ISSN 2278 – 0211 (Online)

Single Phase Shunt Active Filter Simulation Based On P-Q Technique Using PID and Fuzzy Logic Controllers for THD Reduction

A. Mrudula
M.Tech. Power Electronics, TKR College Of Engineering and Technology, Hyderabad, India

Abstract:
This paper presents a single phase shunt active power filter based on instantaneous power theory. The active filter will be connected directly to utility in order to reduce THD of load current. The instantaneous power theory also known as p-q theory is used for three phase active filter and this paper proves that the p-q theory can also be implemented for single phase active filter. Since the system has only single phase signal for both voltage and current, thus the dummy signal with 120 ° different angels must be generated for input of the p-q theory. The p-q technique will generate six signals PWM for switching IGBT, but only two of the signals will be used to control the switching IGBT. The simulation results are on MATLAB/Simulink environment tools presented in order to demonstrate the performance of the current load on single phase shunt active power filter. A simulation of single phase shunt active filter is simulated using MATLAB/Simulink. The non-linear load with 3KVA for compensation is connected before single phase diode rectifier. There are some advantages of implementing shunt active filter on grid power system since it can be installed at housing estate or others system that using single phase grid power system. The aim of this paper is to implement the p-q theory in single phase shunt active filter connected directly to gird power system. The technique is simulated by using MATLAB/Simulink simulation development tools environment using PID controller .The same technique is simulated also by using a Fuzzy Logic controller in the control circuit.

Keywords: *Shunt Active Power Filter, Total Harmonic Distortion (THD), Instantaneous Power Theory, Proportional Integral Derivative (PID) Controller, Fuzzy Logic Controller*

1. Introduction

Increasing demand on power converter or others nonlinear load will cause usage of active power filter which widely applied eliminates the total harmonic distortion of load current. By generating harmonic that came from nonlinear load, will facing a serious problem in the power system such as low power factor, increases losses, reduces the efficiency and increase the total harmonic distortion. The instantaneous power theory or p-q theory was introduced by Akagi, Kanazawa and Nabae in 1983.

The p-q theory was introduced and implemented only for three phase power system as shows in Fig. 1.

Based on the term of p and q, the p-q theory will manipulate the active and reactive power in order to maintain the purely sinusoidal current waveform at three phase power supply.

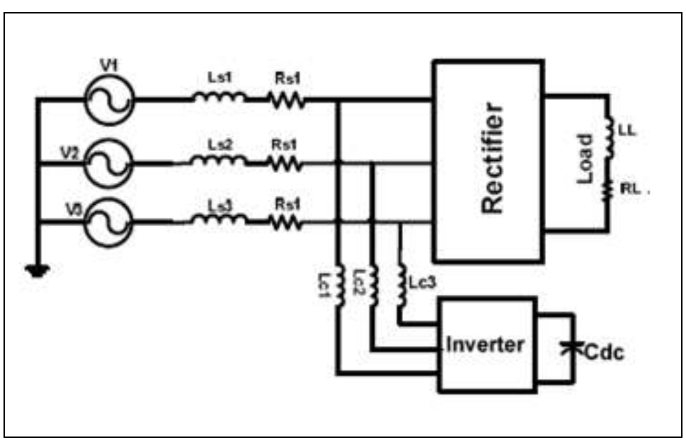

Figure 1: Three Phase Active Filter

There are a few techniques which can be used to eliminate harmonic others than active filter namely: L-C filter and Zig-Zag transformer. These techniques facing many disadvantage either the controller or the system such as fixed compensation, possible resonance, bulkiness, electromagnetic interference, voltage sag and flicker [1- 6].
There are some advantages of implementing shunt active filter on grid power system since it can be installed at housing estate or others system that using single phase grid power system. The aim of this paper is to implement the p-q theory in single phase shunt active filter connected directly to gird power system. The technique is simulated by using MATLAB/Simulink simulation development tools environment.

2. PID Controller

The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller .The PID controller is used for a wide range of problems like motor drives, automotive, flight control, instrumentation etc.PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly

A PID controller is described by the following transfer function in the continuous s-domain
Gc(s) = P + I + D = Kp+ Ki /s + Kds………….. (1)
Or Gc(s) = Kp (1 + 1/ Tis + Tds) ………………..(2)
Where Kp is the proportional gain, Ki is the integration
coefficient and Kd is the derivative coefficient. Ti is known as integral action time and Td is referred to as derivative action time. Such a controller has three different adjustments (Kp, Ti,& Td), which interact with each other.

