Auto-Tuned Passive Filter using IsinΦ Controller for Power Quality Improvement in Distribution Networks

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Abstract—**Power quality improvement can be done effectively by adding passive or active filters in series or parallel with the line. Active filters perform efficiently but it is not cost effective. Traditional passive filters are cost effective but they are permanently connected to the system and draw large amount of source current even under light load conditions. By using auto tuned filters, the passive filter components can be controlled according to load variations and hence required reactive power compensation along with current harmonic elimination can be done efficiently. Auto-tuned filter with TSC-TSR combinations is designed and simulated in MATLAB/SIMULINK using Artificial Neural Network controller and a new controller called Isin Φ controller. Performance of both the controllers are compared. Simulation results show that Isin controller performs fast because of its reduced complexity and also easy to implement. The THD has reduced to a great extent along with reactive power compensation there by reducing the reactive power issues in transmission and distribution networks.**

Keywords-power quality; harmonics; autotuned filters; reactive power compensation; artificial neural network; total harmonic distortion

I. INTRODUCTION

In the present power system network, providing good quality power to consumers has emerged as a figure of merit for the power distribution utilities. Now a days modern and sensitive power electronic device find wide applications at domestic, industrial and commercial purposes. Devices such as rectifiers, inverters, adjustable speed drives and cyclo-converter draw non-linear currents from the source, which degrade the electric power quality. The quality degradation leads to low power-factor, low efficiency, and malfunctions of sensitive devices.

In recent years, the main means of harmonic suppression is the harmonic filtering devices installed in power system. The harmonic filtering devices include the passive filter and the active filter. The active filter can filter out all the harmonics in the grid and it also has better effect. But its structure and control strategy are more complex. So the active filter is hard to be applied in the high-voltage and large-capacity systems. The passive filter has simple structure, less initial cost, and mature technology. The passive filter is widely used in power system in domestic and abroad. But the capacitance of the traditional passive filter would change with temperature and the other external factors, and result in the resonance frequency deviating from the resonant point. The filtering effect becomes poor.

Auto-tuned passive filters are cheaper compared to active filters and it is more flexible than passive filters. So for loads with varying reactive power we can use Auto-tuned passive filters for power quality improvement and reactive power compensation. Here an Auto-tuned passive filter with TSC-TSR combination is chosen for power quality improvement in which the control is done using two different techniques, Artificial Neural Network (ANN) controller and Isin controller [1] to [9].

II. ARTIFICIAL NEURAL NETWORK

Artificial Neural Networks are a group of algorithms which are made from the observation of biological neural networks. These algorithms can be used to estimate or approximate functions that can depend on a large number of inputs and are generally unknown. They are generally considered as systems of interconnected "neurons" which can compute values from inputs, and are capable of machine learning as well as pattern recognition thanks to their adaptive nature [10],[11].

III. ISINΦ CONTROLLER

Isin is the reactive component of the current. It can be stated as the value of current corresponding to the zero crossing of system voltage as shown in fig 1. As the reactive power drawn by the load changes, reactive component of the load current will also changes, so Isin Φ magnitude is a measure of reactive power drawn by the load.
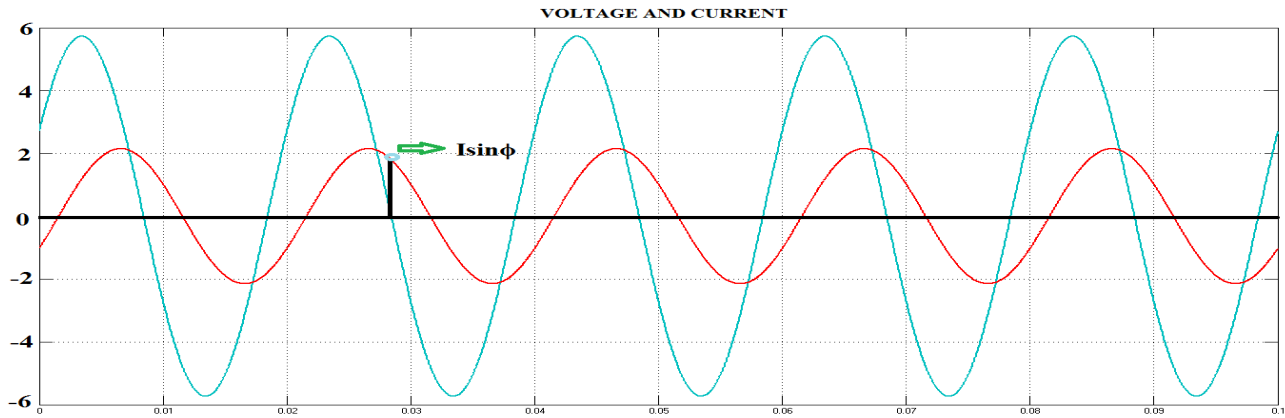
VOLTAGE AND CURRENT

