Series Hybrid Filter for Harmonic Compensation in Three Phase System using Fuzzy Logic Controller

Nisha Tilwani, Dipesh Sharma

***Abstract*— with the increasing demand of power electronic devices, the harmonic generation is becoming a serious problem to the power system. Conventionally passive filters were used to solve this problem of harmonics, which may not have satisfactory performance but the auto tuned active filter is a mature technology to solve this serious problem of harmonic generation. But the use of active filter alone has some drawbacks like high initial cost, and high power loss. Therefore a new approach of combined active and passive filter has been discussed in this paper. The combination of active filter and passive filter is called Hybrid Filter. Synchronous Reference Frame (SRF) is used for the generation of reference compensating current, a Fuzzy Logic Controller is used for dc voltage regulation, and for the generation of gating signals for the IGBTs used in active filter, hysteresis band controller is used. The results and efficiency of the system are verified through MATLAB simulation. The results are found to be quite satisfactory as the proposed system maintains the THD, as per the limits of IEEE-519 standard.**

***Index Terms*— Hybrid filter, Series active filter, Hysteresis band controller, Fuzzy logic controller, Synchronous reference frame.**

I. Introduction

The power electronic devices like; computers, electronic ballasts, battery chargers, switch mode power supplies, and variable frequency drives generate harmonic distortions and cause a large economic loss every year.

The increasing use of these power electronic devices introduced serious problems in the electric power distribution grids. The flow of harmonic currents in the electric grids can also cause voltage harmonics and disturbance. These harmonic currents and voltages can disturb the other loads connected at the point of common coupling of the electric power distribution grid.

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Nisha Tilwani, *Power Electronics, Raipur Institute of Technology, Raipur, India.*

Dipesh Sharma, *Computer Science Engineering, Raipur Institute of Technology, Raipur, India.*

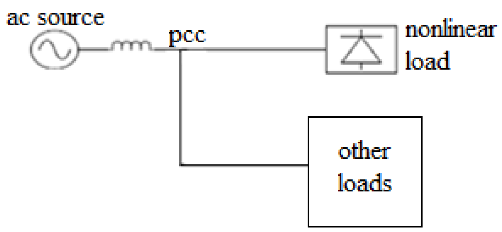

Fig -1: Power System

A. *Harmonics*

Ideally, the electricity supply should show a perfect sinusoidal voltage and current at every point of the power system. But practically it is almost impossible to achieve such a desirable condition. Voltage and current waveforms deviate largely from a sinusoidal waveform. The deviation of these waveforms can be described by the use of waveform distortion, oftenly called harmonic distortion. Although the harmonic distortion is a quite old phenomenon, it today presents one of the main problems for distribution system operators, their end customers and public utilities as well. In the beginning these harmonics came from mercury vapor rectifiers, which were used in industries. The major issue at this time was the effect that harmonic distortion had for the electric machines itself. Another common problem was interference with the telephone lines. But now a days, it can be said that harmonic distortion in former times did not have the such dangerous potential like it has today. Especially machines have been designed much more conservative and the distribution networks have not been on their limit loads. The term "harmonics" is originated from the physical eigenvalue problems, meaning that the waves whose frequencies are integer multiples of one another. A perfect alternating current is defined by the sinusoidal wave in which electrical voltage smoothly changes from positive polarity to negative polarity and back again to positive polarity 50 (50Hz) or 60 (60Hz) times per second. Thus harmonic component in a power system can be defined as a sinusoidal component of a periodic waveform that contains a frequency equal to an integer multiple of the fundamental frequency of the system.

