International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

# Performance of Fuzzy Based Shunt Active Power Filter Using Indirect Current Control Technique

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**Abstract:** ***Active filters are widely employed in distribution system to reduce the harmonics produced by non-linear loads. These results in voltage distortion and leads to various power quality problems. Shunt Active Power Filters are the best solution for the elimination of harmonics occurred in the power system. This paper presents the optimization of shunt active power filter parameters based on fuzzy logic control, which is employed to drive the switching signals and also to choose the optimal value of the coupling inductance. The fuzzy control is based on a linguistic description and does not require a mathematical model of the system. It can adapt its gain according to the changes in load. The indirect current control method is used for calculating the compensating currents. A fuzzy logic-based controller is developed to control the voltage of the DC side Capacitor. The conventional hysteresis controller gives very fast response and good accuracy, but it causes uneven switching. This work presents and compares the performance of the fuzzy-controller with a conventional controller under constant load. The harmonic distortions are analysed and compared. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, have been analysed. The proposed systems are implemented with Matlab/Simulink***

**Keywords:** Shunt Active power filters (SAPF), Fuzzy, hysteresis, coupled inductor,Total Harmonic Distortion(THD)

## 1. Introduction

In recent years power quality distortion has become very serious problem in electrical power system due to the wide increase of nonlinear loads such as power electronic devices. Pollution has been introduced into power systems by nonlinear loads such as transformers etc. however; perturbation rate has never reached the present levels. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of power electronic devices. Approximately 10% to 20% of today's energy is processed by power electronic devices; mainly due to the fast growth of power electronic devices capability. A race is currently taking place between increasing power electronics pollution and sensitivity, on the one hand, and the new power electronics based corrective devices, which have the ability to attenuate the issues created by power electronic devices, on the other hand.

Increase in 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 non-linearity may become serious problem over the next few years. Hence it is very important to overcome these undesirable features. Classically, shunt passive filters, consisting of tuned LC filters or high passive filters are used to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions.

Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components.

Various topologies of active power filters have been developed so far. The shunt active power filter has been proved to be effective even when the load is highly non-linear. To extract the fundamental component of source current indirect current controller technique is used because of its easy mathematical calculations. A conventional PI controller was used for the generation of a reference current template. The PI controller requires precise linear mathematical models, which are difficult to obtain and fails to perform satisfactorily under parameter variations, nonlinearity, etc. Recently, fuzzy logic controllers (FLCs) are used in most of the applications. The advantages fuzzy logic controllers over conventional controllers are that they do not require an accurate mathematical model and can work with imprecise inputs and also having the ability of handling non-linearity. In this paper both PI and fuzzy logic controlled shunt active power filter are implemented. The three-phase currents/voltages are detected using only two current/voltage sensors. The DC capacitor voltage is regulated to estimate the reference current template. The role of the DC capacitor is described to estimate the reference currents. A design criterion is described for the selection of power circuit components. Both the control schemes are compared and performance of both the controllers is investigated.

## 2. Proposed Topology

### 2.1 Shunt Active Power Filters (SAPF)

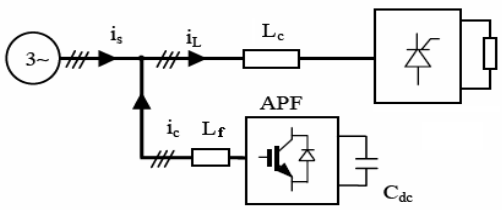


**Figure 1:** block diagram of SAPF


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Shunt active filters are the most widely accepted and dominant filter of choice in most industrial processes. The above fig.1 shows system configuration of the shunt design. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic currents to the nonlinear load effectively resulting in pure fundamental supply currents. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel at the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents.

The APF consists of a DC-bus capacitor, power electronic devices and coupling inductors ($L_f$ ). Shunt APF acts as a current source for compensating the harmonic currents due to nonlinear loads. This is achieved by "shaping" the compensation current waveform ($i_f$), using the Current Controlled-VSI. The required compensating currents are obtained by measuring the load current ($i_L$) and subtracting it from a sinusoidal reference. The aim of shunt APF is to obtain a sinusoidal source current ($i_s$) using the relationship: $\boldsymbol{is = i_L - i_f}$.