3. Fuzzy Logic Controller

Among the various power filter controller, the most promising is the fuzzy logic control. A fuzzy controller consists of stages: fuzzification, knowledgebase, inference mechanisms and defuzzification. The knowledge bases designed in order to obtain a good dynamic response under uncertainty in process parameters and external disturbances. The input and output variables are converted into linguistic variables. We have chosen seven Fuzzy subsets, NL(Negative Large), NM(NegativeMedium),NS (Negative Small), ZE (Zero), PS(PositiveSmall), PM(Positive Medium) and PL (Positive large).
The Fuzzy Logic Controller can be constructed using the following steps:

- 1)create membership values
- 2)specify the Rule Table.
- 3)Determine the procedure for defuzzifying the result.

.

4. Mathematical Model of Shunt Active Filter

The p-q theory also known as instantaneous power theory is widely used for three wires three phase power system and also extended to four wires three phase power system. Although this theory using three current and three voltage signals, it also can be used for single phase active filter by duplicating two more current and voltage signal with 120º angel shifting. This theory based on separation power component separation in mean and oscillating values. Consider load current of single phase load as phase “a” and others phase (phase “b” and phase “c”) are generated by duplicating technique. The load current can be assumed as phase “a” current and with be expressed mathematically as shows in eq. (1).
By assuming that eq. (1) as phase “a” load current, load current for phase “b” and c can be represented as eq. (2) and eq. (3).

$$i_a = \sum_{i=0}^{n} \sqrt{2} I_i \sin(w_i + \theta_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$i_b = \sum_{i=0}^{n} \sqrt{2} I_i \sin(w_i + \theta_i - 120^\circ) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$i_c = \sum_{i=0}^{n} \sqrt{2} I_i \sin(w_i + \theta_i + 120^\circ) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Equation (1), (2) and (3) can be transformed in matrix form as shown in (4) and (5) for load current and load voltage respectively:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 \\ 1\angle 120^\circ \\ 1\angle 240^\circ \end{bmatrix} [i_a] \quad \ldots\ldots\ldots\ldots\ldots (4)$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1 \\ 1\angle 120^\circ \\ 1\angle 240^\circ \end{bmatrix} [v_a] \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Determine the α and β reference current by using Clarke transformation as shown in (6) for load current and in (7) for load voltage.
Determine the α and β reference current by using Clarke transformation as shown in (6) for load current and in (7) for load voltage.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{......... (6)}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{.......... (7)}$$

The active and reactive power is written as:

$$p = v_\alpha i_\alpha + v_\beta i_\beta + v_o i_o \quad \text{........... (8)}$$

$$q = v_\alpha i_\alpha - v_\beta i_\beta \quad \text{.......... (9)}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad \text{............. (10)}$$

Active power and reactive power consist of two part which are mean part and oscillating part also known as DC part and AC part. The equations of active power and reactive power can be given as:

$$p = p + \sim p \quad \text{............ (11)}$$

$$q = q + q\sim \quad \text{........... (12)}$$

The DC part can be calculated by using low-pass filter, which is can remove the high frequency and give the fundamental component or the DC part. From DC part active power and reactive power, the α-β reference current can be represented in (13).

$$i_{\alpha\beta} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad \text{........... (13)}$$

Where $\Delta = v_\alpha^2 + v_\beta^2$

The three phase current reference of active power filter is given in (14) before the signal will subtracted to load current. The subtracted three phase current will be used to generated PWM signal using hysteresis band. Hysteresis band will produce six PWM signals and for single phase active filter it is only two are used as input of hysteresis band.

$$i_{abc}^{*} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} i_{\alpha\beta}^{*} \quad \text{......... (14)}$$

The following figure shows the schematic implementation of active power filter with static power converter.

