Simulation of Current Harmonic Compensation Using Series Active Filter in Distribution System

K.G.ANU REKHA, T.GUNASEKAR, Dr. R.ANITA

Abstract— **Electric power becomes one of the most essential things in today's world. Maintaining a quality power supply is an important potential problems to the power Engineers. All the primary and secondary distribution systems use three-phase four-wire systems (3P4W) to provide the electric supply to the consumer. Many single phase loads are connected to the three-phase four-wire system which leads to the system unbalance. Since all the loads connected the 3P4W system is not same. Due to improvement in power electronic technology, a lot of power devices are used in the industrial and commercial applications. These types of converters have non-linear characteristics and create a flow of harmonic component in lines. Due to this effect, load voltages, load currents and the neutral current waveform due to unbalance gets distorted. If this component is not mitigated, then it affects the performance of the overall system. In this project, the above effects are mitigated by Fuzzy Hysteresis Controller based series active filter in the phase conductor. By single installation of the filter, load voltage becomes nearly sinusoidal and the distortion in the load and neutral current is reduced significantly. In this project, MATLAB/Simulink model is used to verify the proposed method.**

Index Terms— **Coupling Transformer, Fuzzy Logic, Hysteresis Controller, Phase Locked Loop, Series Active Filter, Synchronous Reference Frame**

I. Introduction

Electric power becomes a most basic need in our day-to-day life. Electric utilities aim is to provide a consumer with uninterrupted sinusoidal voltage of constant magnitude. However this is becoming increasingly difficult to do, because the size and number of non-linear and poor power factor loads such as adjustable speed drives, computer power supplies, Furnaces and traction drives are increasing rapidly. Due to their non-linear nature these solid state converters generates harmonics in current and voltage waveforms and it also cause excessive neutral currents in three phase four wire distribution systems.

Power quality in ac three-phase systems could be analyzed by; Voltage distortion, Voltage sags, Voltage swells, partial or total loss of one or more phases.

A major cause of voltage unbalances is the uneven distribution of single-phase loads, which may be continuously changing across a three phase power system. Additional causes of power system voltage unbalances can be asymmetrical transformer winding impedances, open wye and open delta transformer banks, and asymmetrical transmission impedances.

Voltage distortion causes a lot of ill effects on induction motors. The adverse effects of voltage distortion in induction motors are overheating, line-current unbalance, derating, torque pulsation, and inefficiency. The overheating leads to winding insulation degradation.

Under normal operating conditions with reasonably unbalanced load, the current in the neutral is expected to be 20% of the normal phase currents. These neutral currents are fundamentally third harmonics and odd multiples of 3rd due to non-linearity of loads.

Due to the presence of non-linear loads, Harmonics are injected to a line and the other loads connected to a Point of Common Coupling (PCC) also affected by harmonics. The poor power quality can degrade or damage the electrical equipment connected to the system.

These harmonics can be eliminated by using Passive filters (Combination of L and C). These types of filters have disadvantages of series resonance, parallel resonance, tuning of passive elements is difficult, etc. Recently, harmonics suppression facilities based on Power Electronics techniques have proved to be important. This harmonics suppression can be done with the help of new emerging ACTIVE POWER FILTERS.

Active filters have the more advantages than the passive filters. It uses the amplifying elements such as op amp, transistors, etc. And also it gains power during processing. The design of passive filter is easier when compared to the passive filter. It eliminates the inductor and the problem related to the inductor is also eliminated the cost gets reduced than passive filter. Active filters are of two type's series active and shunt active filter.

In this paper Series Active Filters (SAF) is connected in series with the phases to reduce the load voltage harmonics and load current harmonics in the phase and the current harmonics in the neutral. Load current distortion can also be reduced by placing Series Active Filter (SAF) in series with the phase conductor.

II. SYSTEM CONFIGURATION

Fig 1 shows the block diagram of series active filter system, it consists of a three-phase source, which is connected to a non-linear load.

The Series Active Power Filter is connected in series with the phases. It consists of the voltage source inverter (VSI) and the dc charging capacitor is used as source for voltage source inverter and it is coupled with the transmission line with the coupling transformer. The series active filter acts as a harmonic isolator between the supply and the load. The

Manuscript received December 19, 2013.