If the nonlinear load current can be written as the sum of the fundamental current component ($i_{L,\ f}$) and the current harmonics ($i_{L,\ h}$) are given as

$$I_L = i_{L,f} + i_{L,h} \quad \text{……..(1)}$$

then the compensation current injected by the shunt APF should be

$$i_f = i_{L,h} \quad \text{……(2)}$$

the resulting source current is

$$i_s = i_L - i_f = i_{L,h} \quad \text{…… (3)}$$

From the above equation (3) the source current contains only the fundamental component of the nonlinear load current and thus free from harmonics. In this way the shunt APF completely cancels the current harmonics from the nonlinear load, thus results in a harmonic free source current.

The shunt APF can be considered as a varying shunt impedance from the nonlinear load current point of view. The current carried by the Shunt APFs is the sum of the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Reactive power compensation is also possible through the Shunt APF. Moreover for higher power rating applications, it is also possible to connect several shunt APFs in parallel to meet the requirement for higher currents.

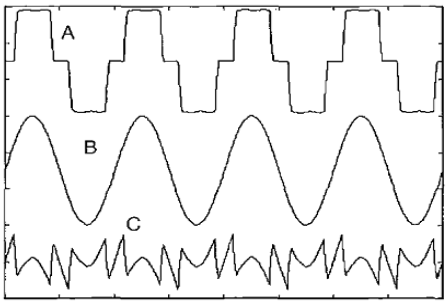


**Figure 2:** Wave forms of A) load current B) supply voltage C) compensating currents

## 2.2 Control Strategy

### A) Indirect Control Technique:

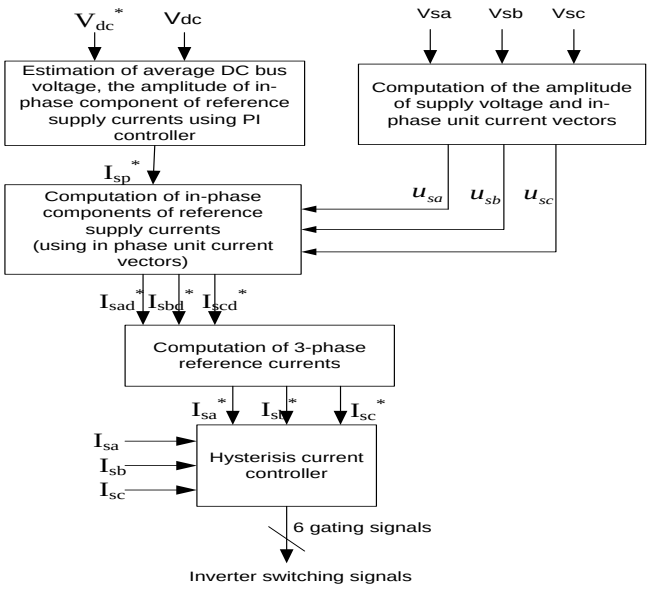


**Figure 2:** Control scheme for indirect current control technique

Above figure: 3 show the basic control scheme of the APF using indirect current control technique. Three-phase voltages at Point of Common Coupling (PCC) along with dc bus voltage of the active filter are used for implementation of control scheme. In real time implementation of the active filter, a band pass filter plays an important role. The three-phase voltages ($v_{la}, v_{lb}, v_{lc}$) are sensed at Point of Common Coupling (PCC) using potential transformers and conditioned in a band pass filter to filter out any distortion. The three-phase voltages ($v_{la}, v_{lb}, v_{lc}$) are inputs and three-phase filtered voltages ($v_{sa}, v_{sb}, v_{sc}$) are outputs from band pass filter.

