Fuzzy Controller based Neutral Current Harmonic Suppression in Distribution System

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***Abstract*—Recent surveys of three-phase four-wire electric systems, buildings and industrial plants with computers and non-linear loads shows the excessive currents in the neutral conductor. This is mainly due to unbalancing system and non-linear loads. Third order harmonics are much dominant in the neutral conductor due to the presence of zero sequence components. In response to this concern, this paper presents a concept of series active filter scheme to suppress the neutral current harmonics to reduce the burden of the secondary of the distribution transformer. In this scheme, the series active filter is connected in series with the neutral conductor to eliminate the zero sequence components in the neutral conductor. In this paper, Fuzzy based controller is used to extract the harmonic component in the neutral conductor. The proposed method improves the overall performance of the system and eliminates the burden of the neutral conductor. To validate the proposed simulation results, a scale-down prototype experimental model is developed.**

Keyword- Active Filter, Total Harmonic Distortion (THD), Fuzzy Logic, Unbalanced system, Neutral current.

I. INTRODUCTION

Importance of uninterrupted power supply and the quality of power becomes more and more important in today's scenario. Due to advancement in technologies, a lot of power converters and other components were used which leads to injection of harmonics. Since these devices are more sensitive, the quality of the power supply should maintain within its standard. The distribution of electrical power is through a 3P4W system in many industrial and commercial sectors. The 3P4W (Three-Phase Four-Wire) distribution system can be realized by providing the neutral conductor along with three power lines from the generating station or by utilizing a delta-star transformer at distribution system. Most of loads in the distribution system are connected to one of the phase of three-phase four- wire distribution system, which leads to the unbalanced loading conditions. The unbalance load currents are very important problem in 3P4W distribution system, which leads to flow of current in the neutral conductor.

A typical low voltage electric distribution system in U.S.[1] which consists of a 208/120V three-phase four-wire has neutral current more than the phase current under normal operating conditions. Due to the presence of non-linear loads, harmonics are injected into the phase and neutral conductor. These harmonic current affects the other linear loads which are connected to the PCC. The Power supplies which consist of rectifier with DC smoothening capacitors may also leads to excessive current harmonics in the neutral [2]. These excessive harmonic current causes problems like over loading of the neutral conductor, increases the size of the neutral conductor, de-rating distribution transformer and overheating of the distribution transformer.

Zero sequence components are more pre-dominant in the neutral conductor. Almost 95% of the harmonic current in the neutral conductor are zero sequence component (3^{rd} order harmonics). In order to reduce neutral current harmonics, various research works on passive and active filters, zigzag transformer were published [3]. To attenuate these harmonic current in the distribution system, traditionally a passive filter was designed [4][5] which was connected across the non-linear load. But this compensation leads to some of the drawbacks like occurrence of series and parallel resonance which causes an incomplete potential. Zigzag transformer based harmonic reduction in neutral conductor was developed for elimination of zero sequence component in neutral conductor [6]. This method offers good attenuation towards harmonics but leads to overheating in windings and increases in the system losses which also lead to the incomplete solution. Due to advancement in power electronic technology, active power filters have become most habitual compensation methods. Shunt active power filters for three-phase three-wire and three-phase four-wire distribution systems have been presented [7-

9]. This filter was widely used in transmission systems but has fewer effects on the distribution systems. Improved solution to harmonic problem uses a hybrid active filter, which consists of shunt active and passive filter or series active and passive filters [10-12]. Fuzzy logic based controller techniques were used in order to mitigate harmonics in phase conductors [13]. In this paper, a series active filter was connected in series with the neutral conductor. The Fuzzy controller is used to trigger the inverter of the series active filter. The inverter injects the harmonic current in the neutral conductor in anti direction in such a way that the content of harmonics present in the neutral conductor gets suppressed. The harmonic content in the neutral and phase conductor before and after insertion of series active filter was measured and the result shows the effectiveness of the filter. To validate the simulation results, a scale-down prototype hardware model was developed.

II. PROPOSED SERIES ACTIVE FILTER

The block diagram of the proposed series active filter is shown in Fig.1. In the proposed system, three phase source is supplied to the non-linear load which consists of the diode rectifier with parallel RC loads through the delta-star transformer. To make the system as unbalance, the loads connected to the each phase of the three-phase system is of different values.

