synthesize the compensating current reference by computing it in real time. Selective and adaptive active filtering is made possible by this technique. Stated differently, a SAPF may track changes in the harmonic content of a nonlinear load on a regular basis and adjust for the harmonic current of the load. The shunt active filter of source current harmonics is controlled by four different algorithms. For this project, PQ theory is being used. In order to create the SAPF reference current for source current harmonic mitigation, the theory (PQ), an adaptive phase-locked loop (PLL), the instantaneous active and reactive current method (DQ), and the synchronous detection method (SD) are designed in Matlab Simulink. For this project, PQ theory is being applied.

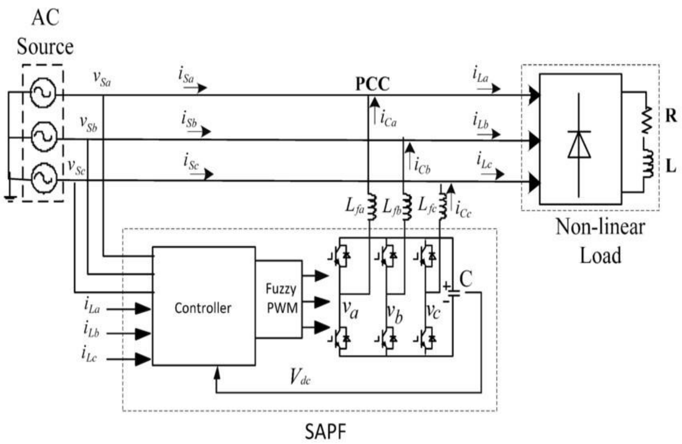

Figure 1.1: Block diagram of SAPF

P-Q Theory:

According to (PQ) theory, the reference current signal computation is based on detecting the three-phase currents and voltages to the power system and then using an algebraic transformation (Clarke Transformation) to convert them into (ϱ-β) coordinates and generates reference currents. DC voltage regulation done by PI controller.

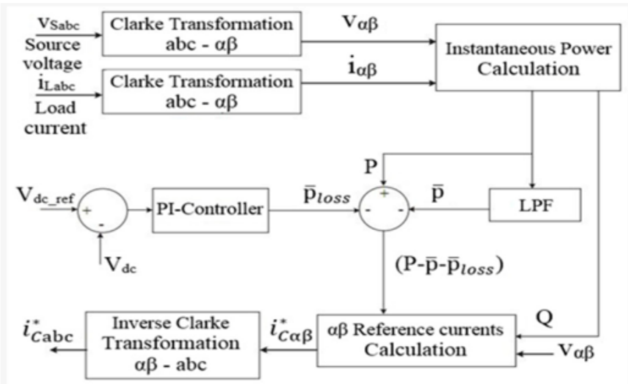

Figure 1.2: Block Diagram of PQ Theory

II. Proposed Controllers

The MATLAB simulative environment was used for the implementation of the proposed reference generation and current control techniques for a SAPF. This study was implemented according to the following scenarios.

- ANN based SAPF
- FUZZY tuned PI based SAPF
- ANFIS based SAPF

ANN Based SAPF:

Shunt active power filter performance is based on how well harmonic components are removed from distorted current waveforms with respect to accuracy and precision. The optimal performance for removing harmonic components from the voltage or current waveform has led to the development of the shunt active power filter control algorithm. In order to control voltage, a conventional PI controller is typically used.

However, because of its limitations, such as the time-consuming and difficult process of detecting PI parameters, as well as other drawbacks like the inability to improve the system's transient response, an artificial neural network (ANN) controller has been introduced in this research work. This is because of the controller's high speed of recognition, learning ability, and adaptability to any system. A mathematical model that draws inspiration from biological neural networks is called an artificial neural network (ANN).

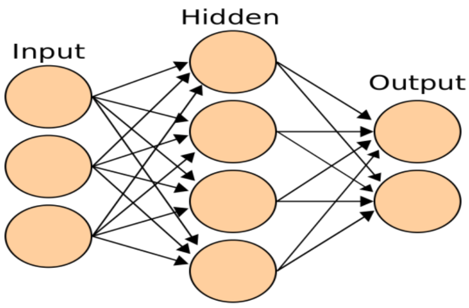

Figure 2.1: Structure of ANN

An artificial neural network is made up of a network of connected artificial neurons that compute information using the connectionist technique. It is similar to the brain in two ways: one is the learning process is how the network gathers the data, two is The data is stored using interneuron connection strengths. The MATLAB workspace has the vast amount of DC-link voltage data for the "n" and "n-1" intervals obtained via the traditional method. After that, the ANN Controller is trained using this data that has been retrieved. To process the information, the number of neurons in the input and output layers is essentially fixed. In order to reduce the likelihood of errors occurring, six validation checks and seven hidden layers with 1000 iterations are performed at each training session. The necessary conditions for the intended compensation in the case of SAPF are the quick identification of the disruptive signals with high accuracy and the quick processing of the reference signals.