In controlling of the Active Filter, the self-supporting dc bus is realized using a PI controller over the sensed ($v_{dc}$) and reference ($v_{dc}^*$) values of dc bus voltage of the AF. The PI controller on the dc bus voltage of the AF provides the amplitude ($I_{sp}^*$) of in-phase components ($i_{sa}^*$, $i_{sb}^*$ and $i_{sc}^*$) of reference supply currents. The three-phase unit current vectors ($u_{sa}, u_{sb}$, and $u_{sc}$) are derived in-phase with the supply voltages ($v_{sa}, v_{sb}$ ,and $v_{sc}$). The multiplication of in-phase amplitude with in-phase unit current vectors results in the in-phase components of three-phase reference supply currents ($i_{sa}^*, i_{sb}^*$ and $i_{sc}^*$). Hence, for fundamental unity power factor supply currents, the in-phase reference supply currents, which are calculated in above described procedure becomes the reference supply currents.

In brief, with three-phase supply voltages ($v_{sa}, v_{sb}$ , and $v_{sc}$) and dc bus voltage ($v_{dc}$) as feedback signals, the control


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algorithm of the AF provides the three-phase reference supply currents ( $i_{sa}^*$ , $i_{sb}^*$ and $i_{sc}^*$ ) as output signals.

A Hysteresis current controller compares reference supply currents ( $i_{sa}^*$ , $i_{sb}^*$ and $i_{sc}^*$ ) and sensed supply currents ( $i_{sa}$ , $i_{sb}$ , and $i_{sc}$ ) to generate gating signals to the IGBT's used in the VSI .

**B) Calculation Of Reference Currents:**

Three-phase in-phase components of the reference supply currents are computed using their amplitude and in-phase unit current vectors derived in-phase with the supply voltages, and are given by:

$$i_{sa}^* = I_{sp}^* . u_{sa}$$
$$i_{sb}^* = I_{sp}^* . u_{sb}$$
$$i_{sc}^* = I_{sp}^* . u_{sc}$$

Where $u_{sa}, u_{sb}$ and $u_{sc}$ are in-phase unit vectors and are derived as,

$$u_{sa} = v_{sa}/V_{sp}$$
$$u_{sb} = v_{sb}/V_{sp}$$
$$u_{sc} = v_{sc}/V_{sp}$$

Where $V_{sp}$ is the amplitude of supply voltage and it is computed as:

$$V_{sp} = \{2/3(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)\}^{1/2}$$

Hence from the above procedure, the three phase reference supply currents are computed.

**C) Hysteresis Current Controller**

Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform. This method controls the switches in the active power filter asynchronously to ramp the current through an inductor up and down so that it follows a reference. Hysteresis current control is the easiest control method to implement. However, the disadvantage is that there is no limit to the switching frequency. Additional circuitry on the other hand can be used to limit the maximum switching frequency.

The principle of the hysteresis control method for an active power filter is implemented by pre-setting the upper and lower tolerance limits which need to be compared to the extraction error signal. The maximum error is the difference between the upper and lower limit, and this hysteresis tolerance bandwidth is mostly equal to two times of the error. If the error signal is within the tolerance band, there will be no switching action for the filter. However, when the error leaves the tolerance band, switching pulses will be generated and the active power filter will produce signals to be injected back into the supply line.

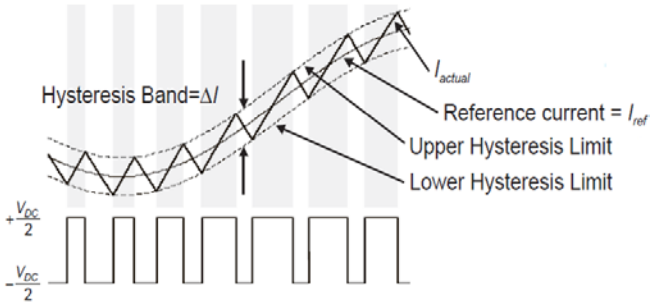


**Figure 4:** Hysteresis Current Control Operation waveform

**D) PI Controller**

The amplitude of reference supply currents is computed using a PI controller over the average value of dc bus voltage $(v_{dc})$ of the active filter and its reference value $(v_{dc}^*)$. Comparison of average and reference values of dc bus voltage of the active filter results in a voltage error, which is fed to a PI controller as shown in below figure.