Figure 1.   Isin magnitude representation

IV. DESIGN OF PASSIVE FILTER

A three-phase 415 V, 50 Hz balanced supply is given to a nonlinear-reactive load which draws a reactive power of 1620 VAR. The filter element values are selected based on reactive power demand, quality factor, tuning frequency and detuning factor. Therefore shunt passive filter is designed such that 50% of the reactive power demand is met by each of 5th and 7th order filters. Hence;

The per phase reactive power demand to be injected by each filter = 1620 / (3x2) = 270 VAR,

The capacitance reactance in 5th order filter = the capacitive reactance in 7th order filter,

$$X_c = V^2/ Q_{demand} = 637.87 \text{ ohm} \qquad (1)$$

Capacitance in 5th and 7th filter arm, $C = 1/ X_c \omega$ (2)

$$C = 1 / (376.44 \text{x} 2\pi \text{x} 50) = 5 \text{ μF}$$

The corresponding inductive reactance in 5th harmonic filter is calculated based on the concept that the filter provides minimum impedance path at fifth order harmonic frequency (ie. $X_L = X_c$)
Inductance in the 5th order filter arm,

$$L_5 = 1/ (C\omega^2) = .0810569 \text{ H}$$

The corresponding inductive reactance in 7th harmonic filter is calculated based on the concept that filter provides the minimum impedance path at 7th order harmonic frequency (ie. $X_L = X_c$).
Inductance of the 7th filter arm $L_7 = 1/ (C\omega^2) = .041355 \text{ H}$
Assuming Quality factor = 40

$$\text{Quality factor, } Q = X_0 / R \qquad (3)$$

$$X_0 = \sqrt{\frac{L}{C}} = 80 \text{ Ω} \qquad (4)$$

Value of series resistance, $R_5 = 2 \text{ Ω}$, $R_7 = 1.4 \text{ Ω}$.

V. AUTO-TUNED PASSIVE FILTER

A three phase non-linear load will draw some harmonic current for its working. This will cause harmonics in the source current and voltage wave form. In order to mitigate this harmonics an Auto-tuned passive filter is used whose block diagram is shown in Figure.2. Auto tuned filters are better than passive filters in mitigating harmonics since detuning will be less in the case of auto-tuned filters. The performance of the adaptive shunt passive filter depends on the efficiency and reliability of the controller used for selection of proper filter element values. Two types of controllers are discussed in this paper and their performances are compared. [12],[13]
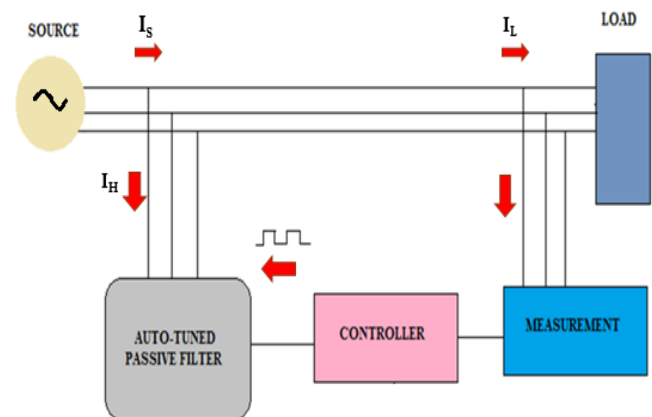
Figure 2.   System block diagram with auto-tuned passive filter