$f_n = n*f_1$

f_n = harmonic frequency

n = order of harmonics

f_1 = fundamental frequency

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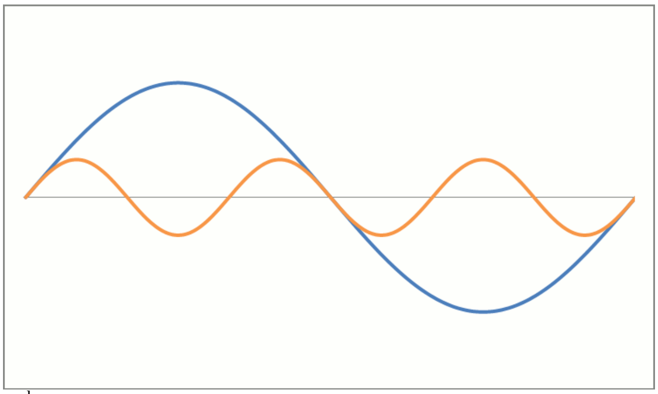
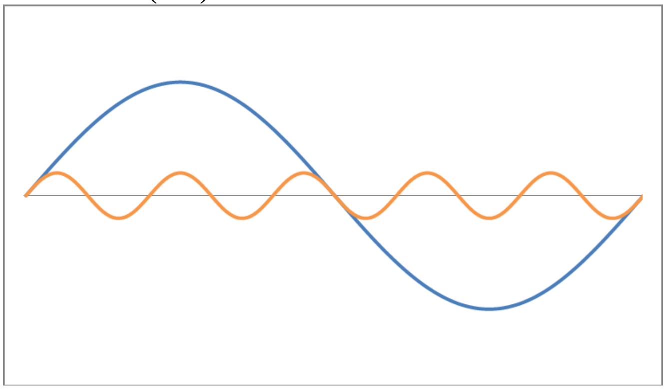
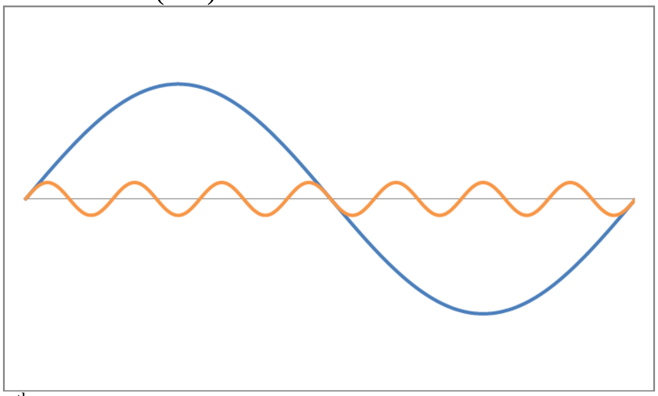
Figure-2 shows an ideal 50-Hz waveform with 3rd, 5th, 7th, and 11th order harmonics.



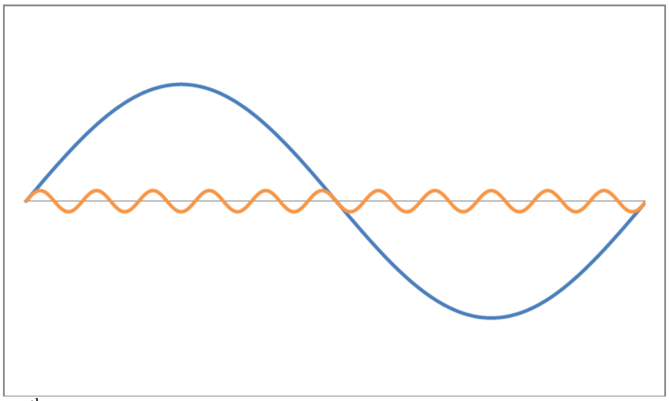
3rd harmonic (n=3)



5th harmonic (n=5)



7th harmonic (n=7)



11th harmonic (n=11)

Fig -2: Harmonic Frequencies

B. Techniques of Harmonic Filtering

The harmonic filtering technology is quite important for the power quality improvement of the system. The harmonics generated in the system can be minimized by the use of various filters that basically referred as ACTIVE FILTER & PASSIVE FILTER.

Passive Filter

A low cost solution to this problem is to use passive filter, which is tuned to eliminate a particular harmonic frequency. It may be single tuned or double tuned [3] as shown in figure-3.

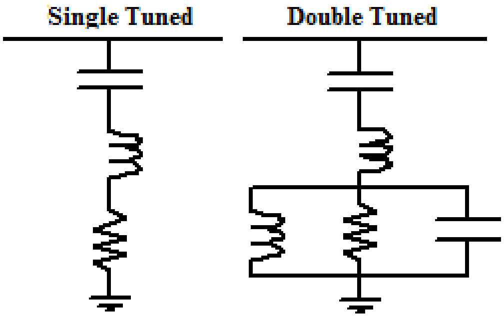


Fig -3: Single and Double Tuned Passive Filters

Though passive filters are economic and have simple structure, they have the disadvantages of fixed compensation, resonance and large size [2]. To overcome the shortcomings of passive filters, active filters were developed.