Fuzzy Tuned PI Controller Based SAPF:

Fuzzy logic is a control approach used in control system engineering for issue solving. In 1965, Zadeh created the idea of fuzzy logic. Mamdani and Pappis produced the first fuzzy controller in 1977, which was a steam engine controller. Later, they developed fuzzy traffic lights [8]. Three regions typically make up the FLC design depicted in Figure 3: allocating the fuzzy area to a linguistic value, developing a fuzzy inference system (rules), and defuzzify into a real value.

Control System Design:

The process of creating a controller for a complicated physical system comprises the subsequent stages: Dividing the large-scale system into a number of different smaller systems, Linearizing is the nonlinear plane dynamics about a set of operational locations by gradually varying the plant dynamics, Assembling a collection of output characteristics, control variables, or state variables for the system under study, Creating basic P, PD, and PID controller designs for the subsystems. Additionally, optimal controllers can be created.

Fuzzification:

The FLC's first component is the fuzzifier that transforms crisp inputs into a set of membership values in the interval [0,1] in the corresponding fuzzy sets. The membership function shapes are typically triangular, trapezoidal, and Gaussian. In these membership functions, Gaussian MF's is good robustness than other membership functions. Gaussian membership function inputs are error (e) and its change in error (Δe) with fuzzy labels NB (negative big), NS (negative small), ZO (zero), PS (positive small) and PB (positive big). The membership functions' corresponding outputs are propagation gain (KP) and integration gain (KI) for respective input labels.

Rule Elevator:

FLC uses linguistic variables instead of numerical values. The basic FLC operation uses the following fuzzy set rules to control the system.

AND–Intersection $\mu A\cap B=\min[\mu A(X),\mu B(X)]$

OR–Union $\mu A\cup B=\max[\mu A(X),\mu B(X)]$

Defuzzification:

FLC rules produce the necessary output in a linguistic variable (Fuzzy Number) based on real-world requirements. It is necessary to convert linguistic variables into clear output (Real number).

(x, mf, type) = defuzz(x)

The argument states that defuzz (x, mf, type) employs multiple defuzzification algorithms to deliver a defuzzified
result from a membership function (MF) positioned at the associated variable value x. The following are possible choices for the variable type:

- Principle of maximum membership
- Weighted average approach
- Centroid Approach

Fuzzy-PI:

The non-linear plant with unpredictable parameter variations requires automatic tuning of the settings of the standard PI controllers. A formal approach for applying human heuristic knowledge gleaned from any system experience is the fuzzy system. To achieve excellent system performance and lessen the impact of parameter fluctuations, a self tuning fuzzy PI controller can be created. Figure displays the block diagram for the suggested self-tuning fuzzy PI controller for the SAPF.

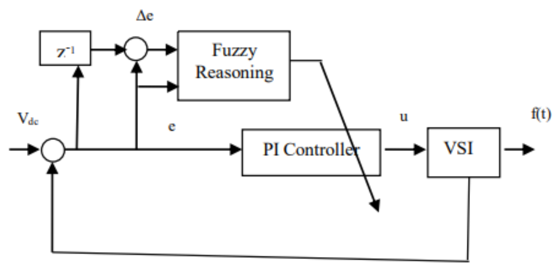

Figure 2.2: Fuzzy tuned PI controller.

ANFIS BASED SAPF:

The Adaptive Neuro-Fuzzy Inference System (ANFIS) combines artificial neural networks with fuzzy logic, two popular soft computing techniques. The fuzzy logic system has numerous inputs and a single output, whereas the neural system has many inputs and multiple outputs. This combination is known as ANFIS, and it is utilised in nonlinear applications. It endows non-linear systems with accuracy. Because of this, ANFIS is the most extensively used controller and is superior to other controllers. ANFIS has the capacity to learn from data and forecast outcomes using that data. The weights of the connections between the neurons in the network can be changed by the learning algorithm. An artificial neural network that is based on the Takagi-Sugeno fuzzy inference system is called adaptive network-based fuzzy inference system (ANFIS).The early 1990s saw the development of the method. It can combine the advantages of neural networks and fuzzy logic in one framework because it incorporates both of these concepts. Two components of the network structure can be distinguished, namely the premise and the portions that follow. To be more specific, there are five levels that make up the architecture. The initial layer decides which membership functions correspond to the input values. It's often referred to as the fuzzification layer.

Structure Of ANFIS:

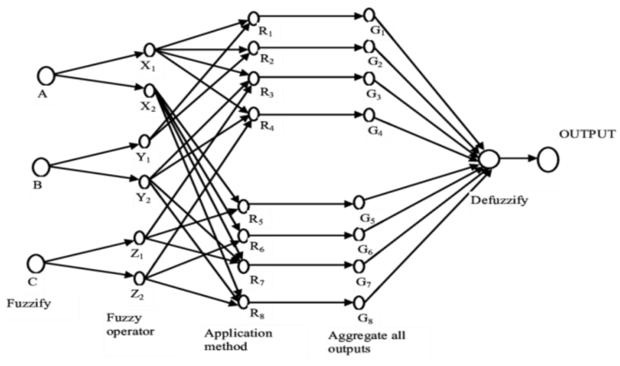

Figure 2.3: Structure of ANFIS

The node functions in each layer are as described below.
Fuzzification Layer: In this layer, membership functions are used to transfer the input variables to fuzzy sets. The linguistic variables that reflect the system's imprecision and uncertainty are represented by the fuzzy sets**.**
Rule Layer: Fuzzy if-then rules are applied to the input variables by the rule layer. A collection of fuzzy if-then statements that are developed based on expert knowledge or taken from data are used to express the rules.
Normalization Layer: To guarantee that the total firing strength is equal to one, the firing strength of each rule is normalized in this layer**.**
Defuzzification Layer: The output of every rule is combined by the defuzzification layer to produce a clear output value. Depending on the application, several defuzzification techniques may be employed, including weighted average, maximal defuzzification, and centre of gravity.
Learning Layer: The ANFIS controller adjusts to system changes in the learning layer. A neural network that has been trained to understand fuzzy rules and membership functions makes up the learning layer. A hybrid learning approach that combines least squares and back propagation techniques is used to train the neural network. When the ANFIS controller is operating, it receives input values and uses the fuzzy rules to produce an output value. In order to modify the input values, the output value is then given back into the system as feedback. By using the learning layer to update the membership functions and fuzzy rules, the ANFIS controller can adjust to changes in the system. All things considered, the ANFIS controller makes use of neural networks to learn from and adjust to system
changes, as well as fuzzy logic to capture the uncertainty and imprecision of the system. The ANFIS controller is an effective tool for managing complex systems with nonlinear or unpredictable dynamics because of its hybrid approach.

III. Result And Discussion

The MATLAB simulative environment was used for the implementation of the following scenarios.

- Without SAPF
- SAPF with conventional PI controller
- ANN
- FUZZY tuned PI
- ANFIS based SAPF

Without SAPF: In this case, SAPF is disabled as shown in figure 3.1 and a Fast Fourier Transform (FFT) analysis is used to determine the distortion in source current caused on by the nonlinear load.

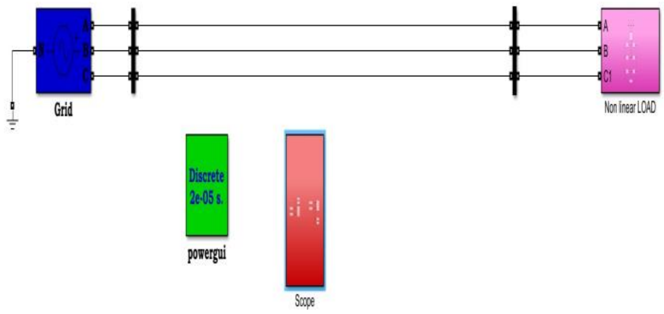

Figure 3.1: Simulink model for without SAPF

Due to the nonlinear loads connected at distribution network lead to distortion in the grid current waveform. After analyzing the FFT spectrum it gives the THD 22.24% as shown in figure 3.2 and figure 3.3.