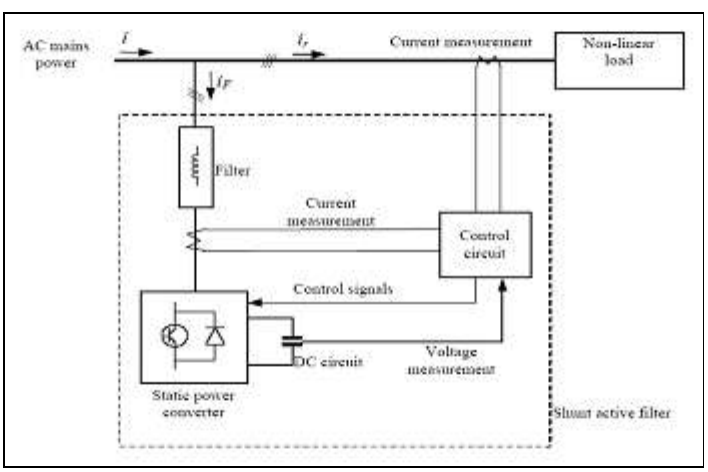

Figure 5: Schematic implementation of active power filter with static power converter

5. Single Phase Shunt Active Filter

Single phase shunt active filter consists of supply utility single phase, single phase rectifier, single phase active filter, controller and load. Schematic of single phase shunt active filter is shown in Fig. 6. They are two kinds of active power filter such as current source active filter and voltage source active filter. The different between these two topologies is the storage element. Current source active filter will use inductance as the storage element mean while voltage source active filter use capacitance as the storage element.

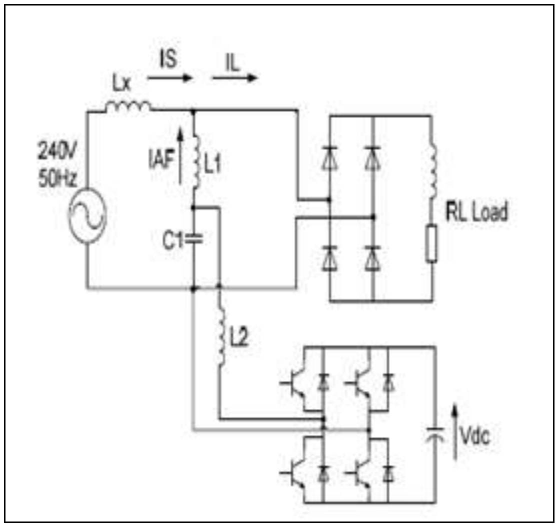

Figure 6: Schematic diagram of Single Phase Shunt Active Filter

Figure 7 shows the control strategy based on p-q theory that is used to generate PWM signal for single phase shunt active filter. The simulation of single phase shunt active filter uses this control strategy on MATLAB/ Simulink software.

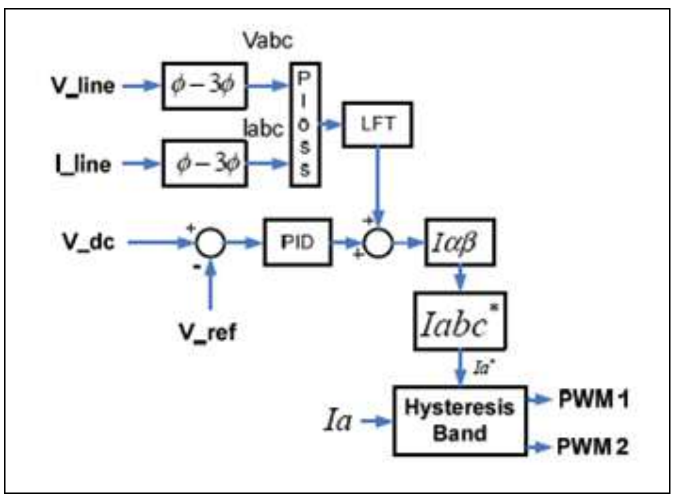

Figure 7: Control strategy

The same control strategy is implemented by replacing PID controller with Fuzzy Logic Controller.

6. Simulation Result

A simulation of single phase shunt active filter is simulated using MATLAB/Simulink. The simulation use single phase system 240V 50Hz directly from TNB as shows in Fig 8.The non-linear load with 3KVA for compensation is connected before single phase diode rectifier.