A. Arrangement of TSC- TSR in one Phase

The typical nonlinear load shown in Figure.1.is used here to study the effectiveness of the adaptive shunt passive filter.
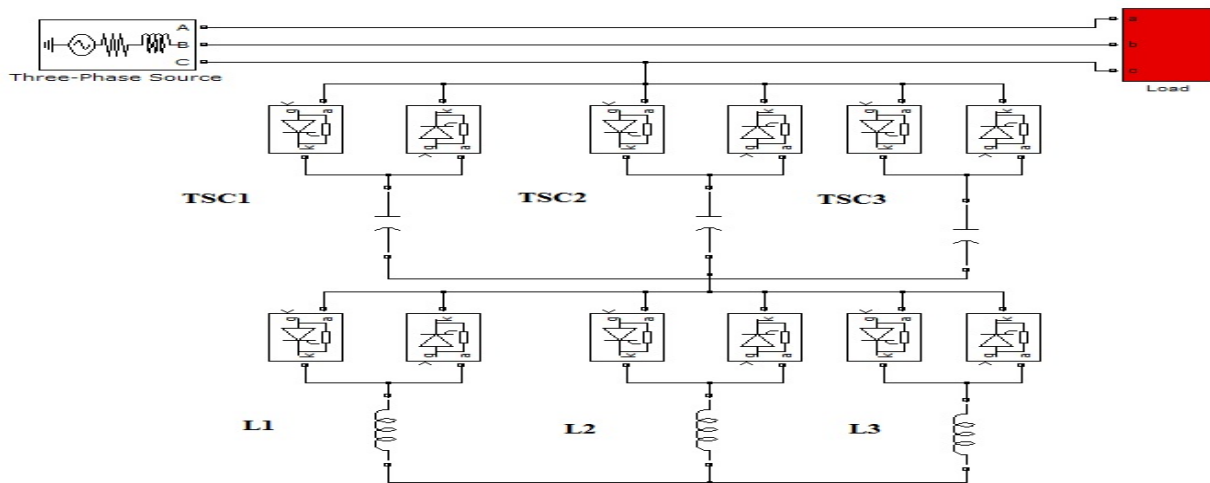
Figure 3. Arrangement of TSC-TSR in one phase

In order to compensate three phase reactive power demand, capacitors of 5μF, 7μF, 10μF are connected in three parallel connected TSCs along with corresponding TSRs. The designed values of filter elements are shown in table I.

TABLE I   ADAPTIVE PASSIVE FILTER ELEMENTS

Load	Reactive power demand (VAR)	Fifth order filter			Seventh order filter		
		R (Ohm)	TSR (H)	TSC (μF)	R (Ohm)	TSR (H)	TSC (μF)
Load 1	1620	2	.0810	5	1.4	.04135	5
Load 2	2200	2	.0578	7	1.8	.02953	7
Load 3	3000	2.1	.04	10	1.1	20	10

VI. DESIGN OF ANN CONTROLLER

ANN is a computational model with the structural or functional aspects similar to biological neural network. It develops structure of control system with the help of training data, relating system input and response quantities. An adaptive system changes its structure with respect to variations in system inputs. Source voltages and load currents are taken as the input for the controller and the output will be switching pulses for TSC and TSR [14].

A. ANN Block Diagram

The back propagation neural network is trained using 4000 training patterns with performance tolerance of .001 and 1000 epochs is shown in Figure.4. The ANN used here comprises of 3 layers. Input layer (6 neurons) output layer (1 neuron) and 10 hidden layers.
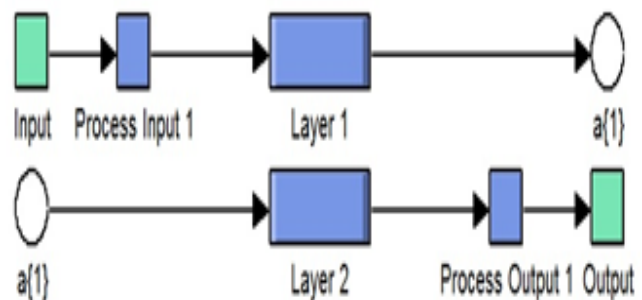

Figure 4. Artificial neural network block diagram

Three phase source voltages and load currents are measured and it is given to the ANN controller. Input signal will pass through many hidden layers which are interrelated by some weights. According to the trained data given for the ANN it will make suitable output which is the ON/OFF sequence of the thyristor switches.

