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DESIGN OF ANFIS CONTROLLER BASED SHUNT ACTIVE FILTER FOR MITIGATION OF HARMONICS IN A THREE PHASE TRANSMISSION LINE

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ABSTRACT

In the three phase transmission line, the use of power electronics converters are very common.The use of power electronic converter with non-linear loadproduces harmonics and causes distortion of the voltage waveform in the system. In this paper the adaptiveneuro fuzzy inference system (ANFIS) controlled shunt active power filter is presented. The proposed controller has the capability of reducing the total harmonic distortion. The sinusoidal pulse width modulation (SPWM) technique is used to get required signals for inverter. The advantage of the fuzzy controller is that, it does not require any mathematical model for system; it can adapt its gain according to the load changes. The simulation result of total harmonic distortion (THD) is demonstrated through MATLAB/SIMULINK.

Keywords: Active filter, Shunt active power filter (SAPF), ANFIS, Fuzzy Logic Controller, SPWM, THD.

I. INTRODUCTION

As the increasing demand of electrical power, the use of power conversion modules and power electronics devices also increased such as Rectifier, DC converters, adjustable speed drives, electronic ballast, arc furnaces etc. But these devices cause the increase in harmonic disturbance in the ac mains currents. These disturbances can be like Overheating on all cables and equipment, Increase in power system losses, Loss of efficiency in electric machines, Electro-magnetic interference with communication systems, Failure in protective relays, capacitors to explode, Increased probability of occurrence of resonance, Errors in measures when using average reading meters, nuisance tripping of thermal protections. [1]

The quality of power mainly aims to maintain pure sinusoidal current wave form in phase with a pure sinusoidal voltage wave form. The recent advancement in semiconductor devices has greatly improved the development of active power filters (APF) which gives the many wonderful impacts on power quality such as: Compensation of current and voltage harmonics, reactive power compensation, regulation of voltage terminal, improved voltage balance in three phase systems. The advantage of active filtering is that it automatically adapts the changes in the network and load fluctuations, this will also eliminates the risk of resonance between the filter and network impedance and takes very little space compared with traditional passive filters. [2]

The APF has several topologies that are shunt active filter, series active filter, hybrid active filter but the shunt APF based on voltage-source inverter topology has proven to be the best solution so far for harmonic current mitigation. The shunt APF gives many advantages: It is cost-effective for low to medium KVA industrial loads, It can damp harmonic propagation in a distribution feeder, It does not create displacement power factor problems, and utility loadings. [3]

The quality of output of the converter and the complete system depends greatly on the control scheme. It is one of the most important harmonic suppression and reactive power compensation technique based on power electronic devices. The PI controller which was used for controlling the APF requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances. [4]

The artificial neural network (ANN) is considered as a new tool to design control circuitry for Power quality (PQ) devices. However, with the advent of the various soft computing methodologies like neural networks, the

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fuzzy logic and the genetic algorithm combined with modern structure optimization techniques. Recently, fuzzy logic controllers have produced the great interest in various applications and have been introduced in the power-electronics field. The advantages of fuzzy logic controllers over other controllers are that they do not need any accurate mathematical model; they can work with imprecise inputs, can handle nonlinearity, and may be more robust than the conventional PI controller. [5]

On considering these facts, this paper aims to improve the steady-state performance, accuracy and dynamic response speed of harmonic compensation and proposes a Shunt active filter with ANFIS controller for controlling the switching of the inverter switches. The objective of the controller is to maintain the inverter output voltage constant within different load changes. The validity of the proposed method is verified through MATLAB simulation.Section I contains the introduction about power quality problems and the solution for harmonic mitigation Shunt active filter, Section II contain the previous work on shunt active filter with different controller, Section III contains the Methodology of proposed work, design of ANFIS controller, design of fuzzy interference system (FIS),neural network for generating FIS, Section IV describes results and discussion and Section V contains the conclusion of research work with future scope.

