Estimation of Compensation Current Reference using Fuzzy Logic Controller for Three-Phase Hybrid Active Power Filter

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ABSTRACT

This research deals with design of three-phase hybrid active power filter to reduce the current distortions caused by non-linear loads. The Instantaneous Active and Reactive Power Method (p-q) is used to perform the identification of disturbing currents. The p-q algorithm generates the reference compensation current signal, while this generated reference compensation current signal is exactly followed by the output current of the voltage source converter. Fuzzy logic controller for three-phase hybrid active power filter is used to generate the switching signals in order to control the output currents of voltage source converter. Simulation results showed that the hybrid active power filter can compensate the harmonic currents effectively and improve power quality.

Keywords

Hybrid Active Filter, p-q theorem, Total Harmonic Distortion, Fuzzy Logic Controller.

1. INTRODUCTION

Nowadays industries prefer to use power electronics based devices due to their effectiveness. Though these power electronics based devices are advantageous to the electronics and electrical industry, these devices generate and inject the harmonics in the power industry. These harmonic are known as electrical disturbance which is the main cause of the power quality associated harms. The industrial process is affected by the power quality problems. Therefore for improving the quality of the power supply this harmonic distortion should be decreased with the help of the filters. In the literature, various topologies of active power filters (APFs) have been presented for mitigation of harmonics [1-3]. The APF topologies are not cost-effective for the application of high power because of their high rating and very high switching frequency of pulse width modulator (PWM) converter. Thus LC passive filters (PFs) are used for harmonic filtration of such large nonlinear loads. Low cost and high reliability is the main advantage of PFs. However, PFs suffer from some shortcomings for example, the performance of these filters is affected due to the varying impedance of the system and with the utility system the series and parallel resonances may be created, which cause current harmonics increase in the supply [4-5]. As discussed above both APFs and PFs suffer from a number of disadvantages. Therefore another solution of harmonic mitigation, called hybrid active power filter (HAPF), has been introduced. Hybrid active power filters (HAPF) provide the combined advantages of APF and PPF and eliminate their disadvantages. These topologies are cost effective solutions of the high-power power quality problems with well filtering performance. This research paper is restricted to the (HAPF). The (HAPF) is specially designed to compensate the reactive power and decrease the harmonic currents occurred on the side of load from the grid, by injecting the current having same magnitude but opposite in the phase direction of the harmonic current [6].

In the literature a number of methods have been emphasized for identification of reference current [7-12]. For identification of disturbing current the instantaneous reactive power method has been used in this paper. For controlling the output currents of the converter, to follow the reference currents, hysteresis current controller have been used in [13-15].The implementation of hysteresis current controller is simple and its performance is also excellent. However, this controller suffers from drawbacks. Its main drawback is to generate the variable switching frequency. Therefore reliability and efficiency of hybrid active power filter is affected [16]. To avoid these drawbacks, this paper present the fuzzy logic based current controller to control the output currents of the voltage source converter. Although to control the output current of converter based on fuzzy based is not new [17-18], this approach with 15 rules has not yet being applied to proposed filter.

2. HYBRID ACTIVE POWER FILTER STRUCTURE

The simulink model of hybrid active power filter (HAPF) control is shown by Figure 1.

It is based on:

- A three-phase three-wire power circuit;
- Non-linear load based on uncontrolled rectifier;
- Reference current estimator block based on p-q theory;
- Pulse generation block, based on fuzzy based current control technique;
- The (HAPF) consists of a voltage source converter (VSC) and capacitor
- DC bus voltage controller block.

3. GENERATION OF COMPENSATION CURRENT REFERENCE

The reference current for the control of (HAPF) can be determined by calculation of instantaneous power components of the p-q theory in a stationary $\alpha\beta$frame [19-20].