B. Error Histogram

The operation of ANN is verified using 1000 validating data and the error histogram is obtained as shown in Figure.5. It clearly shows that error is very much closes to the   zero   error
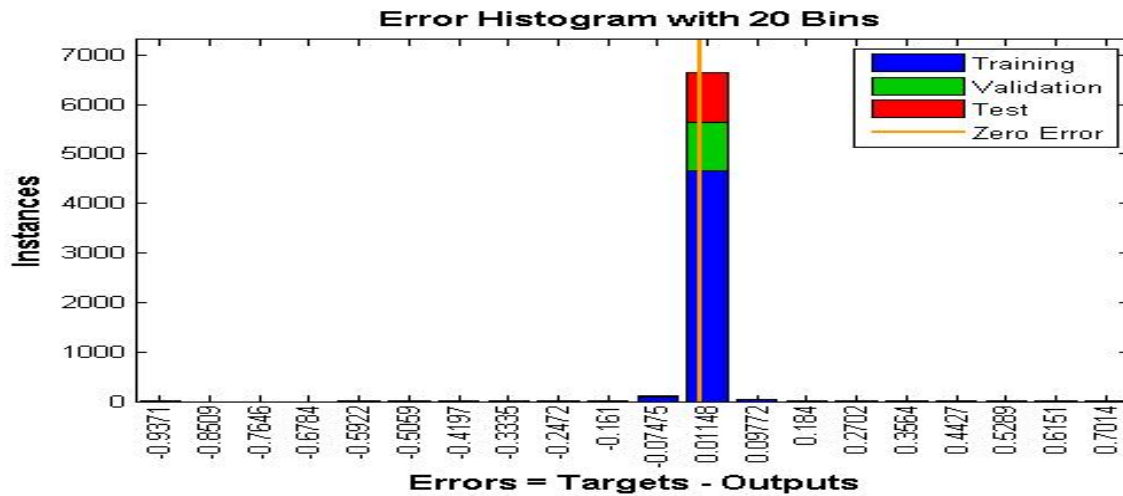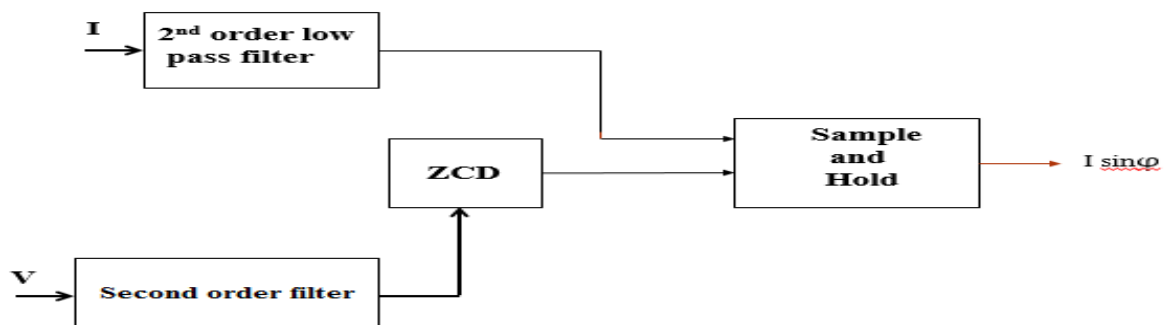
Figure 5.   Error histogram for TSC

VII. DESIGN OF ISIN Φ CONTROLLER

Magnitude of current at voltage zero crossing can be extracted by using the blocks shown in Figure.6.

Figure 6.   Block diagram for extracting Isin Φ

Measured voltage and current signals are given to second order filter which will give the fundamental waveform with 90 degree phase shift as the output. Voltage fundamental waveform is given to the zero crossing detector to sense the zero crossing of the wave form. Both the signals are given to sample and hold circuit. Output of the sample and hold circuit will give Isin Φ magnitude.

VIII. SIMULATION RESULTS

The simulation model of the three-phase system with the auto-tuned passive power filter is shown in Figure.7. TSC-

TSR based passive filters tuned to the 5th and 7th harmonic frequencies are connected in parallel as harmonic sinks. The ANN based digital controller receives the load currents and the phase voltages at the point of common coupling (PCC) as inputs. Based on the appropriately tuned knowledge base, the controller selects the proper combination of the passive filter elements.
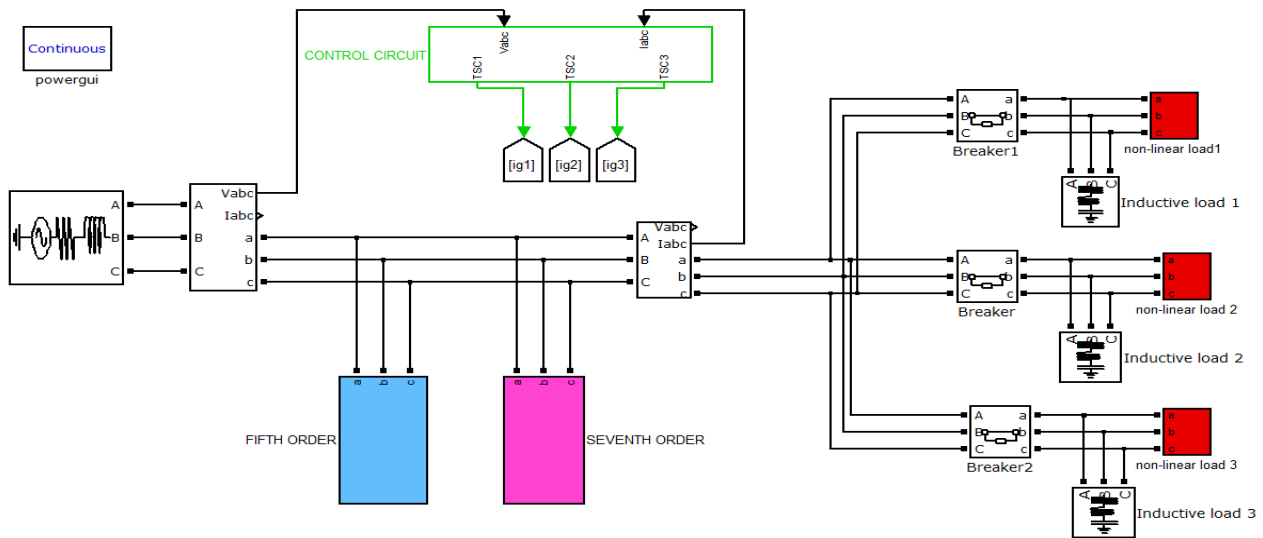
Figure 7.   MATLAB/SIMULINK diagram of auto-tuned filter