II. RELATED WORK

In this section the previous researches on shunt active filter with different controller strategies is discussed.
R. Shilpa, P.S.Puttaswamy [6] a review on power quality issues in power system, this paper describes the various power quality issues which affect the power system and what are the solutions.

Angelo araujo et.al [7]Implementation and Comparison of DifferentSwitching Techniques for Shunt Active Power Filters, this paper gives a comparison between 3 switching techniques that can be used in 3-phase 4-wire Shunt Active Power Filters (SAPFs). The implemented switching techniques are: Periodic-Sampling (PS), Triangular CarrierPulse-Width Modulation (TC-PWM) and Space Vector PWM (SVPWM).

Zhenfeng Xiao et.al [8]Shunt active power filter with enhanced dynamicperformance using novel control strategy, To find out the accurate and real-time compensation of the harmonics of a power system, the study proposed of this novel control strategy for shunt active power filter (SAPF) is effective. This paper adopted the composite strategy of neural network proportional-integral (PI) control and dual-repetitive controller (DRC). In DRC, one repetitive controller is used to ensure current tracking accuracy and the other one is used to improve dynamic performance dynamic response. The neural network PI control is adopted to improve the response speed by turning the parameters of PI adaptively and sets optimisation parameters online.

N. Das, S. Mude [9] Power Quality Improvement of Three Phase System using Shunt Active Power Filter, this paper presents the power quality improvement by SAPF to eliminate voltage and load current harmonics and for reactive power compensation. This SAPF based on the instantaneous active and reactive current component (Id – Iq) method is proposed to compensate harmonic unbalance. A theoretical studies based on synchronous detection method is used in this paper and the simulation results are analysed for harmonics compensation. Simulations are carried out with PI controller for the (Id – Iq) control strategies for different voltage condition using MATLAB/ SIMULINK.

R.B. Yadiki& C. S. Rao [10] Performance Analysis of Instantaneous Harmonic Power Theory Based Active Power Filter Under Different Loading Conditions, In this paper the APF connected with Distribution system with Non-linear loads or industrial loads connected. In this work instantaneous harmonic power is used for compensation of harmonics. The APF performances at constant load, increment in load and decrement in load condition is shown in MATLAB/SIMULINK.

E.J. Acordi et.al [11]Application of fuzzy systems in the control of a shunt active power filter with four-leg topology, this paper presents the application of fuzzy controllers to act in the current control loop of SAPF. The SAPF consists of a three-phase inverter with four-leg topology, and it has been used to reduce the harmonic content and reactive power compensation. In this paper he generation of the reference currents is based on the synchronous reference frame (SRF), which requires the use of a PLL (Phase Locked Loop) synchronization algorithm with the grid and classic PI control is replaced by a fuzzy controller that has features that allows fast convergence and robustness when there are parametric variations in system.
T.D. Raheni, P.Thirumoorthi [12] Intelligent Control of Shunt Active Power Filter for Minimization of Current Harmonics, The proposed an intelligent controller in this paper is used to minimize the harmonics in power

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distribution system due to the presence of non-linear load. Conventional PIcontroller is implemented in the system and compensated reference current is generated by IRP theory. Shunt Active Power Filter is mainly used to minimize the harmonics in the power system feeding non-linear load. This system is implemented with ANN and ANFIS based controller and the results are compared. The system is executed in simulation environment using MATLAB Simulink**.**

K.K. Pedapenki, S.P.Gupta [13] Two Controllers for Shunt Active Power Filter based on Fuzzy Logic, this paper deals with fuzzy logic control and neurofuzzy control for SAPF. Neuro fuzzy logic has improved THD when compared to fuzzy logic controller and it is demonstrated through simulation results.

III. METHODOLOGY

In this section methodology is discussed which has three parts- description of proposed system, design of ANFIS controller,neural network for generating fuzzy inference system.

