Journal of Science and Technology
ISSN: 2456-5660 Volume 06, Issue 01, Jan-February 2021

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2020.v6.i1.pp21-45*

Fuzzy Controller Based Power Quality Improvement Using VLLMS Based Shunt Active Power Filter

Dhavala Pranusha[1], Thumuganti Ramya[2]
[1](Dept of EEE, Vignan Institute of Technology and Science, Hyderabad)
[1]Corresponding Author: 29pranusha@gmail.com

To Cite this Article
Dhavala Pranusha and Thumuganti Ramya, "Fuzzy Controller Based Power Quality Improvement Using VLLMS Based Shunt Active Power Filter", Journal of Science and Technology, Vol. 06, Issue 01, Jan-February 2021, pp21-45

Article Info
Received: 18-07-2020 Revised: 15-10-2020 Accepted: 04-11-2020 Published: 18-11-2020

Abstract: *The power quality problem in the power system is increased with the use of non-linear devices. Due to the use of non-linear devices like power electronic converters, there is an increase in harmonic content in the source current. Due to this there is an increase in the losses, instability and poor voltage waveform. To mitigate the harmonics and provide the reactive power compensation, we use filters. There are different filters used in the power system. Passive filters provide limited compensation, so active filters can be used for variable compensation. In this work, a shunt active filter has been made adaptive using a Variable Leaky Least Mean Square (VLLMS) based controller. Proposed adaptive controller can be able to compensate for harmonic currents, power factor and nonlinear load unbalance. DC capacitor voltage has been regulated at a desired level using a PI controller and a self-charging circuit technique. But, this scheme as two disadvantages such as, tuning issues of current controller pre-requisites the traditional PI controller, which is controlled by intelligent based Hybrid-Fuzzy-Logic controller for achieving good performance features. The design concept of proposed intelligent Hybrid-Fuzzy controller for shunt active filter has been verified through simulation analysis and results are presented with proper comparisons.*

Keywords*: APF, harmonics, neural network, power quality, Variable Leaky Least Mean Square (VLLMS).*

I. Introduction

Early equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Pollution has been introduced into power systems by nonlinear loads such as transformers and saturated coils; however, perturbation rate has never reached the present levels. Due to its nonlinear characteristics and fast switching, PE creates most of the pollution issues. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of PE. Approximately 10% to 20% of today's energy is processed by PE; the percentage is estimated to reach 50% to 60% by the year 2010, due mainly to the fast growth of PE capability. A race is currently taking place between increasing PE pollution and sensitivity, on the one hand, and the new PE-based corrective devices, which have the ability to attenuate the issues created by PE, on the other hand.

Increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. The effect of such non-linearity may become sizeable over the next few years. Hence it is very important to overcome these undesirable features.

Modern day power systems are complicated networks with hundreds of generating stations and load centers being interconnected through power transmission lines. An electric power system has three separate components - power generation, power transmission and power distribution.

Almost all power generation takes place at generating stations that may contain quality nature of our power. The basic structure of a power system is shown in Fig 1.1. It contains a generating plant, a transmission system, a subtransmission system and a distribution system. These subsystems are interconnected through transformers T], T2 and T3. Let us consider some typical voltage levels to understand the functioning of the power system.

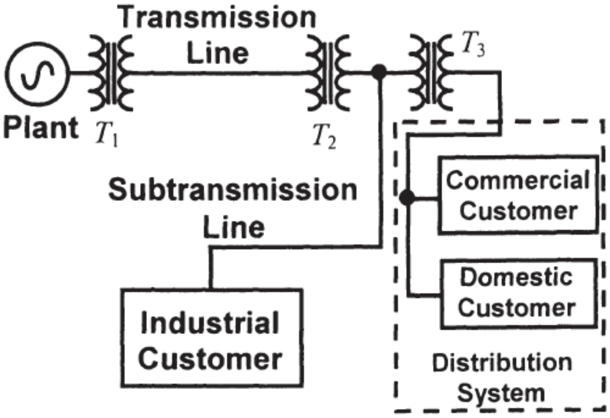


Fig.1.1 An Typical power system network

It can therefore be seen that there are various stages between the point of power generation to the stage when electric power is delivered to the end users. The correct operation of all components of a power system is absolutely critical for a reliable power delivery. There are many issues involved here such as the maintenance of power apparatus and system, the stability of the system operation, the operation of power distribution system, faults etc.

Even a few years back, the main concern of consumers of electricity was the reliability of supply. Here we define reliability as the continuity of electric supply. It is however not only reliability that the consumers want these days, quality too is very important to them.

Transmission lines are exposed to the forces of nature. Furthermore, each transmission line has its load ability limit that is often determined by either stability considerations or by thermal limits. Even though the power quality problem is a distribution side problem, transmission lines often have an impact on the quality of power supplied. It is however to be noted that while most problems associated with transmission systems arise due to the forces of nature or due to the interconnection of power systems, individual customers are responsible for a more substantial fraction of the problems of power distribution systems.

II. Related Work

Fang Z. Peng and Donald J. Adams "Harmonic Sources and Filtering Approaches"

Traditionally, nonlinear loads have been represented as a current source because their current waveforms are distorted from pure sine-waves at fundamental frequency. A typical harmonic source isa phase-controlled thyristor rectifier having a sufficient dc inductance to produce a non-pulsating dc current. Accordingly, parallel (or shunt) passive and parallel active filters are commonly applied to nonlinear loads to mitigate harmonics. The principle of the parallel passive filter is to provide a low-impedance shunt branch to the load's harmonic current, thus reducing harmonic current flowing into the source.

J. C. Das," Passive Filters—Potentialities and Limitations"

Most of the distribution systems require reactive power compensation to improve the power factor, save demand charges, or to release additional active power from existing equipment or for voltage support, i.e., the reactive power support required to arrest the voltage drop on loss of a plant generator. The nonlinear loads are increasing, i.e., pulp and paper mill distribution systems invariably have adjustable-speed drive (ASD) systems, which may form a considerable percentage of overall plant load. When power capacitors are used for reactive power compensation, it becomes necessary to turn them in to filters to escape harmonic resonance problems with one of the load-generated harmonics It is not uncommon to apply passive filters in the mega Var range and filters totaling some tens of mega var in a large installation may be required. An improvement in power factor from 0.85 to 0.9 for a system demand of 100 MVA requires approximately 10 Mvar of compensation. Passive filters have been extensively used to simultaneously meet one or more objectives and also meet the requirements of IEEE Std. 519 with respect to total demand distortion (TDD) at the point of common coupling (PCC). Passive filters have also been extensively used in HVDC systems, arc-furnace installations, and static var compensators (SVCs) to name a few more applications.

Herbert L. Ginn, IIIand Leszek S. Czarnecki "An Optimization Based Method for Selection of Resonant Harmonic Filter Branch Parameters"

Resonant harmonic filters (RHFs) are effective devices for reducing supply current harmonics when only those load generated harmonics for which they are tuned are present. Other current harmonics as well as supply voltage harmonics may reduce the effectiveness of RHFs in harmonic suppression. To counter such reductions in effectiveness, an optimization based method for selection of filter branch parameters is developed for the conventional RHF. It takes into consideration the interaction of the filter with the distribution system and provides filter parameters that give the maximum effectiveness with respect to harmonic suppression. Due to the presence of harmonic generating loads (HGLs) in distribution systems, resonant harmonic filters very often operate in the presence of distribution voltage harmonics as well as load current harmonics other than those to which the filter is tuned. Some of the voltage and current harmonics could be amplified by the filter resonance with the distribution system inductance, as seen from the bus where the RHF is installed. Moreover, the filter as seen from the distribution system has very low impedance at tuned frequencies. Consequently, with the increase of distortion of the distribution voltage and the amount of non-characteristic harmonics in the load current, the effectiveness of the filter in reducing distortion of the bus voltage and the supply current declines. Harmonic amplification caused by the filter resonance with the distribution system inductance depends on frequencies of this resonance and can be reduced by appropriate selection of the filter parameters. Harmful effects due to the filter's low impedance at the tuned frequencies can be reduced, by detuning the filter from frequencies of characteristic harmonics. Unfortunately, this detuning reduces the attenuation of the load current harmonics.

José Antenor Pomilioand Sigmar Maurer Deckmann" Characterization and Compensation of Harmonics and Reactive Power of Residential and Commercial Loads"

Depending on the nonlinear load characteristics, the usual representation of nonlinear loads as a simple combination of harmonic current sources may greatly simplify the analyses of their effects on the overall system under similar conditions where distortion has been derived. However, additional conclusions may not be reliable if any modification is introduced in the circuit, such as the connection of a filter or a change in the loading condition. This certainly limits the usefulness of linear models to study nonlinear processes.