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = H \begin{bmatrix} e_r \\ e_y \\ e_b \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = H \begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} \tag{2}$$

Where,

$$H = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

The above equations show that α and β coordinates are orthogonal to each other. They also indicate that e_α and i_α are on the α-axis while e_β and i_β are on the β-axis. In three-phase circuit the equation of instantaneous real power can be computed as:

$$p = e_r i_r + e_y i_y + e_b i_b = e_\alpha i_\beta + e_\beta i_\beta \tag{3}$$

The instantaneous reactive power can be computed as:

$$q = e_\alpha i_\beta + e_\beta i_\alpha \tag{4}$$

From (3) and (4) equations, the instantaneous powers are recomputed as in equation (5)

$$\begin{bmatrix} p \\ q \end{bmatrix} = K \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{5}$$

Where,

$$K = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}$$

Based on above equations, the thee-phase voltage v_r, v_y and v_b and currents of the non-linear load can be transformed in to $\alpha\beta$ frame as:

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = H \begin{bmatrix} v_r \\ v_y \\ v_b \end{bmatrix} \tag{6}$$

And

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = H \begin{bmatrix} i_{Lr} \\ i_{Ly} \\ i_{Lb} \end{bmatrix} \tag{7}$$

The instantaneous powers (p_L *and* q_L) of the load can be computed as:

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = K \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{8}$$

Equation (8) is rearranged as:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = K^{-1} \begin{bmatrix} p_L \\ q_L \end{bmatrix} \tag{9}$$

The p_L is divided in to average power($\bar{p}_L$) and oscillating power ($\tilde{p}_L$) . Similarly q_L is divided in to average power ($\bar{q}_L$) and oscillating power ($\tilde{q}_L$) as in equation (10).

$$p_L = \bar{p}_L + \tilde{p}_L \text{ and } \quad q_L = \bar{q}_L + \tilde{q}_L \tag{10}$$

From equation (9) the α-phase load current $i_{L\alpha}$ can be computed as follows:

$$i_{L\alpha} = \frac{e_\alpha}{e_\alpha^2 + e_\beta^2}\bar{p}_L + \frac{-e_\beta}{e_\alpha^2 + e_\beta^2}\bar{q}_L + \frac{e_\alpha}{e_\alpha^2 + e_\beta^2}\tilde{p}_L + \frac{-e_\beta}{e_\alpha^2 + e_\beta^2}\tilde{q}_L \tag{11}$$

From equation(11), it can be observed that in order to cancel out harmonic distortion in power system line, the second, third and fourth term of equation (11) must be compensated by the HAPF. The reference compensating currents can be expressed as follows:

$$\begin{bmatrix} i^*{}_r \\ i^*{}_y \\ i^*{}_b \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} K^{-1} \begin{bmatrix} p^* + p_{ave} \\ p^* \end{bmatrix} \tag{12}$$