Three non-linear inductive loads are connected to a three phase balanced supply. The loads are connected through circuit breaker such that each load will be connected to the supply for a specified interval. Switching pulses generated by ANN controller and Isin Φ controller are shown in Figure.8 and Figure.9 respectively.
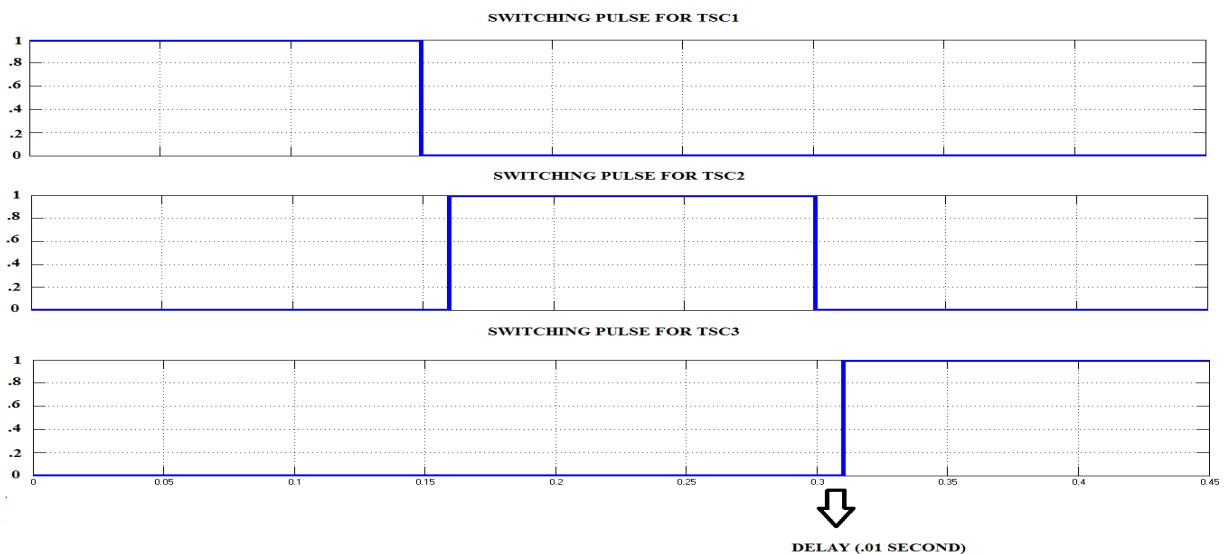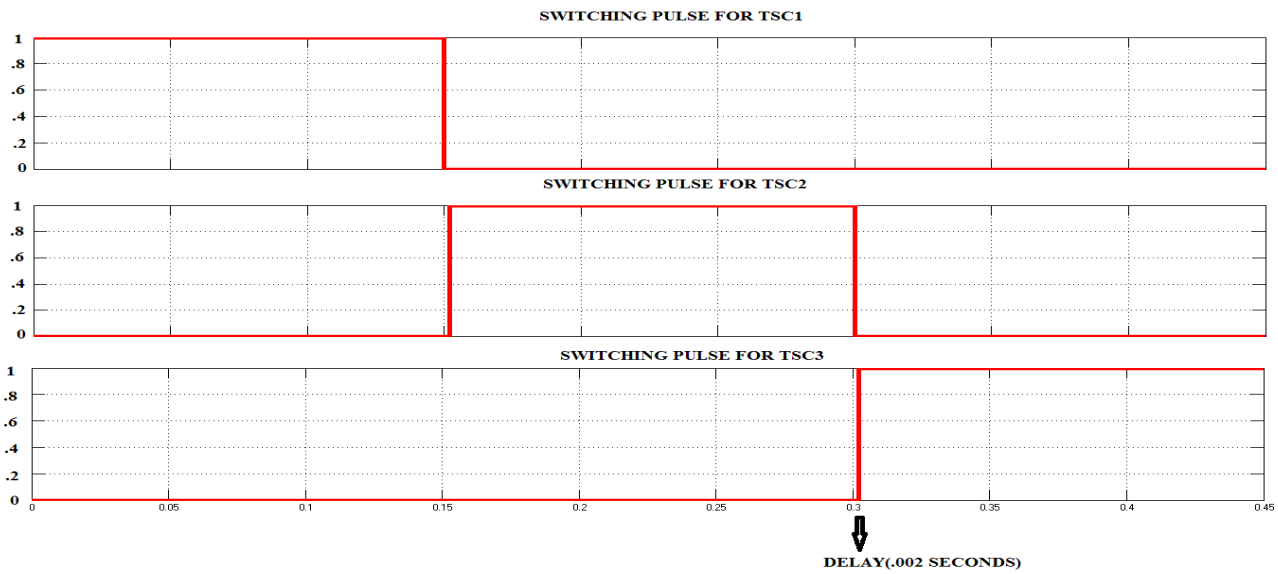