$$v_{dc\ error} = v_{dc}^* - v_{dc}$$

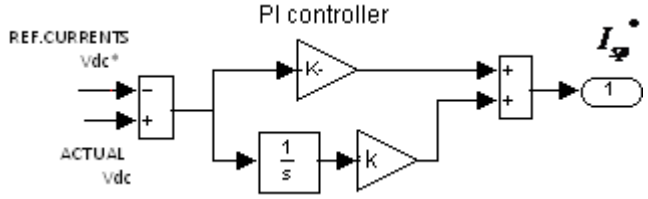


**Figure 5:** PI Controller

**E) Implementation Of Hysteresis Based Current Controller In Matlab:**

The switching of upper and lower switches of the inverter leg takes place when carrier signals crosses the error signal "iref" and actual signal "iact". A comparison of carrier signals with the error signal of iref and iact realizes the PWM switching. It can be described as below:

1) if (iact) > (iref+hb) upper switch of a leg is ON and lower switch is OFF.
2) if (iact) < (iref-hb) upper switch of a leg is OFF and lower switch is ON.

The generated switching pulses from the hysteresis current controller are given to the VSI. The model of hysteresis controller, which is implemented in MATLAB, is shown in below Fig.

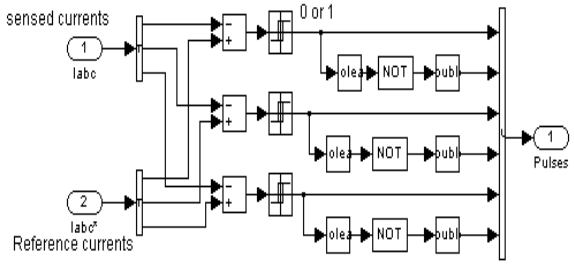


**Figure 6:** Implementation of hysteresis controller in MATLAB


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**F) Fuzzy Logic Controller**

Now-a-days, fuzzy logic controllers (FLCs) are used in most of the applications, the advantage of fuzzy systems is that they do not require an accurate mathematical model; which can work with imprecise inputs and also has an ability to handle non-linearity. Fuzzy logic controller is a multilevel logic scheme in which each variable have associated membership function, triangular membership function has been used due to its simplicity, easy implementation and symmetry along the axis. Triangular membership functions used as the input and output variables.

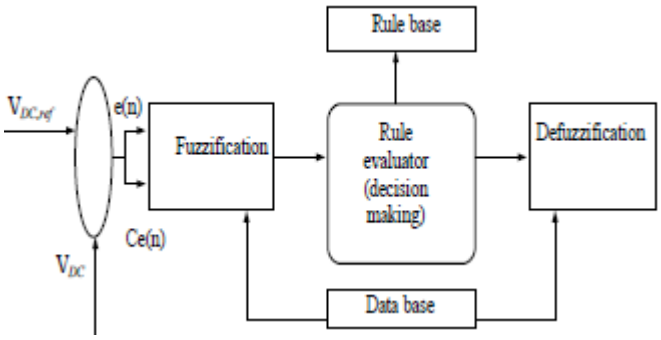


**Figure 7:** Control scheme for fuzzy logic

Capacitor voltage is compared with the reference voltage and the voltage error e(n) and the integration of the error i.e. change in error e(n-1) are the input to the fuzzy logic.

*(i).Fuzzification:*

Fuzzification is used to convert of the crisp variables to linguistic variables. Assign the values to the membership function each represents the degree of the corresponding values on the Y axis. There are many types of membership functions. By comparing best one that is triangular membership function is used. Mandeni type function is used.

*ii) Rule base*:

Based on the rules table error and change error output reference current will be generated.

**Table1:** Rules for FLC

| Ce(n) / e(n) | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | ZE |
| NM | NB | NB | NB | NM | NS | ZE | PS |
| NS | NB | NB | MN | NS | ZE | PS | PM |
| ZE | NB | NM | MS | ZE | PS | PM | PB |
| PS | NM | MS | ZE | PS | PM | PB | PB |
| PM | NS | ZE | PS | PM | PB | PB | PB |
| PB | ZE | PS | PM | PB | PB | PB | PB |

*iii) Defuzzification*:

Conversion of linguistic variables to crisp variables is known as defuzzification.lot of methods is available for this. This paper is focused on centre of area method (COA).