Where p^* and q^* are given by,

$$p^* = -\tilde{p}_L \qquad q^* = -\tilde{q}_L \tag{13}$$

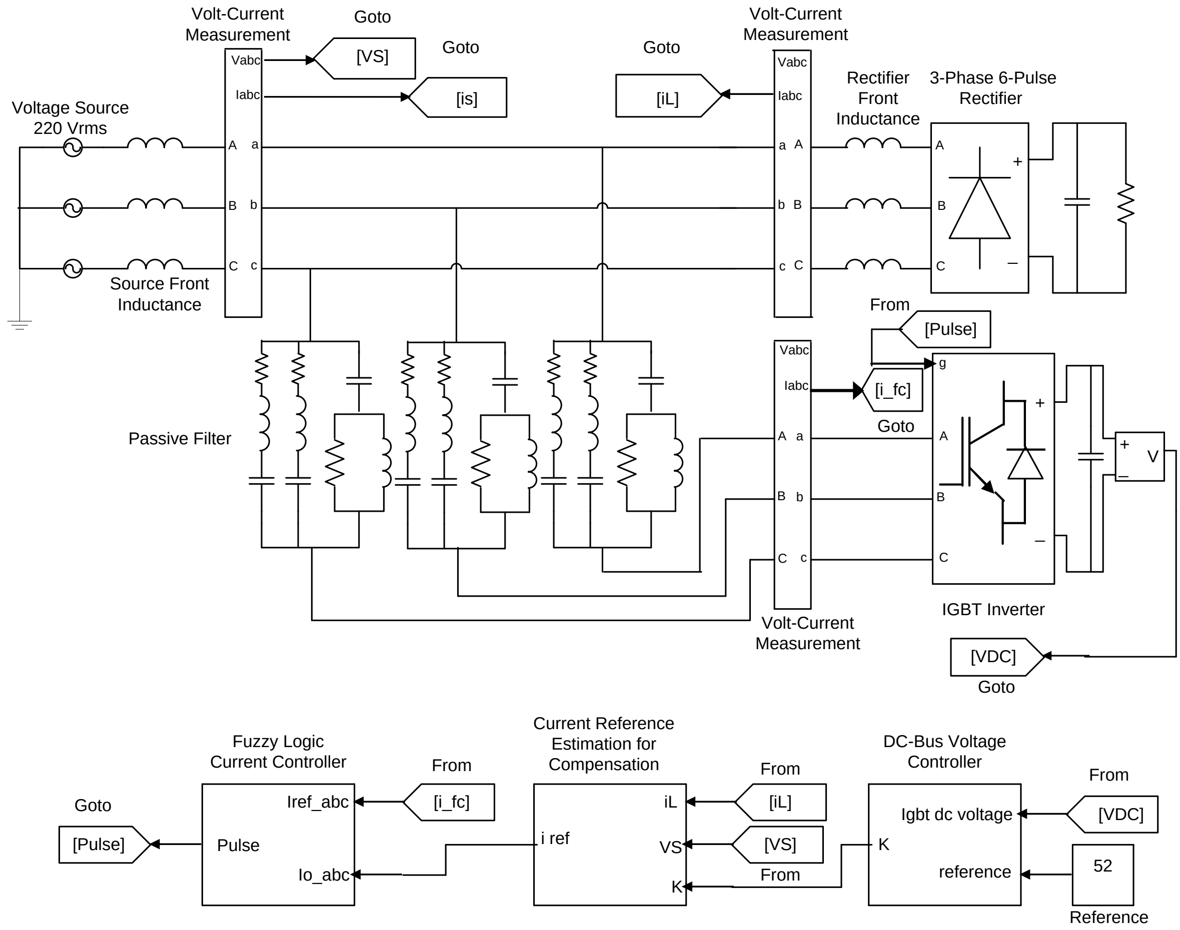

Fig 1: General structure of hybrid active power filter and its control

4. DC BUS VOLTAGE CONTROLLER

The DC Bus voltage controller is used to control the power supply to the insulated gate bipolar transistor converter. To avoid using external power such as DC power supply, Batteries, and many more, the charging and discharging phenomenon of capacitor element is manipulated. The charging and discharging phenomenon of capacitor is controlled by the DC bus voltage controller for maintaining the DC voltage level at constant and the transient response reached the stability. There are different control techniques that can be implemented for the DC bus voltage controller such as using the PI controller and fuzzy controller but in this paper, the approach used is based on [21]. Figure 2 shows the voltage controller of DC bus. Voltage controller of DC-bus regulates the voltage of the capacitor on DC side of the converter and compensates losses of the converter. The voltage of the capacitor is measured and then it is compared to constant value. The resultant difference is then fed into gain. In this way, hybrid active power filter controls and builds up the DC voltage of capacitor without using external supply.