Figure 8   Switching pulses by ANN controller

The time delay for pulse generation using Isin Φ controller (2 milli second) is much less compared to Artificial Neural Network controller (10 milli second). So after this delay only switching of filter element taking place.

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Figure 9   Switching pulses generated by Isin Φ controller

Load current is a periodically increasing waveform which contains harmonics. Up to 0.15s the amplitude of load current is 9 A and after that it changes to 10.3A till 0.3s. Finally current reaches to an amplitude of 11.6 A till .45s. This periodical change in amplitude is due to the change in load. Source current is free from harmonics and its amplitude is almost similar to the load current which means that filter is drawing only small amount of current for its working. Waveform of Source voltage, source current, load current are shown in Figure.10.
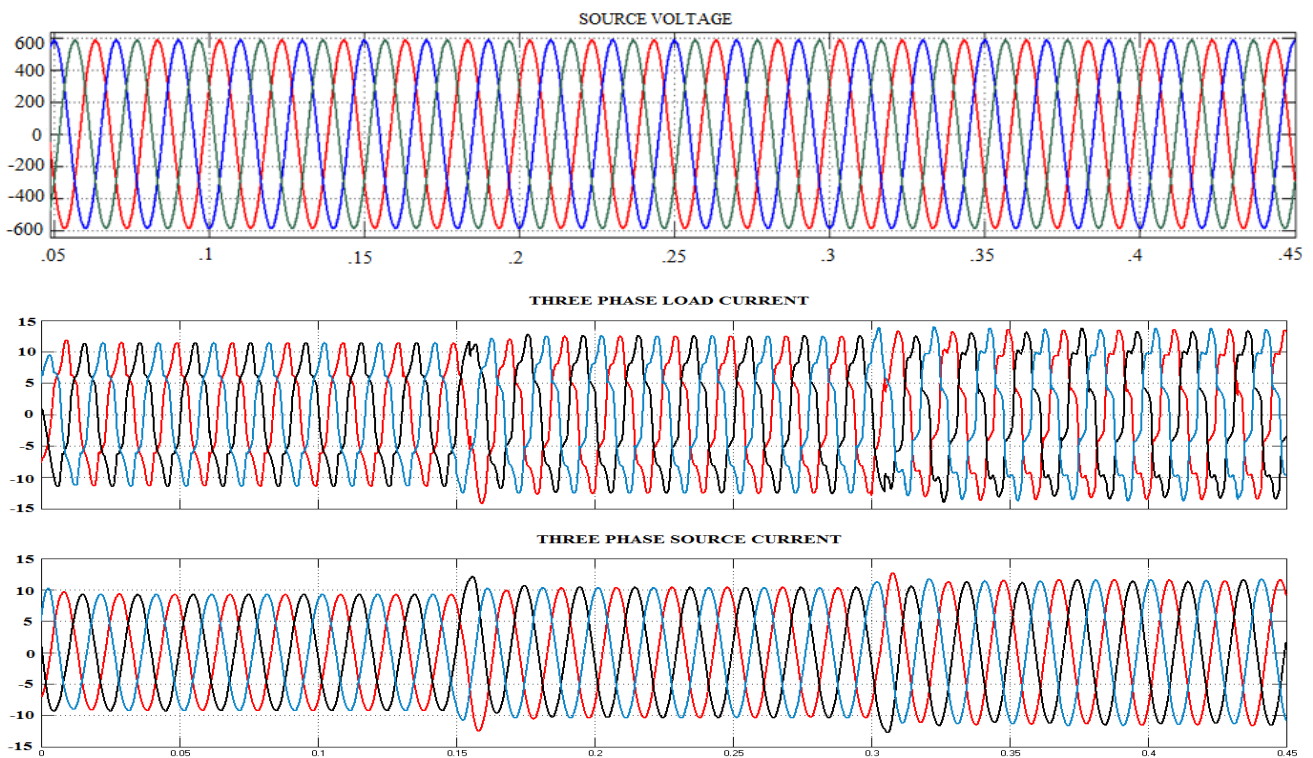