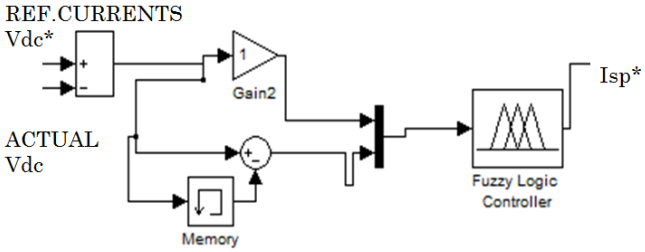


**Figure 8:** design of fuzzy based pi controller in matlab

**G) Fuzzy Hysteresis Current Control**

The commonly used current control technique is hysteresis current control. This method is very simple and easy to implement, but has the disadvantage of an uncontrollable high switching frequency. This high frequency places great stress on the power devices which induces switching losses. In this case, the operating conditions must be known to achieve sufficient, accurate control. Consequently, a fuzzy hysteresis control is developed. The harmonic distortion is reduced very much when compared to the conventional controller.

To improve the active filter performance without precise knowledge of the APF parameters, the hysteresis band value can be implemented with a fuzzy logic controller. In this case, the supply currents and reference currents can be selected as input variables to the fuzzy controller.

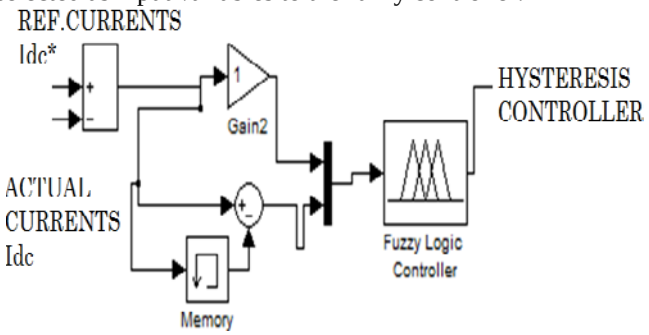


**Figure 9***:* design of fuzzy hysteresis controller in matlab

**System Parameters:**

**Table 2:** Tabular form of system parameters

| System parameter | Values |
|---|---|
| Supply voltage | 415V(L-L),50Hz |
| Load | L=30mH,R=50ohm |
| DC Capacitor | 1500μF |
| $Vdc_{ref}$ | 800 |
| $K_p$ | 0.35 |
| $K_i$ | 2 |
| Coupling inductance | 3.35 mH |

## 3. Matlab/Simulink Modeling and Simulation Results

The system parameters for simulation study are considered as supply voltage 415V(L-L), 50Hz AC supply.Load resistance and inductance are choosen as L=30mH,R=50ohm respectively. Figure.10 shows the matlab/Simulink circuit of conventional APF.The system parameters for simulation study are supply voltage 415V(L-L), 50Hz AC supply.Source


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resistance and inductance are choosen as 0.1mH and 0.3ohm respectively. Load resistance and inductance are choosen as L=30mH,R=50ohm respectively. Inverter series resistance is 3.35mH. Dc bus capacitance is 1500µF.

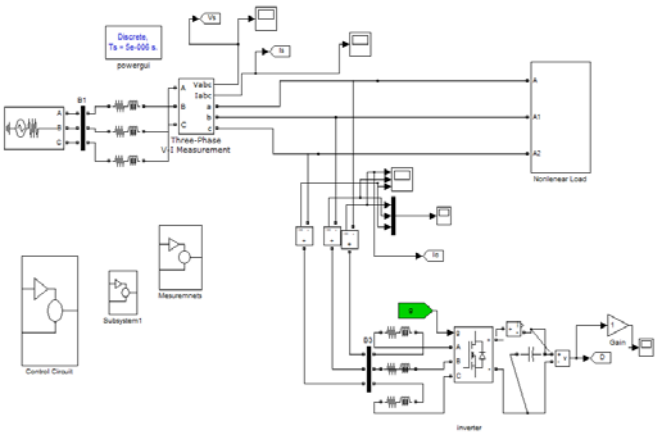

**Figure 10:** Matlab/simulink model Circuit of conventional APF

Figure.11 shows the three phase source voltages, three phase source currents with APF .It is clear that with APF the supply currents are sinusoidal even with non-linear load.