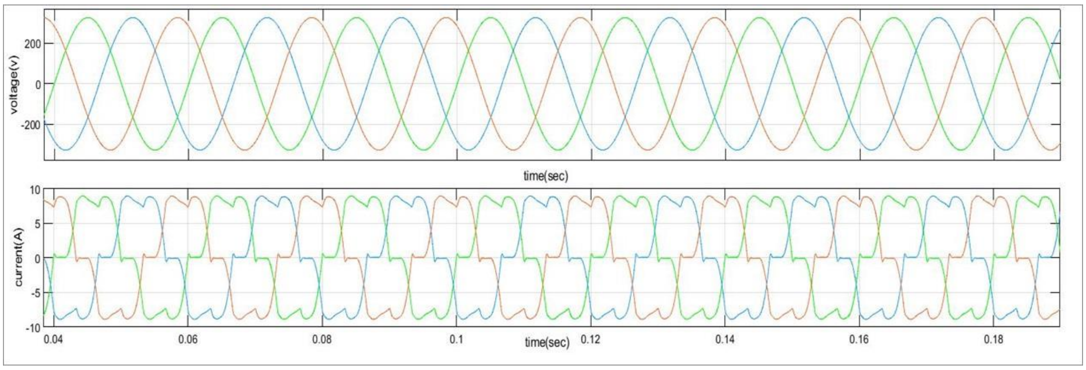

Figure 3.2: Waveforms of Voltage and Current for the system without SAPF

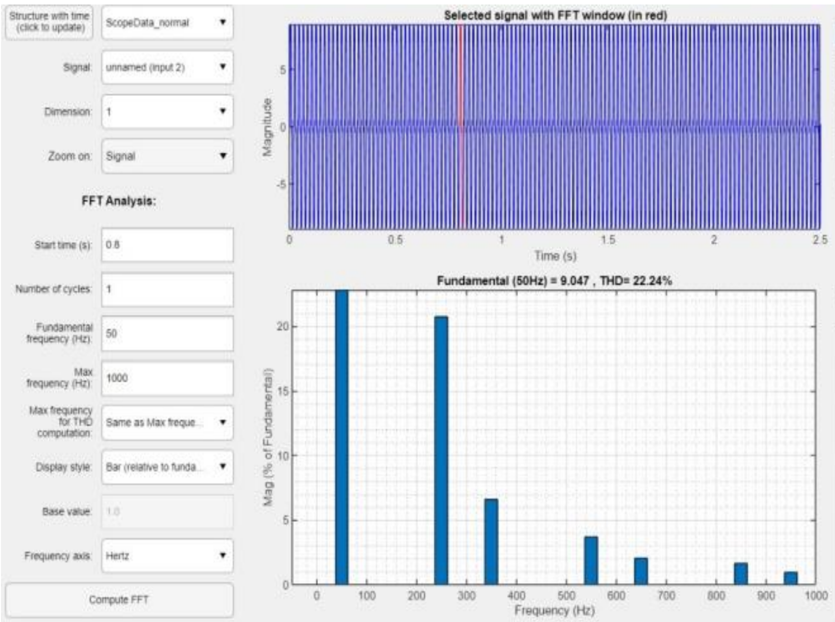

Figure 3.3: THD for without SAPF

SAPF With Conventional PI: In this case Conventional PI controller is connected to SAPF shown in figure 3.4. Fast Fourier Transform (FFT) analysis is performed to know the distortion in source current.

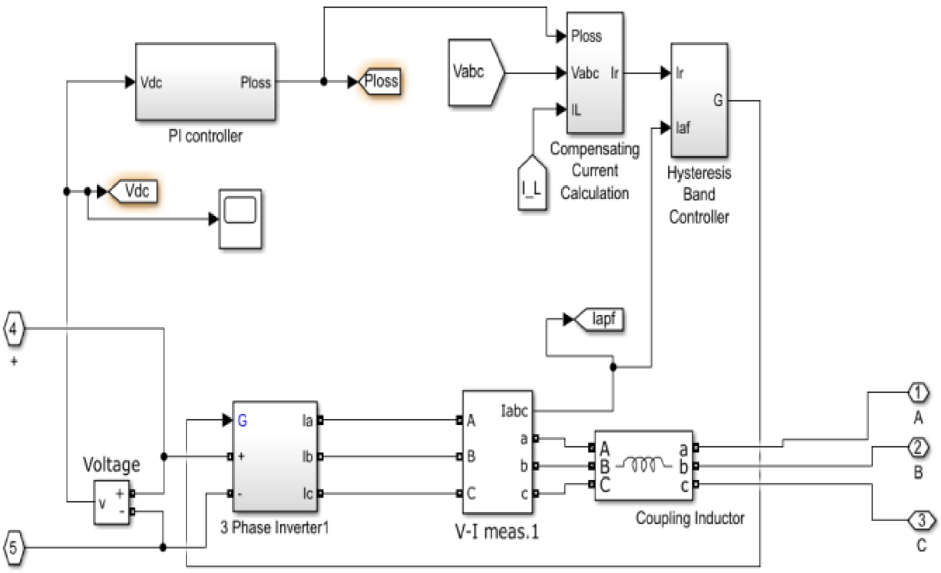

Figure 3.4: Simulink model for SAPF with conventional PI controller.

By using SAPF with PI Controller in Power system network reduces the distortion in the grid current waveform, which makes the current waveform sinusoidal. THD reduces to 1.83% as shown in figure 3.5 and 3.6.