K.G.Anu Rekha, Electrical and Electronics Engineering, Kongu Engineering College, Perundurai, Erode, India
T.Gunasekar, Electrical and Electronics Engineering, Kongu Engineering College, Perundurai, Erode, India
DR.R.Anita, Electrical and Electronics Engineering, IRTT Erode, India

triggering for the inverter circuit is given through the control circuit. The inverter can be implemented by IGBTs operating with the fuzzy hysteresis controller for the filtering function.

Fig 1: Block Diagram

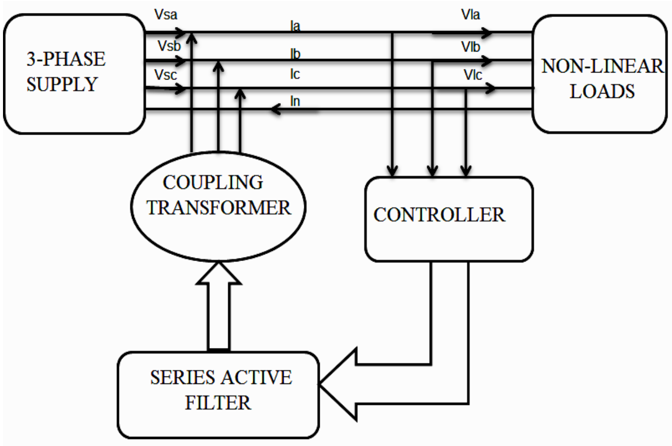

Fig 1: Block Diagram

III. WORKING PRINCIPLE

The three phase source voltage is given to non-linear loads which consists of three phase diode rectifier with parallel RC loads in order to make the system as load unbalance, an excess non-linear load of single phase rectifier with parallel RC load is connected in phase B. Due to the non-linear characteristics of load, the load voltage and load current get distorted. Since the loads are non-linear and unbalanced an excess current flows in the neutral conductor.

In order to overcome the above effects, series active filter is connected in series with the phase conductor through the coupling transformer. The series active filter consists of IGBT based inverter with dc charging capacitor. The three phase load voltage and load currents are sensed and given to the controller circuit.

In order to extract the fundamental component of voltage and current synchronous reference frame theory is used. The extracted value is compared with actual value to get the error signal, which is given as input to the fuzzy hysteresis controller. Fuzzy hysteresis controller produces the gating signal to the IGBT inverter, which in turn inject the harmonic content into phase in anti-direction. Thus the harmonic content of load voltage and load current gets reduced. Due to this effect the harmonic content in the neutral current is also reduced significantly.

IV. .SYNCHRONOUS REFERENCE FRAME WITH PLL

The synchronous reference frame theory is used to extract the fundamental component in the supply voltage or current. It is based on the transformation of the currents or voltages in synchronously rotating d-q frame. Fig. explains the basic building blocks of the theory. If θ is the transformation angle, then the currents transformation from α-β to d-q is defined as in the Fig 2.

The 3-Phase load currents of system i.e. V_{LA}, V_{LB}, V_{LC} of stationary reference system in a-b-c coordinates are transformed to two phase system with α-β coordinates, this can be done by algebraic transformation, known as —Clark's

Fig 2: Block diagram of SRF

transformation, which also produces a stationary reference system, again these Voltages are transformed to synchronously rotating reference frame by Park's transformation. The voltage templates (sine and cosine) are generated using phase locked loop (PLL). The sine and cose function is to maintain the synchronization with the supply voltage and current and then we calculate V_d, V_q the which are passed through LPF which filter out the harmonics in voltage signals and again these two phase voltages in rotating reference frame are transformed to two phase stationary reference frame using reverse park's transformation and then transformed to three phase coordinates which are called as the reference voltage signals.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

SRF isolator extracts the dc component by low pass filters (LPF) for each Vd and Vq realized by moving averager at 100Hz. The extracted DC components V_{ddc} and V_{qdc} are transformed back into α-β frame as shown below:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & 1 \\ \sin(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) & 1 \\ \sin(\theta + \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (2)$$

From here the transformation can be made to obtain three phase reference Voltages in a-b-c coordinates using Reverse Park's transformation and Clark's transformation. The transformation angle θ is generated by using the PLL. The output of the PLL is given to the SRF and the reference signal is generated.