Active Filter

Due to the disadvantages of passive filters like fixed compensation, resonance, and large size, new methods are needed. To remedy the shortcomings of passive filters, active filters were developed. An Active filter consists of a voltage source or current source inverter, output filter and dc link storage. Basically the active filters are of two types; the shunt active filter and the series active filter.

Shunt Active Filter

Figure- 4 shows a shunt active filter, which is used for the elimination of current harmonics, balancing of unbalanced currents, and reactive power compensation. It is usually connected at the input of the load, because the current harmonics are generated by nonlinear loads. It injects compensating currents, which are equal in magnitude and opposite in phase with the harmonic currents, for the cancellation of harmonic components of the nonlinear load current at the point of common coupling. The power stage is, basically, a voltage-source inverter with a capacitor in the DC side, controlled in a way that it acts like a current-source. The active filter does not require any internal power supply.

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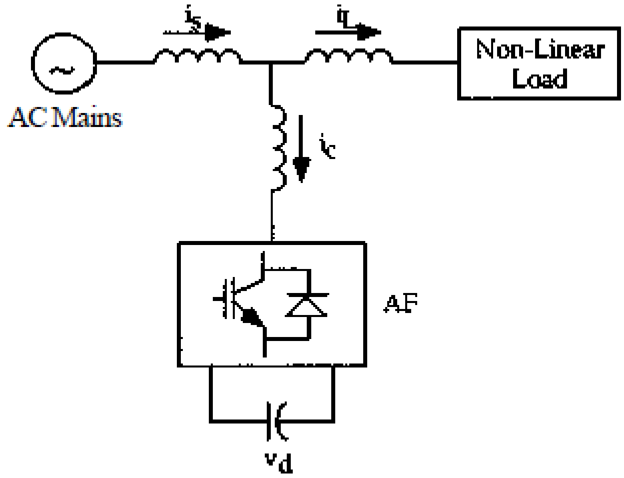

Fig -4: Shunt Active Filter

Series Active Filter

Figure- 5 shows a series active filter for a three-phase power system. The series active filter is connected at the source side with a coupling transformer. It acts as a harmonic isolator. It provides very high impedance at harmonic frequencies and forces the load harmonics to circulate through the passive filter. In this way it prevents the load harmonics from reaching towards source and thereby improves the source waveforms.

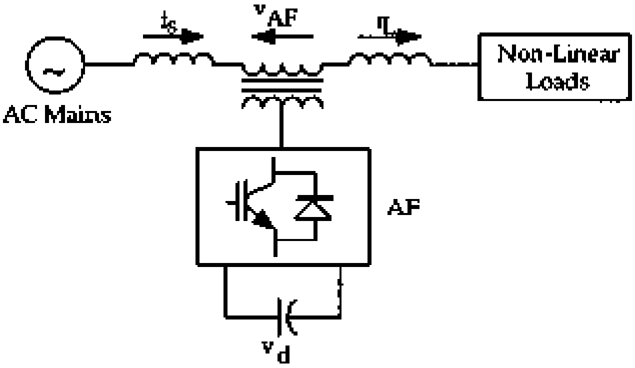

Fig- 5: Series Active Filter

Shunt active filters are already commercially available; therefore the series active filters are at prototype level.

II. PROPOSED TOPOLOGY

Even though the active filters are an effective compensation system, their cost is very high with the high power rating. This is the major drawback of active filters.

To reduce the power rating and hence the cost of active filters, the hybrid filters [2, 4, 5, 6, 7, 8, 9, 10, 11] have been developed, which are the combination of active filters and passive filters. Figure- 6 shows the proposed topology of Hybrid Filter.