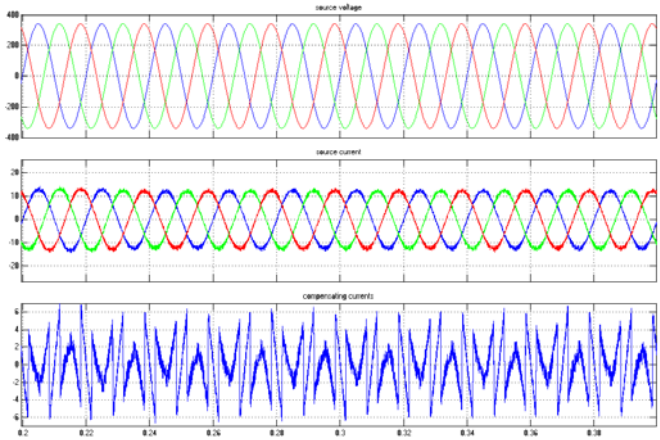

**Figure 11:** source voltage, source current and compensating currents for the conventional circuit

Figure.12 shows the harmonic spectrum of source currents with APF is 2.50%

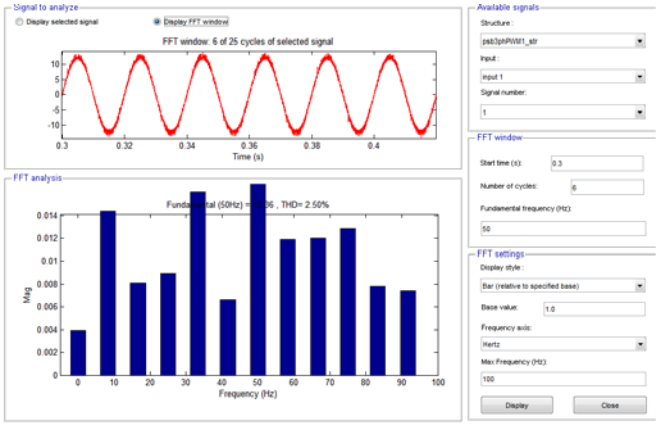

**Figure 12:** Total Harmonic Distortion

Figure.13 shows the matlab/Simulink circuit with APF using Fuzzy logic controller.The system parameters for simulation study are supply voltage 415V(L-L), 50Hz AC supply.Source resistance and inductance are choosen as 0.1mH and 0.3ohm respectively. Load resistance and inductance are choosen as L=30 mH,R=50ohm respectively. Inverter series resistance is 3.35mH. Dc bus capacitance is 1500µF.

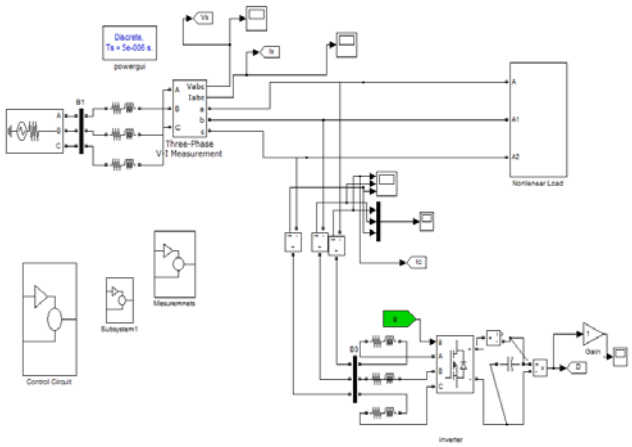

**Figure 13:** Matlab/simulink model Circuit of APF using FLC

Figure.14 shows the three phase source voltages, three phase source currents with APF using FLC .It is clear that with APF the supply currents are sinusoidal even with non-linear load.