Description of Proposed System:

The proposed work of ANFIS controller based shunt activepower filter is designed for the mitigation of harmonics in source current and for reactive power compensation. The basic equations for the shunt active filter and thesystem can be given as:

$$Vsa = v_a + r_f i_{fa} + l_f \frac{di_{fa}}{dt} \quad (1)$$

$$Vsb = v_b + r_f i_{fb} + l_f \frac{di_{fb}}{dt} \quad (2)$$

$$Vsc = v_c + r_f i_{fc} + l_f \frac{di_{fc}}{dt} \quad (3)$$

The block diagram of overall proposed system is divided into six sections as shown in figure 1.

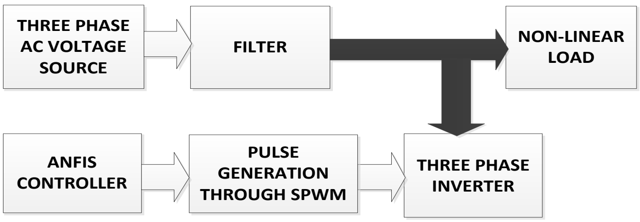

Figure 1 Block diagram of ANFIS controller based shunt active filter

1st section: This is the three phase AC voltage source in transmission line which is supposed to be 415v, 50 Hz.
2nd section: This is LC filterused here to remove unwanted changes in the wave from AC voltage source.
3rd section: This is three-phase controlled IGBT bridge rectifier with ohmic–inductive loading are here considered as a non-linear load on three-phase ac mains. This load draws non-sinusoidal currents from ac mains and can be controlled by changing its firing angle.
4th section: This is three phase inverter which is operated here as a current source in parallel with the non-linear load. This inverter has six IGBT switches and an energy storage dc capacitor connected in parallel for two main purposes- first is that, it will maintain the voltage constant with small ripples in the steady state and in transient state it will supply the real power difference between load and source. If the load change then there is also change in the real power difference between source and load. This real power is compensated by the capacitor changes the voltage from the reference voltage.
5th section: This is the controller designed here called ANFIS controller which take the constant capacitor voltage (reference signal) and the three phase voltage and line current which is measured through a sensor and compare to generate the error and change in error. Both the error will then give to the fuzzy logic controller. Its output then given to ANFIS to train and control the output CI.
6th section: This includes the pulse generation through SPWM technique. In this technique the carrier signal frequency is 3 KHz and fundamental frequency is 50 Hz.
Control Index is defined by:

$$\mathrm{CI} = \frac{V_r}{V_c} \quad (4)$$

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Where, Vc=triangular carrier wave, Vr =Sinusoidal reference wave

This will control the switching of inverter to generate equal and opposite current as produced by harmonic current.So, our aim is to control the SAF in such a way so that it can give equal magnitude but opposite compensating current and cancel out the harmonics.

Design of ANFIS Controller

The main aim of ANFIS is to automatically realize the fuzzy system by using the neural networks; it permits the combination of numerical and linguistic data. It has the ability to obtain fuzzy number from real number. The basic principle of the ANFIS method is the use of the network neuron to optimize the membership's functions of the fuzzy controller or in other words we can say that an ANFIS is optimized fuzzy inference system (FIS).

ANN has strong learning capabilities where, the fuzzy logic has a good capability of interpretability and can also integrate expert's knowledge. In this ANFIS controller first of all, an FIS is developed which have five membership functions for each of the two inputs and an output. There are two input variables and one output variable. Error (Er) and the rate of change of error (Der) derived from the constant voltage and the capacitor voltages sent to the MATLAB work space. In the next step, the ANFIS is invoked to the work space with dataset and it is trained.

The neural network is used to generate the new membership functions for the ANFIS controller. The newly trained and developed ANFIS is now used in place of FIS controller. The system is again made to run and the process of collecting the dataset is repeated and ANFISis re-trained using inbuilt back propagation optimization method.

The newly trained system is checked and validated for the inputs and output service, they are selected as the input variables while the output variable is required control signal for adjusting the width of the sinusoidal pulses, by varying the control index (CI). Figure 2 shows the design of FIS.