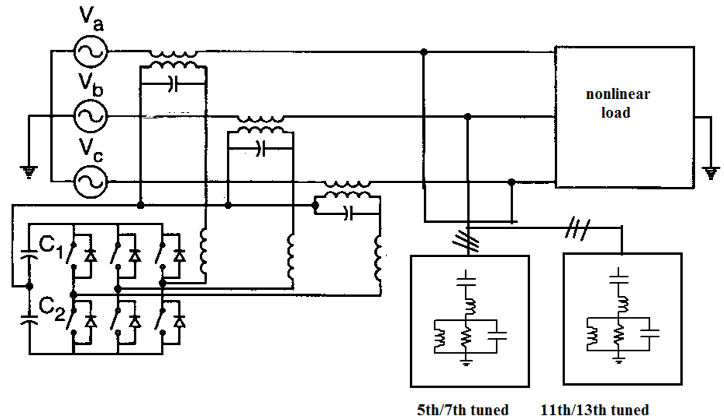

Fig -6: Proposed Topology

Here the active filter is used in series and the passive filter is used in parallel with the line. The system is capable to remove current as well as voltage harmonics. The passive filter is tuned to eliminate the dominant current harmonics generated by nonlinear load as well as to supply the nominal reactive power, and the active filter improves the compensation characteristics of passive filter as well as eliminates the voltage harmonics generated due to non ideal source conditions.

III. CONTROL STRATEGY

For proper operation of active filter, an appropriate control strategy is necessary. The control strategy is designed to generate the gating signals for IGBTs used in active filter.

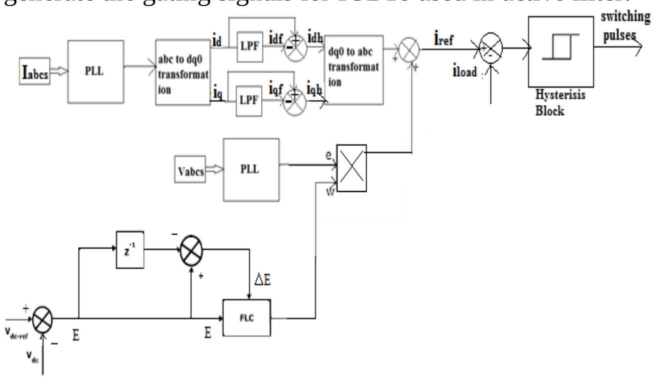

Fig -5: Block Diagram of Control Strategy

The control strategy is divided into three parts.

A) Generation of reference compensating current.
B) DC voltage regulation.
C) Generation of gating signals.

A) Generation of Reference Compensating Current

For the generation of reference compensating current, synchronous reference theory is used, which uses park transformation. It converts the three phase time domain signals from stationary abc coordinates to rotating dq0 coordinates. It reduces the three phase ac quantities (eg. Ua, Ub, and Uc) into two dc quantities (eg. Ud, Uq). For balanced system the 0 component is zero. The main purpose of this conversion is that the dc quantities are easier to filter and control.

The d-component of the signal consists of fundamental and harmonics active components, i.e., id = idf + idh. The q-component consists of fundamental and harmonics reactive components, i.e., iq = iqf + iqh. The fundamental active and reactive components (idf and iqf) are separated by low pass filters and subtracted from the complete d and q components respectively to get the harmonics active and

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reactive (idh and iqh) components. These harmonics components are then transformed back from dq coordinates to abc coordinates [6].

B) DC Voltage Regulation

The fuzzy logic controller [14, 15, 16] is used for the regulation of dc bus voltage of active filter. Conventionally PI controller was used for the regulation of dc bus voltage. Many other methods have been developed to replace PI controller. Some of them are optimal regulator control [12], sliding mode control [13], and model reference adaptive control. The designs of these methods are dependent on precise linear mathematical models, which cannot be obtained easily and may not give satisfactory results under dynamic conditions of load. Recently, fuzzy logic controllers have been developed for dc bus voltage regulation of active filter. The advantages of fuzzy logic controllers over conventional controllers are that they can work without accurate mathematical model, with imprecise inputs, and can be capable to handle non-linearity.

Figure- 8 shows the structure [14] of fuzzy logic controller.