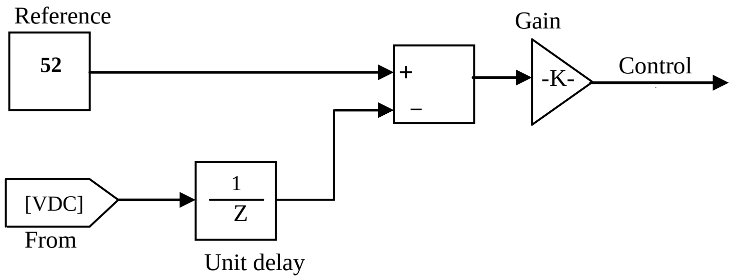

Fig 2: Voltage controller of DC bus

5. FUZZY CURRENT CONTROL TECHNIQUE

The fuzzy logic controller is used to generate switching signals for voltage source converter to follow the reference current. For the control purpose of (HAPF) the fuzzy controller uses two inputs and one output known as error (e) error rate (Δe) and control signal (u) respectively.

The error can be defined as difference between the output currents of the (VSC) and reference currents of the individual phase. The current control method is related to fuzzy controller based PWM current controller has been used in this paper. By comparing carrier signal with fuzzy controller output the switching signals are generated for three-phase VSC as shown in Figure 3.

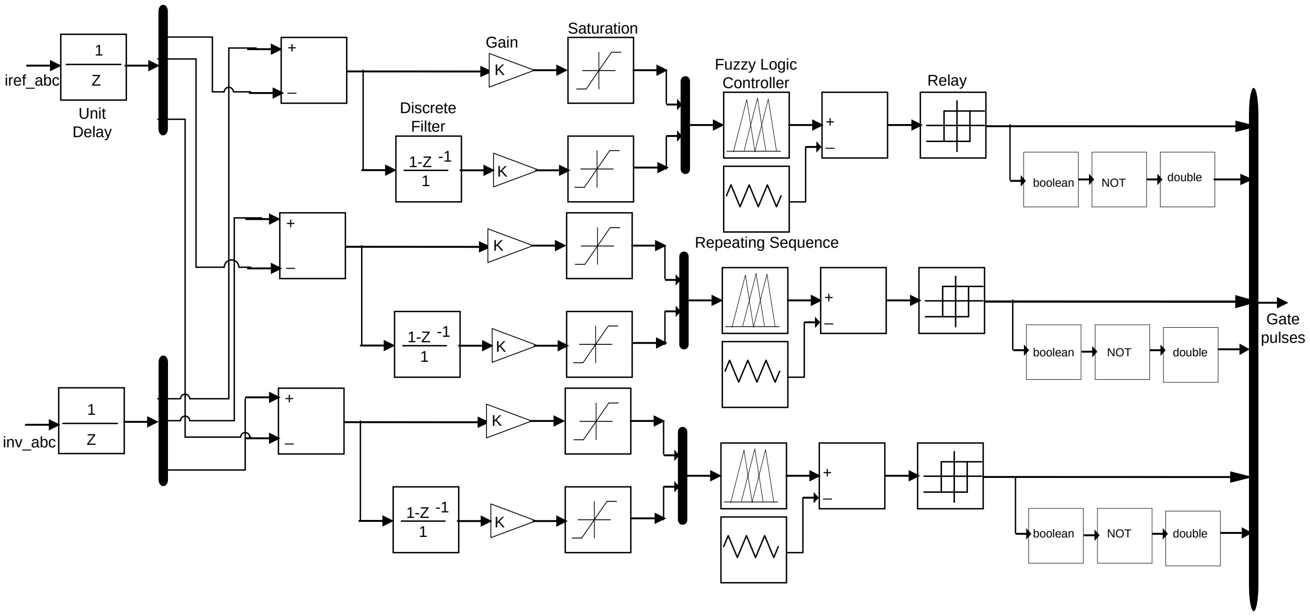

Fig 3: Three-phase fuzzy logic current controller for three-phase HAPF

In this controller, we have used five fuzzy sets (Very Small, Small, Zero, Big, Very Big) for the error and by three fuzzy sets (Low, Zero, High) for the error rate. The output is characterized by five fuzzy sets (Very Decrement, Decrement, Constant, Increment, Very Increment). Their member functions are shown in Figures 4, 5 and 6.