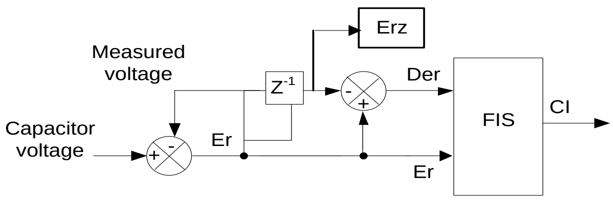

Figure 2 Design of FIS.

Where, $Er = Vc - Vm$ (5)

$$Der = Er - \frac{d}{dt}(Er) \quad (6)$$

The system is then run. The error dataset, change in the error dataset and the dataset of the corresponding output from the controller is given to the MATLAB workspace. Then, the ANFIS is invoked and with work space dataset, it is trained. The neural network is used to generate the new membership functions for the ANFIS controller. Hence, trained and developed ANFIS is now used in place of FIS controller. The system is again run and the process of collecting the dataset is repeated and ANFIS is again trained by the use of built back propagation method. Initially designed FIS is inputted with the error signal 'Er' and the rate of change of error 'Der' they have 5 degrees of membership functions.

$$Er = \{Er_{NB}, Er_{PB}, Er_z, Er_{NS}, Er_{PS}\} \quad (7)$$

$$Der = \{Der_{NB}, Der_{PB}, Der_z, Der_{NS}, Der_{PS}\} \quad (8)$$

The range of theEr is from (7 to 14) similarly, the range of second input variable Der is from {-0.4 to 0.4}. The output variable 'CI' of the controller has 5 linguistic variables or membership functions, i.e.

$$CI = \{CI_{NB}, CI_{PB}, CI_z, CI_{NS}, CI_{PS}\} \quad (9)$$

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Triangular membership functions are chosen on account of its feasible presentation. The fuzzy rules for the FIS controller are tabulated in Table1. This shows a rule matrix which is named as NB- negative big; PB- positive big; Z-zero; NS- negative small; PS- positive small?The membership functions are arranged in such a way that the control output should maintain the voltage within prescribed limits under all loading conditions. The criterion followed by the FIS rule base is:

i. When the negative or zero memberships of inputs Er and Der -value of output MI should be negative.
ii. When the positive or zero memberships of inputs Er and Der - The MI should be positive.
iii. When both memberships of inputs Er and Der are zero - The MI should be zero.

Table 1.FIS rules for controller

CI		Er				
		Er_{NB}	Er_{PB}	Er_{Z}	Er_{NS}	ER_{PB}
Der	Der_{NB}	CI_{NB}	CI_{NB}	CI_{NB}	CI_{PB}	CI_{Z}
	Der_{PB}	CI_{NB}	CI_{NB}	CI_{PB}	CI_{Z}	CI_{NS}
	Der_{Z}	CI_{NB}	CI_{PB}	CI_{Z}	CI_{NS}	CI_{PS}
	Der_{NS}	CI_{PB}	CI_{Z}	CI_{NS}	CI_{PS}	CI_{PS}
	Der_{PS}	CI_{Z}	CI_{NS}	CI_{PS}	CI_{PS}	CI_{PS}

Neural Network for Generating Fuzzy Inference System:

The neural network is the integral part of the ANFIS. The ANFIS is trained with dataset produced by the firstly developed FIS. The neural network next generates the new FIS and this ANFIS is placed in the control system for further interaction with system.

The neural network avoids the repetition of tuning and is adaptable to variation in the system parameters through its self-adjusting property. The neurons are very necessary part of the neural network which performs all the mathematical computational work. The learning of the ANFIS is the supervised learning which incorporated with back propagation of error with each epoch (fixed time interval). The ANFIS structure is shown in the figure 3.

