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Fuzzy Controlled Active Power Filter for HarmonicCompensation in Distributed Generation System

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Abstract:

The increased infiltration of nonlinear loads and power electronic interfaced distribution generation system creates power quality issues in the distributed power system. In this paper, a comprehensive survey on micro grid to improve the power quality parameters is taken as the main objective. Shunt active filter based on current controlled PWM converters are seen as a most viable solution. Furthermore, the detailed investigations are explored in this paper for the enhancement of power quality issues with the help of an optimization technique, filters, controllers, FACTS devices, compensators, and battery storage. The ability of fuzzy logic to handle rough and unpredictable real world data made it suitable for a wide variety of applications, especially, when the models or processes are too complex to be analyzed by classical methods. In this paper fuzzy logic controller is used for controlling the DC capacitor voltage. The results show that the proposed controller has fast dynamic response, high accuracy by using MATLAB / SIMULINK are carried out to verify the performance of the proposed controller.

Keywords:
Voltage Disturbances, Nonlinear Loads, PCC, Power Quality, Shunt Active Power Filter (SAPF), fuzzy logic controller.

I. INTRODUCTION:

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation.

The market liberalization and government's incentives have further accelerated the renewable energy sector growth. The sun and wind energy are the alternative energy sources. Previously, they were used to supply local loads in remote areas, outside the national grid. Later, they have become some of main sources.The widespread increase of non-linear loads, significant amounts of harmonic currents are being injected into power systems. The harmonic currents flow through the power system impedance causing voltage distortion at the harmonic currents frequencies. The current and voltage harmonics in power system decreases the power factor, increases losses in the line and can cause timing errors in sensitive electronic equipments. The harmonic currents and voltages produced by balanced 3- phase non-linear loads such as motor drivers, silicon controlled rectifiers, large uninterruptible power supplies (UPS) are positive-sequence harmonics (7th, 13th, etc.) and negative-sequence harmonics (5th, 11th, 17,etc.).However, harmonic currents and voltages produced by single phase nonlinear loads such as switch-mode power supplies in computer equipment which are connected phase to neutral in a 3-phase 4-wire system are third order zero-sequence harmonics (triplen harmonics—3rd, 9th, 15th, 21st, 27th etc.). These triplen harmonic currents unlike positive and negative-sequence harmonic currents do not cancel but add up arithmetically at the neutral bus. This can result in neutral current that can reach magnitudes as high as 1.73 times the phase current. In addition to the hazard of cables and transformers overheating the third harmonic can reduce energy efficiency [1]. Even though there are some demerits such as uncertainty of power, hybrid DGs can be used to overcome this problem. Passive power filter in power system has some problems such as, source impedance affect the characteristics of filter and system impedance [2]. So as to overcome these problems hybrid filters are used. Controllers of different types are known as nonlinear loads which draws sinusoidal current with some distortion from the mains [3]. For many considerations hybrid filters play an important role in improving the power quality.

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In the case of dispersed generation power quality is the major problem due to the uncertainty of power [4]. These problems can be solved using hybrid filters. New type of hybrid filter is designed with varying inductance in the passive side for the power quality improvement [5]. This new type of filter is used to compensate current harmonics and unbalanced load. Shunt active filter and shunt passive filters are used to filter the higher order harmonics [6].

The Total Harmonic Distortion is well within the limits according to the power quality standards (IEEE-519). Fuzzy logic controller based filtering arrangements are made, which also do the role of damping, load balancing, reactive power control, power factor correction, voltage regulation, and voltage flicker reduction [1]. The filtering arrangements are made for three phase system. Distributed power generation system with hybrid filter which is used for different configurations are presented [7]. Adaptive signal processing controller is proposed. Simulation is done using MATLAB.

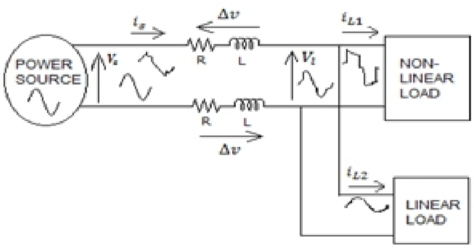

Figure1 SAPF block diagram.