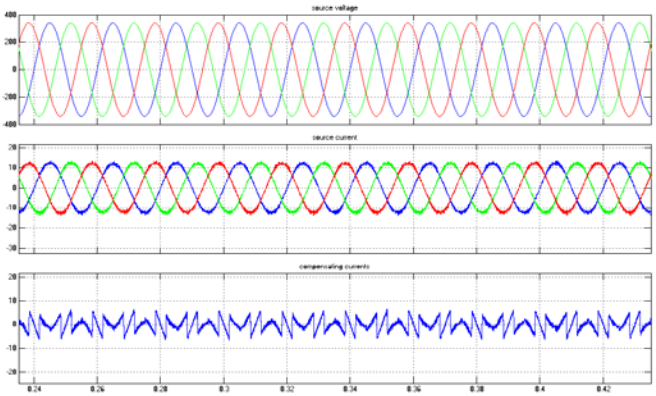

**Figure 14:** source voltage, source current and compensating currents of an active power filter with Fuzzy controller

Figure.15 shows the harmonic spectrum of source currents with APF using FLC is 2.35% Harmonic distortion is reduced compared to the conventional circuit.

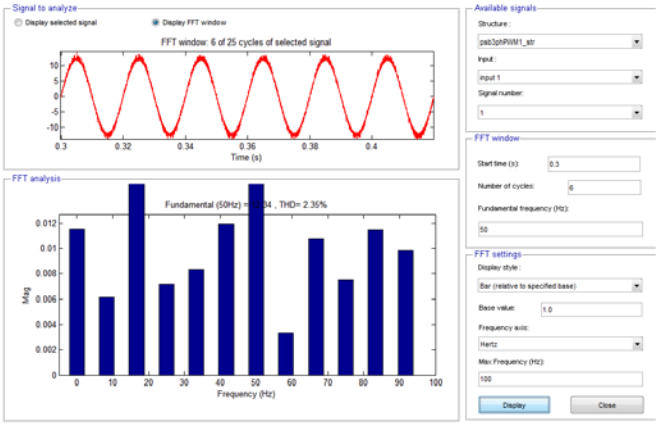

**Figure 15:** Total Harmonic Distortion


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Figure.16 shows the three phase source voltages, three phase source currents with Pre-compensated Fuzzy pi controller. It is clear that with APF the supply currents are sinusoidal even with non-linear load.

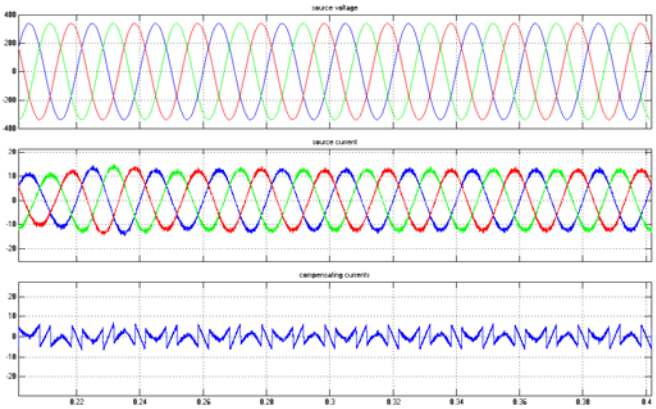

**Figure 16:** source voltage, source current and compensating currents of an active power filter with pre-compensated pi controller.

Figure.17 shows the harmonic spectrum of source currents of Pre-compensated Fuzzy pi controller is 2.28%Harmonic distortion is reduced compared to the conventional circuit.