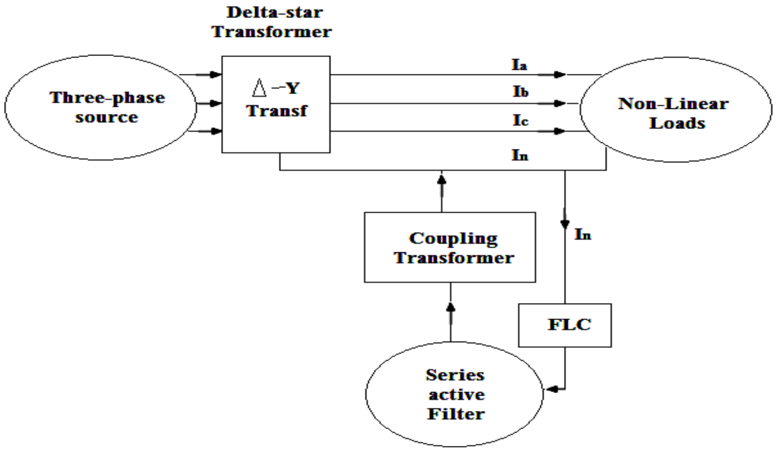

Fig.1. Proposed block diagram of the system

The series active filter is connected in series with the neutral conductor with the coupling transformer. The main function of the coupling transformer is to connect the isolated series active filter with the neutral conductor. The neutral current is sensed via Hall Effect sensor and given to the fuzzy logic controller. The controller senses the neutral current and reference signal is generated. The neutral current is compared with the reference and the error signal and its derivative are given as input to the fuzzy controller. The series active filter consists of two-leg IGBT based inverter with dc charging capacitor. The input to the inverter is maintained constant at 100V by using DC capacitor.

III. NEUTRAL CURRENT ANALYSIS IN THREE-PHAS FOUR-WIRE SYSTEM

The equivalent circuit of the proposed method is shown in Fig.2.The series active filter connected in the neutral conductor acts as high impedance to the harmonic current. It blocks the flow of current harmonics in the neutral conductor because of the zero sequence harmonic impedance. It has two-leg inverter in which IGBT acts as a switching devices. IGBT has low switching losses when compared to other power devices.

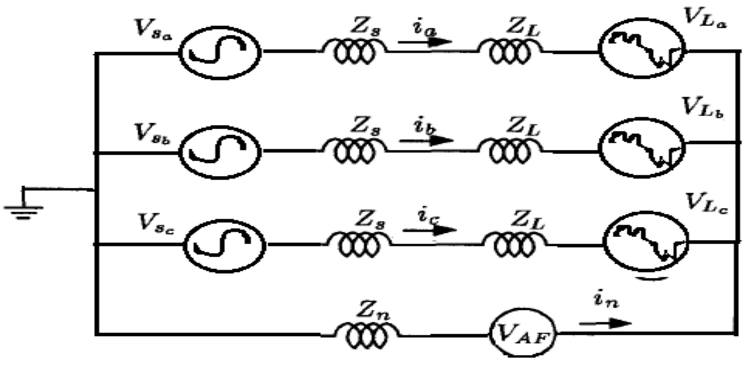

Fig 2 Equivalent circuit of the proposed scheme

V_{La}, V_{Lb} and V_{Lc} are the non-linear loads connected in each phases. Z_L is the impedance offered by the each phase load. Z_s is the source impedance, V_{sa}, V_{sb} and V_{sc} are the voltage sources taken from the secondary of the distribution transformer. i_a, i_b and i_c are the currents in each phases where in is the current in the neutral conductor which flows due to the non-linearity of the loads. V_{AF} is the inverter output voltage of a series active filter.

$$V_F = Z_h G I_N \tag{1}$$

$$I_N = \frac{(V_{La} + V_{Lb} + V_{Lc}) - (V_{sa} + V_{sb} + V_{sc})}{Z_s + Z_L + 3Z_h G} \tag{2}$$

Value of G=0 for fundamental frequency and G=1 for harmonic frequencies.

IV. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy control is a non-linear control method, which apply the expert knowledge of an experienced user to design of a controller. The modelling of fuzzy provides the ability to linguistically specify the approximate relationships between the inputs and the desired output. The input and output relations are represented by a set of fuzzy If-then rules. The input given to the fuzzy systems are error and its derivative. The difference between the actual neutral current and the reference signal is taken as an error signal which is fed as input to the controller. The output command from the fuzzy controller is based on the fuzzy set of rules.