H. Akagi "Active Harmonic Filters"

Active filters are typically used with diode/thyristor rectifiers, electric arc furnaces, etc. Their use in electric power utilities, industry, office buildings, water supply utilities, and transportation is increasing as cost reductions in power semiconductor devices and signal processing devices make use of these filters more economically attractive. In addition to harmonic filtering, active harmonic filters are used for damping, isolation, termination, power-factor correction, voltage regulation, load balancing, and voltage-flicker reduction, Compared to passive filters, active harmonic filters provide superior filtering performance and more flexible operation, and they are more compact. However, both the cost of active filters and their operating loss are currently slightly higher than for passive filters. Unlike passive filters, active filters provide the capability of controlling reactive power for inductive loads. While active filters for power conditioning are now commercially available, Akagi believes that manufacturers should strive to improve the filtering performance and efficiency of these units and to reduce costs so they can better compete with traditional passive filters. As an example of a pure active filter, Akagi describes a filter that draws compensating current from an ac supply to cancel out harmonic currents produced by the load. A passive high-pass filter on the ac side of the active filter eliminates switching ripples, but plays no role in canceling out dominant fifth- and seventh-harmonic currents produced by the load. The active filter control circuit uses digital signal processors, field-programmable gate arrays, and A/D converters for digital signal processing, operational and isolation amplifiers for analog signal processing, and Hall-effect current/voltage sensors.

III. Problem Statement

Over the past few years, rapid increase in the use of non- linear loads causes many power quality issues, like high current harmonics, low power factor and excessive neutral current. The increased harmonics, reactive power and un- balance cause increase in voltage distortion, linlosses and instability when harmonic current travel upstream and produce drop across the line impedance, which leads distortion in power system. Usually, passive filters are used for suppression of harmonics but their applications are limited to fixed amount of compensation. Passive filters are also not capable in providing solutions in presence of unbalance and variable reactive power compensation.

Another disadvantage with passive filter is the problem of resonance which amplifies current of certain harmonic frequencies. The solution to above mentioned problem can be realized using a shunt active power filter

IV. Shunt Active Power Filters

This class of filters constitutes the most important and widely used filter configuration in industrial process. It is connected in parallel to the main power circuit as shown in Fig.4.2. The concept of the shunt active power filter is based on harmonic cancellation through the act of injecting equal and opposite harmonic currents into the supply line by means of solid-state converter circuits. Normally these filters are connected in parallel with the load, and carry only a fraction of the fundamental current. Furthermore, they can be designed to provide compensation for all of the system non-linear ties at the point of common coupling (PCC) under distorted and non-distorted supply.

$$i_s + i_{inj} = i_{L1,p} + i_{L1,q} + i_{Ln}$$

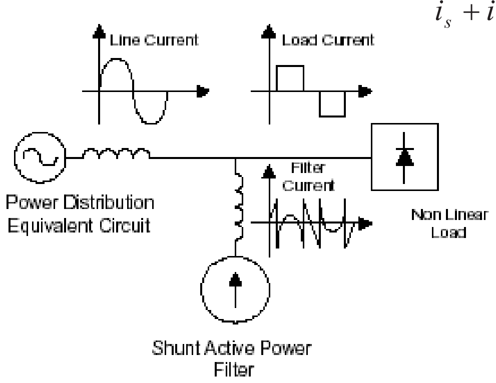


Fig. 4.1 Schematic Diagram of Shunt active power filter

These filters have disadvantages of injection of switching frequency harmonics in the system. Due to the need of high switching frequency fully gate controlled devices these filters are limited to low and medium power range only. Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180°. This principle is applicable to any type of load considered a harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non linear load and the active power filter as an ideal resistor. The current compensation characteristic of the shunt active power filter is shown in Fig.4.1.

V. Active Power Filter Driven By VLMMS Control Technique

A. Active Power Filter

The current source $i_L$is used to model the instantaneous current of the nonlinear load that can be represented by

$$i_L = i_{L1}\sin\omega t\cos\phi_{L1} + i_{L1}\sin\phi_{L1}\cos\omega t + \sum_{n=2}^{\infty} i_{Ln}\sin(\omega t + \phi_{Ln})$$

Where i_{L1} is the peak value of the fundamental component and i_{Ln} is the peak value of the harmonic component. ϕ_{L1} and ϕ_{Ln} are the phase angles of the fundamental and the harmoniccomponents. Fig. 1 shows the circuit for shunt APF. Voltage source v represents the instantaneous supply voltage at the PCC with i_s as its instantaneous supply current. The injection current of the shunt active filter is denoted by i_{inj}. The first order low-pass filter in series with the VSI output is represented by inductor L_{sh} with resistor R_{sh}as the inverter losses. V_{dc} /2 denote the voltage of each capacitorunit.In (1) above, the instantaneous current of the nonlinear load is expanded into 3 terms.The first term is the load instantaneous fundamental phase current $i_{L1,p}$which is always in phase with the supply voltage. The second term $i_{L1,p}$is the load instantaneous fundamental quadrature current which is always 90° out of phase withthesupplyvoltage.Thethirdtermi_{Ln}istheloadinstantaneous harmoniccurrents.FromFig.5.1,itcanbeshownthat

(5.2)

In order to have i_S that is almost in phase with v and at thesame timeconsistsonlyofthefundamentalcomponent,from(2)

$$i_{inj} = i_{L1,q} + i_{Ln} \qquad (5.3)$$

The dc voltage of each capacitor $V_{dc}/2$ is also measured and passed to the self-charging circuit to regulate to its reference voltage level $V^*_{dc}/2$. The output signal from the self-charging circuit i_{dc} together with $i_{L1,q}$ and i_{Ln} will form the reference injection current of the adaptive shunt active filter i^*.

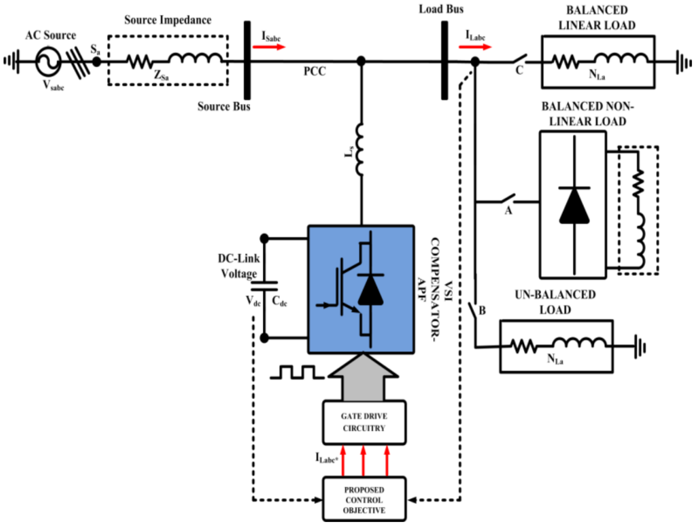


Fig.5.1. Block Diagram of Proposed APF Compensation Scheme

B. Proposed VLLMS Algorithm

$$y(k) = \sum_{n=1}^{N} [A_n \sin(n\omega kT)\cos\phi_n + A_n \cos(n\omega kT)\sin\phi_n]$$

Here a VLLMS algorithm is used for extraction of fundamental active component of current from load current. For that, signal can be modeled as

$$y(t) = \sum_{n=1}^{N} A_n \sin(n\omega t + \phi_n)$$

(5.4)

(4) can be rewritten in parametric form as follows

$$y(k) = H(k)X$$

(5.5)

$$H(k) = [\sin(\omega kT)\ \cos(\omega kT) \dots \sin(n\omega kT) \cos(n\omega kT)] \qquad (5.6)$$

The vector of unknown parameter

$$X = [A_1\cos(\phi_1)\ \ A_1\sin(\phi_1)\ \ \dots\ A_n\cos(\phi_n) A_n\sin(\phi_n)]^T \qquad (5.7)$$

The VLLMS algorithm is applied to estimate the state. The algorithm minimizes the square of the error recursively by altering the unknown parameter X_k a teachs ampling instant using(8)given below

$$\hat{X}_{k+1} = (1 - 2\mu_k \gamma_k)\,\hat{X}_k + 2\mu_k e_k\,\hat{y}_k$$

$$\hat{y}_k = H(k)\,\hat{X}_k \tag{5.8}$$

Where the error signal is

$$e_k = y_k - \hat{y}_k \tag{5.9}$$

Step size μ_k is varied for better convergence of the VLLMS algorithm in the presence of noise.

$$\mu_{k+1} = \lambda\mu_k + \gamma_k R_k^2 \tag{5.10}$$

Where R_k represents the autocorrelation of e_k and e_{k-1}. It is computed as

$$R_k = \beta R_{k-1} + (1-\beta) e_k e_{k-1} \tag{5.11}$$

Where β is an exponential weighting parameter and $0<\beta<1$, and $\lambda(0<\lambda<1)$ and $\gamma > 0$ control the convergence time.The variable leakage factor γ_k can be adjusted as

$$\gamma_{k+1} = \gamma_k - 2\mu_k \rho e_k \hat{y}_k X_{k-1} \tag{5.12}$$

After the updating of the vector of unknown parameter using VLLMS algorithm

$$i_{L1,p} = X_1 H_{11} \tag{5.13}$$

As seen from Fig. 1, the current output of the VLLMS based fundamental extraction circuit is subtracted from the load current. The subtracted output serves as amajor component in reference current generation. Fig. 5.2 shows the flow chart of the active component of fundamental current extraction scheme using VLLMS algorithm.