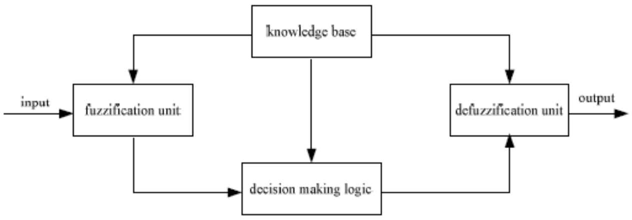

Fig -8: Structure of Fuzzy Logic Controller

The main parts of fuzzy logic controller are:

1) **Fuzzification unit** is used to convert the input variables into linguistic variables or fuzzy variables. For this purpose seven fuzzy levels are selected which are NL(negative large), NM(negative medium), NS(negative small), EZ(equal to zero), PS(positive small), PM(positive medium), PL(positive large).
2) **Knowledge base** is used to keep necessary data to set the control methods.
3) **Decision making logic** is used to get the output using data sets and rule base from second part.
4) **Defuzzyfication unit** is used to convert the fuzzy variables into easy understanding variables.

Figure- 9 shows the block diagram [15] of fuzzy inference system.

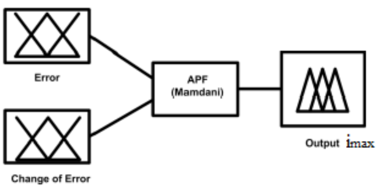

Fig -9: Fuzzy Inference System

It has of two input membership functions which are error (e) and change of error (ce), and an output membership function which is the peak supply current (i_{max}). These membership functions are shown in figure- 10.

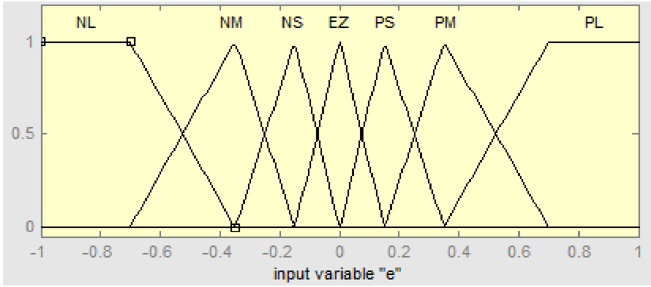

Fig -10(a): Input Membership Function (Error e)

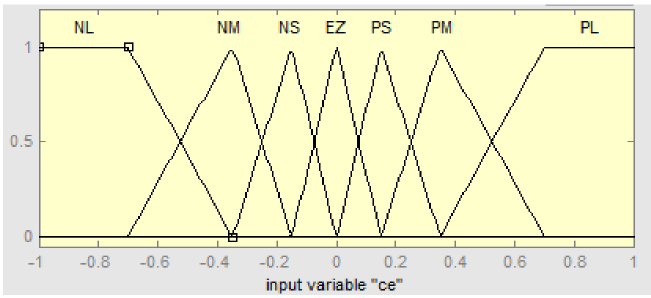

Fig -10(b): Input Membership Function (Change of Error ce)

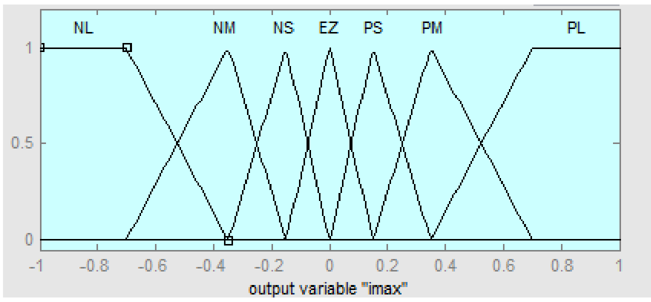

Fig -10(c): Output Membership Function (Peak Supply Curent i_{max})

The rule base table of fuzzy inference system is shown in table-1

Table-1: rule base table

c\ce	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	EZ	PS	PM	PL	PL	PL	PL

Figure- 11 shows the fuzzy logic controller for the generation of reference compensating current.

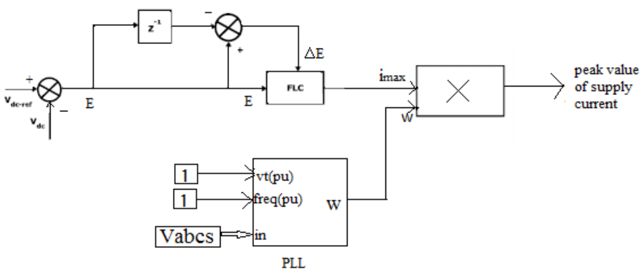

Fig -11: Generation of Reference Compensating Current using Fuzzy Logic Controller

The input to the fuzzy logic controller is the error and change in error. The error is nothing but the difference of desired dc bus voltage (Vdc_ref) and the actual dc bus voltage. The

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fuzzy logic controller processes this error. The output of fuzzy logic controller is the peak supply current, which is multiplied by the unit sine vector in phase with the respective source voltage, to get the peak supply current in the form of sinusoidal signal [5, 8].