Mamdani fuzzy model is used in this system due to its robustness. The input membership function used is Gaussian and output membership function used is triangular function which is shown in Fig.3. The rule viewer of fuzzy system is also shown in Fig.4

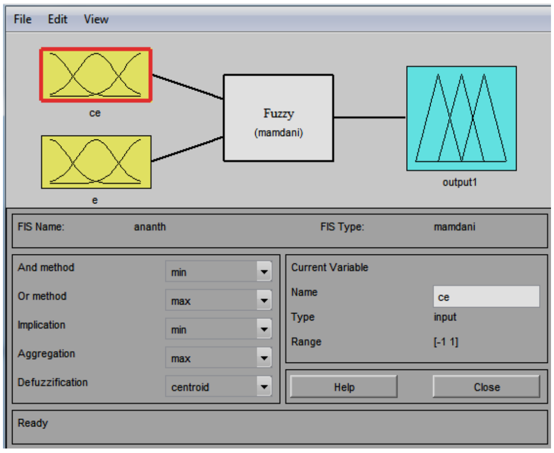

Fig.3 Fuzzy model of input & output membership function

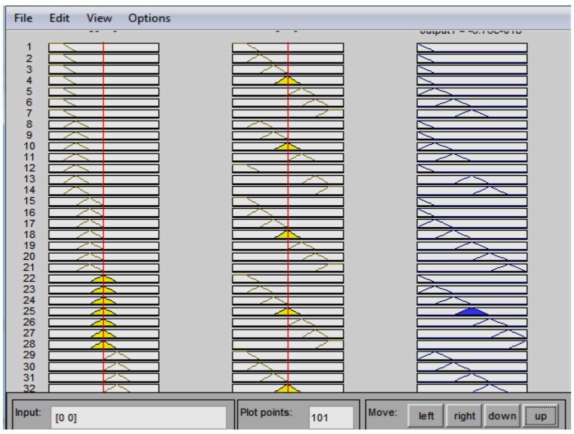

Fig.4 Fuzzy rule viewer

The seven linguistic codes like PB, PM, PS ZE, NS, NM and NB are used based on that 49 rules are framed. Table.1 shows the fuzzy rules. Depends on the linguistic rules, the output command signal is generated which is given as input signal to the inverter circuit of the series active filter circuit. The active filter injects the harmonic current into the neutral conductor through the coupling transformer so that the zero sequence components present in the neutral gets suppressed.

TABLE 1 –
Fuzzy Rules

Change in Error/Error	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

V. MATLAB MODEL OF THE SYSTEM AND SIMULATION RESULTS

The simulation is carried out using Matlab/Simulink software and the simulation parameters are shown in Table. II.

TABLE II –
Simulation parameters

Parameters	Values
Line to neutral voltage	120 V
Frequency of the system	50 Hz
Leakage reactance of the distribution transformer	0.35 mH
Switching frequency	20 KHz
Filter inductance	0.2 mH
Filter capacitance	1 µF
Capacitance voltage V_{DC}	100 V
Load Values at rectifier side	R_A=15Ω R_B=25Ω R_C=50Ω C_A=C_B=C_C =1000 µF

The waveform of neutral current without series active filter is shown if Fig.5. Due to the presence of non-linear diode rectifier and unbalanced load, waveform of phases and neutral current are highly distorted. The magnitude of the neutral current is high, due to the unbalanced nature of the load and highly distorted due to the non-linearity of the load. The highly distorted neutral current affects the transformer performance and leads to over sizing of the neutral conductor.