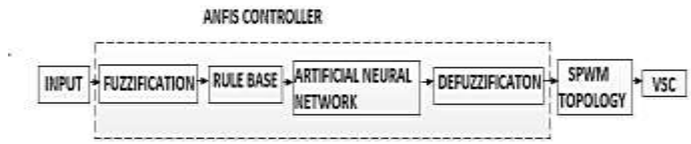

Figure 3 Block representation of controller

In figure 3, the fuzzification unit changes the input error data (crisp form) into variables. The output from the fuzzification block is fed to the rule-base block. The set of 25 rules is written. The rule-base block is connected to the ANN block. The ANN block, uses Back-propagation algorithm for training the neural network so that it can choose the appropriate set of rules. Training of the network is an essential step for selection of the appropriate rules for generating a control signal. Figure 4 shows the rule structure of ANFIS controller with 5 layers.

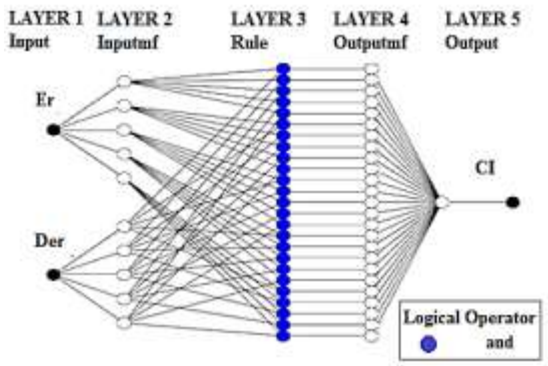

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Figure 4 Rule structure of ANFIS controller

Layer 1: This layer is the input layer which consists of input membership functions, Er and Der. Here, triangular membership unction (MFs)are used. The input layer 1 is a layer with two nodes that supplies the input values to the next layer.
Layer 2: This is the fuzzification layer. Neurons in this layer perform fuzzification.

$$If\ Er\ is\ x\ and\ Der\ is\ y\ then\ CI\ is\ f(x,y) \qquad (10)$$

Layer 3: This is the rule layer. Each neuron in this layer corresponds to a single Sugeno-type fuzzy rule. A rule neuron receives inputs from the respective fuzzification neurons and calculates the firing strength of the rule it represents.
Layer 4: This is the normalisation layer. Each neuron in this layer receives inputs from all neurons in the rule layer, and calculates the normalised firing strength of a given rule.
Layer 5: This is the defuzzification layer. Each neuron in this layer represents a single output of the neuro-fuzzy system. It takes the output fuzzy sets clipped by the respective integrated firing strengths and combines them into a single fuzzy set output CI.

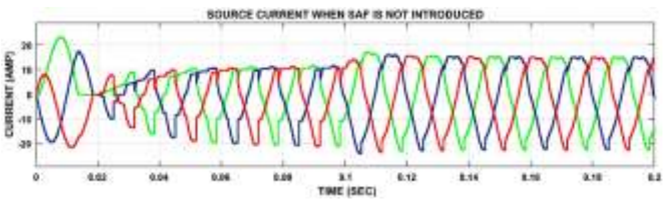
IV. RESULTS AND DISCUSSION

This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy for the active filter to reduce the harmonics. The system parameters are given in Table 2.

Table.2 Simulation Parameters

System Parameters	**Values**
Supply phase to phase voltage, Frequency	100V (rms), 50 Hz
Source impedance	Rs=0.1Ω, Ls=0.5mH
Filter impedance(R , L)	Rs=1Ω, Ls=1mH
Inverter DC bus capacitor	C_{dc}=100µF
Reference DC link voltage	V_{dc}=14v
Non-linear Load impedance	R_{L1}=7Ω, L_1=200mH, R_{L2}=10Ω, L_2=10mH