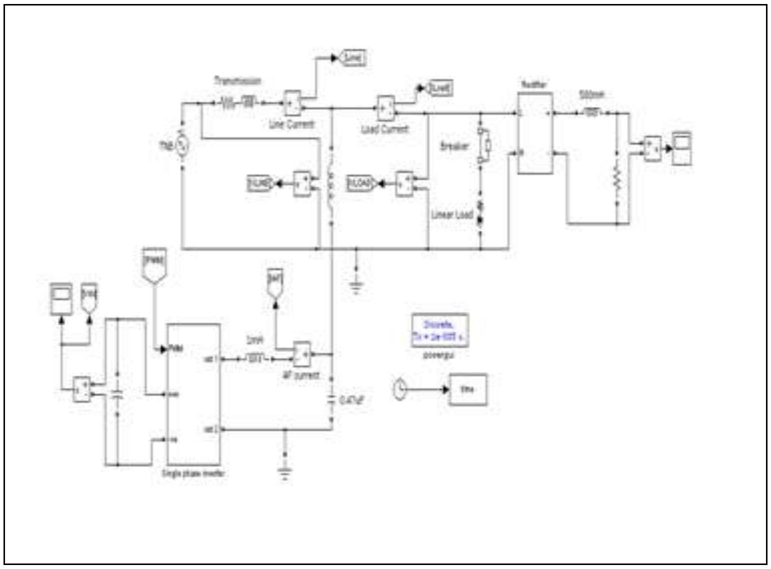

Figure 8: Modeling of Single Phase Active Filter

Fig 9.shows the modelling of p-q theory which consists of single to three phase block, algebra transformation of p-q theory three phase to two phase, two phase to three phase transformation and hysteresis band. Hsyteresis band will produce six signals PWM and for single phase active filter only use two signals to control the single phase active filter.

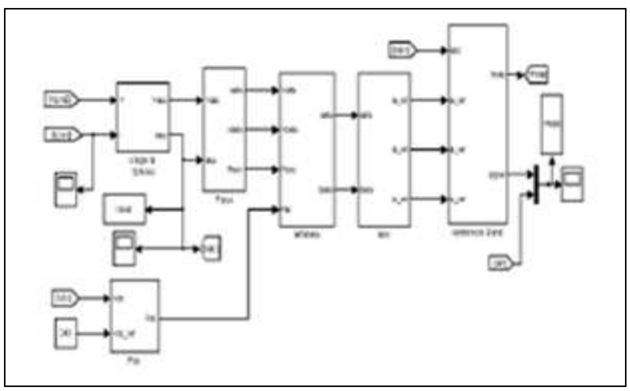

Figure 9: Modeling Of P-Q Theory

6.1. PID Controller Results

The current response for single phase active filter using PID Controller is shown in Fig 10.

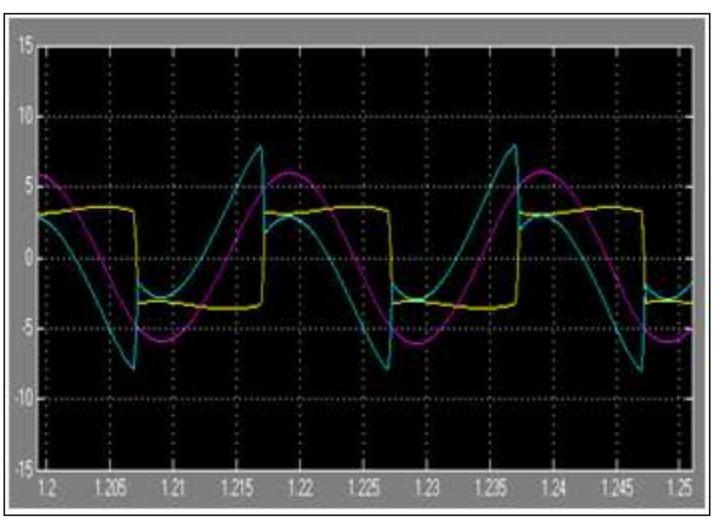

Figure 10: Current Response For Single Phase Active Filter Using PID Controller

Fig 11 shows the active filter and PWM signal using PID Controller.

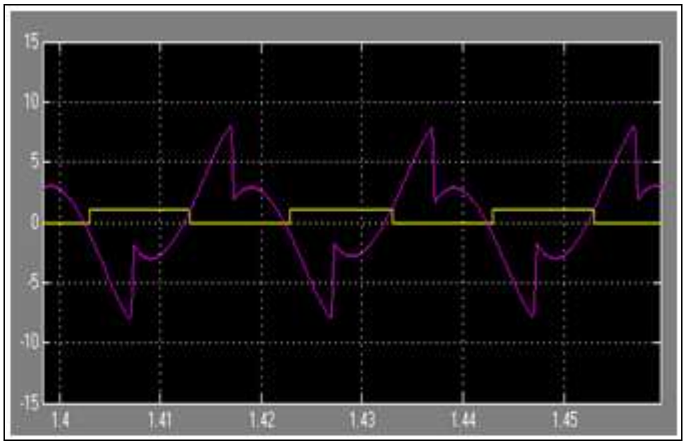

Figure 11: Active Filter and PWM Signal Using PID Controller

Fig 12 shows the THD for load current and Fig 13 shows the THD for line current using PID Controller