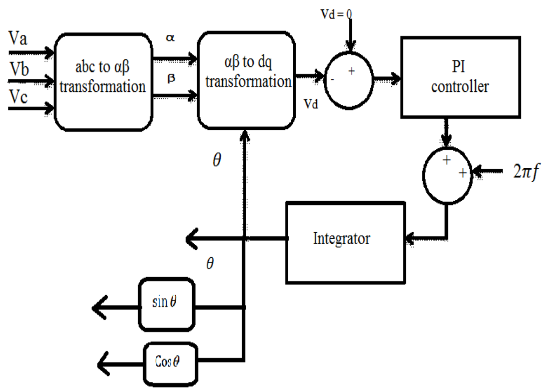

Fig 3: Block diagram of PLL

The generated reference signal is compared with the actual signal and the error signal is generated. The error signal is given as the input to the fuzzy controller.

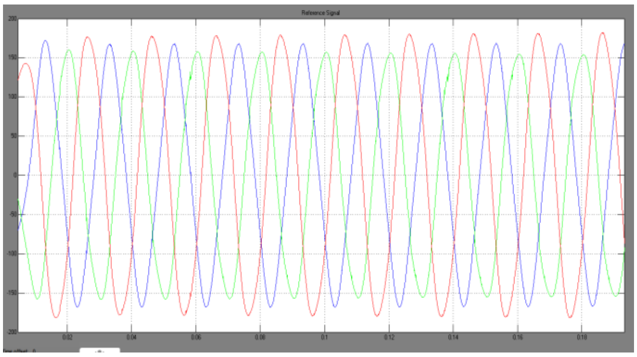

Fig 4: Reference Signal

V. FUZZY LOGIC CONTROLLER

The fuzzy control algorithm is implemented to control the load phase voltage based on processing of the voltage error e(t) and its variation Δe (t) in order to improve the dynamic of SAF.

The main advantages of fuzzy control are its linguistic description, independence of mathematical model, robustness, and its universal approximation. A fuzzy logic controller is consisting of four stages: fuzzification, knowledge base, inference mechanism and defuzzification.

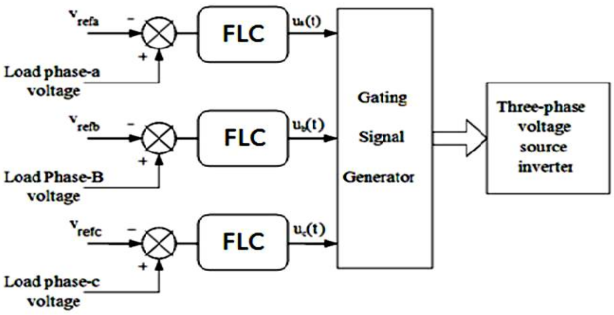

Fig. 5: Fuzzy Logic Controller Structure Block Diagram

The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances .The data base consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified Output. Finally, defuzzification is used to convert the fuzzy outputs into control signals. In designing of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance

The mamdani type fuzzy logic controller is used;the max-min inference method is applied in this study.