The results obtained from simulation gives the information of compensated harmonics by using proposed system. The results are discussed as follows:
Figure 5(a) shows the source current waveform without any compensation. From the waveform it is clear that there many harmonics present in the system.
Figure 5(b) shows the source voltage in this the harmonics are presents from 0.04 sec to 0.1 sec but when we introduce SAF the spikes get resolved and smoothing sinusoidal source voltage is attained.
Figure 5(c) shows the compensating current injected by the shunt active filter.
Figure 5(d) shows source current with the 0 degree firing angle in the non linear load applied for 0.02 to 0.2 sec which gives harmonic distortion and when SAF is introduced for time 0.1 to 0.14 sec. the harmonics get compensated.
Figure5(e) shows source current with the 30 degree firing angle in the non linear load applied for 0.02 to 0.2 sec which gives harmonic distortion and SAF is introduced for time 0.1 to 0.14 sec.
Similarly, figure 5(f) shows source current with the 60 degree firing angle in the non linear load applied for 0.02 to 0.2 sec which gives harmonic distortion and when SAF is introduced for time 0.1 to 0.14 sec the harmonics removed.



(a)

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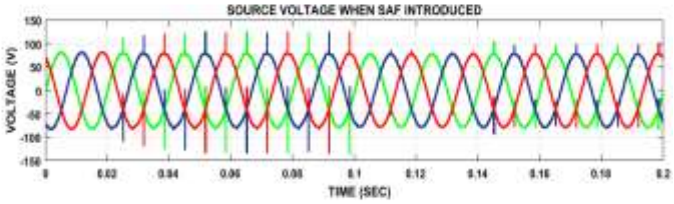
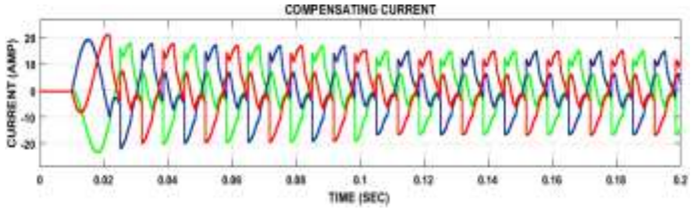
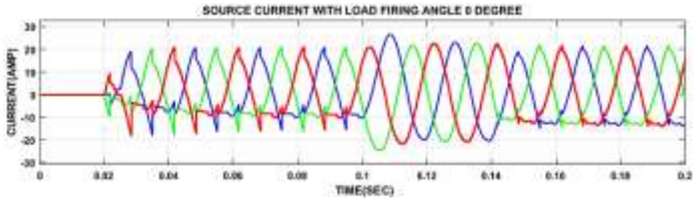


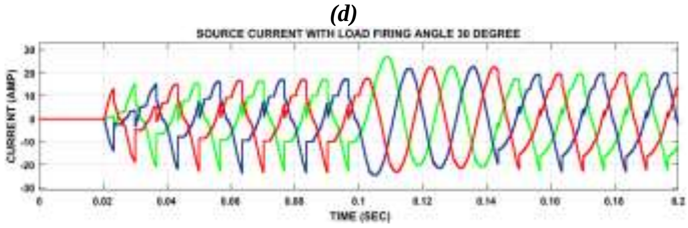
(b)



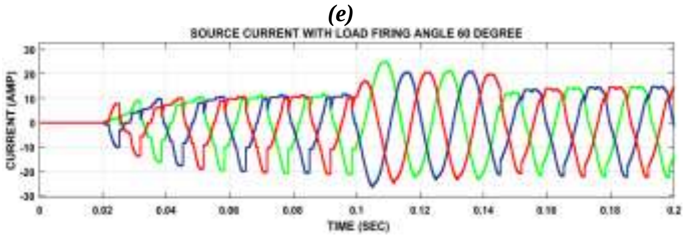
(c)



(d)



(e)



(f)

Figure 5 Waveforms of Source voltage and Source Current obtaing by applying proposed system

The FFT analysis of the waveforms helps us to know the presence THD in the waveform. This is basically the ratio of the root mean square of the harmonic content, considering harmonic components up to the **50th** order and specifically excluding inter-harmonics, expressed as a % of the fundamental.

$$\mathrm{THD} = \frac{\sqrt{\mathrm{A_{rms}} - \mathrm{A_{1,rms}}}}{\mathrm{A_{1,rms}}} \qquad (11)$$

Where, $A_{1,rms}$= RMS Value of Fundamental signal.
A_{rms}= Total RMS Value of the complete signal.