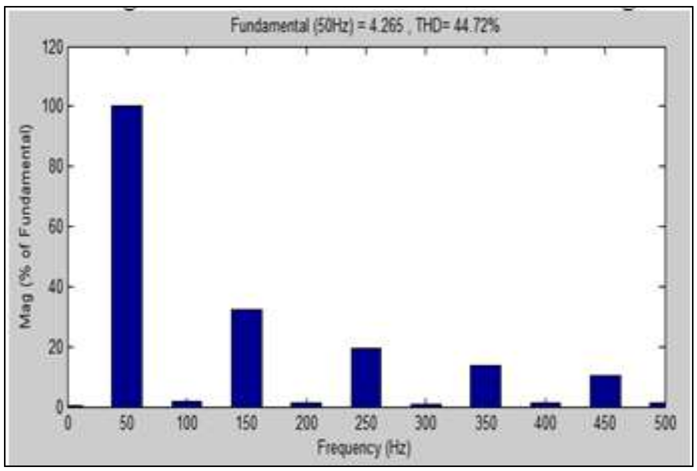

Figure 12: THD for Load Current

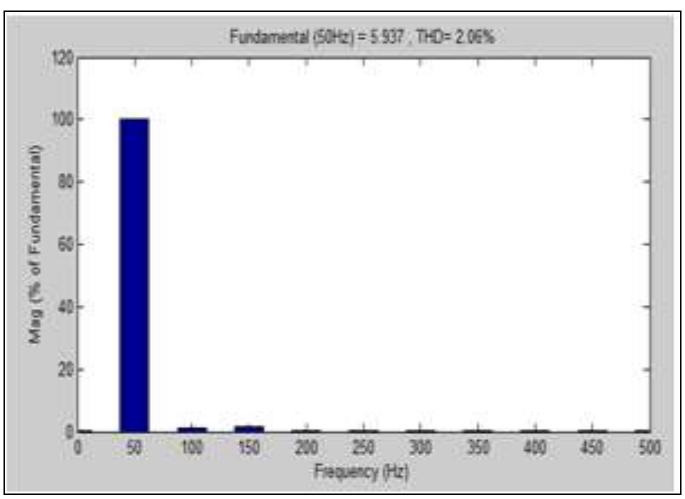

Figure 13: THD for Line Current

6.2. FIS Editor

The FIS Editor displays general information about a fuzzy inference system. Figure 14 shows the names of each input variable on the left, and those of each output variable on the right. Below the diagram is the name of the system and the type of inference used. The default, Madman-type inference, is what we'll continue to use for this example. “Centroid” method was used to defuzzify the implied fuzzy control variables.

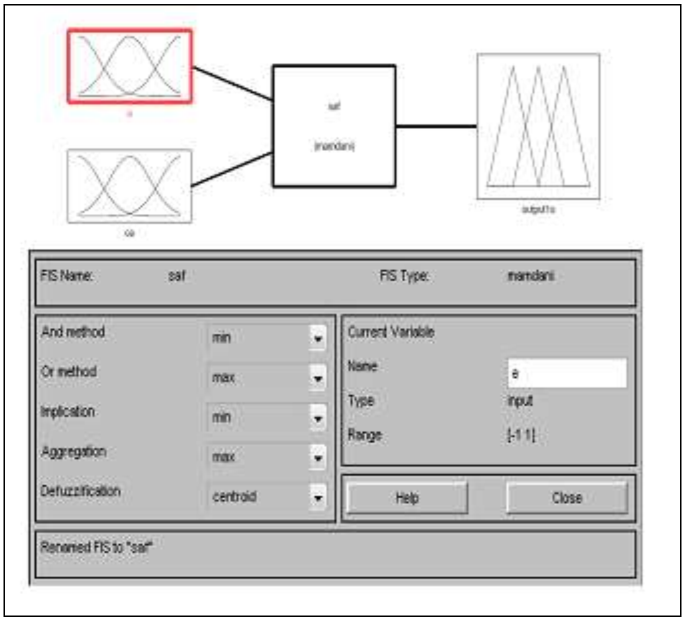

Figure 14: FIS Editor

e / ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	ZE
NM	PB	PM	PM	PS	PS	ZE	NS
NS	PM	PM	PS	PS	ZE	NS	NS
ZE	PM	PS	PS	ZE	NS	NS	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	PS	ZE	NS	NS	NM	NM	NB
PB	ZE	NS	NS	NM	NM	NB	NB

Table 1: Fuzzy Control Rule Table

In this paper, only two fuzzy membership functions are used for the two inputs error e and change in error ce. membership functions for the output parameter are shown in table. The input and output variables are converted into linguistic variables. We have chosen seven Fuzzy subsets, NB (Negative Big), NM(NegativeMedium), NS (Negative Small), ZE (Zero), PS(PositiveSmall), PM(Positive Medium) and PB (Positive Big).