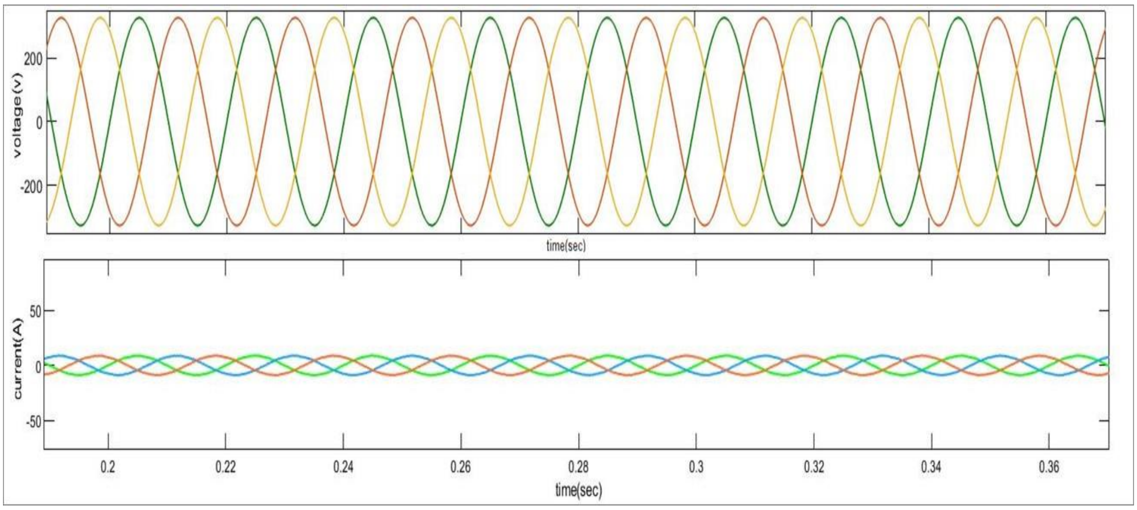

Figure 3.5: Waveforms of Voltage and Current of system with SAPF

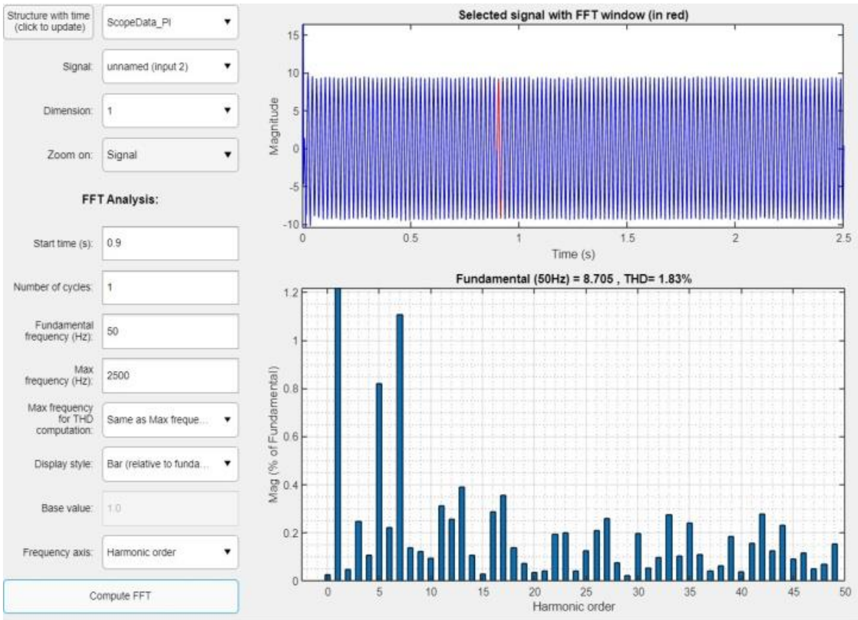

Figure 3.6: THD for Conventional PI Controller based SAPF

ANN Based SAPF: In this case ANN is connected to SAPF shown in figure 3.7. Fast Fourier Transform (FFT) analysis is performed to know the distortion in source current.

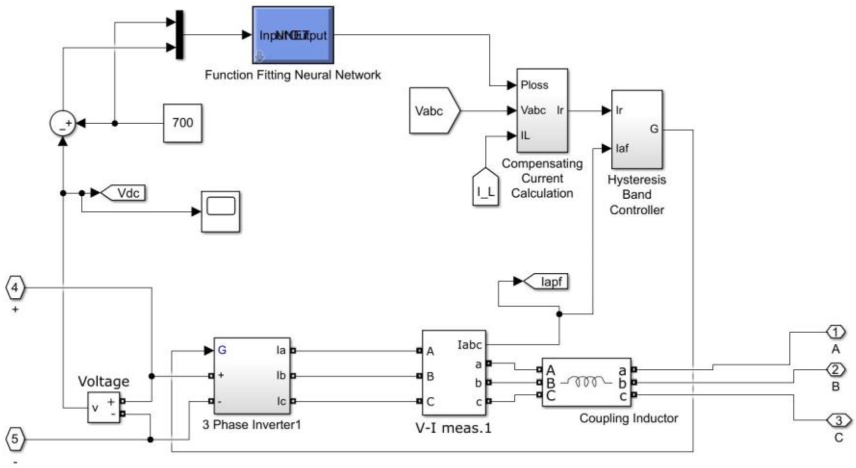

Figure 3.7: Simulink model for ANN based SAPF

The total harmonic distortion (THD) by using Artificial Neural Network based Shunt active power filter is 1.77% as shown in figure 3.8 and figure 3.9. We observed that the total harmonic distortion by ANN is reduced when compared with conventional PI controller based SAPF.