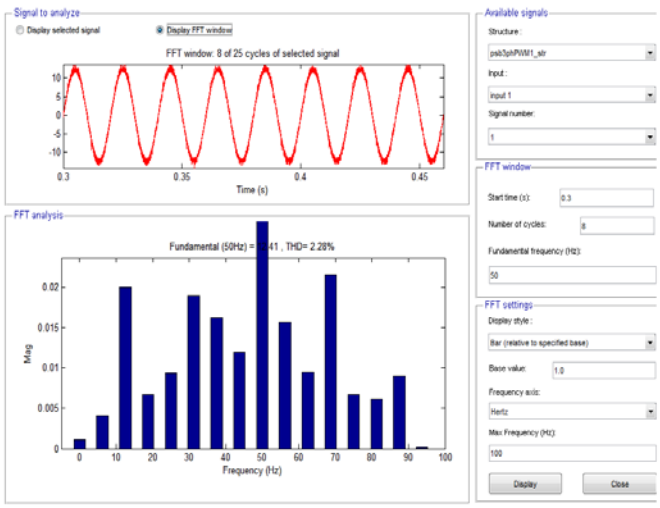

**Figure 17:** Total Harmonic Distortion

Figure.18 shows the three phase source voltages, three phase source currents of circuit with Fuzzy based pi and hysteresis controller. It is clear that with APF the supply currents are sinusoidal even with non-linear load.

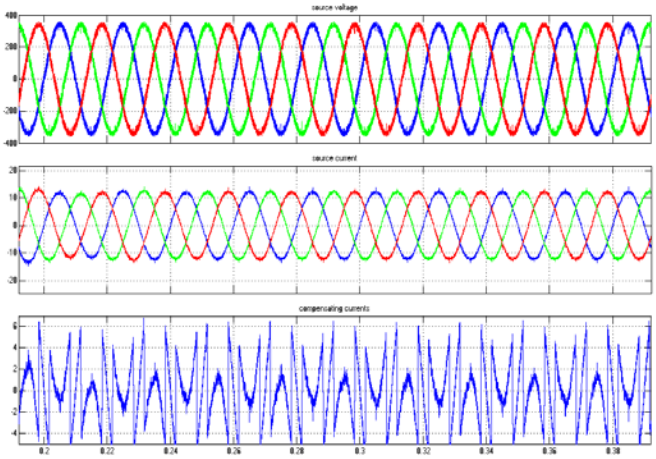

**Figure 18:** Source voltage, source current and compensating currents of an active power filter with Fuzzy based pi and hysteresis controller

Figure.19 shows the harmonic spectrum of source currents of circuit with Fuzzy pi and hysteresis controller is 2.21%Harmonic distortion is reduced compared to the conventional circuit.

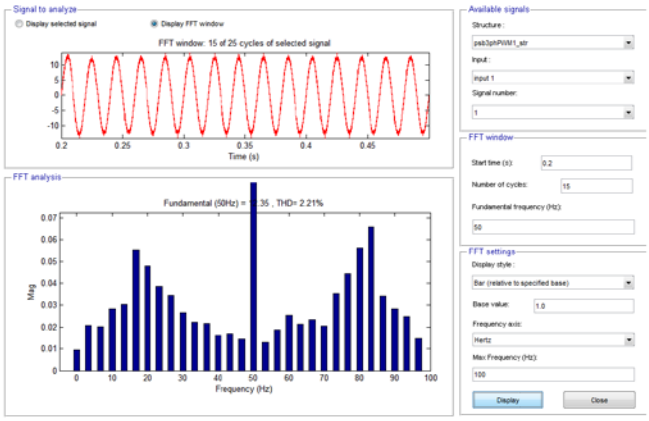

**Figure 19:** Total Harmonic Distortion

**Table 3:** THD values comparison

| *Name of the controller* | *THD value* |
|---|---|
| Conventional circuit | 2.50 |
| APF with Fuzzy controller | 2.35 |
| APF with Pre-compensated PI controller | 2.28 |
| APF with Fuzzy based pi and hysteresis controller | 2.21 |

## 4. Conclusion

A shunt active power filter has been investigated for power quality improvement. Various simulations are carried out to analyse the performance of the system. Both PI controller and fuzzy logic controller based Shunt active power filter are implemented and compared the harmonic distortion values in percentage. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The fuzzy controller based shunt active power filter has a comparable performance to the PI controller in steady state except that settling time is very less in case of fuzzy controller.


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