C. Self-Charging DC-Capacitor Circuit

To regulate the dc capacitor voltage at the desired level, an additional real power has to be drawn by theadaptive shunt active filter from the supply side to charge the two capacitors. The energy Estored in each capacitor can be representedas

$$E = \frac{1}{2} C \left(\frac{V_{dc}}{2}\right)^2 \tag{5.14}$$

If the value of the dc capacitor voltage changes from V_{dc} to V the change in energy is represented by

$$\Delta E = \frac{1}{2} C \left[\left(\frac{V'_{dc}}{2}\right)^2 - \left(\frac{V_{dc}}{2}\right)^2\right] \tag{5.15}$$

$$\begin{aligned} E_{ac} &= 3Pt \\ &= 3(V_{rms} I_{dc\,rms} \cos\phi)t \end{aligned}$$

The charging energy delivered by the three-phase supply side to the inverter for each capacitor will be

P: additional real power required

t: charging time

Vrms: value of instantaneous supply voltage v

Idc-rms: value of the instantaneous charging current idc

ϕ: phase difference between supply voltage and charging current

$$E_{ac} = 3\frac{V}{\sqrt{2}}\frac{I_{dc}}{\sqrt{2}}\frac{T}{2} = \frac{3VI_{dc}T}{4} \tag{5.16}$$

Neglecting the switching losses in the inverter and according to the energy conservation law, the following equation holds from (5.15) and (5.16).

$$\Delta E = E_{ac}$$

$$\frac{1}{2}C\left[\left(\frac{V'_{dc}}{2}\right)^2 - \left(\frac{V_{dc}}{2}\right)^2\right] = \frac{3VI_{dc}T}{4}$$

$$I_{dc} = \frac{2C\left[\left(\frac{V'_{dc}}{2}\right)^2 - \left(\frac{V_{dc}}{2}\right)^2\right]}{3VT} \tag{5.17}$$

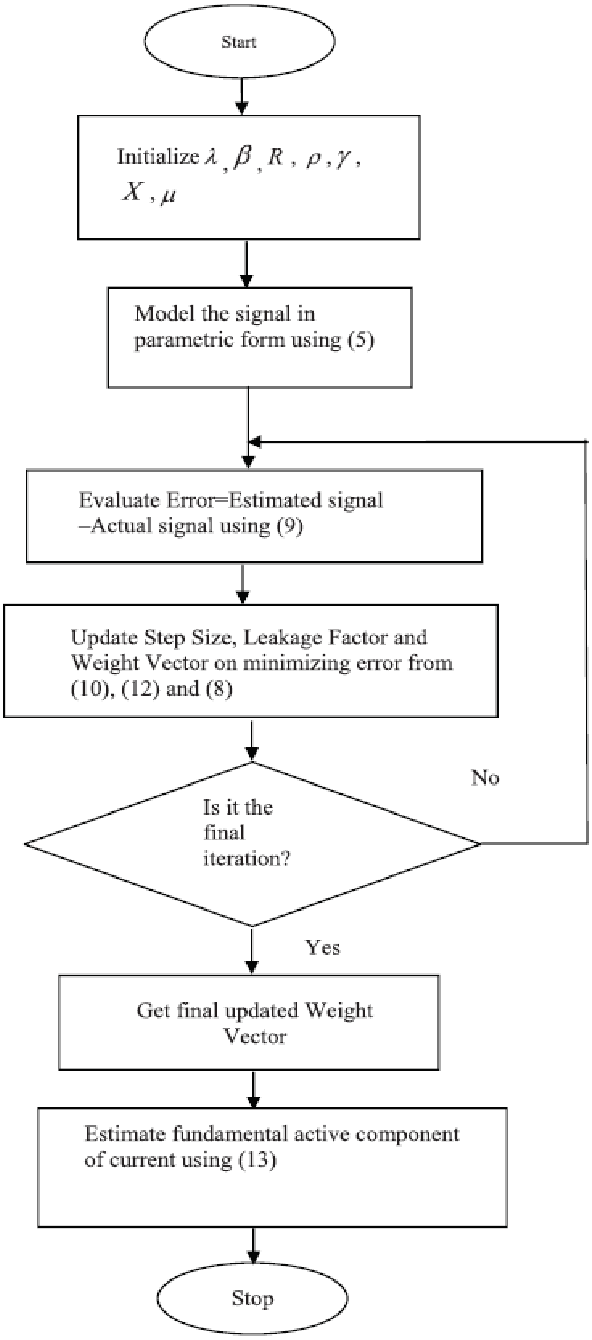


Fig. 5.2. Flow chart of the active fundamental current extraction scheme of VLLMS algorithm

To maintain the value of each dc capacitor voltage at the reference level V*dc / 2, Vdc / 2 is measured and fed back to a PI controller as shown in Fig. 5.3 to manipulate V'dc/ 2. So that it can be used in (17) to compute the required peak value of the charging current Idc from the supply side. The PI controller also helps in reducing the steady state offset between the reference V* dc / 2 and the actual Vdc / 2. The PLL synchronizes itself with the supply voltage of phase a i.e vaand gives three output sine-waves which are 120° out of phase with each other. These sine waves are multiplied with Idc to obtain three phase idc. In order to force the supply side to deliver idc, a term consisting of this idcis added to the three phase injection currents iinjthat can be represented by

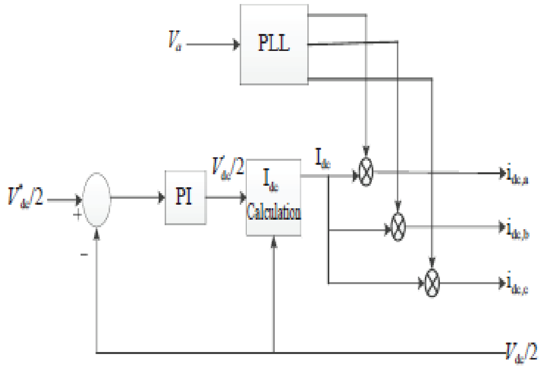
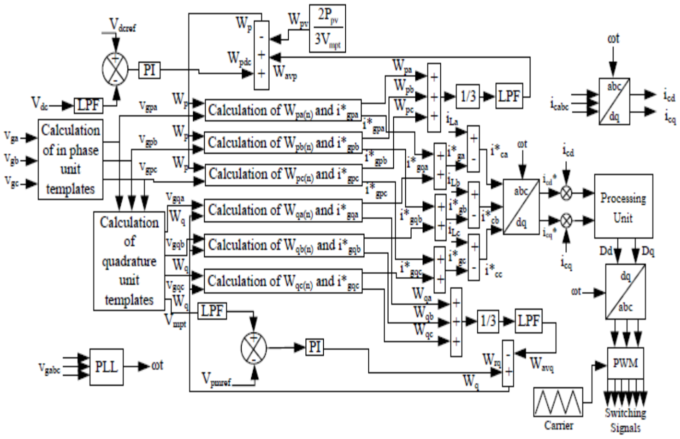


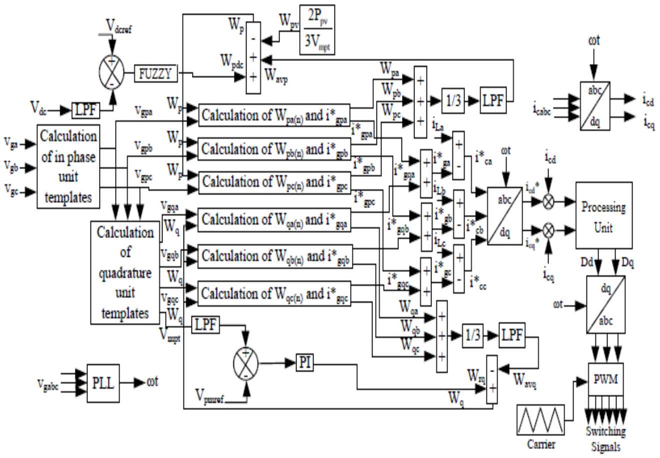
Fig.5.3. Three phase self-charging circuit with PI controller

$$\begin{aligned} i_{inj,a} &= i_{L1,qa} + i_{Ln,a} - I_{dc}\sin\omega t \\ i_{inj,b} &= i_{L1,qb} + i_{Ln,b} - I_{dc}\sin(\omega t - 120^{\circ}) \\ i_{inj,c} &= i_{L1,qc} + i_{Ln,c} - I_{dc}\sin(\omega t + 120^{\circ}) \end{aligned} \tag{5.18}$$

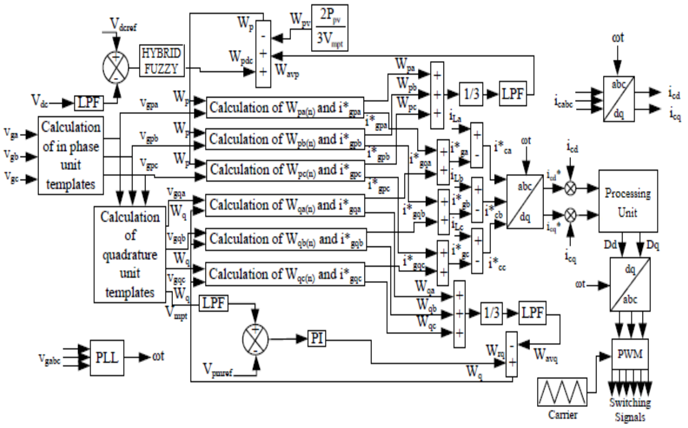
Fig. 5.3 shows the schematic of three phase self-charging circuit with PI controller. The negative sign indicates the flow of charging current into the VSI. For each phase it lags by an angle of 120°. The reference currents calculated shows that the adaptive shunt APF injects iLnand iL1,qinto the line to compensate the harmonic currents and the reactive power respectively, and at the same time it receives the charging current idcfrom the supply to regulate the dc capacitor voltage. An inductor which acts a low pass filter is connected in between the filter and the PCC to eliminate the higher order harmonics. The compensating signals along with the original injecting currents are given to a adaptive hysteresis current controller to generate the switching pulses for the IGBTs or switches in the inverter to produce the required currents.The block diagram representation of proposed VLLMS controller is depicted in Fig.5.4.