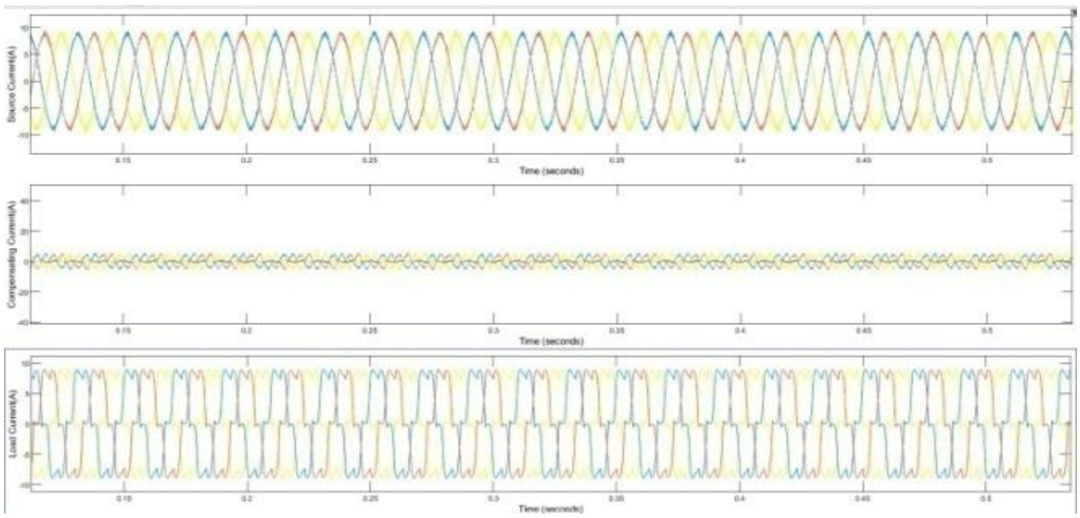

Figure 3.8: Voltage and Current waveforms of network with ANN based SAPF

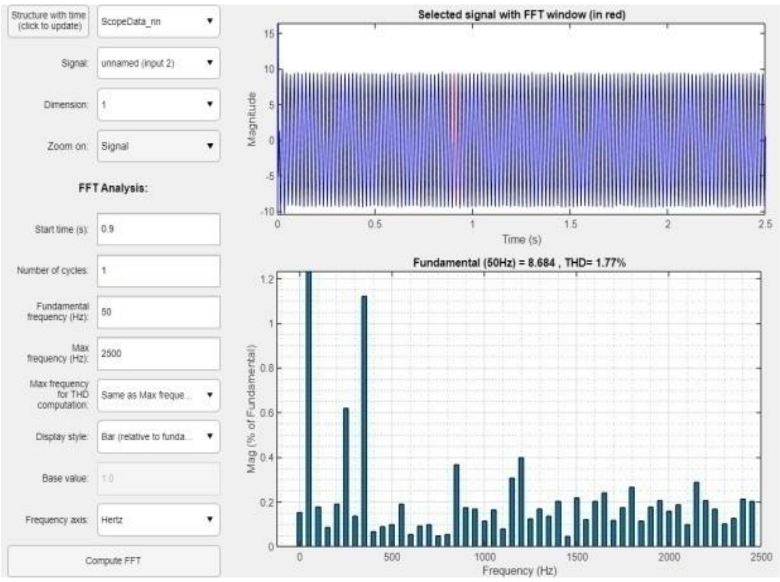

Figure 3.9: THD for ANN based SAPF

Fuzzy Tuned PI Controller: In this case Fuzzy tuned PI controller is connected to SAPF shown in figure 3.10. Fast Fourier Transform (FFT) analysis is performed to know the distortion in source current.

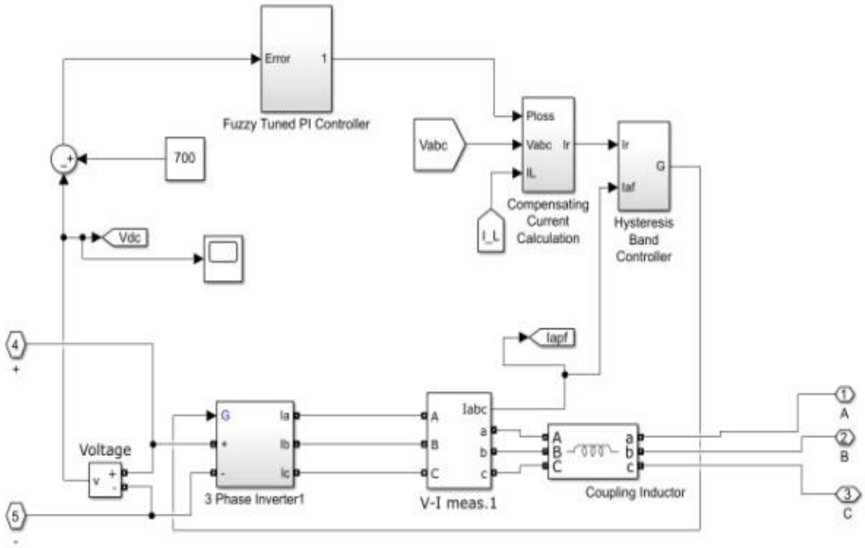

Figure 3.10: Simulink model for Fuzzy tuned PI controller based SAPF

The total harmonic distortion (THD) by using Fuzzy tuned PI based SAPF is 1.62%. We can observed that the total harmonic distortion by fuzzy tuned PI is reduced when compared with ANN based SAPF shown in figure 3.11 and figure 3.12.

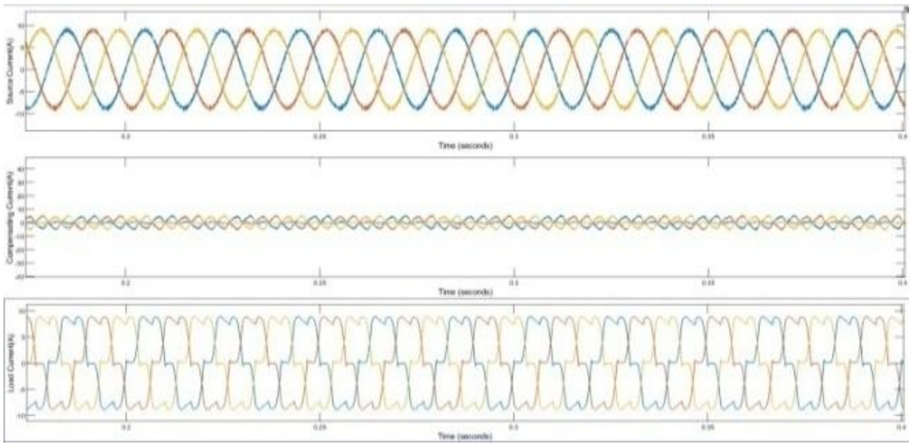

Figure 3.11: Voltage and Current waveforms of network with Fuzzy tuned PI based SAPF