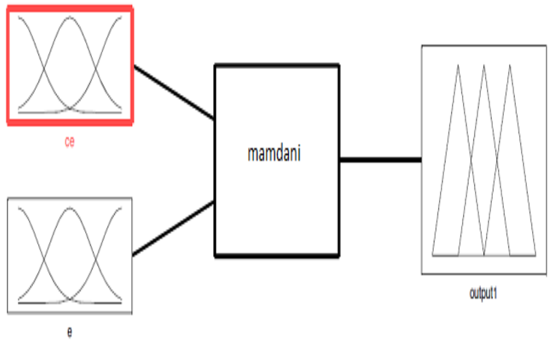

Fig 6: Input Mamdani In Matlab

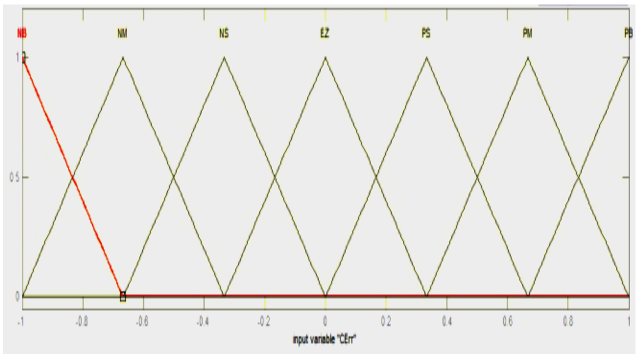

Fig 7(a): Input Membership Function

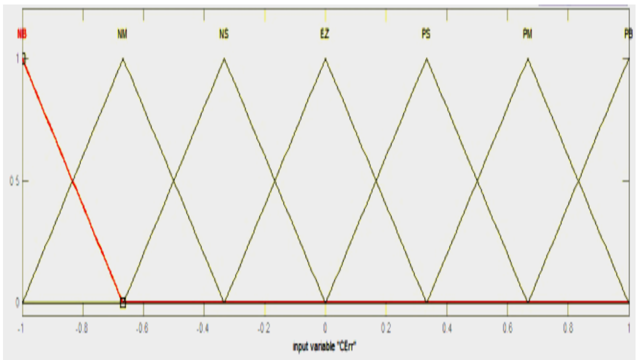

Fig 7(b): Input Membership Function

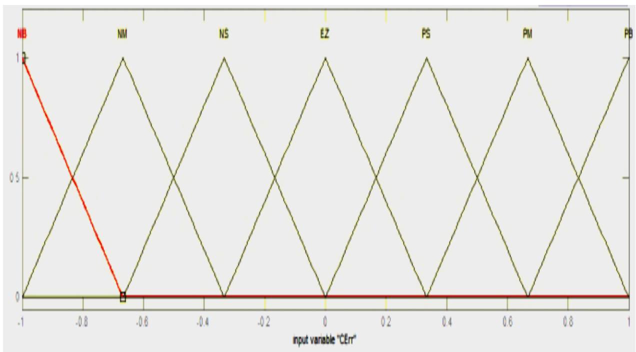

Fig 8: Output Membership Function

Table 1 Fuzzy Rule Table

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

VI. GATING SIGNAL GENERATION

The gating signals of the inverter are generated by hysteresis controller. The output of the fuzzy controller is given as the input to the hysteresis controller and the switching pulses are generated and given to the inverter.

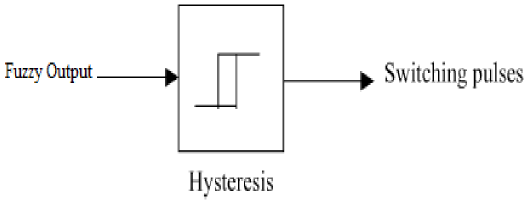

FIG 9: GATING SIGNAL GENERATION

VII. RESULTS OF THE PROPOSED SYSTEM WITHOUT FILTER AND WITH FILTER

The three phase voltage source is given as input to the distribution transformer. Single phase RC load and three phase RC load is considered as the system load. The value of resistance and capacitance in single phase load is R=5Ω, C =1500uF.

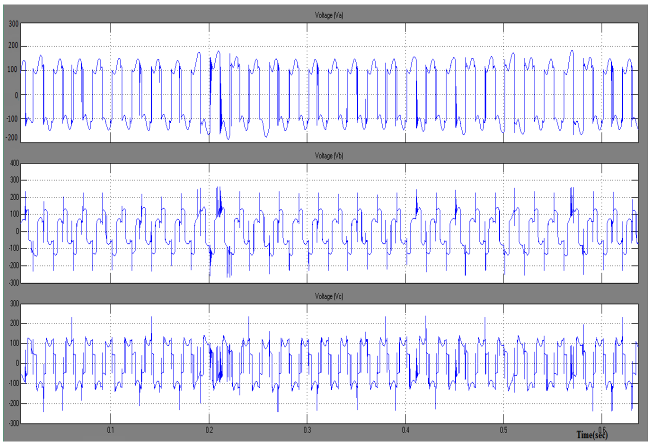

Fig 10: Voltage waveform without filter

value of resistance and capacitance in three phase load is R=15Ω, C=1500uF .The unbalanced condition is achieved by connecting the single phase load to the phase B and the Neutral. Because of this condition there will be a flow of current in the neutral conductor consisting of both harmonic and fundamental component.

Due to variation in the values of load, the magnitude in each phase will vary and the neutral current harmonics will be high. The simulation output for load voltage in unbalanced condition is shown in Fig 10 and load current and neutral current in Fig 11.