(a) Block Diagram of Classical PI based VLLMS Controller



(b) Block Diagram of Proposed Fuzzy based VLLMS Controller



(c) Block Diagram of Proposed Hybrid-Fuzzy based VLLMS Controller

Fig.5.4 Proposed VLMMS Controller

D. Adaptive Hysteresis Current Controller

Adaptive hysteresis control has been used in this work to actualize (18) at the output of VSI. The mathematical expression derived in (18) has been used as the reference signal i* injfor the adaptive hysteresis control [22]. The injected current iinjat the output of VSI is measured and fed back to the adaptive hysteresis control as it's another input. The adaptive hysteresis control will take the difference between i* injand iinjas given by

$$\Delta i_{inj} = i^*_{inj} - i_{inj} \tag{5.19}$$

Taking into account the value of ∆iinj, the adaptive hysteresis control will switch the IGBT of VSI as per the expression given in (20).

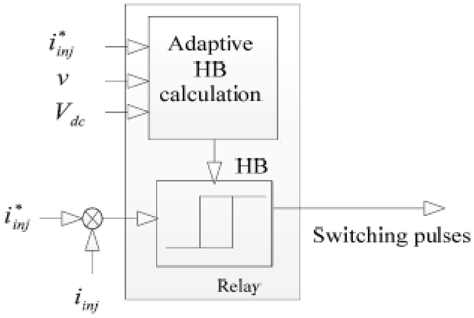


Fig.5.5. Adaptive hysteresis band current controller

$$Sw = adaptive\ hys\,(\Delta i_{inj}) = \begin{cases} 1\ if\ \Delta i_{inj} > HB \\ 0\,if\ \Delta i_{inj} < -HB \end{cases} \tag{5.20}$$

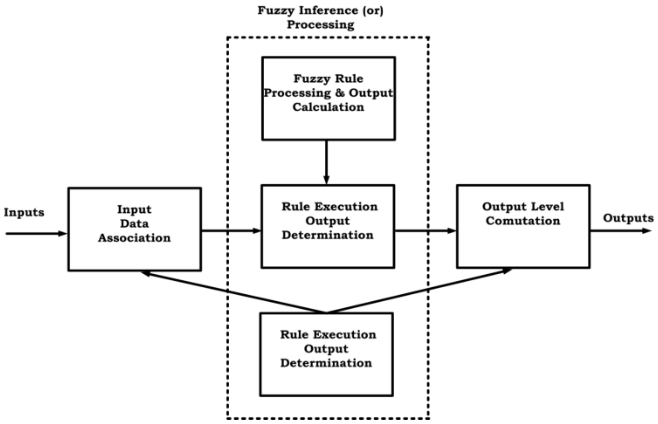
Where HB is the hysteresis band and Swis the status of the IGBT, "1" represents on and "0" represents off. The value of "u" shown in Fig.5.5 will be "1" if Sw= "1" and "-1" if Sw= "0". In hysteresis band current control, it has a fixed hysteresis band due to which the switching frequency is not constant, are uneven in nature. Due to this uneven switching frequency acoustic noise is produced. To overcome these drawbacks, an Adaptive Hysteresis Band Current Control technique has been used which adaptively changes the hysteresis band according to system parameters such as reference source current, source voltage, switching frequency and dc capacitor voltage, so that the switching frequency is maintained almost constant. The hysteresis band [18] can be calculated according to the following equation.

$$HB = \frac{0.125V_{dc}}{f_c L}\left[1 - \frac{4L^2}{V_{dc}^2}\left(\frac{v}{L} + m\right)^2\right] \tag{5.21}$$

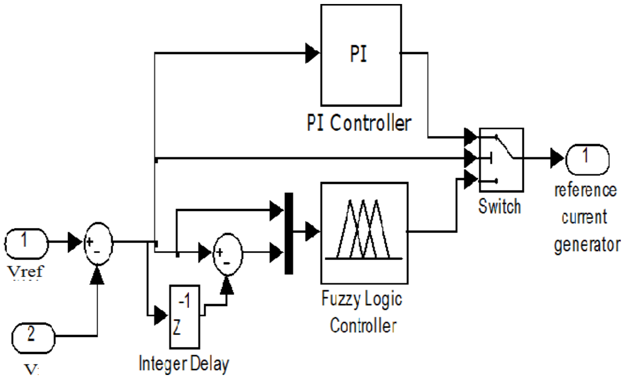
In adaptive hysteresis band current controller, since modulation frequency fc, almost remains constant, this improves the PWM performances and APF substantially. Calculated hysteresis band using above (21), is applied to hysteresis band current controller as shown in Fig. 5.5 for switching pulse generation to be fed back to inverter.

D. Fuzzy-Logic Controller

The Fuzzy-Logic (FL) controllers authorize based on knowledge system which includes Fuzzy member-ship functions and Fuzzy rule-base to assimilate the human knowledge for getting subjective decisions. Some efforts have been developed to attain improved characteristics on system performance by integrating learning mechanism by regulating membership functions and/or rule-base system of the Fuzzy-controller [23]. The heart of the Fuzzy controller is a knowledge system which comprises of information unit for providing linguistic variables and fuzzy rule base. The system associated with database is used to characterize the fuzzy-rule functions and manipulation of fuzzy data in a Fuzzy-Logic controller and the heuristic rules of the knowledge are highly influencing the controller performance [24]. The inference mechanism decides how the fuzzy-logical operations are accomplished, and knowledge base is simultaneously determines the output of fuzzy logic controller based on IF-THEN rules.



(a) Fuzzy Logic Inference



(b) Block Diagram of Proposed Intelligent Controller

Fig.5.6 Design and Interface of Proposed Intelligent Controllers

The Fuzzy-Logic controller is used to furnishing the reference voltage/current signal for generation of optimal switching states to compensator based on mamdani structure. For better enhancement a combination of proposed Fuzzy controller with a VLLMS controller is used which increases the stability index and overall compensation characteristics. As well as, shunt-VSI is used to compensate current harmonics, reactive power compensation, power factor correction, etc. The error is attained from comparison of actual and reference components in terms of current and voltage imperfections are considered as input/output for FL controller with seven linguistic variables.

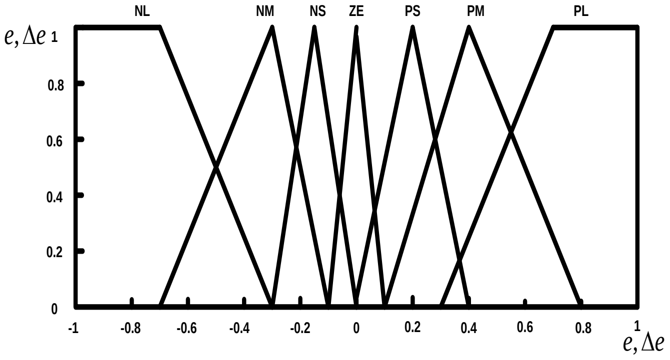


Fig. 5.7 Membership Functions of Hybrid FLC

Table.5.1 Rule-Base of FLC

e Δe	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	NM	NS	EZ	PS	PM	PL

All the membership functions of error, change in error and output are considered as triangular functions because of simple control functions as linearity principle. These membership functions are transformed to fuzzy data by using fuzzification process for making the favourable decisions as rule-base system and provide the output signals and again re-transformed into general data by using centroid method of defuzzification process. The utilized membership functions are Zero (ZE), Positive-Large (PL), Positive-Medium (PM), Positive-Small (PS) and Negative-Large (NL), Negative -Medium (NM), Negative -Small (NS), respectively as depicted in Fig.5.7 and the rule-base is depicted in Table.5.1.