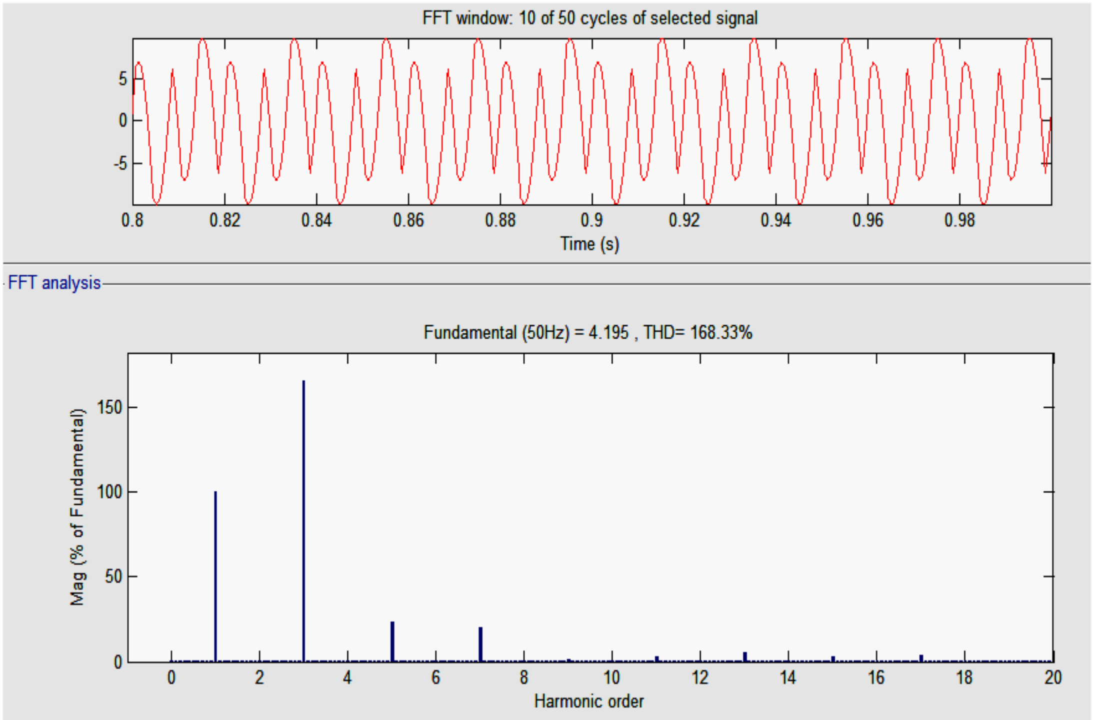

Fig 5. Waveform and THD analysis of neutral current without filter

The FFT analysis of the harmonic content of the neutral current is shown is also shown in Fig.5. The THD values are very high due to the presence of third harmonic content in the neutral conductor. The Matlab/Simulink model of the proposed method is shown in Fig.6. The test simulation shown below is unbalance non-linear load model of the system..

The waveform of the neutral current after inserting the series active filter with the neutral current is shown in Fig.7. The gating signal for active filter is generated using fuzzy control technique as mentioned in chapter IV. The simulation results shows the neutral current has very less distortion and nearly sinusoidal. The THD value shown in Fig.7 was also very less due to impact of series active filter