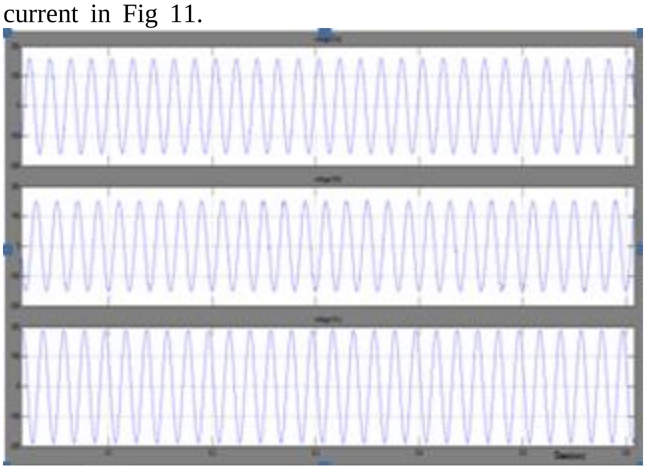

Fig 11: Load current and Neutral current Waveform without filter

The series active filter is installed in the phases and the results are obtained and shown below in Fig 12 and Fig 13.

From the figure given below we can observe that the harmonic distortion in all three phases is reduced and neutral conductor current is also reduced while fundamental component remains unaffected. The harmonic content has been suppressed to a great value.

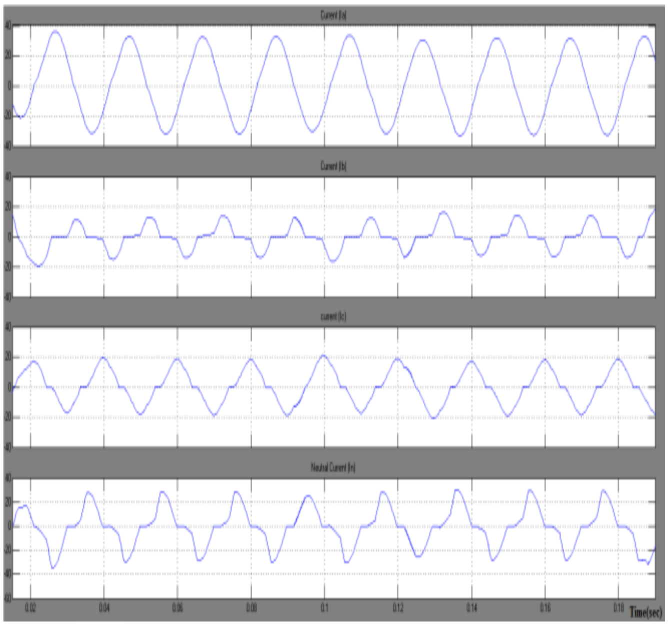

Fig 12: Voltage waveform with filter

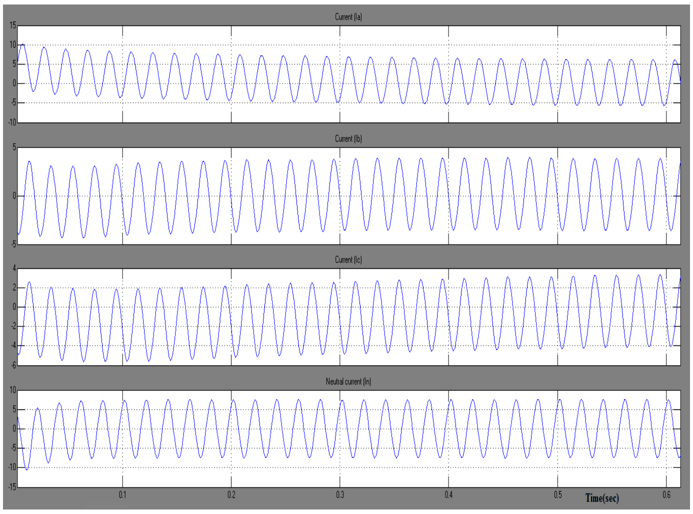

Fig 13: Load current and Neutral current Waveform without filter

The THD values without filter and with filter are compared and the bar chart is made. It shows that the THD values with filter get reduced efficiently.

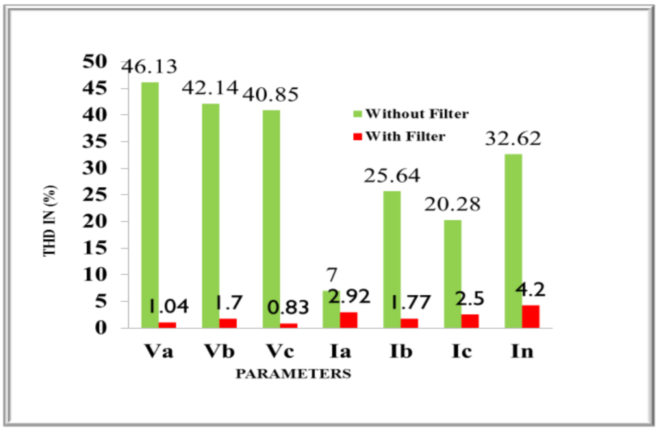

Fig 14: Comparision of THD (in %)

VIII. CONCLUSION

The paper has outlined the design of controller for series active power filters. The observed performance of the SAF has demonstrated the ability of the proposed control technique to compensate the Load voltage, Load current and Neutral current harmonics and reduce harmonic distortion at PCC, The indirect current control scheme is used to reduce the Load current harmonics The scheme has the advantage of simplicity and effectiveness and it is equivalent to the performance of Unified Power Quality Conditioner.