6.3. Fuzzy Logic Controller Results

The current response for single phase active filter using Fuzzy Logic Controller is shown in Fig 15.

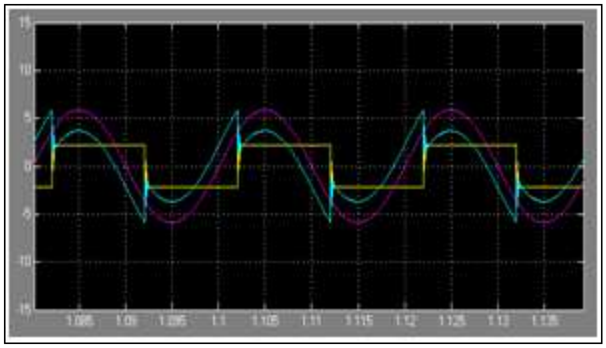

Figure 15: Current Response for Single Phase Active Filter Using Fuzzy Logic Controller

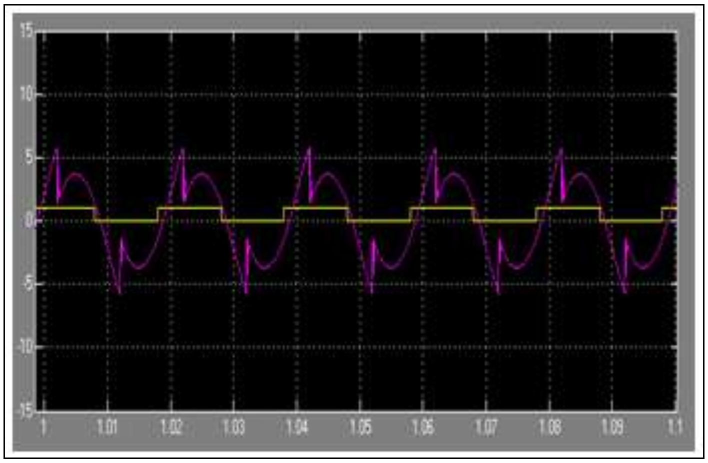

Figure 16: shows the active filter and PWM signal using Fuzzy Logic Controller

Fig 16. Active Filter and PWM Signal Using Fuzzy Logic Controller

Fig 17 shows the three phase load current, Fig 18 shows the load current, Fig 19 shows the line current and Fig 20 shows the active filter current using Fuzzy Logic Controller.