Fig. 1 shows the basic compensation principle of the three phase shunt APF. It is designed to be connected in parallel with the nonlinear load to detect its harmonic and reactive current and to inject into the system a compensating current. In the conventional p-q theory based control approach for the shunt APF, the compensation current references are generated based on the measurement of load currents. However, the current feedback from the SAPF output is also required and therefore, minimum six CSs are desired in a unbalanced system.

In addition, the reference current calculation algorithm are simplified and easily implemented in the experimental prototype. In the reduced current measurement control algorithm, sensing only three-phase voltages, three source currents and a DC-link voltage is adequate to compute reference currents of the three phase SAPF. In this way, the overall system design becomes easier to accomplish and the total implementation cost is reduced.

II. VOLTAGE SOURCE CONVERTERS:

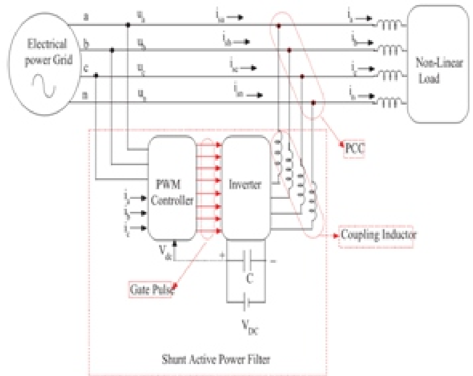

Figure2 Shunt active power filters topology.

The active power filter topologies mostly use as voltage source converters. This topology, shown in Figure 2, converts a dc voltage into an ac voltage by appropriately gating the power semiconductor switches. A single pulse for each half cycle can be applied to synthesize an ac voltage. For these purposes most applications requiring dynamic performance, pulse width modulation is the most commonly used for active power filter. PWM techniques applied to control the VSI for chopping the dc bus voltage to produce an ac voltage of an arbitrary waveform.

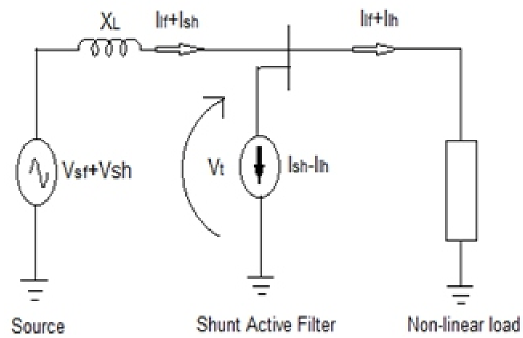

Figure3 Principle of shunt current compensation.

Voltage source converters are preferred over current source converter because it has higher efficiency and lower initial cost than the current source converters [4, 5, and 9]. They can be readily expanded in parallel to increase their combined rating and their switching rate can be increased if they are carefully controlled so that their individual switching times do not coincide. Therefore, higher-order harmonics can be eliminated by using converters without increasing individual converter switching rates. Because of non linear load current having harmonics, hence the load current will be the summation of fundamental and all other harmonics, all harmonics will be integer multiple of fundamental frequency. Load current can be written as

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$$i_L(t) = \sum_{n=1}^{\infty} i_n \sin(n\omega t + \varphi_n)$$
$= i_l \sin(\omega t + \varphi_l) + \sum_{n=2}^{\infty} \sin\,(n\omega t + \varphi_n)$.................. (1)
Instantaneous Load can be written as
$p_L(t) = v_S(t) \times i_L(t)$... (2)
Putting value of $i_L(t)$from equation (1) in equation (2)

$p_A(t) + p_R(t) + p_H(t)$.. (3)

Here $p_A(t)$ is active or fundamental power. Only fundamental component of voltage and current can deliver power to the load and $p_R(t)$ is reactive power. Harmonic power denoted by $p_H(t)$. So active or real power drawn by the load from the source is

$p_A(t) = v_m i_1 \sin^2 \omega t \times \cos\varphi_1 = v_s(t) \times i_s(t)$.... (4)
Therefore, source current after compensation will be given by equation (5)

$i_s(t) = \frac{p_A(t)}{v_S(t)} = i_1 cos\varphi_1 \times sin\omega t = i_m sin\omega t$........... (5)

Where $i_m = i_1 cos\varphi_1$
In a practical converter, there are switching, conducting and capacitor leakage losses. So that losses must be supplied by the supply or by the grid itself. So total current delivered by supply will be given as
$i_{sp} = i_m + i_{slo}$.. (6)
Where i_{sp} =peak current supplied by source.
i_{slo} = loss current of converter supplied by the source.
If total harmonic and reactive power of the load is supplied, by the Active Power Filter then there will not be any harmonic in source current and source current will be in phase with the source voltage. Therefore, the total source current including losses will be given as $i_s^*(t) = i_{sp}\ sin\omega t$, so compensating current will be given as

$i_c(t) = i_l(t) - i_s^*(t)$.. (7)

It is obvious from above discussion that for instantaneous compensation of reactive power in addition, harmonic power, source (grid) should be able to supply current $i_s^*(t)$. Therefore, it is necessary to find $i_s^*(t)$ which is known as reference current.