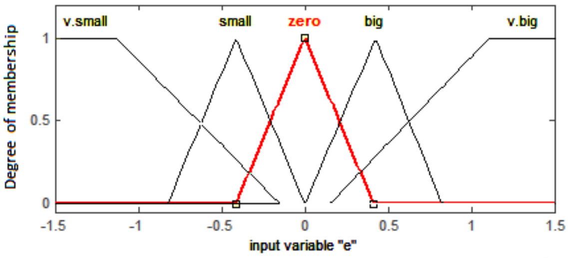

Fig 4: The degree of membership for the error (e)

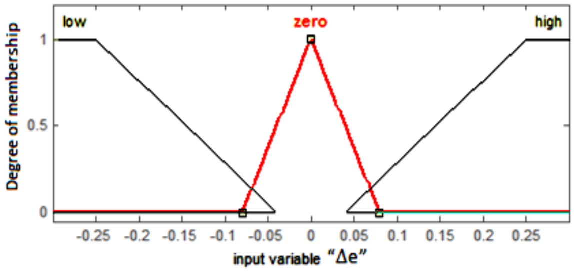

Fig 5: The degree of membership for the rate change of error (Δe)

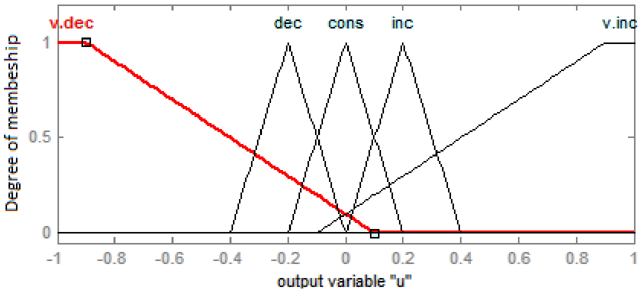

Fig 6: The degree of membership for the output signal (u)

The linguistic rules for the fuzzy logic controller are given in table 1:

Table 1. Fuzzy control rules

Δe e	Low	Zero	High
V.Small	V.Inc	V.Inc	V.Inc
Small	V.Inc	Inc	Inc
Zero	Inc	Cons	Dec
Big	Dec	Dec	V.Dec
V.Big	V.Dec	V.Dec	V.Dec

6. SIMULATION RESULTS

The circuit parameters used in simulation are presented in table2:

Table 2. Simulation parameters [22].

Supply voltage	Vs = 220Vrms
Supply/ line inductance	Ls = 0.0016 Henery
Rectifier front-end inductance	L_L = 0.023 Henery
Capacitance of the load	C_L= 50 micro Farad
Resistance of the load	R_L=78 Ohm
Capacitance of inverter dc-bus	C_{dc} = 4500 micro farad

Simulations were performed to show the usefulness of the HAPF which actually compensates the harmonic currents of the source current effectively.

A nonlinear load, consisting of a three-phase uncontrolled rectifier and adjustable speed drives, is fed by sinusoidal and symmetrical mains phase voltages (220 Vrms, 50 Hz).

Figures 7 and 8 show the source current before filtering (only one phase current has been shown for the clearness) and its harmonic spectrum respectively.

