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Three- Phase Shunt Active Power Filter Based Fuzzy Logic Controller for the Reduction of Total Harmonic Distortion (THD)

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Abstract

The proliferations of power electronics equipment and devices have led to the problems of power quality on both consumers and utilities. Some of the power quality problems are, voltage sag, voltage swell, notches, DC off set, inter harmonics and harmonics. Among the power quality problem is the harmonic which produced a distorted current wave form. To overcome this problem, a classical passive power filters is required to mitigate this harmonic produced by non-linear loads. But passive power filter is very limited in service, because it produced series and parallel resonances, heavy in size, very bulky and cannot mitigate the whole harmonics. To solve this problem, shunt active power filter is now in service which is superior to passive power filter. Shunt active power filter is tested and proven to be a viable solution to mitigate current produced by non-linear load. In this article, synchronous reference frame (SRF) algorithm is used to extract the harmonic current of the shunt active power filter. Also, a traditional fuzzy logic controller is designed to control the Dc link capacitor with the help of hysteresis current controller (HCC) which used to trigger the gating signal of the IGBT switching device of the voltage source inverter (VSI). Simulation was achieved the famous MATLAB/SIMULINK environment. Simulation results of the total harmonic distortion (THD %) of load and source currents of 25.17% and 0.83% were obtained

without and with shunt active power filter respectively. The simulation results obtained are within the imposed harmonic standard limit set by IEEE 519-2024.

Keywords: Fuzzy Logic, Synchronous Reference Frame, THD, Shunt Active Power Filter & IEEE 519-2014

Introduction

There is growing concern over power quality of ac supply systems. Various power quality problems can be classified as voltage dips and swells, transients, harmonics, distorted waveforms of voltage or of current, flicker, voltage imbalance, frequency deviation, transient interruptions, and outages [1], [2]. These problems may be due to external disturbances such as the phenomena of switching and of atmospheric nature, which cannot be predicted, or to internal problems in existing systems at sites, which result from heavy use of nonlinear loads. Rapid growth in power electronic technologies and applications, through development of various electrical and electronic products, contributes to increased operation of nonlinear loads.

Harmonics can cause interference as well as undesired power losses within sensitive electrical equipment [3]. These harmonics cause an array problem such as equipment overheating, machine vibration, motor failures, capacitor fuses blown, inaccurate power metering etc. It is necessary to compensate them to obtain clean power and to avoid unwanted losses. A power harmonic filter is introduced to reduce harmonic levels or distortion and to increase power factor performance. This mitigation tool is of two types: passive and active [4]. The passive power filter, considered the simplest and the most economical of harmonic mitigation tools [5], which consists of passive energy-storage elements (inductors and capacitors) built and arranged to provide a low-impedance path to ground so selected harmonic components are suppressed. It can correct only specific load conditions or a particular state of power system operation; it cannot work directly with changing or dynamic load conditions usually installed at distribution level.

A more powerful harmonic mitigation tool is needed, that is able to respond dynamic changes in load conditions. The tool is active power filter (APF), which is developed from advances of power electronics technology, is capable to filter harmonic distortion at various levels. This modern APF is superior in its filtering performance, smaller, and more flexible in application, than traditional passive harmonic filters [6].

The APF is a device that injects equal but
opposite distortion into the ac power line,
thereby canceling the original power
system harmonics and simultaneously improving power quality in the connected power system. APFs can be referred to as active power line conditioners, active power quality conditioners, and self-commutated static Var compensators (SVCs). Their applications are not only for harmonic filtering, but could also be considered for harmonic damping, harmonic isolation, harmonic termination, reactive power control for power factor correction and for voltage regulation, load balancing, voltage flicker reduction, or any combinations of them.

The APF can be connected in shunt configuration [7]. This configuration specifically cancels load current harmonics fed to the supply. It can also contribute to reactive power compensation and the balancing of three-phase currents. Most of previous research reports relate to inverter-based configurations [8], [9], that usually use large dc-link capacitors which increases cost, and high switching frequency, which increases system losses.

In this Paper, simulation of three-phase shunt active power filter to minimize the total harmonic distortion (THD) using synchronous reference frame (SRF) algorithm is explored. Simulation is achieved using MATLAB software.