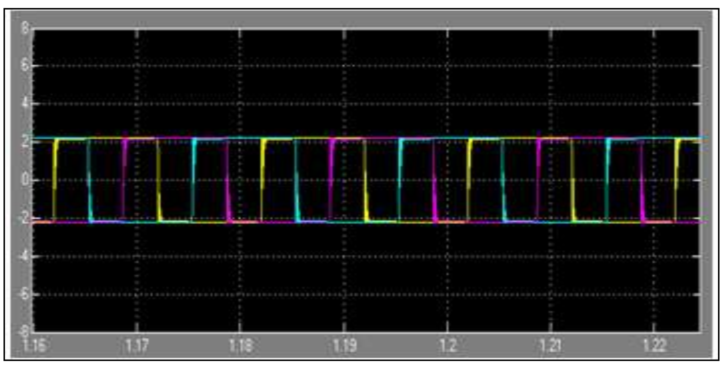

Figure 17: Three Phase Load Current

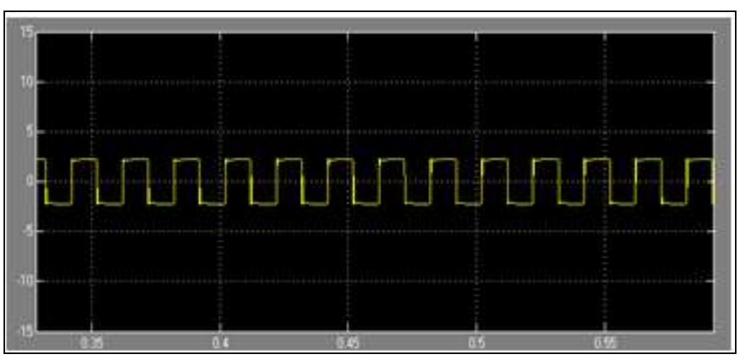

Figure 18: Load Current

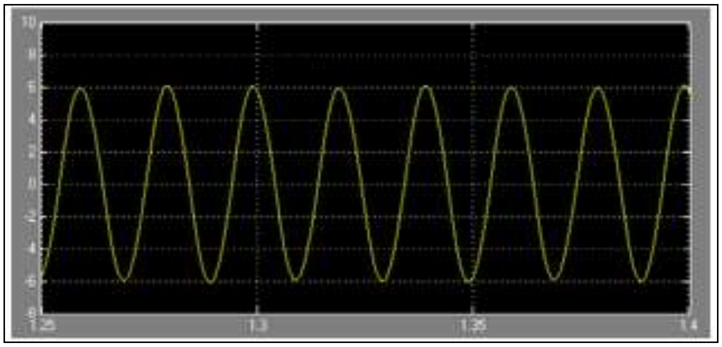

Figure 19: Line Current

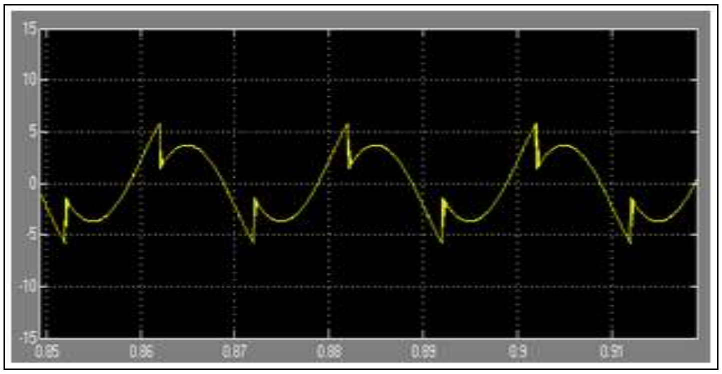

Figure 20: Active Filter Content

Fig 21 shows the THD for load current and Fig 22 shows the THD for line current using Fuzzy Logic Controller.