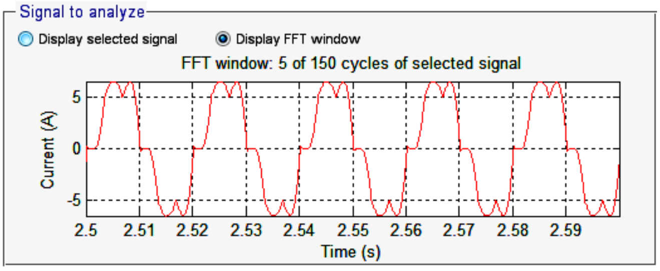

Fig 7: Source current before filtering

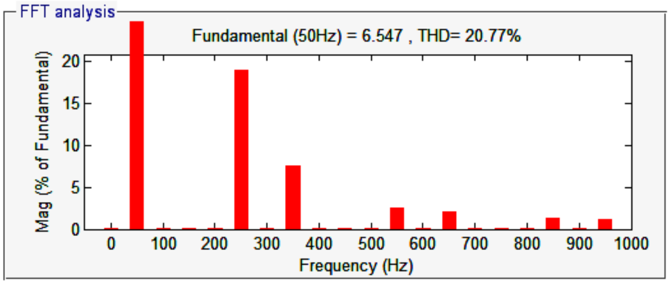

Fig 8: Frequency spectrum of source current before filtering

It is clearly shown that the THD of the source current is 20.77% for the proposed system. After filtering simulation results have been shown in next figures. Thus, Fig. 9 shows that the distortion of the source current is reduced and it becomes sinusoidal and now it is in phase with the source voltage, thus power factor of the system is improved. The THD of the source current is reduced from 20.77% to 2.01% as depicted in Figure 10. In Figure 11, the output current of the HAPF tracks the reference current closely.

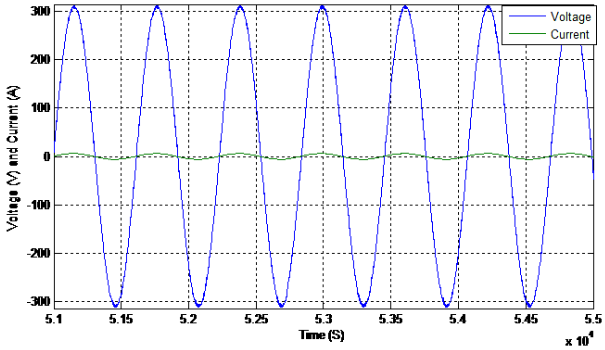

Fig 9: After filtering source voltage and current are in phase

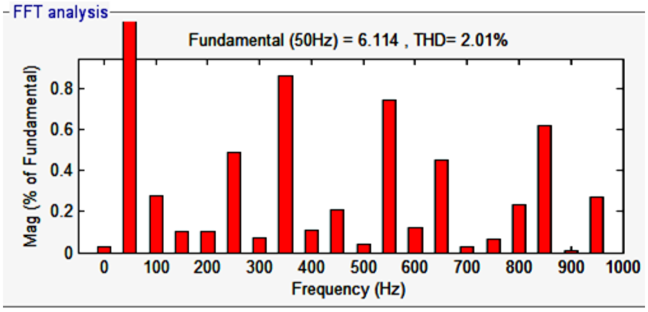

Fig 10: Frequency spectrum of source current after filtering

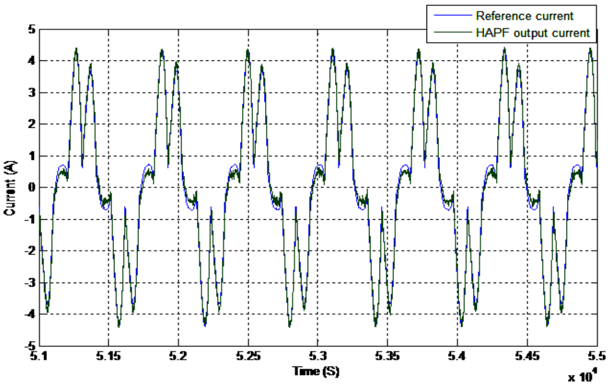

Fig 11: Hybrid active power filter output current and reference current

7. CONCLUSION

In this paper we have presented the three-phase hybrid active power filter with 15-rules base fuzzy logic controller for compensation of harmonic currents generated by the non-linear load. The fuzzy logic control based HAPF for three-phase system is modeled and simulated in MATLAB/SIMULINK environment. The main objective of this research work has been accomplished. The total harmonic distortion of the supply current has been decreased at a high level of expectation from 20.77% to 2.01% in the simulation. Which is a achievement to meet the IEEE 519 recommended harmonic standard.

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