Principle Compensation of Shunt Active Power Filter

The general block diagram of the designed active filter system is shown in the Figure 1.1. The three phase shunt active harmonic compensator works like other conventional active harmonic filter. It introduces the harmonic current into the main current to cancel the harmonic created by the nonlinear load. The general idea of three phase shunt active power filter system can be simplified in equations (1.1) to (1.3) [10], [11], [12].

$$i_L = i_f + i_h \quad (1.1)$$

$$i_f = -i_h \quad (1.2)$$

$$i_L = I_s + i_f \quad (1.3)$$

Where i_s is the source current i_f is filter current and i_h is the harmonic current. .

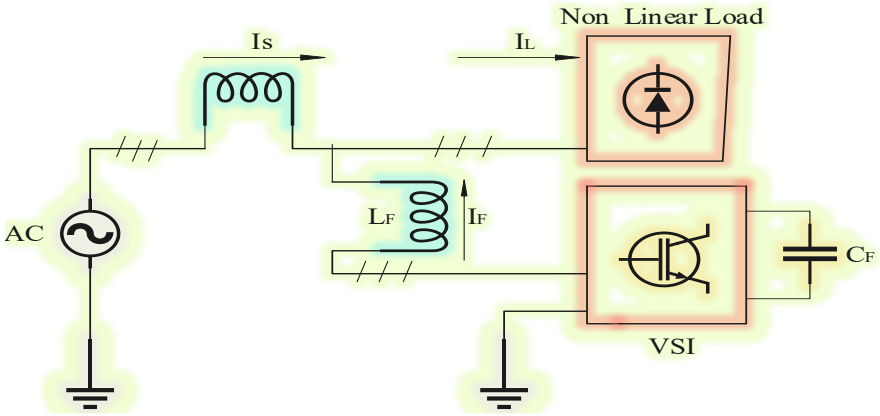


Figure 1.1 Configuration of three-phase shunt Active Power filter [13]

Structure of Fuzzy Logic Controller

The idea of fuzzy logic controller was brought by Zadeh Lotfi of University California in 1965.

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 [14]. 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 [15]. Figure 1.2 shows the structure of fuzzy logic controller.

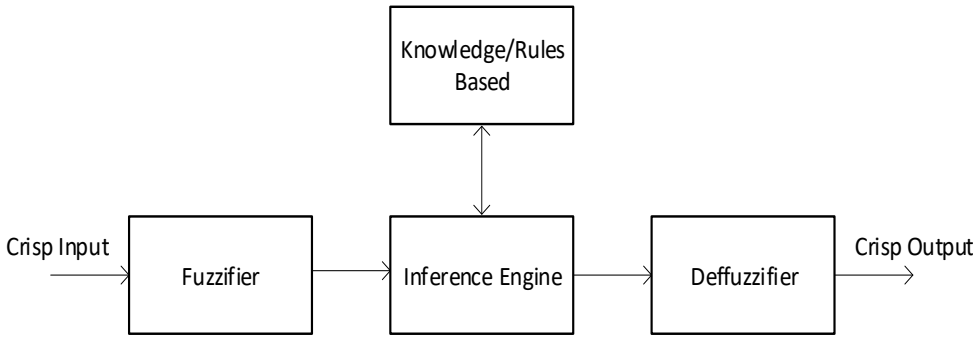


Figure 1.2 Structure of Fuzzy Logic Controller [16]

As seen from Figure 1.2, the input to the fuzzy logic controller is the ordinary crisp values that entered the fuzzifier block. The output of the fuzzifier block is now converted from the ordinary crisp values into the fuzzy sets. The fuzzy sets then

received by inference mechanism which defines the linguistic rules by the fuzzy sets. The output of the defuzzifier then converted the fuzzified values into the crisp output [17].

Fuzzy Logic Controller Design

In the design of the fuzzy logic controller, the following parameters where used:

- Two inputs error and change of error are used.
- One single output was selected.
- Three triangular membership functions where used for both two inputs error and change of error, while five triangular membership functions are used for the single output.
- Mamdani Fuzzy Inference System (FIS) where deployed, because of its simplicity in implementation and does not required any mathematical model.
- The method of centre of area (COA) or simply called centre of gravity (COG) was also employed in the defuzzification process.

Table 1.1 shows the rules designed of the proposed fuzzy logic controller [18].