Figure 10 Source voltage, load current, source current

Comparison of source current and load current waveforms for one phase is shown in Figure.11.
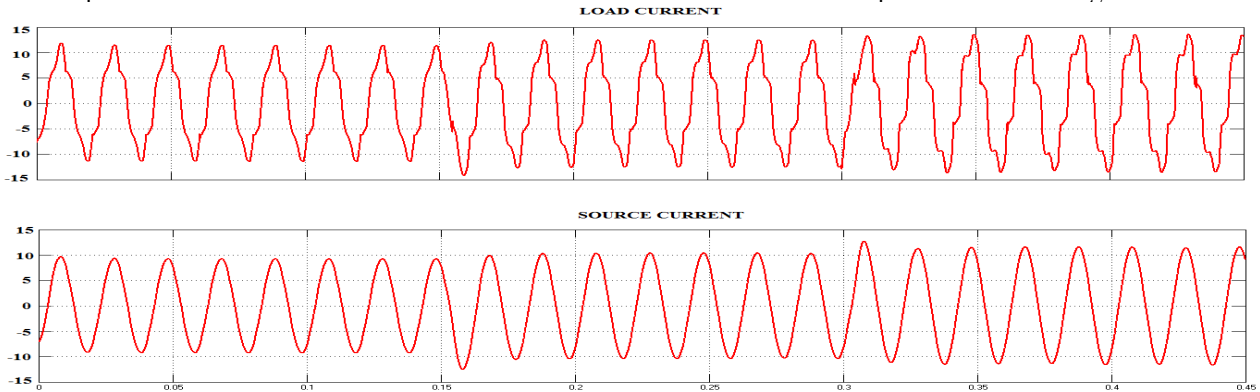