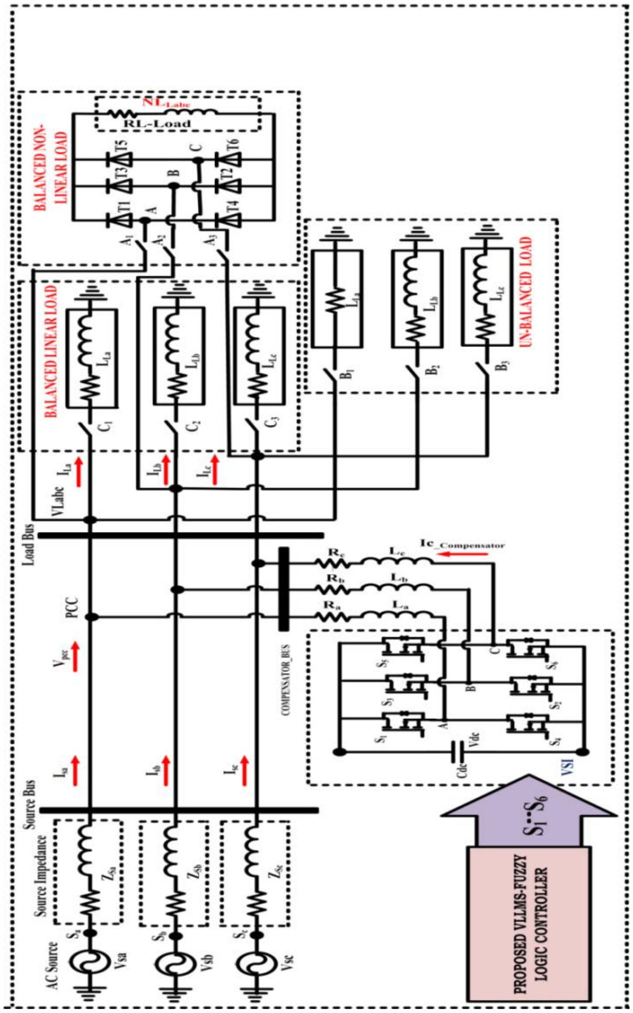


Fig.5.7 Over-all Schematic Diagram of Proposed Hybrid-Fuzzy Logic Controller Fed VLLMS Driven APF for PQ Enhancement

VI. Simulation Results

The simulation analysis is conveyed by implementation of Active-Power Filter by using proposed VLLMS-Fuzzy Logic Control scheme in a three phase power systems under several load situations with the help of system parameters, system parameters are shown in below Table.6.1

Table.6.1. System Parameters

Parameters	Values
Source Voltage	220V, 50Hz
Source Impedance	0.1+j0.282Ω
Load Impedance	2+3jΩ
DC-Link Capacitor	1500µF
VSI Filter Units	R-0.001; L-10mH
PI Controller Gains	Kp-0.8; Ki-0.5

Case A: Without Presence of any Active-Power Filter

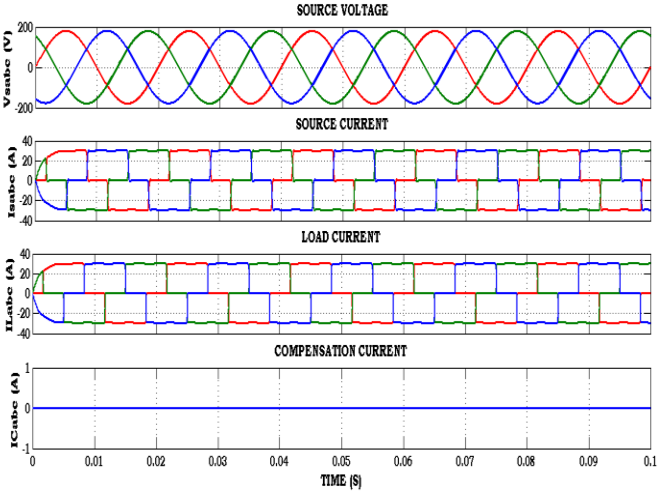


Fig.6.1 Simulation Results of Three Phase Power System under Non-Presence of APF

Fig.6.1. illustrates the various simulation outcomes of three phase power system non-presence of APF, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the balanced non-linear load, due to the NL-load device the PCC currents goes to affects as a harmonized components which is reflected the PQ concerns. Without APF compensator load parameters is always equal to source parameters, that's why both are stared as same.

Case B: Presence of VLLMS Driven APF under Balanced Linear Load

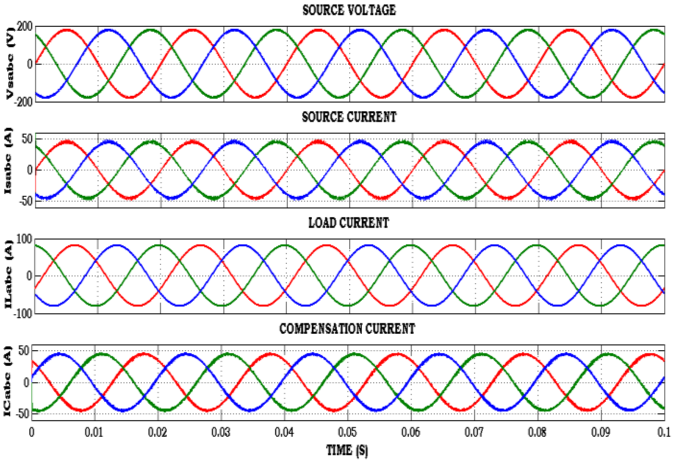


Fig.6.2 Simulation Results of Three Phase Power System Presence of VLLMS driven APF under Balanced Linear Load

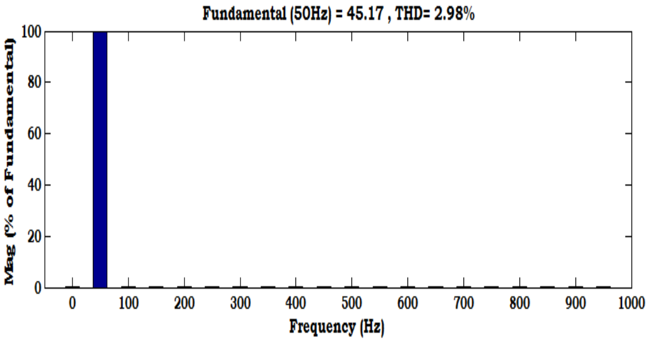


Fig.6.3 THD analysis of Source Current

Fig.6.2 illustrates the various simulation outcomes of three phase power system presence of VLLMS driven APF under balanced linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the balanced linear load, due to the linear-load device the PCC currents maintains as constant and THD of source current well with in standards as depicted in Fig.6.3, attains 2.98%.

Case C: Presence of VLLMS Driven APF under Un-Balanced Linear Load

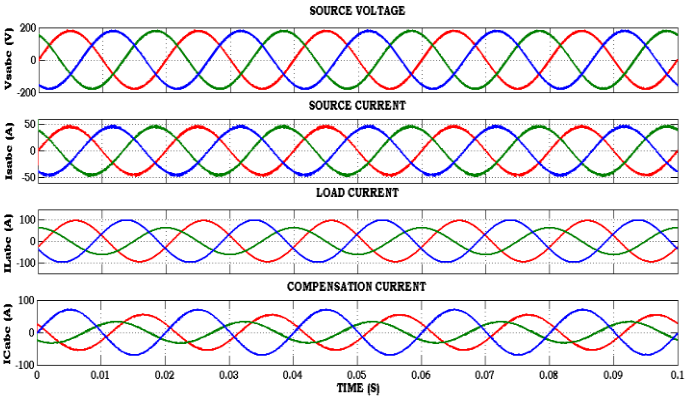


Fig.6.4 Simulation Results of Three Phase Power System Presence of VLLMS driven APF under Un-Balanced Linear Load

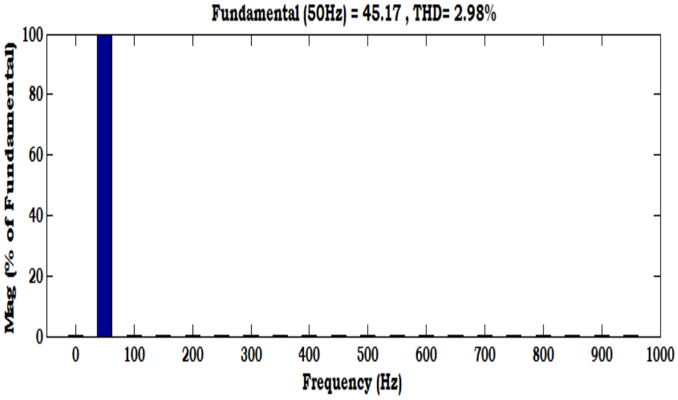


Fig.6.5 THD analysis of Source Current

Fig.6.4 illustrates the various simulation outcomes of three phase power system presence of VLLMS driven APF under unbalanced linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the unbalanced linear load, due to the unbalanced linear-load device the PCC currents are maintains as constant due to presence of APF. But load currents are maintained as unbalanced, as well as the APF injects compensated current to power system which regulates balanced nature and THD of source current well with in standards as depicted in Fig.6.5, attains 2.98%.