This peak supply current is then added to the abc output of inverse park transform. The result is then the reference compensating current.

C) Generation of Gating Signals

A hysteresis band controller [9] is used for the generation of gating signals. It compares the actual load current wit the reference current. When the actual load current crosses the lower boundary of reference current, upper switch is turned on. When the actual load current crosses the upper boundary of reference current, lower switch is turned on. In this way gating signals are generated for the active filter switches.

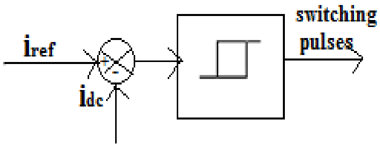

Fig -12: Hysrerisis Band Controller

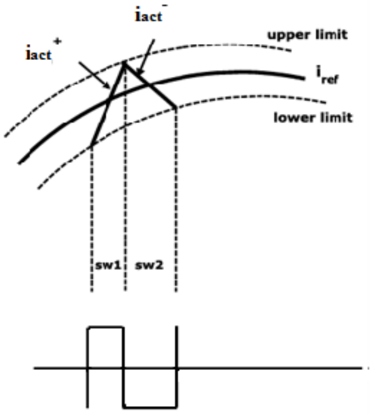

Fig -13: Generation of Gating Signals

IV. SIMULATION RESULTS

The overall simulation diagram is shown in figure- 14.

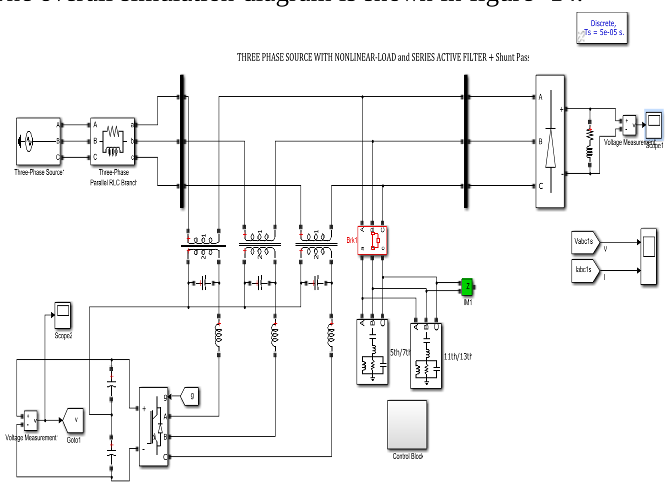

Fig -14: MATLAB Model for Proposed System

The harmonic compensation technique is implemented for a three phase power system, by using a hybrid filter. The source current waveform and its Total Harmonic Distortion (THD) spectrum, without filter are shown in figure 11(a), and figure 11(b) respectively. It indicates a THD of 12.20%, and the source voltage waveform and its Total Harmonic Distortion (THD) spectrum, without filter are shown in figure 11(c), and figure 11(d) respectively. It indicates a THD of 20.99%. The source current waveform and its Total Harmonic Distortion (THD) spectrum, with hybrid filter are shown in figure 12(a), and figure 12(b) respectively. It indicates a THD of 3.20%, and the source voltage waveform and its Total Harmonic Distortion (THD) spectrum, without filter are shown in figure 12(c), and figure 12(d) respectively. It indicates a THD of 3.57%. From these figures it is clear that the series hybrid filter reduces the harmonics to the limits as specified by IEEE-519 standard.