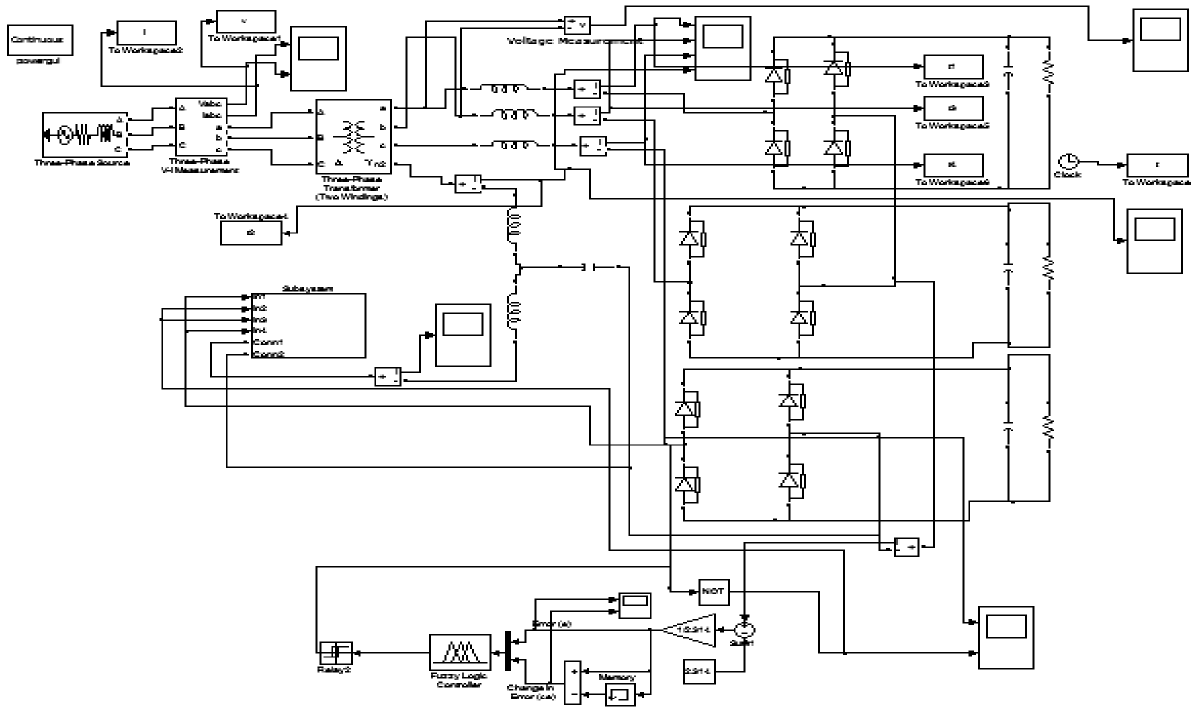

Fig.6. Matlab model of controller for unbalanced non-linear system

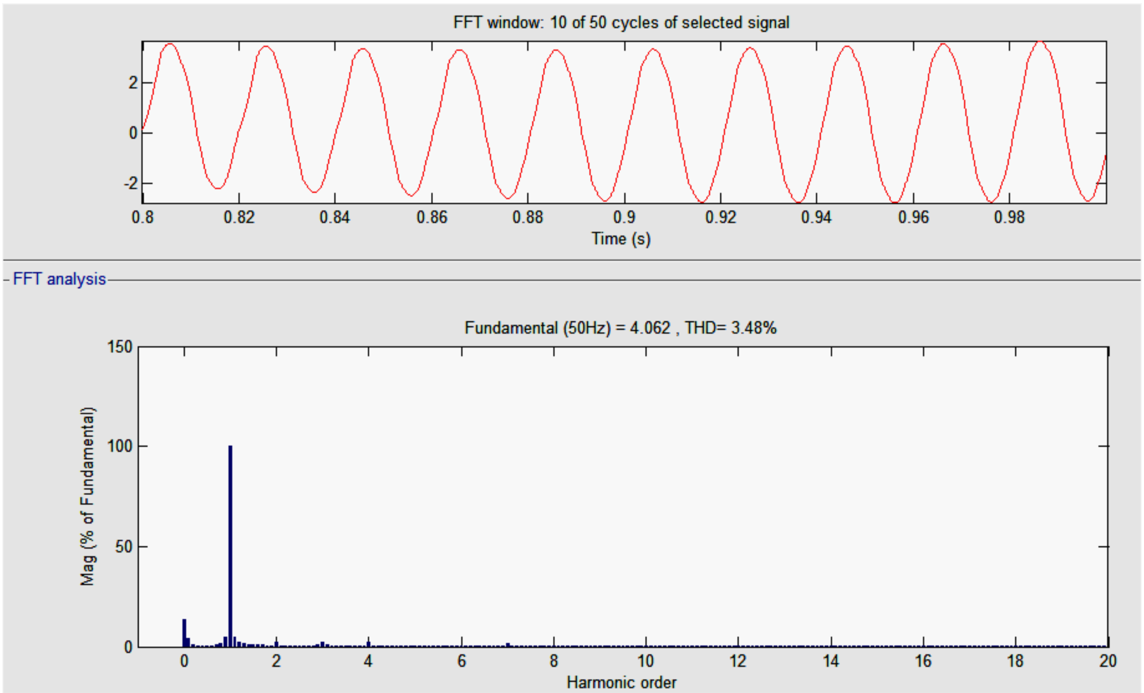

Fig 7. Waveform and THD analysis of neutral current with filter

VI. PROTOTYPE HARDWARE MODEL FOR SIMULATION VALIDATION

The scaled-down hardware model is developed to verify the effectiveness of the simulation result. A three single-phase step-down transformer is used to provide a three-phase four-wire experimental system. Single-phase loads are connected between one of the three lines and the neutral conductor. The DC sides of the rectifiers are connected with parallel RC loads. The Fig.8 shows the model of hardware setup.