So, When the shunt active filter is not introduced in system, the total harmonic distortion is 39.78% shown in figure 6.
Figure 7 shows FFT analysis of source current with load firing angle 0 degree and the total harmonic distortion is 0.61%. the harmonics get compensated.

Figure 8 shows FFT analysis of source current with load firing angle 30 degree and the total harmonic distortion is 1.25%.

Figure 9 shows FFT analysis of source current with load firing angle 60 degree and the total harmonic distortion is 1.40%.

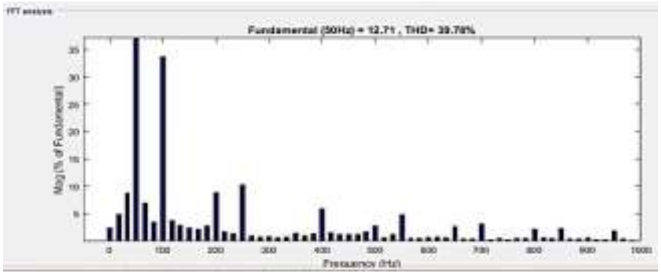


Figure 6 FFT analysis of source current without using SAF

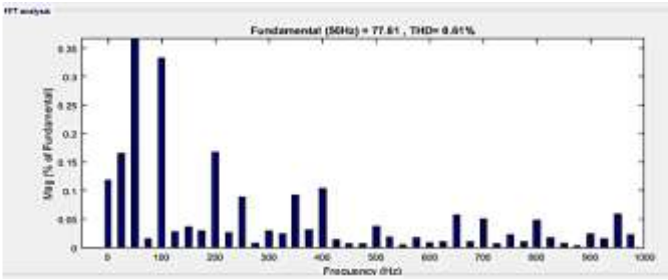


Figure 7 FFT Analysis of Source Current with load firing angle 0 degree

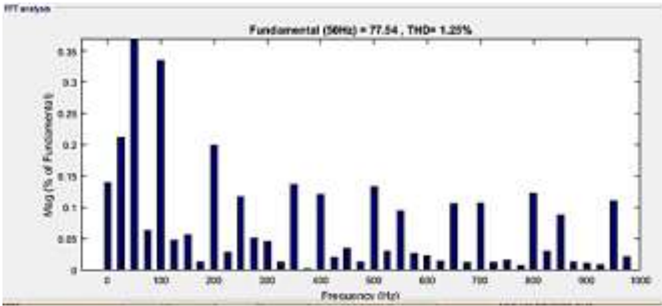


Figure 8 FFT Analysis of Source Current with load firing angle 30 degree

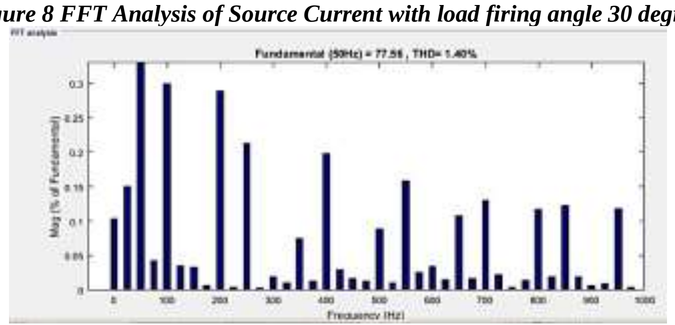


Figure 9 FFT Analysis of Source Current with load firing angle 60 degree

V. CONCLUSION

The reduction of harmonics and improving the power factor of the system is very important. In this paper work an ANFIS controlled shunt active power filter has been studied to improve the power quality by compensating harmonics and reactive power requirement of the nonlinear load. The simulation Results with the performance of ANFIS controllers shows that supply current is maintained as sinusoidal in phase with supply voltage. Hence, this control strategy has been successfully applied to a 100 MVA, ANFIS controller based shunt active filter with the SPWM technique is found to be successful in mitigation of harmonics.

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