Case D: Presence of VLLMS Driven APF under Balanced Non-Linear Load

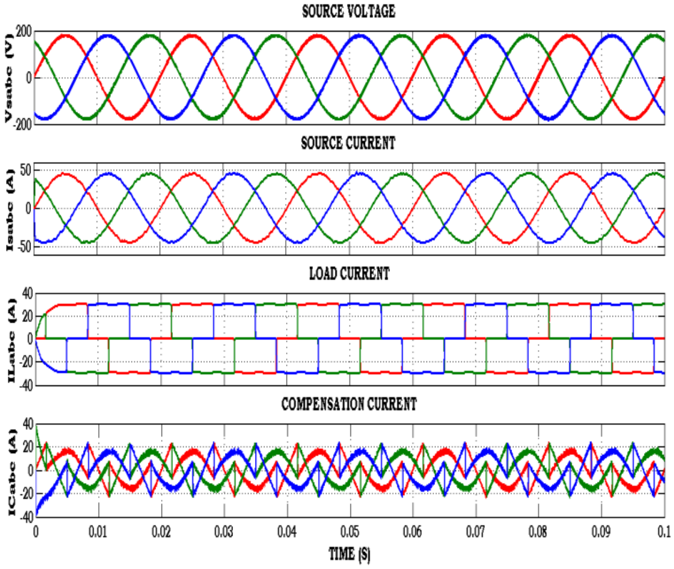
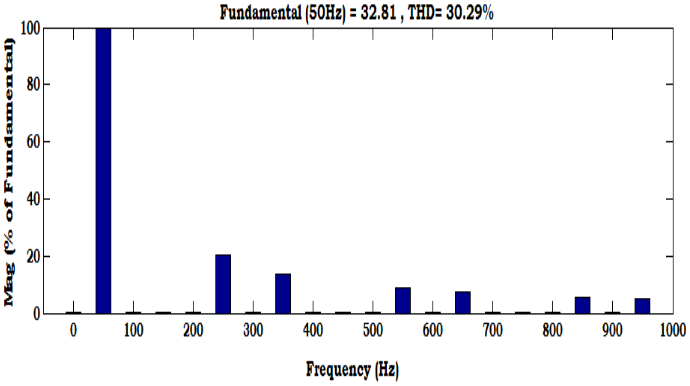
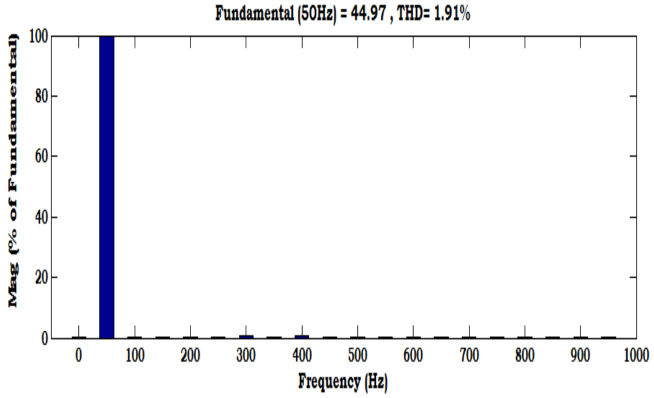


Fig.6.6 Simulation Results of Three Phase Power System Presence of VLLMS driven APF under Balanced Non-Linear Load



(a) THD Analysis of Source Current without Compensation (without APF)



(b) THD Analysis of Source Current with Compensation Device (with APF)

Fig.6.7 THD Analysis of Source Current with and without APF

Fig.6.6 illustrates the various simulation outcomes of three phase system presence of APF with proposed VLLMS control strategy under balanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the balanced non-linear load, due to this load device load currents are harmonized components. But source currents maintain as harmonic-free and well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current without APF is 30.29% have more harmonic values and THD of source current is 1.91% have low harmonics well compensated by APF and within a IEEE-519 standard's as depicted in Fig.6.7.

Case E: Presence of VLLMS Driven APF under Un-Balanced Non-Linear Load

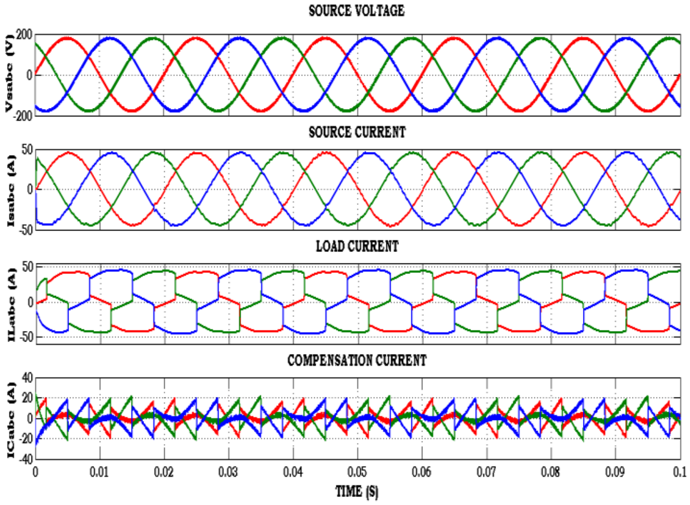
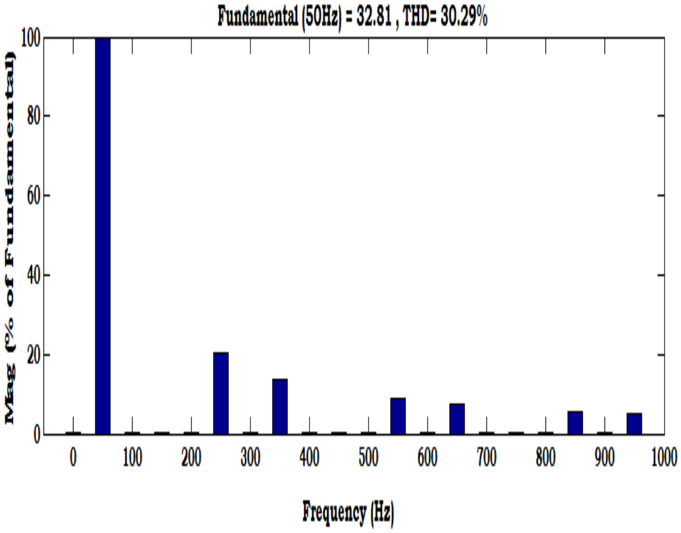
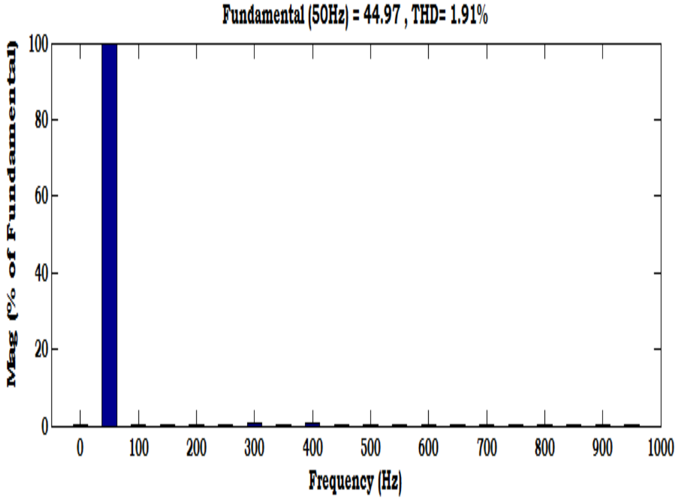


Fig.6.8 Simulation Results of Three Phase Power System Presence of VLLMS driven APF under Un-Balanced Non-Linear Load



(c) THD Analysis of Source Current without Compensation (without APF)



(d) THD Analysis of Source Current with Compensation Device (with APF)

Fig.6.9 THD Analysis of Source Current with and without APF

Fig.6.8 illustrates the various simulation outcomes of three phase system presence of APF with proposed VLLMS control strategy under unbalanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the unbalanced non-linear load, due to this load device load currents are unbalanced and harmonized components. But source currents maintain as harmonic-free and balanced nature well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current without APF is 30.29% have more harmonic values and THD of source current is 1.91% have low harmonics well compensated by APF and within a IEEE-519 standard's as depicted in Fig.6.9.

Case F: Presence of Fuzzy-Logic Controller based VLLMS Driven APF under Balanced Non-Linear Load

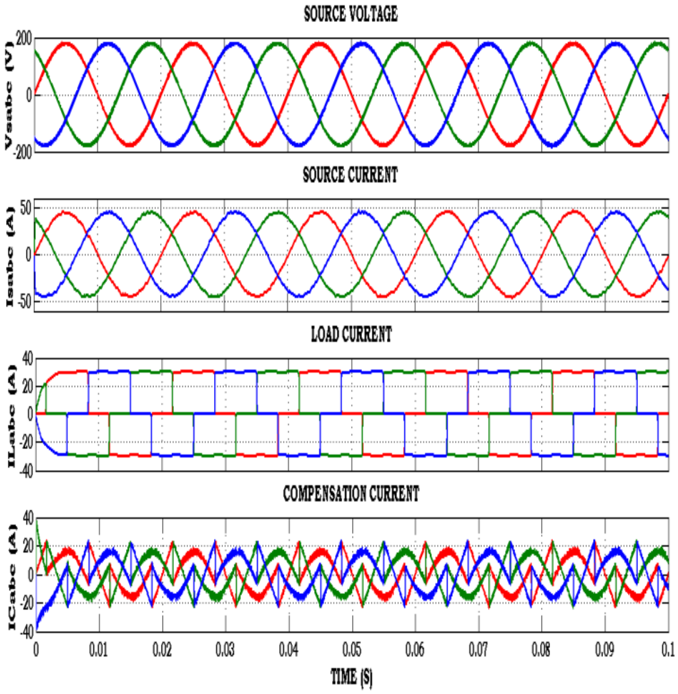


Fig.6.10 Simulation Results of Three Phase Power System Presence of Fuzzy-VLLMS driven APF under Balanced Non-Linear Load

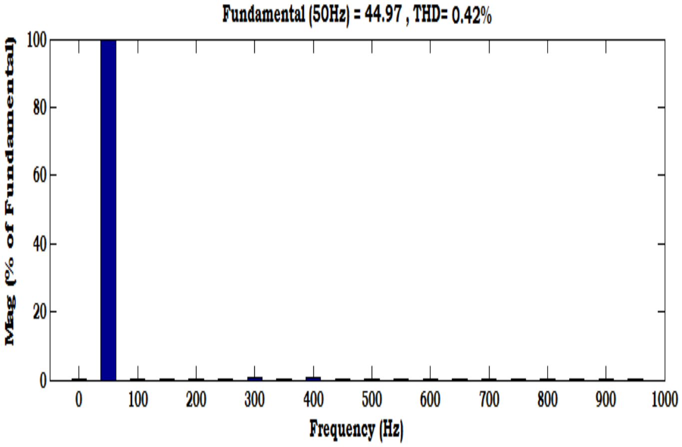


Fig.6.11 THD Analysis of Source Current with Compensation Device (with APF)

Fig.6.10 illustrates the various simulation outcomes of three phase system presence of APF with proposed Fuzzy-VLLMS control strategy under balanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the balanced non-linear load, due to this load device load currents are harmonized components. But source currents maintain as harmonic-free and well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current with Fuzzy-VLLMS controller driven APF is 0.42% have low harmonics well compensated by APF and within a IEEE-519 standards as depicted in Fig.6.11.