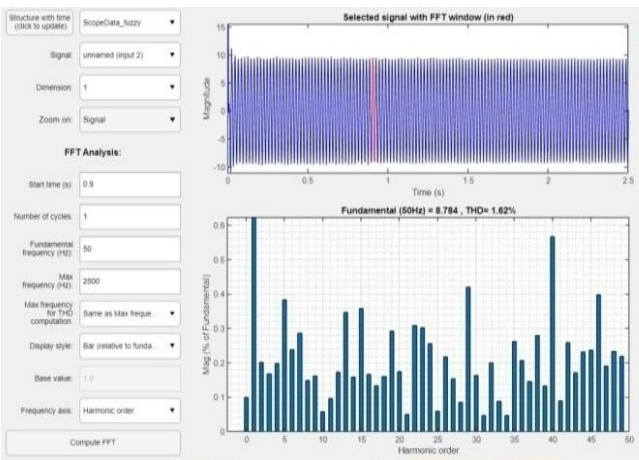

Figure 3.12: THD for Fuzzy tuned PI controller based SAPF

ANFIS based SAPF:

In this case ANFIS (Adaptive Neuro Fuzzy Inference System) is connected to SAPF shown in figure 3.13. Fast Fourier Transform (FFT) analysis is performed to know the distortion in source current. ANFIS controls the DC link voltage and reduces the harmonics in source current. Hence, ANFIS based SAPF able to restore the distorted source current to its original sinusoidal waveform. ANFIS consists of set of fuzzy rules and neural network and trained by fuzzy rule base. The fuzzy rule base defines the mapping between input variables and output variables and these are represented by fuzzy sets and linguistic variables.

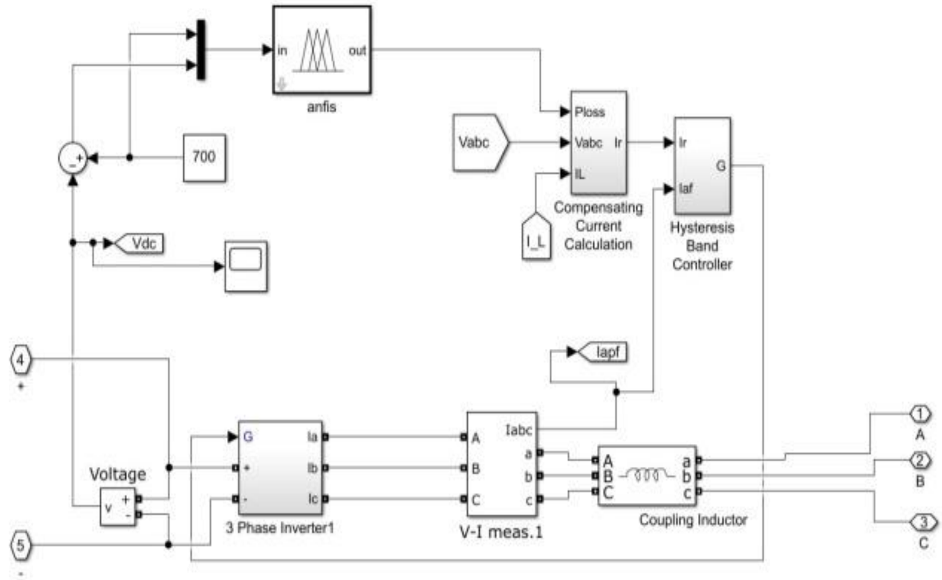

Figure 3.13: Simulink model for ANFIS based SAPF

The total harmonic distortion (THD) by using ANFIS based SAPF is 1.57%. We can observed that the total harmonic distortion by ANFIS based SAPF is reduced when compared with Fuzzy tuned PI based SAPF shown in figure 3.14 and 3.15.