III.ESTIMATION OF REFERENCE SOURCE CURRENT:

The instantaneous currents can be written as

$i_s(t) = i_l(t) - i_c(t)$... (8)

Source voltage is given by

$v_s(t) = v_m sin\omega t$.. (9)

If a non-linear load is applied, then the load current will have a fundamental component and harmonic components which can be represented as
$i_L = \sum_{n-1}^{\infty} I_n \sin(n\omega t + \emptyset_n)$.............................. (10)
$= I_n \sin(n\omega t + \emptyset_1) + \sum_{n-2}^{\infty} \sin\,(n\omega t + \emptyset_n)$...... (11)
The instantaneous load power can be given as
$P_L(t) = v_s(t) \times i_1(t)$
$= V_m I_1 \sin^2 \omega t \times \cos\emptyset_1 + v_m I_1 \sin\omega t \times \cos\omega t \times \sin\emptyset_1 + V_m \sin\omega t \times \sum_{n-2}^{\infty} I_n \sin(n\omega t + \emptyset_n)$
$P_L(t) = P_f(t) + P_r(t) + P_h(t)$............................ (12)
From the real (fundamental) power drawn by the load is
$P_f(t) = V_m I_1 \sin\omega\, t \times \cos\emptyset_1 = v_s(t) \times i_s(t)$....... (13)
The source current supplied by the source, after compensation is as follows.
$i_s(t) = \frac{P_f(t)}{v_s(t)} = I_1 \cos\emptyset_1 \sin n\omega t = I_m \sin\omega t$........ (14)
Where $I_{sm} = I_1 cos\emptyset_1$.
There are also some switching losses in the PWM converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load. The total peak current supplied by the source is therefore
$I_{sp} = I_{sm} + I_{s1}$.. (15)
If the active filter provides the total reactive and harmonic power, then is(t) will be in phase with the utility voltage and purely sinusoidal. At this time, the active filter must provide the following compensation current:
$i_C(t) = i_L(t) - i_S(t)$.. (16)
Hence, for accurate and instantaneous compensation of reactive and harmonic power it is necessary to estimate, i.e. the fundamental component of the load current is the reference current. The design of the power circuit includes three main parameters $L_c, V_{dc\,ref}\, and\ C_{dc}$.

A. SELECTION OF L_c, $V_{dc,ref}$ and C_{dc}:

The design of these components is based on the following assumptions:

- Fixed capability of reactive power compensation of the active filter.
- The PWM converter is assumed to operate in the linear modulation mode (i.e. $0 \le m_a \le 1$).

As per the compensation principle, the active filter adjusts the current i_{c1} to compensate the reactive power of the load [3]. If the active filter compensates all the fundamental reactive power of the load, i_{s1}will be in phase and i_{c1} should be orthogonal to V_s. The three-phase reactive power delivered from the active filter can be calculated from a vector diagram.
$Q_{c1} = 3V_s I_{c1} = \frac{3V_s V_{c1}}{\omega L_c [1 - (\frac{V_s}{V_{c1}})]}$ .... (17)
That is the active filter can compensate the reactive power from the utility only when $V_{c1} > V_s$. If the PWM converter is assumed to operate in the linear modulation

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mode (i.e. $0 \leq m_a \leq 1$), the amplitude modulation factor ma is

$$m_a = v_m/(\frac{V_{dc}}{2}) \quad (18)$$

Where $v_m = \sqrt{2}V_c$ and hence $V_{dc} = 2\sqrt{2}V_{c1}$ for $m_a = 1$.The filter inductor L_c is also used to filter the ripples of the converter current, and hence the design of L_c is based on the principle of harmonic current reduction. The ripple current of the PWM converter can be given in terms of the maximum harmonic voltage, which occurs at the frequency $m_{f\omega}$.