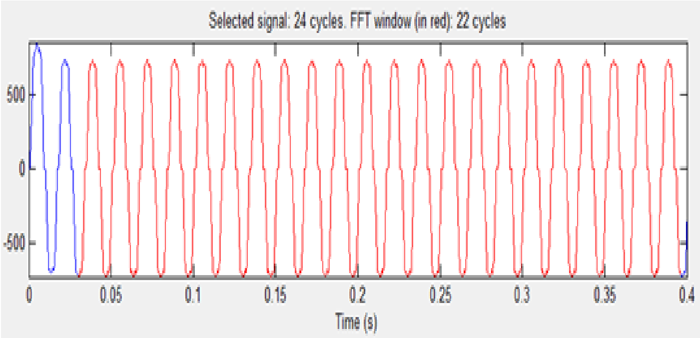

Fig -15(a): Source Current Waveform in Phase-a Without Filter

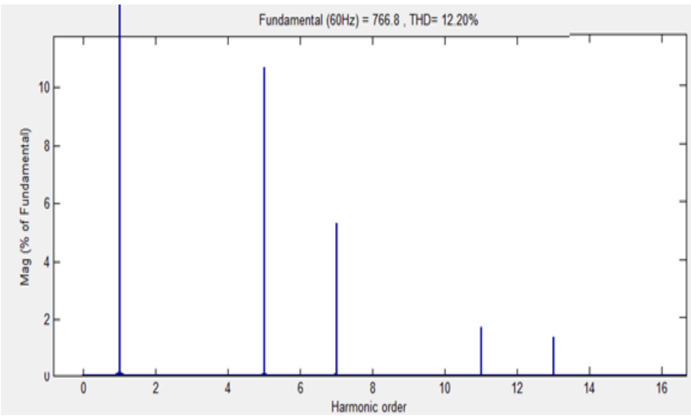

Fig -15(b): THD of Source Current Waveform in Phase-a Without Filter

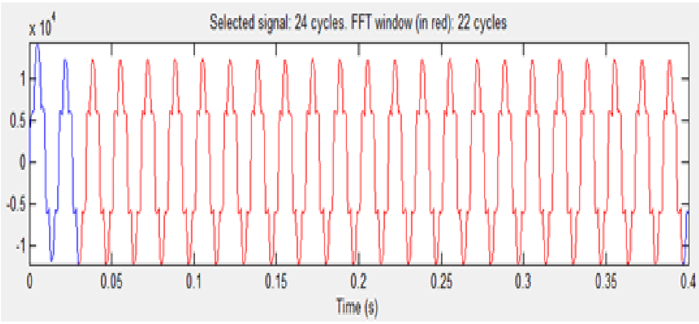

Fig -15(c): Source Voltage Waveform in Phase-a Without Filter

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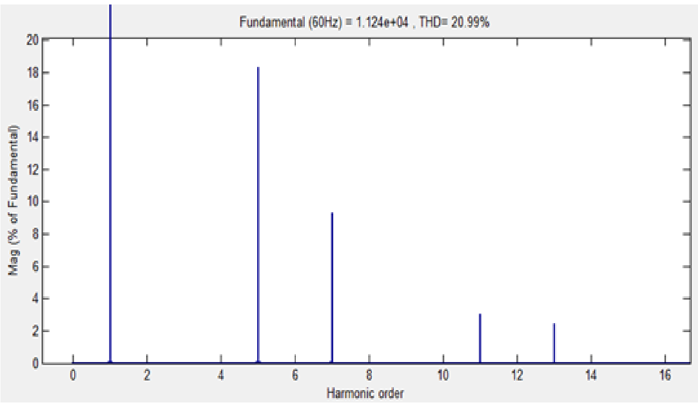