E	CE	N	Z	P
N		N	LN	Z
Z		LN	Z	LP
P		Z	LP	P

Table 1.1 shows the two inputs error and change of error (E) and (CE). Nine rules are used in the design as seen in the table.

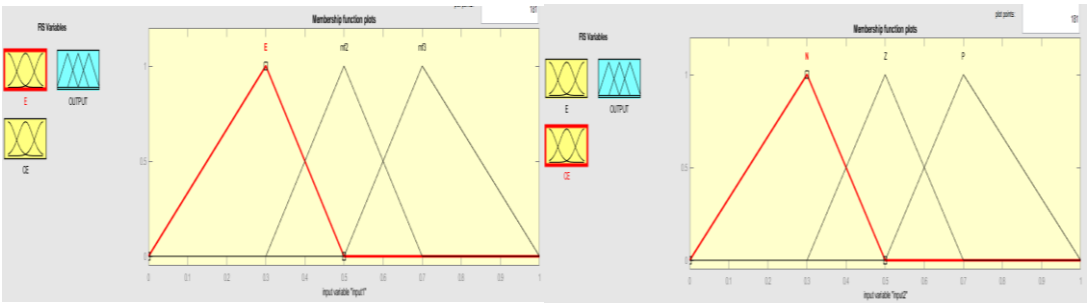


Figure 1.3 Two inputs error and change of error respectively

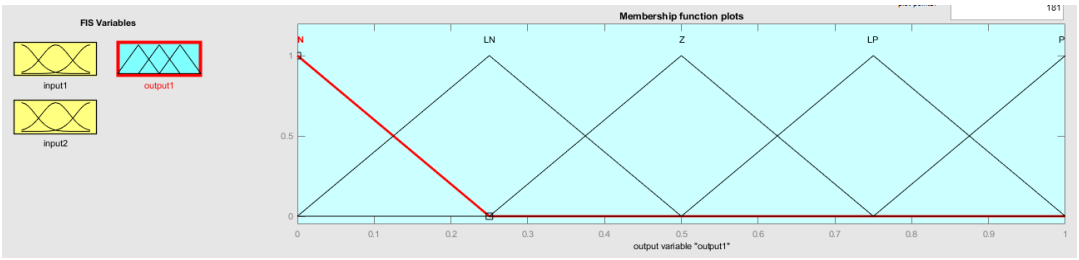


Figure 1.4 Single output

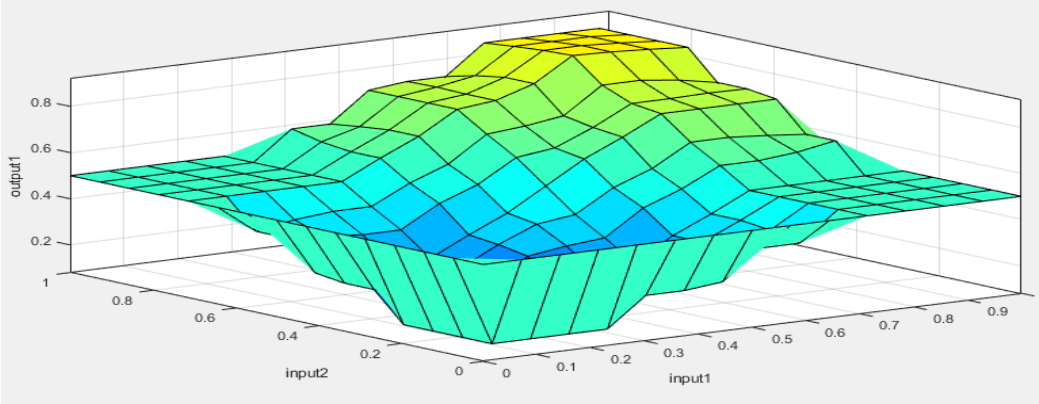


Figure 1.5 3D of the two inputs error and change of error

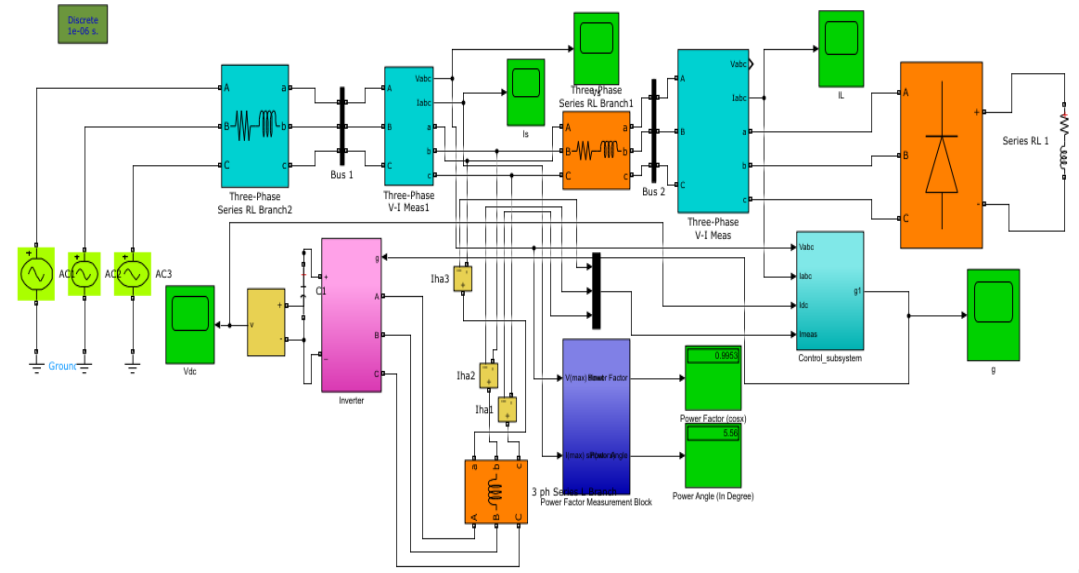
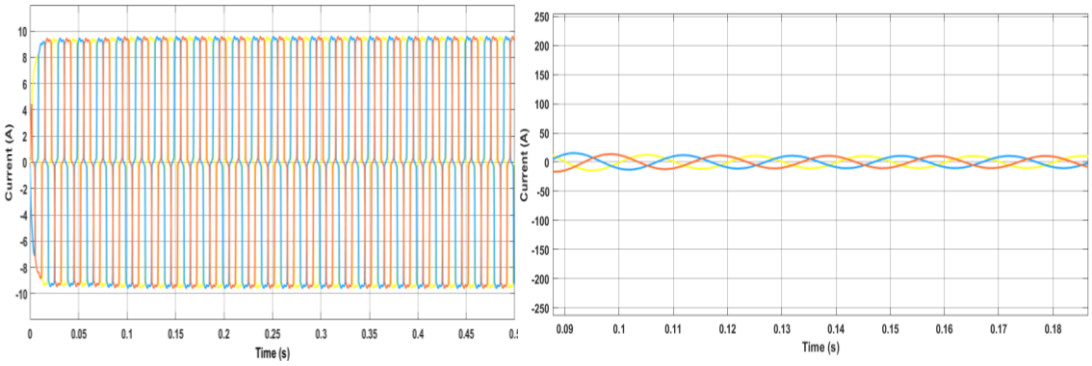


Figure1.6 Complete Simulation Model of the three- phase Shunt Active Power Filter.

Figure 1.6 shows the complete Simulink model of the three-phase shunt active power filter. The model, consist of three-phase source of supply fed to the three-phase current and voltage measurement block in order to measure the line source current and voltage respectively. Also the system modeling extended to the three-phase diode bridge rectifier which is connected to RL load. The diode bridge rectifier is the main source of the current harmonics in the system. However, the simulation model, have help in improving the reactive power as while as the power factor which was also improved to near unity.

Results and Discussions

As seen in Figure 1.7(a), this is the load current without shunt active power filter. The waveform looks so distorted due to the effect of nonlinear loads. It shows the current of about 9A. Figure 1.7 (b) is the source current after compensation with shunt active power filter. The result shows the source current which is purely sinusoidal in nature. However, the source current and source voltage are now in phase to each other. Meanwhile, Figure 1.8 depicts the source voltage which is entirely pure sinusoidal and also in the same phase with the source current. Figure 1.9, shows the DC link voltage of the shunt active power filter. The Dc link voltage is purposely there to maintain the filter voltage constant, in case the AC main supply voltage is absent. Figure 1.10 shows the Fast Fourier Transform (FFT) analysis of the load current before compensation with shunt active power filter. The result shows a (THD %) of 25.17% which does not met up with the IEEE 519-2014 harmonics norms. In Figure 1.11, the Fast Fourier Transform of the source current after compensation with shunt active power filter was determined. The result shows a reduction of about 0.83% (THD %), which implies a reduction of the harmonic content due to nonlinear load. The results signified that, it's complied with IEEE 519-2014 harmonics norms.