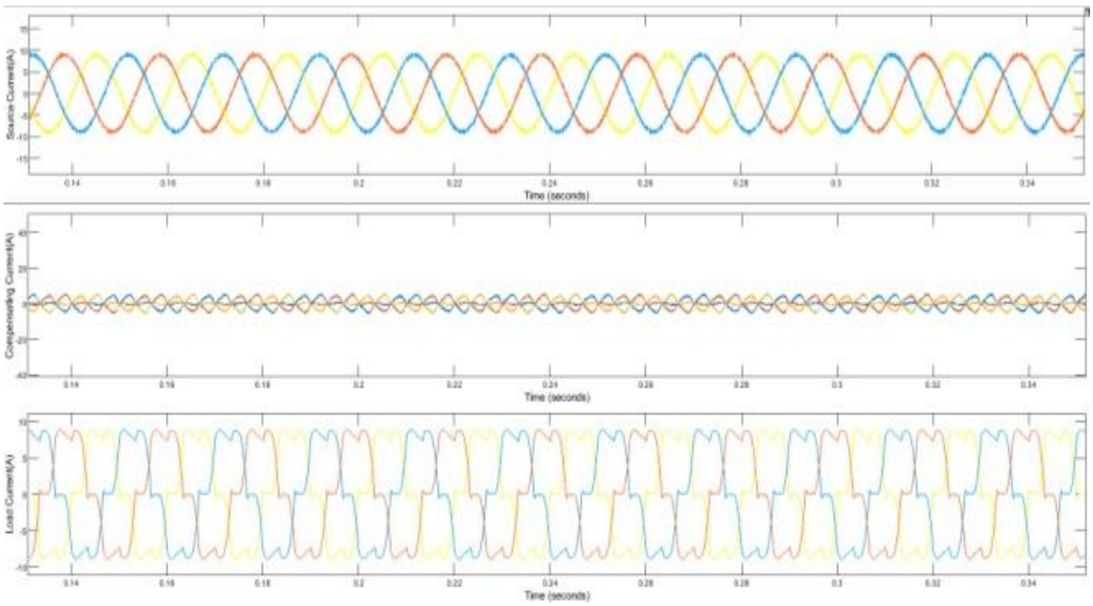

Figure 3.14: Voltage and Current waveforms of network with ANFIS based SAPF

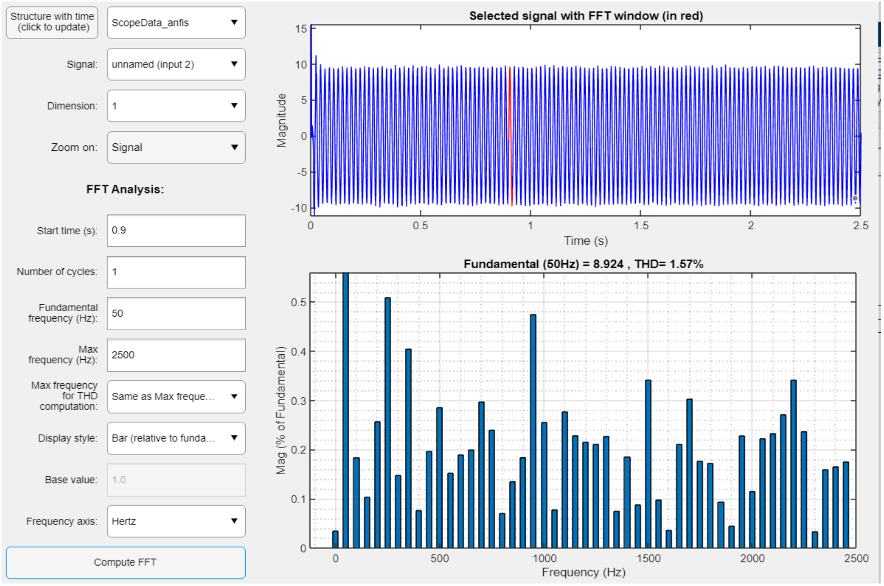

Figure 3.15: THD for ANFIS based SAPF.

Table no 1: Comparison of THD

CONTROLLER	THD%
Without SAPF	22.24%
Conventional PI CONTROLLER based SAPF	1.83%
ANN based SAPF	1.77%
FUZZY tuned PI CONTROLLER based SAPF	1.62%
ANFIS based SAPF	1.57%

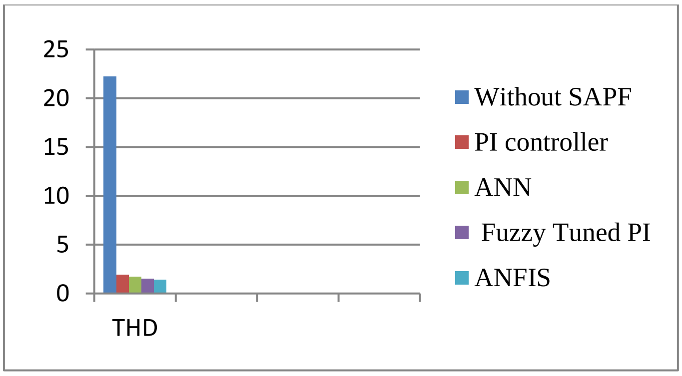

Figure 3.16: THD Comparison

IV. Conclusion

Reactive power and harmonics are only two instances of the growing intricacy of power quality problems. Artificial intelligence-developed solutions used by active filters are very good at reducing harmonics and balancing reactive power. We suggest using the ANFIS based SAPF control approach as a substitute to the SAPF within the context of this paper. The efficacy of the SAPF is evaluated and contrasted in a range of contexts. Five distinct scenarios are simulated using Matlab-Simulink, which then displays the results. Simulation results show that in terms of lowering THD in the source current, the suggested ANFIS based SAPF performs better than alternative scenarios. The distribution system WITHOUT SAPF, CONVENTIONAL PI, ANN, FUZZY TUNED PI, ANFIS Controllers are developed and verified for three phase three wire system. In this work it has been observed without any control circuitry the THD is very high around 22.24% . With PI Controller based SAPF, it is reduced to 1,83% and with ANN Controller it is reduced to 1.77% ,with FUZZY

TUNED PI based SAPF it is reduced to 1.62% and with ANFIS based SAPF further THD reduced to 1.57%. The performance of these all controllers has been studied and compared in MATLAB. It has been seen that, ANFIS based SAPF controller is more efficient to reduce THD than WITHOUT SAPF,CONVENTIONAL PI, ANN, FUZZY TUNED PI Controllers.

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