$$I_{ch(mfw)} = V_{ch(mfw)}/m_f\omega L_c \quad (19)$$

IV. PI CONTROL SCHEME:

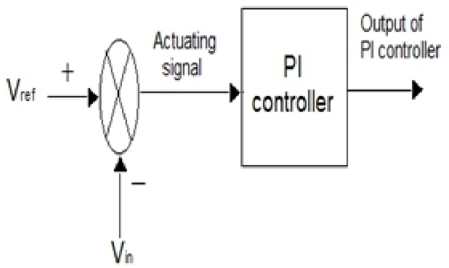

Figure.4 APF Control scheme with PI controller.

The error signal is fed to PI controller. The output of PI controller has been considered as peak value of the reference current. It is further multiplied by the unit sine vectors u_sa,u_sb.u_(sc)in phase with the source voltages to obtain the reference currents (i_sa^*,i_sb^*,i_sc^*). These reference currents and actual currents are given to a hysteresis based, carrier less PWM current controller to generate switching signals of the PWM converter [6]. The difference of current template and actual current decides the operation of switches. These switching signals after proper isolation and amplification are given to the switching devices. Due to these switching actions current flows through the filter inductor L_c, to compensate the harmonic current and reactive power of the load, so that is the reason to draw active power from the source.

V. FUZZY LOGIC CONTROLLER:

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [6]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior.

Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been a potential ability to improve the robustness of converters. The basic scheme of a fuzzy logic controller is shown in Fig 5 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

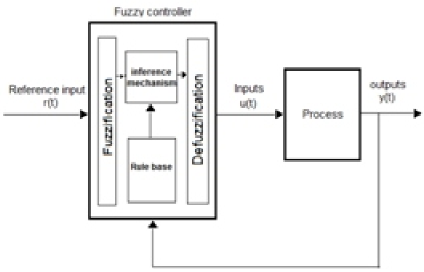

Figure.5 General Structure of Fuzzy Logic Controller

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10].

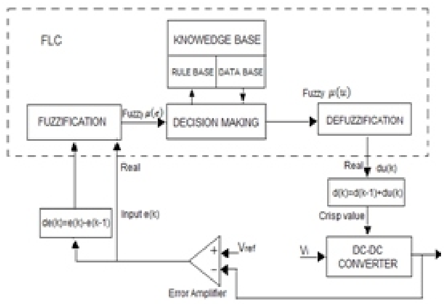

Figure.6 Block diagram of the fuzzy logic controller (FLC) for proposed converter.

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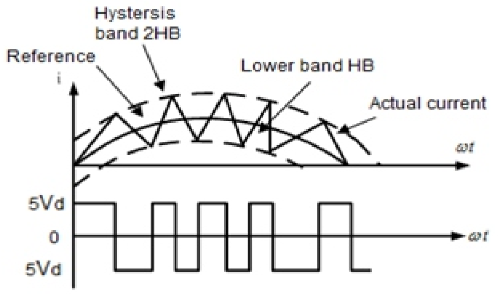

Figure.7 Hysteresis current Modulation

With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [1]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

VI.MATLAB/SIMULATIONS RESULTS:

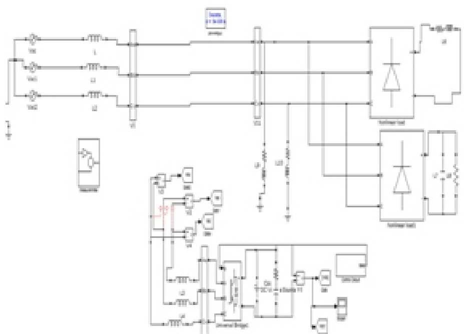

Figure.8 Matlab/Simulink Model of Shunt active power filters topology without APF.