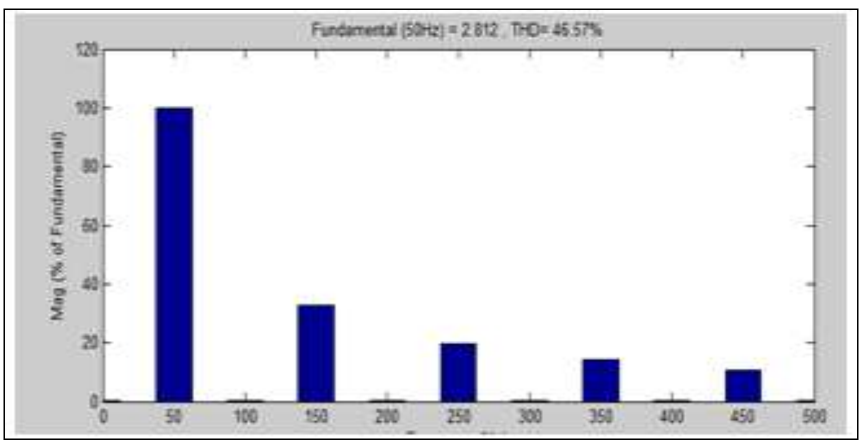

Figure 21: THD for Load Current

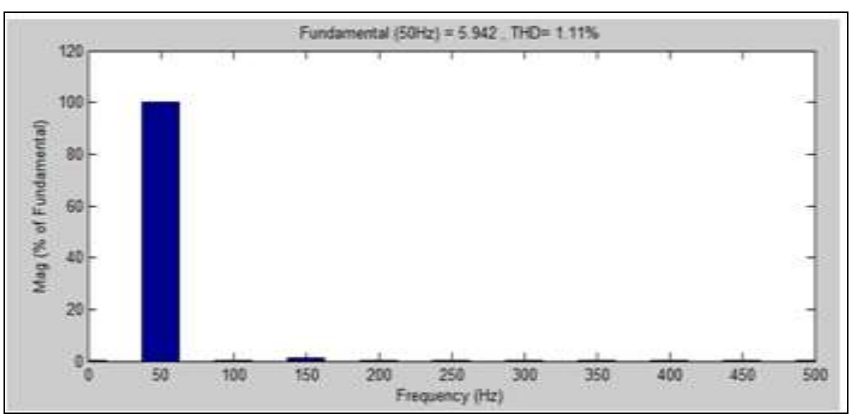

Figure 22: THD for Line Current

7. Conclusion

In recent years the increasing usages of non-linear load facing of harmonic and power factor problem in power system. Many technique or topologies can be used to eliminate harmonics from power system; one of the techniques is active power filter. This paper proves that pq theory can be implemented to control single phase active filter, which the theory widely used to control three phase active power filter. It is discovered from simulation that by implemented the p-q theory the THD of the line current using PID Controller can be reduced to 2.06%. By using Fuzzy Logic Controller the THD for line current can be reduced from 2.06% to 1.11%.

8. References

1. A. Emadi, A. Nasiri, and S. B. Bekiarov, Uninterruptible power supplies and active filters: CRC, 2005.
2. H. Akagi, E. H. Watanabe, and M. Aredes, Instantaneous power theory and applications to power conditioning: WileyIEEE Press, 2007.
3. N. A. Rahim, S. Mekhilef, and I. Zahrul, "A single-phase active power filter for harmonic compensation" Industrial Technology. IEEE International Conference, 2006, pp. 1075-1079.
4. K. Ryszard, S. Boguslaw, and K. Stanislaw, "Minimization of the source current distortion in systems with single-phase active power filters and additional passive filter designed by genetic algorithms," Power Electronics and Applications, European Conference, 2006, p. 10.
5. D. W. Hart, Introduction to power electronics: Prentice Hall PTR Upper Saddle River, NJ, USA, 1996.
6. M. McGranaghan, "Active filter design and specification for control of harmonics in industrial and commercial facilities,"Knoxville TN, USA: Electrotek Concepts, Inc., 2001.
7. S. Round, H. Laird, R. Duke, and C. Tuck, "An improved three-level shunt active filter." vol.1: Power Electronic Drives and Energy Systems for Industrial Growth International Conference, 2004, pp. 87-92.
8. H. Lev-Ari and A. M. Stankovic, "Hilbert space techniques for modeling and compensation of reactive power in energy processing systems." vol. 50: IEEE Transcactions on Circuits and System Part 1: Regular Papers, 2003, pp. 540-556.
9. A. Emadi, "Modeling of power electronic loads in ac distribution systems using the generalized state-space averaging method." vol. 51: IEEE Transactions on Industrial Electronics, 2004, pp. 992-1000.
10. J. Afonso, C. Couto, and J. S. Martins, "Active filters with control based on the pq theory," IEEE Industrial Electronics Society newsletter. ISSN 0746-1240. 47:3, 2000.
11. C. Cai, L. Wang, and G. Yin, "A three-phase active power filter based on park transformation," Nanning Computer Science & Education 2009. 4th International Conference, 2009, pp. 1221-1224.
12. M. George and K. P. Basu, "Three-Phase Shunt Active Power Filter." vol. 5: American Journal of Applied Sciences, 2008, pp. 909-916.
13. G.Jayakrishna and K.S.R.Anjaneyulu," Fuzzy Logic Control based Three Phase Shunt Active Filter for Voltage Regulation and Harmonic Reduction". Vol.10: International Journal of Computer Applications,2010.
14. Ahmed A. Helal, Nahla E. Zakzouk, and Yasser G. Desouky," Fuzzy Logic Controlled Shunt Active Power Filter for Three-phase Four-wire Systems with Balanced and Unbalanced Loads", World Academy of Science, Engineering and Technology 34 2009.
15. G. M. Sarhan ,A. A. Elkousy and A. A. Hagras and Sh. M. Saad," Adaptive Control of Shunt Active Power Filter Using Interval Type-2 Fuzzy Logic Controller", Proceedings of the 14thInternational Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 159.
16. K. Sebasthi Rani and K. Porkumaran," Performance Evaluation of PI and Fuzzy Controller Based Shunt Active Power Filter", European Journal of Scientific Research ISSN 1450-216X Vol.61 No.3 (2011), pp.381-389 © EuroJournals Publishing, Inc. 2011.