Figure 11. Source current and load current

FFT analysis of load current is shown in Figure.12. Load current is having a THD of 21.41% in which Fifth order (19.78%) and Seventh order (7.23%) harmonics are dominant.
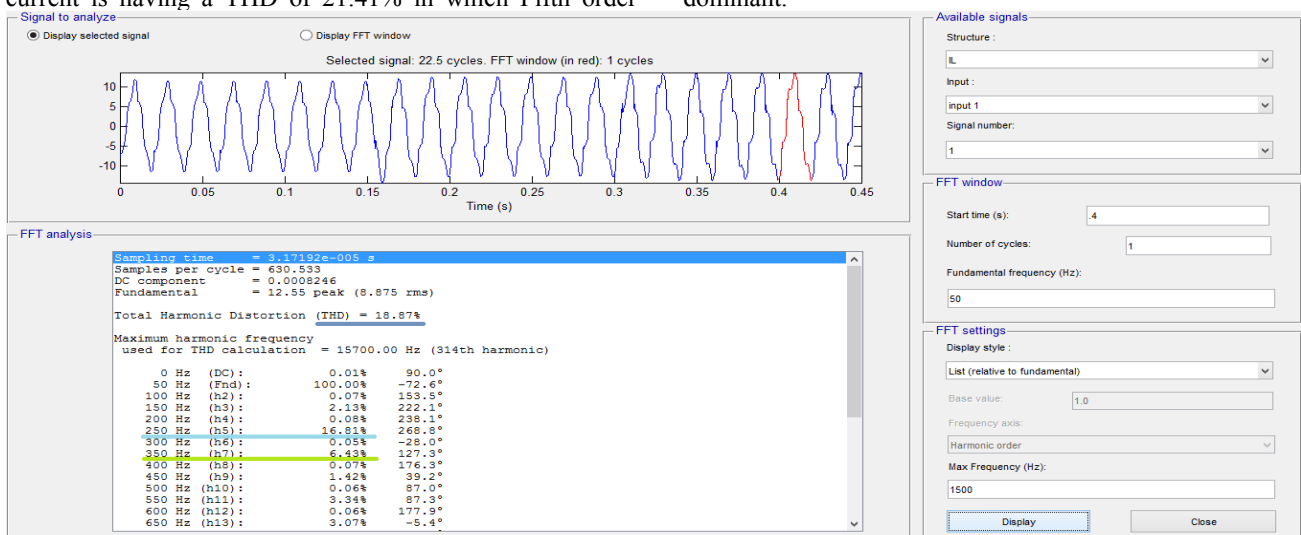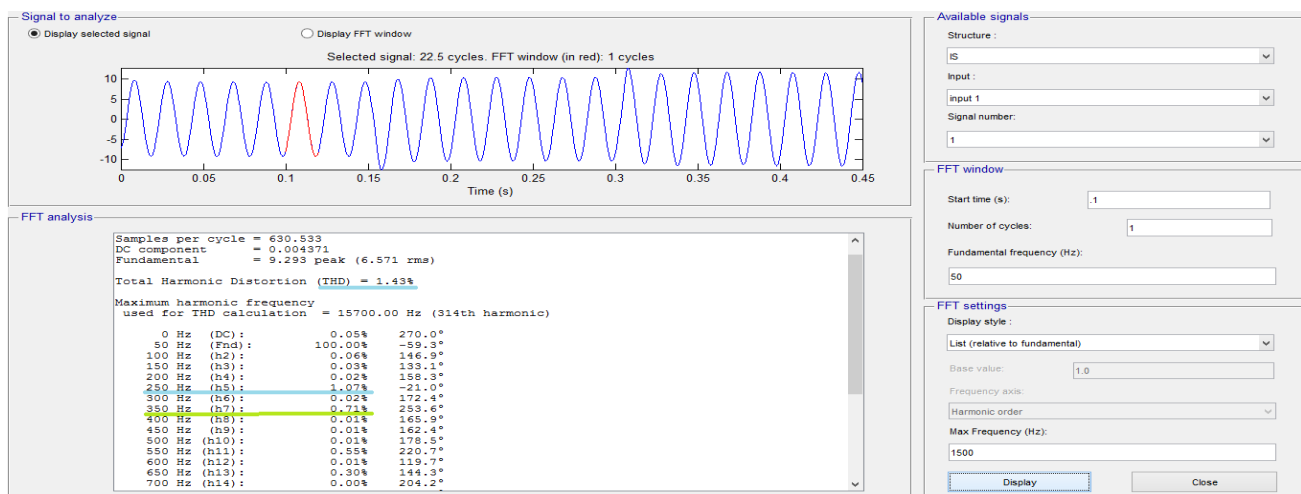

Figure 12. FFT analysis of load current

Figure 13. FFT analysis of source current

FFT analysis of source current after compensation is shown in Figure.13. It shows that THD is reduced to 1.44 % by using auto-tuned filters. Fifth order harmonics THD is reduced to 0.75% and seventh order harmonics THD is reduced to 0.96%. Comparison of THD for all the loads with and without filter is shown in table II.

TABLE II   COMPARISON OF THD

LOAD	% THD OF SOURCE CURRENT					
	Without Filter			With Auto-tuned filter		
	%THD	5th	7th	%THD	5th	7th
Load 1	23.54	21.54	7.47	1.8	1.01	.92
Load 2	21.09	18.98	8.04	1.73	1.2	.87
Load 3	21.41	19.78	7.23	1.44	.75	.96

Reactive power requirement is compensated by auto-tuned passive filter so that only small amount of power is drawn from the source. Reactive power requirement of the load and reactive power needed to be supplied by the source is shown in table III.

TABLE III   REACTIVE POWER REQUIREMENT

LOAD	Reactive power requirement of the load (VAR)	Reactive power supplied by the source (VAR)
Load 1	1620	161
Load 2	2200	220
Load 3	3000	324

IX. CONCLUSION

A three phase system with highly nonlinear and reactive load is chosen for the simulation. Auto-tuned passive filter is designed and simulated with ANN controller and Isinϕ controller and their performances are compared. The simulation result shows that the Isin ϕ controller is much faster compared to ANN based controller in generating switching pulses. Auto-tuned passive filter with both the controllers can achieve effective harmonic elimination and also performs reactive power compensation. Further modifications is possible in this system such as changing TSR branches by TCR, using double tuned filters or C type filters instead of single tuned filters etc.

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