In this study, a fuzzy controller with fast response to regulate distorted load voltage, load current and neutral current in three-phase system is presented and analyzed. The simulation results show a very good performance of the proposed algorithm and control scheme under arbitrary fault conditions of the utility supply.

It has been observed that the system has a fast dynamic response with the proposed control scheme and is able to keep the THD of the voltage and current within the limits of IEEE 519 standard.

REFERENCES

[1] Ali Ajami,Seyed Hossein (2006) "An Implementation of a Novel Control Strategy for Shunt Active Filter",IEEE Transactions on Industry Applications, Vol 25, No. 2.

[2] Bhim Singh,Vishal Verma ,"A New Control Scheme of Series Active Filter for Varying Rectifier Loads" 2003

[3] Bhim Singh , Venkateswarlu.P, "A Simplified Control Algorithm for Three-Phase Four-Wire Unified Power Quality Conditioner"2010

[4] Dastfan.A, Platt.D, and Gosbell. V.J(1998), "Design and Implementation of a new Three- phase Four-Wire Active Power Filter with minimum components," in IEEE/IAS Conference Proceedings, IEEE.

[5] El-sadek.M.Z, E.A.Lbrahim, R.M.Kamel, "series active filter for voltage harmonic suppression and 50 hz voltage boosting" 2006

[6] Fatiha Mekri , Mohamed Machmoum , Nadia Ait Ahmed , Benyounes Mazari, "A Fuzzy hysteresis voltage and current control of An Unified Power Quality Conditioner

[7] Hurng-Liahng Jou, *Member, IEEE*, Jinn-Chang Wu, Yao-Jen Chang, and Ya-Tsung Feng,"A Novel Active Power Filter for Harmonic Suppression" 2005

[8] Luis Sainz, Joaquin Pedra, *Member, IEEE*, and Juan José Mesas, "Study of Neutral Conductor Current in Three-Phase Networks With Single-Phase Converters" *IEEE Transactions On Power Delivery, Vol. 21, No. 3, July 2006*

[9] Mukhtiar Singh, Vinod Khadkikar, Ambrish Chandra, and Rajiv K. Varma, "Grid Interconnection of RenewableEnergy Sources at the Distribution LevelWith Power-Quality Improvement Features" IEEE Transactions On Power Delivery, Vol. 26, No. 1, Jan 2011

[10] Myoung Lee.G, Dong-Choon Lee, Member, IEEE, and Jul-Ki Seok, Member IEEE, "Control of Series Active Power Filters Compensating for Source Voltage Unbalance and Current Harmonics" *IEEE Transactions On Industrial Electronics, Vol. 51, No. 1, February 2004*

[11] Mortazavi.S.S , M. Razaz, and E. Khavari ,"power quality improvement using a fuzzy logic control of a series active filter" *Journal of Theoretical and Applied Information Technology 2005 – 2010*

[12] Po-Tai Cheng ,Yung-F'u Huang, Chung-Chuan Hou, "A new harmonic suppression scheme for three-phase four-wire distribution systems", 2001

[13] Peng.F.Z. H.Akagi, and A.Nabae (1990), "A new Approach to Harmonic Compensation in Power Systems-A Combined System of Shunt Passive and Series Active Filters," IEEE Transactions on Industry Applications, Vol 26, No. 6.

[14] Ram Kumar.P.V, M. Surya Kalavathi, "Fuzzy Based Hysteresis Current Controlled Shunt Active Power Filter for Power Conditioning" *International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.3, Issue.1, Jan-Feb. 2013 pp-477-485*

[15] Rubens Marcos dos Santos Filho, Paulo F. Seixas, Porfírio C. Cortizo, "A Comparative Study Of Three-Phase And Single-Phase Pll Algorithms For Grid-Connected Systems"2007