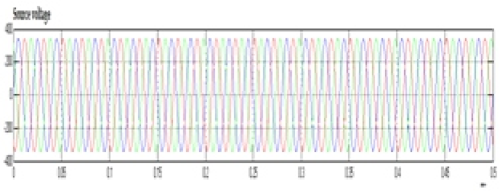

Figure.9 Source voltage without APF

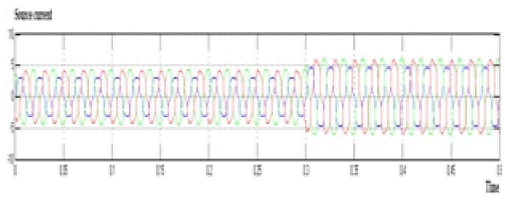

Figure.10 Source current without APF

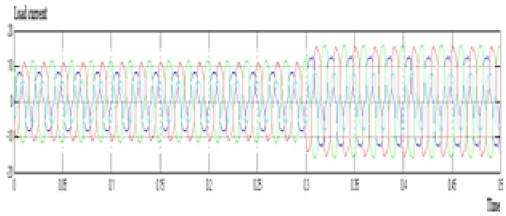

Figure.11 Load Current without APF

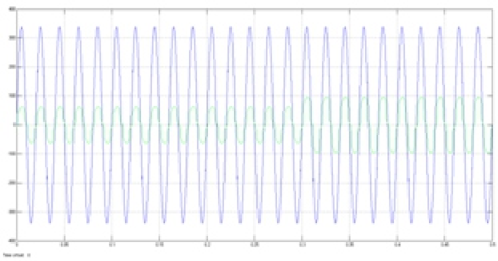

Figure12 Source Voltage and Current are without APF.

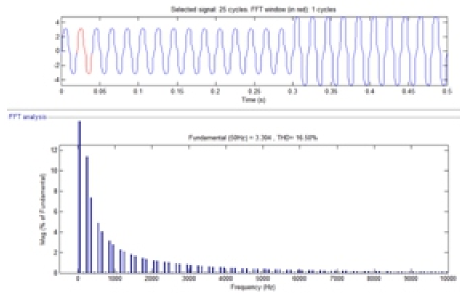

Figure.13 Source Current THD For Without APF

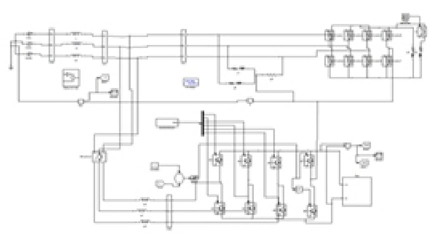

Figure.14 Matlab/Simulink Model of Shunt active power filters topology with PI controller.

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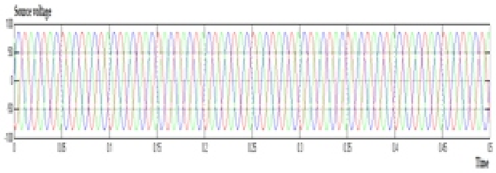

Figure.15 Source Voltage with PI Controller

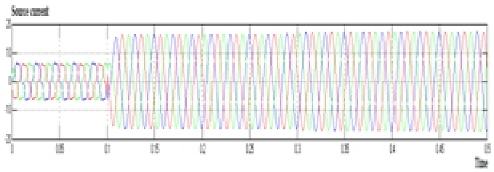

Figure.16 Source Current with PI Controller

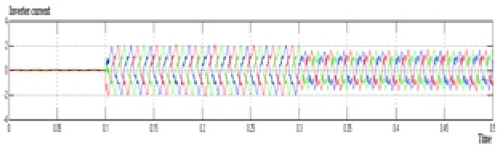

Figure.17 Inverter Current with PI Controller

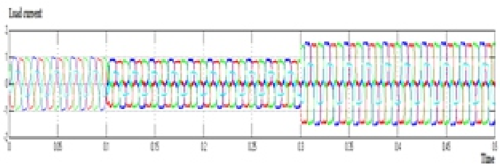

Figure.18 Load Current with PI Controller

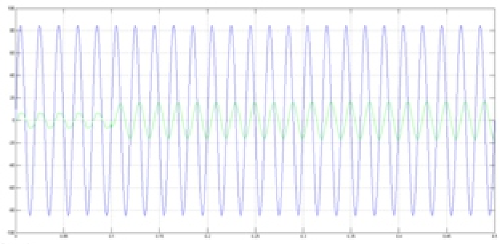

Figure.19 Source Voltage and Current are in Phase Using PI Controller.