(a) (b)

Figure 1.7 (a) Load Current before compensation with Filter (b) Source Current after compensation with Filter.

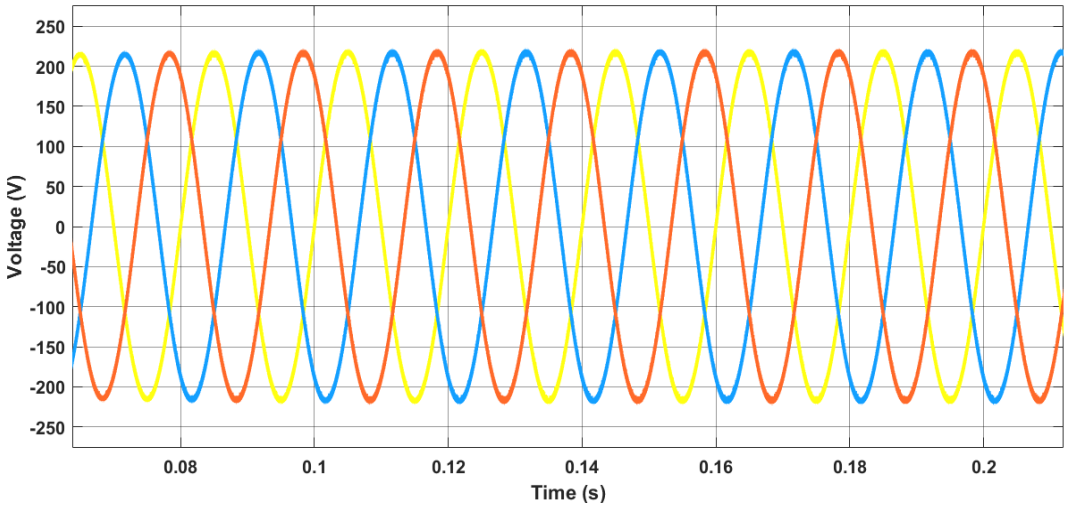


Figure 1.8 Source Voltage

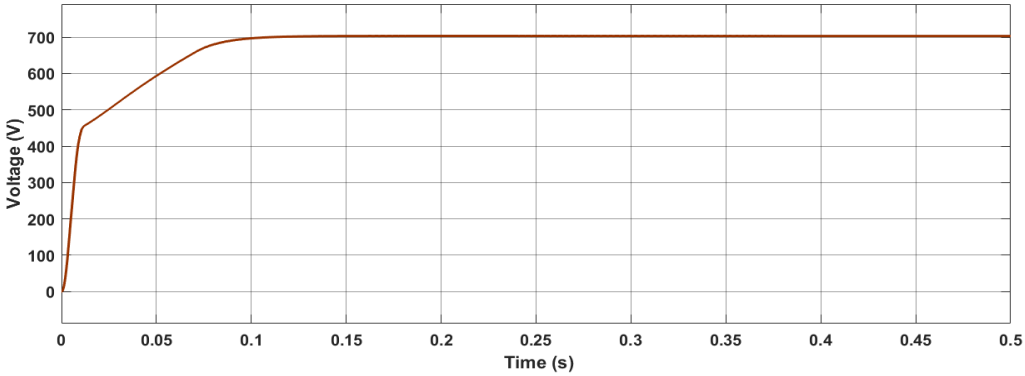


Figure 1.9 DC Link Voltage of the Filter

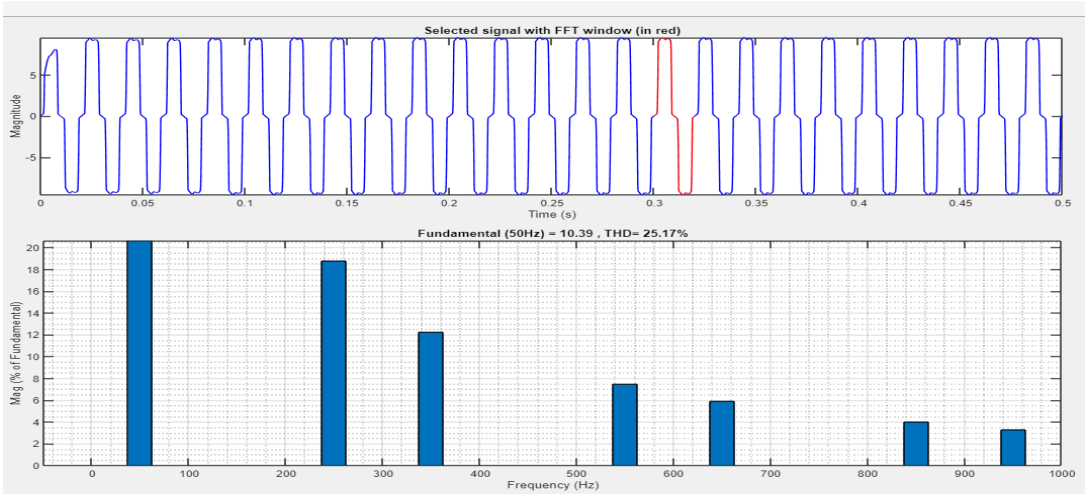


Figure 1.10 Fast Fourier Transform of the Load Current before compensation with filter.

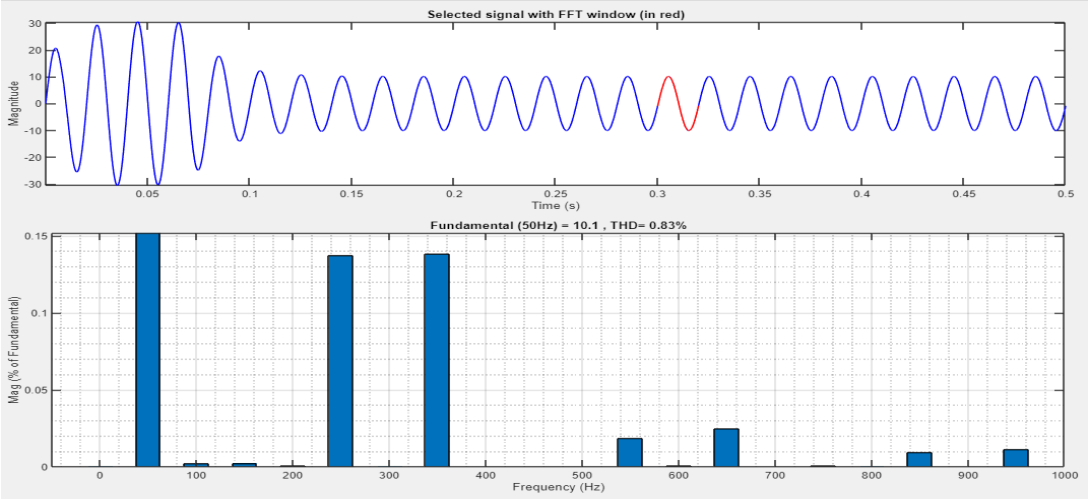


Figure 1.11 Fast Fourier Transform of the Source Current after Compensation with filter

Conclusion

Modeling and simulation of three phase shunt active power filter using synchronous reference frame algorithm for minimization of total harmonic distortion (THD) was presented. Hysteresis current controller was deployed for controlling the gating signal of the voltage source inverter (VSI). Fuzzy logic controller was used to control the DC link capacitor constant.The result of the THD% of 25.17% was obtained for the load current before compensation with shunt active power filter. However, the THD% of 0.83% was found for the source current, this means that the result of the source current is within the imposed IEEE 519-2014 harmonic standard limit. Finally, the effectiveness of the controlled algorithm has shown it capability in mitigating current harmonics due to non linear loads.

Recommendations

In this article, the design and modeling of three-phase shunt active power filter using Fuzzy Logic Controller using MATLAB SIMULINK environment was accomplished. Various simulation results where explored. It is recommended by the authors that:

- The same design and modeling be carryout with other artificial intelligence controllers.
- Proto-type, laboratory set-up be carryout in order to validate the simulation results, so as to see the performance and robustness of the control algorithm.

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