Fig -15(d): THD Spectrum of Source Voltage Waveform in Phase-a Without Filter

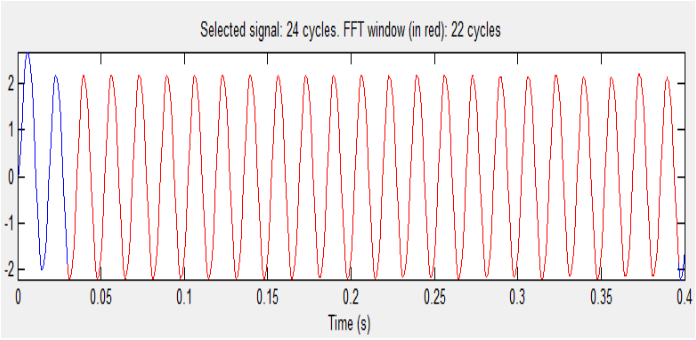

Fig -16(a): Source Current Waveform in Phase-a With Hybrid Filter

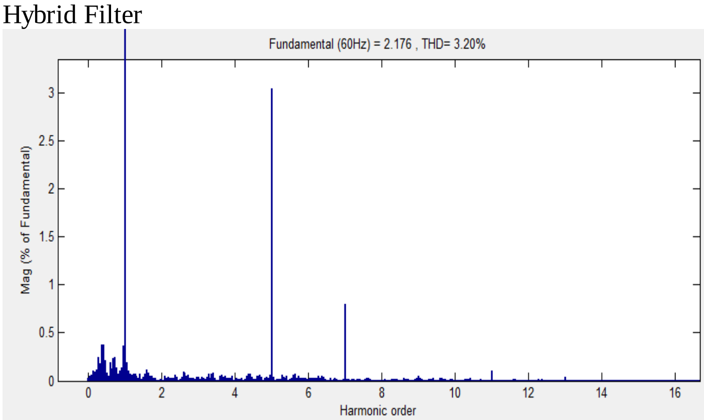

Fig -16(b): THD of Source Current Waveform in Phase-a Without Filter

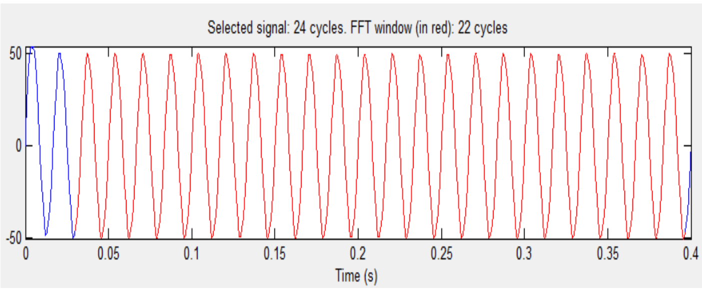

Fig -16(c): Source Voltage Waveform in Phase-a With Hybrid Filter

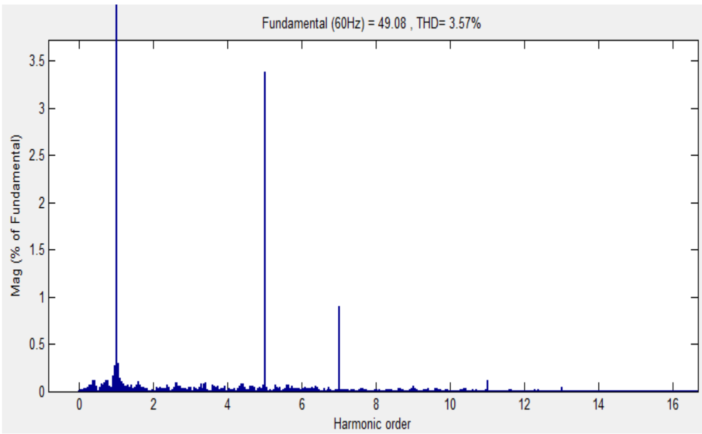

Fig -16(d): THD Spectrum of Source Voltage Waveform in Phase-a With Hybrid Filter.

V. CONCLUSIONS

A three phase series hybrid filter with fuzzy logic controller has been proposed here for the compensation of voltage and current harmonics, which has been simulated by a MATLAB based model. The system has been found capable of operating satisfactorily. It has reduced the harmonics effectively below 5%, which meets the regulation of IEEE 519 STANDARDS.

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Nisha Tilwani received her B.E. degree in Electronics and Telecommunication from Chhattisgarh Swami Vivekananda Technical University, Bhilai in 2012. She is perusing M.E. in Power Electronics from Chhattisgarh Swami Vivekananda Technical University, Bhilai.

Dipesh Sharma received his B.Tech degree in Electrical Engineering and M.Tech degree in Computer Technology. He has six years of industrial experiences, 3 years of experience of teaching in National Institute of Technology, Raipur, and eight years of experience of teaching in Chhattisgarh Swami Vivekananda Technical University, Bhilai. His research area includes Power Quality Improvement. He is currently an associate professor in Raipur Institute of Technology, Raipur.

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