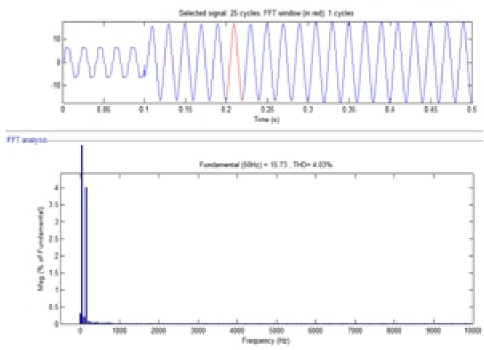

Figure.20 Source current THD for PI controller

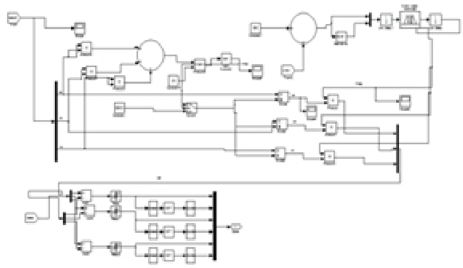

Figure.21 Simulation Design for Fuzzy Logic Control

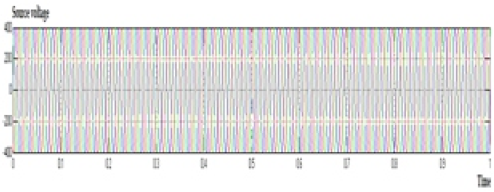

Figure.22 Source Voltage with Fuzzy Logic Controller

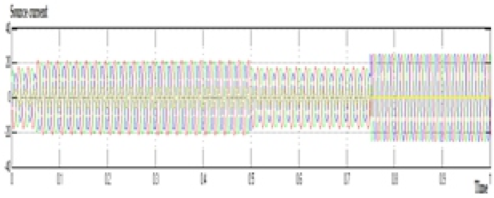

Figure.23 Source Current with Fuzzy Logic Controller

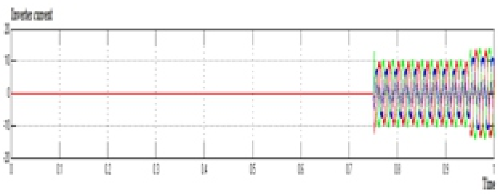

Figure.24 Inverter Current with Fuzzy Logic Controller

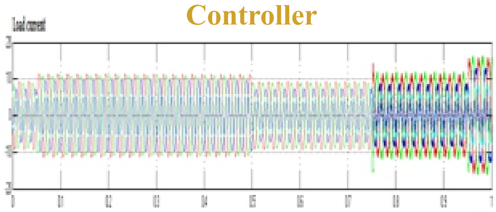

Figure.25 Load Current with Fuzzy Logic Controller

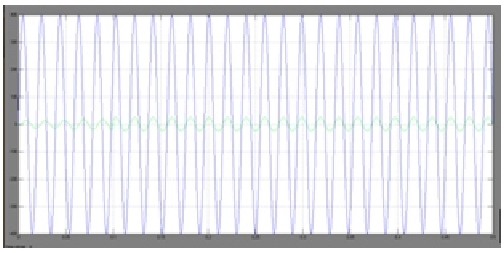

Figure.26 Source Voltage and Current are in Phase Using Fuzzy Logic Controller.

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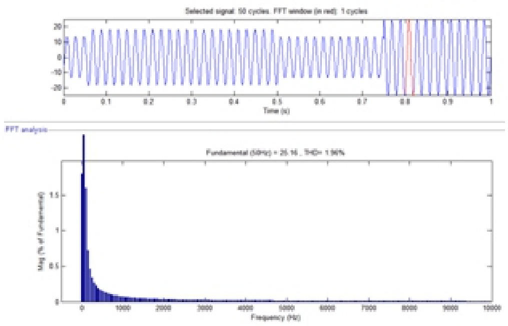

Figure.27 Source Current THD for Fuzzy Logic Controller

VII. CONCLUSION:

PI controller based shunt active power filter simulated in MATLAB are implemented for harmonic and reactive power compensation of the non-linear load at PCC. It is found from the simulation results that shunt active power filter improves power quality of the distribution system by eliminating harmonics and reactive power compensation of non-linear load. This inverter can be utilized to inject the power generated from RES to the grid and/or to operate as a shunt Active Power Filter (APF). This process eliminates the need for additional power conditioning equipment to improve of power at PCC. MATLAB/ Simulink simulation and Fuzzy logic based results have validated this process and thus this inverter can be utilized as a multifunction device.

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