Case G: Presence of Hybrid-Fuzzy-Logic Controller based VLLMS Driven APF under Balanced Non-Linear Load

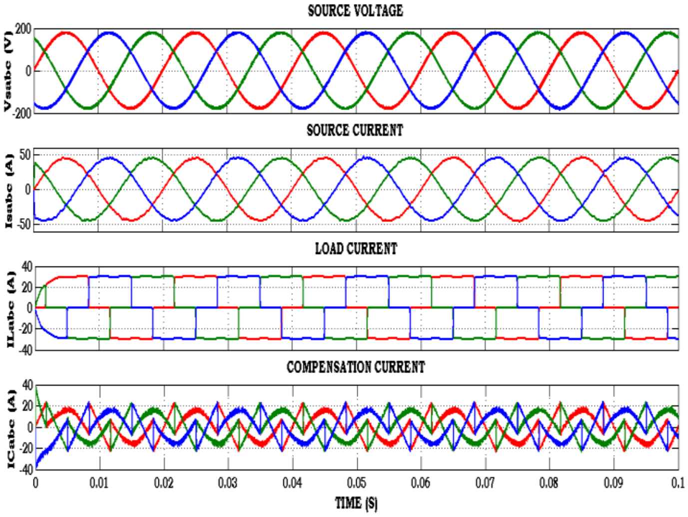


Fig.6.12 Simulation Results of Three Phase Power System Presence of Hybrid-Fuzzy-VLLMS driven APF under Balanced Non-Linear Load

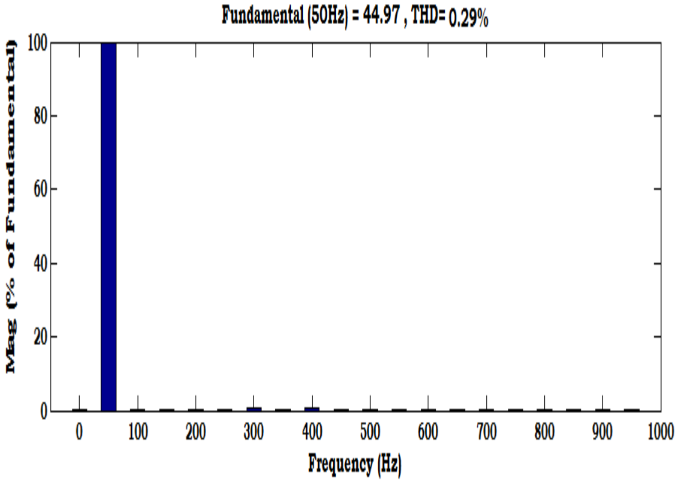


Fig.6.13 THD Analysis of Source Current with Compensation Device (with APF)

Fig.6.12 illustrates the various simulation outcomes of three phase system presence of APF with proposed Hybrid-Fuzzy VLLMS control strategy under balanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the balanced non-linear load, due to this load device load currents are harmonized components. But source currents maintain as harmonic-free and well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current with Hybrid-Fuzzy VLLMS controller driven APF is 0.29% have low harmonics well compensated by APF and within an IEEE-519 standards as depicted in Fig.6.13.

Case H: Presence of Fuzzy-Logic Controller based VLLMS Driven APF under Un-Balanced Non-Linear Load

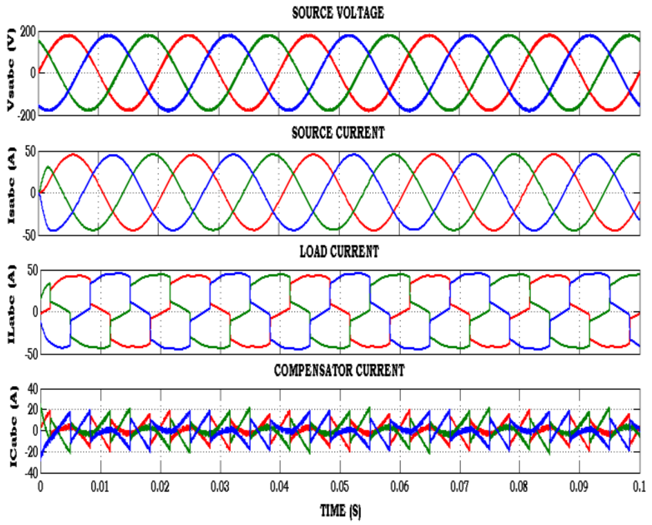


Fig.6.14Simulation Results of Three Phase Power System Presence of Fuzzy-VLLMS driven APF under Un-Balanced Non-Linear Load

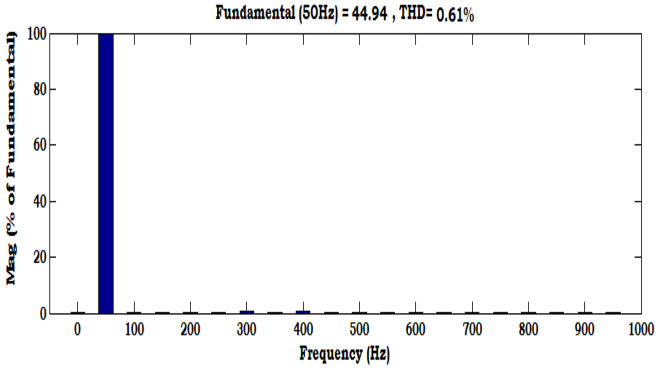


Fig.6.15 THD Analysis of Source Current with Fuzzy-VLLMS Controller

Fig.6.14 illustrates the various simulation outcomes of three phase system presence of APF with proposed Fuzzy-VLLMS control strategy under un-balanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the un-balanced non-linear load, due to this load device load currents are harmonized components and unbalanced nature. But source currents maintain as harmonic-free and sinusoidal, balanced, well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current with Fuzzy-VLLMS controller driven APF is 0.61% have low harmonics well compensated by APF and within IEEE-519 standards as depicted in Fig.6.15.

Case I: Presence of Hybrid-Fuzzy-Logic Controller based VLLMS Driven APF under Un-Balanced Non-Linear Load

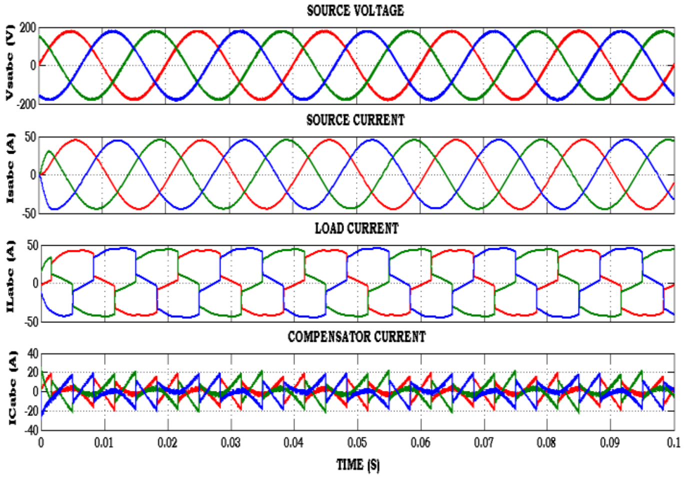


Fig.6.16 Simulation Results of Three Phase Power System Presence of Hybrid-Fuzzy-VLLMS driven APF under Un-Balanced Non-Linear Load

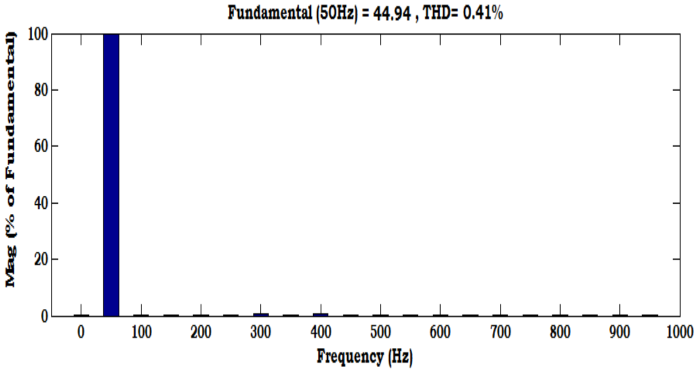


Fig.6.17 THD Analysis of Source Current withHybrid-Fuzzy-VLLMS Controller

Fig.6.16 illustrates the various simulation outcomes of three phase system presence of APF with proposed Hybrid-Fuzzy VLLMS control strategy under un-balanced non-linear load device, in that (a) Source Voltage, (b) Source Current, (c) Load Current, (d) Compensation Current, respectively. In this case load is treated as the un-balanced non-linear load, due to this load device load currents are harmonized components, unbalanced. But source currents maintain as harmonic-free and sinusoidal, balanced nature, well with in IEEE standards by using APF compensator by using attractive fundamental frequency based compensation currents. The THD of source current with Hybrid-Fuzzy VLLMS controller driven APF is 0.41% have low harmonics well compensated by APF and within an IEEE-519 standards as depicted in Fig.6.17. A Comparative analysis of Source Current THD’s in Various Control Objectives under Balanced and Un-Balanced Load Condition is depicted in Table.6.2. In that, the hybrid-fuzzy controlled based APF is best suited over classical PI and Fuzzy logic controller because of attaining very low THD over these controllers and well within IEEE standards.A Comparative analysis of Source Current THD’s in Various Control Objectives under Balanced and Un-Balanced Load Condition is depicted in Table.6.2. In that, the hybrid-fuzzy controlled based APF is best suited over classical PI and Fuzzy logic controller because of attaining very low THD over these controllers and well within IEEE standards. The graphical view of source-current THD in several control schemes under balanced and un-balanced load conditions as depicted in Fig.6.18.