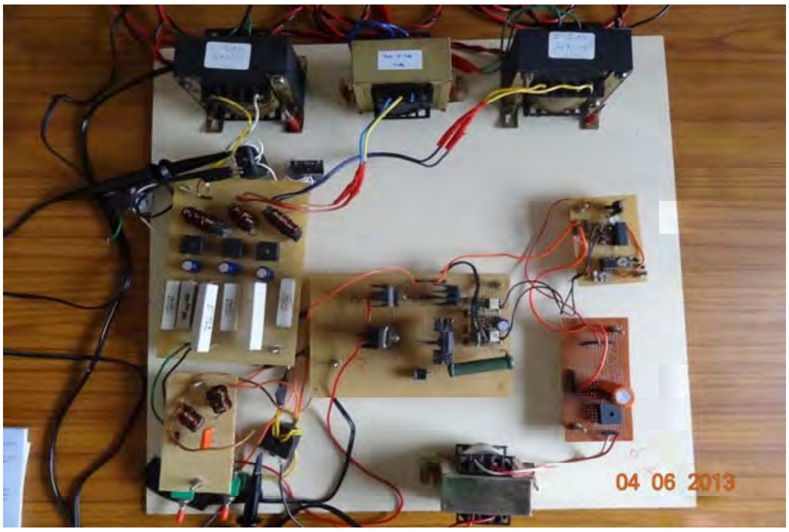

Fig.8. Hardware setup

In the controller circuit, the neutral current is sensed and given to the controller circuit through A/D converter. The control signal generated from the controlled is given as triggering command to the inverter of series active filter, which injects harmonic components to the neutral conductor in anti-direction, such that zero sequence in the neutral gets suppressed. The hardware results of neutral current without and with controller are shown in Fig.9 and Fig.10.

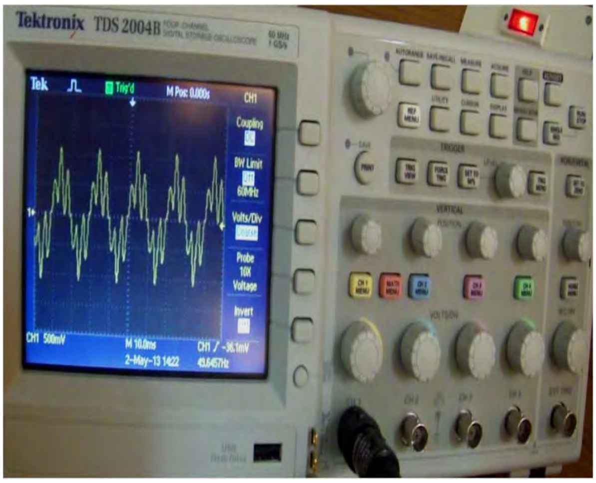

Fig.9. Experimental result of neutral current without Controller

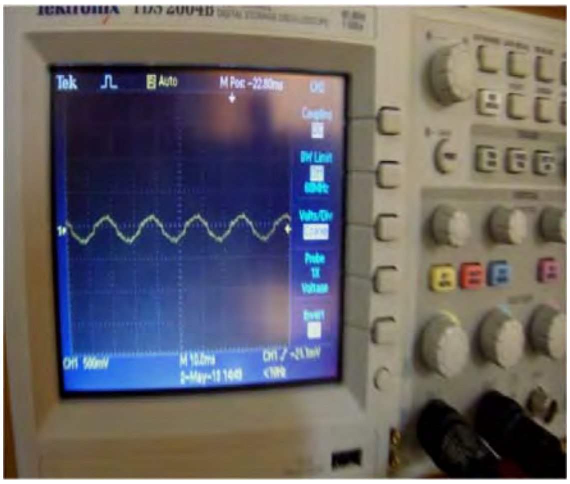

Fig.10. Experimental result of neutral current with Controller

The neutral current waveform shown in Fig.9 without controller is much distorted due to zero sequence components and also the magnitude of current is high because of harmonic component and unbalance load conditions. The waveform after implementation of controller circuit shown in Fig.10 is nearly sinusoidal and has very less distortion. The harmonic component in the neutral conductor is suppressed after inserting controller circuit in series with neutral conductor.

VII. CONCLUSION

In this work, suppression of harmonics in the neutral conductor of three-phase four-wire system was implemented. The simulation results using fuzzy controller shows that after inserting series active filter in neutral conductor the harmonic content in neutral and phase conductors reduced significantly when compared to the existing methods. Also an experimental model was developed to validate the simulation results.

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