Table.6.2 Comparison of Source Current THD's in Various Control Objectives under Balanced and Un-Balanced Load Condition

THD (%)	**Without Controller**	**PI-VLLMS Controller**	**Fuzzy-VLLMS Controller**	**Hybrid-Fuzzy-VLLMS Controller**
Source Current (Under Balanced Non-Linear Load)	30.29 %	1.91%	0.42 %	0.29%
Source Current (Under Un-Balanced Non-Linear Load)	30.29 %	1.79%	0.61 %	0.41%

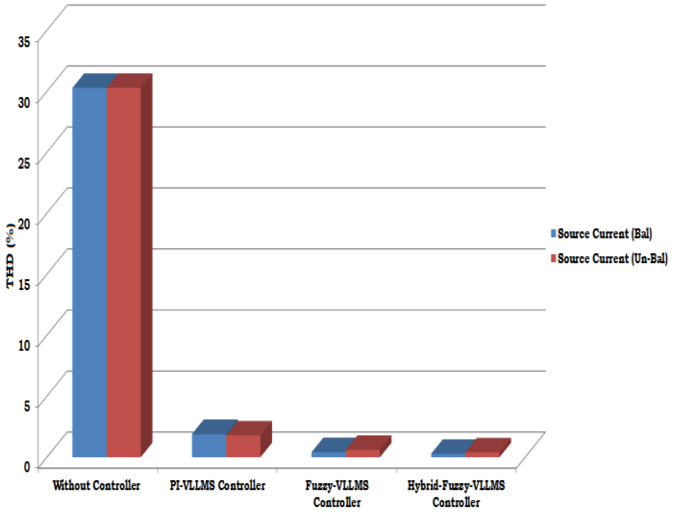


Fig. 6.18 Graphical View of Source Current THD under Various Controllers

VII. Conclusion

In this work, a new control design for the shunt active power filter has been presented. The controller design is based on Hybrid-Fuzzy-Logic controller based VLLMS algorithm for fundamental current extraction. With the use of this proposed algorithm, the performance of shunt active filter has been enhanced in various load conditions like balanced and unbalanced nonlinear load currents. Self-charging capability has also been integrated into the proposed shunt active power filter for regulating the dc capacitor voltage. Simulation results under various system operating conditions have verified the effectiveness and robustness of the proposed adaptive shunt active filter under balanced and unbalanced load conditions. The THD of source currents under classical PI and intelligent hybrid fuzzy controllers are evaluated, the hybrid-fuzzy is the best suited due to low THD profile, high stability index, and the well within IEEE-519 standards.

References

[1] B. Singh, A. Chandra, K. Al. Haddad. Power Quality Problems and Mitigation Techniques. Hoboken, NJ, USA: Wiley Publishers, 2015.

[2] De Araujo R, De Azevedo C, De Sousa R. A robust adaptive control strategy of active power filters for power factor correction, harmonic compensation, balancing of non-linear loads. IEEE Transactions on Power Electronics. 2012; 27 (2): 718-730

[3] Pomilio J, Deckmann S. Characterization and compensation of harmonics and reactive power of residential and commercial loads. IEEE Transactions on Power Delivery. 2007; 22(2): 1049-1055.

[4] Lam C S, Choi W H, Wong M C, and Han Y D. Adaptive Dc-link voltage controlled hybrid active power filters for reactive power compensation. IEEE Transactions on Power Electronics. 2012; 27 (4): 1758-1772.

[5] M. I. M. Montero, E. R. Cadaval, and F. B. González, “Comparison of control strategies for shunt active power filters in three-phase four-wire systems,” IEEE Transactions on Power Electronics, vol. 22, no.1, pp. 229-236, Jan. 2007.

[6] B. Singh, K. Al-Haddad, and A. Chandra, “A review of active filter for power quality improvement,” IEEE Trans. on Ind. Electron., vol. 46, no. 5, pp. 960-971, Oct. 1999.

[7] P. Jintakosonwit, H. Akagi, H. Fujita, and S. Ogasawara, “Implementation and performance of automatic gain adjustment in a shunt active filter for harmonic damping throughout a power distribution system,” IEEE Trans. Power Electron., vol. 17, no. 3, pp. 438-447, May 2002.

[8] D. Gao and X. Sun, “A new method to generate current reference for active power filter,” in Proc. IEEE CIEP, Alcapulco, Mexico, 2000, pp. 99-103.

[9] H. Akagi, Y. Kanazawa, and A. Nabae, “Instantaneous reactive power compensators comprising switching devices without energy storage components,” IEEE Transactions on Industry Applications, vol. 20, no. 3, pp. 625-630, May/June 1984.

[10] S. D. Swain and P. K. Ray, “Harmonic current and voltage compensation using HSAPF based on hybrid control approach for synchronous reference frame method,” International Journal of Electrical Power &Energy Systems, vol. 75, pp. 83-90, 2016.

[11] M. Rezkallah, A. Chandra, B. Singh, and R. Niwas, “Modified PQ control for power quality improvement of standalone hybrid wind diesel battery system,” in Proc. IEEE Power India Conference, New Delhi, 19-22 Dec. 2012.

[12] B. Singh, P. Jayaprakash, S. Kumar, and D. P. Kothari, “Implementation of neural network controlled three leg VSC and a transformer as three phase four wire DSTATCOM”, IEEE Transactions on IndustrialApplications, vol. 47, no.4, pp. 1892-1901, July/Aug 2011.

[13] N. Pecharanin, “An application of neural network to harmonic detection in active filter,” in Proc. WCCI-ICNN, 1994, vol. 6, pp. 3756-3756.

[14] B. Singh, V. Verma, and J. Solanki, “Neural network based selective compensation of current quality problems in distribution system,” IEEE Transactions on Industrial Electronics, vol. 54, no.1, pp. 53-60, Feb 2007.

[15] Y. Fang, J. Fei, and K. Mab, “Model reference adaptive sliding mode control using RBF neural network for active power filter,” InternationalJournal of Electrical Power and Energy Systems, vol. 73, pp. 249-258, 2015.

[16] J. Fei and C. Lu, “Adaptive sliding mode control of dynamic systems using double loop recurrent neural network structure,” IEEE Transactionson Neural Network and Learning Systems, vol. 29, no. 4, pp. 1275-1286, 2017.

[17] S. D. Swain, P. K. Ray and K. B. Mohanty “Improvement of power quality using a robust hybrid series active power filter,” IEEE Transactionson Power Electronics, vol. 32, no. 4, pp. 3490-3498, 2017.

[18] A. K. Pradhan, A. Routray, and AbirBasak, “Power system frequency estimation using least mean square technique,” IEEE Trans. PowerDel., vol. 20, no. 3, pp.1812-1816, 2005.

[19] B. Subudhi, P. K. Ray, and S. Ghosh, “Variable leaky LMS algorithm based power system frequency estimation,” IET Science, Measurement& Technology, vol. 6, no. 4, pp. 288-297, 2012.

[20] P. K. Ray, P. S. Puhan, and G. Panda, “Real time harmonics estimation of distorted power system signal,” International Journal of ElectricalPower and Energy System, vol. 75, pp. 91-98, 2016

[21] L. H. Tey, P. L. So, and Y. C. Chu, “Improvement of power quality using adaptive shunt active filter,” IEEE Transactions on Power Delivery, vol. 20, no. 2, pp. 1558-1568, 2005.

[22] M. Kale and E. Ozdemir, “An adaptive hysteresis band current controller for shunt active power filter,” Electric Power System Research, vol. 73, pp. 113-119, 2005.

[23] G. Satyanarayana, K.N.V. Prasad, G. Ranjith Kumar, K. Lakshmi Ganesh, "Improvement of power quality by using hybrid fuzzy controlled based IPQC at various load conditions", *Energy Efficient Technologies for Sustainability (ICEETS) 2013 International Conference on*, pp. 1243-1250, 2013.

[24] G. Satyanarayana, K. Lakshmi Ganesh “Tuning a Robust Performance of Adaptive Fuzzy-PI Driven DSTATCOM for Non-Linear Process Applications” is Published in Springer LNCS Series-8947, ISSN-0302-9743, pp.523-533, July 2015