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THREE PHASE FOUR WIRE SHUNT ACTIVE POWER FILTER BASED FUZZY LOGIC DC-BUS VOLTAGE CONTROL

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ABSTRACT: In this paper a simple fuzzy logic control is proposed in order to ensure DC-bus voltage regulation and to keep the capacitor voltages balanced with minimizing the zero-sequence component in the source current in three phase four wires active power filter. A comparison of the proposed method against the conventional proportional integral one is illustrated through simulation results and a clear advantage of the fuzzy logic control can be observed. Moreover, identification of reference currents will be developed by the use of Multi-Variable Filter having the advantage of extracting harmonic voltages directly from the αβ axis. Computer simulation results show that the dynamic behavior of the fuzzy controller is better than the conventional proportional-integral (PI) controller.

KEYWORDS: Fuzzy logic control, DC-bus voltage control, Four-wire shunt active filter, harmonics current compensation, multi-variable filter

INTRODUCTION

Conventionally, the major part of electrical power was consumed by linear loads. In recent years, the application of power electronics has grown tremendously. These power electronics systems offer highly non-linear characteristics and draw non sinusoidal current from utility, causing harmonic pollution into supply system. Increase in such non-linearity results in undesirable features such as distortion of supply voltage, low system efficiency and a poor power factor. They also cause disturbance to other consumers and interference in near by communication networks [12].

Since their basic operating principles were firmly established in 1970s, active filters have attracted the attention of power electronics researchers/engineers who have had a concern about harmonic pollution in power systems [1].

They compensate, in real-time, the disturbances due to a nonlinear load. However, the control of active filter is difficult [9]. In many commercial and industrial installations, electric power is distributed through a there phase four wire system with incorrectly distributed or uncompensated loads.

Such systems may suffer from excessive neutral currents caused by nonlinear or unbalanced loads. This type of system has a problem. If nonlinear single phase loads are present or the three phase load is unbalanced, line currents are unbalanced and neutral currents flow. In severe cases, the neutral currents are potentially damaging to both the neutral conductor and the transformer to which it is connected.

Three phase three wire shunt active power filters cannot effectively reduce or eliminate line harmonics in this situation. Three phase four wire active power filters have been proposed by researchers as an effective solution to these problems [5].

Most active filters can use as their power circuit either a voltage-source pulse width-modulated (PWM) converter equipped with a dc capacitor or a current-source PWM converter equipped with a dc inductor. At present, the voltage-source converter is more favorable than the current-source converter in terms of cost, physical size, and efficiency [1].

The shunt-active filter allows a compensation of the load currents, so that compensation drawn from the network is sinusoidal, balanced and minimized. It is connected in a back-to-back which the shunt converter is responsible for regulating the common DC-link voltage [10].

The PI controller used requires precise linear mathematical models, which are difficult to obtain, and fails to perform satisfactorily under parameter variations, nonlinearity, load disturbance, etc. It will cause DC voltage overshoot and inrush source current which will lead to protection or even equipment damage when APF is plunged into the system. The voltage overshoot and inrush current have been the constraints which restrict the development of active power filter [11].

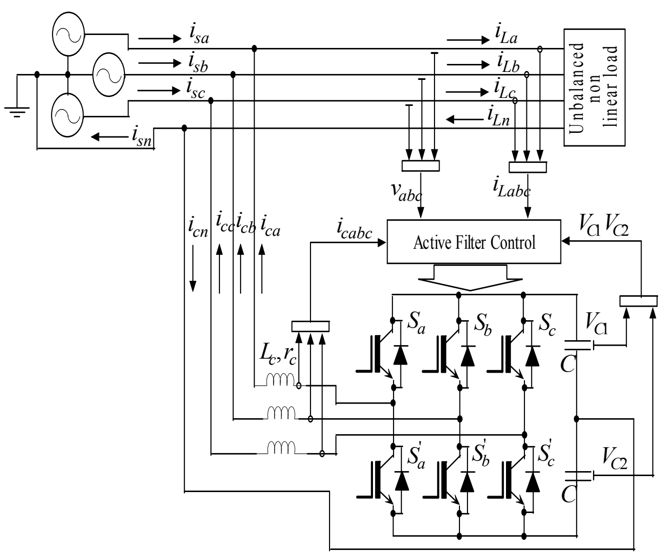

Figure 1. Three-phase four-wire active power filter

Recently, Fuzzy Logic Controller (FLC) is used in power electronic systems; for adjustable motor drives and active power filter applications.

The advantages of FLC's over the conventional controllers are: It does not need accurate mathematical model; it can handle nonlinearity and is more robust than conventional controllers [8].

In this paper, an active power filter is proposed to eliminate harmonics both in the three phases and in the neutral conductor of an unbalanced three phase four wires electrical distribution system, feeding three single non-linear loads where the problem of DC-bus voltage control in three-phase four-wire shunt active filter is treated by a simple fuzzy logic control and the identification of reference currents is developed by the use of Multi-Variable Filter to extract harmonic voltages directly from the $\alpha\beta$ axis.

This combination improves the active power filter performances.

CIRCUIT CONFIGURATION

The main circuit of the shunt active parallel filter shown in figure 1 uses a Three-Leg Split-Capacitor (TLSC) and the neutral current is provided through the fourth wire connected directly to the midpoint of this bus.

This configuration (TLSC) which used in this paper is preferable to the Four-leg Full Bridge FLFB, that provides the neutral current through the fourth leg.

From the point of view control, the TLSC topology permits each of the three legs to be controlled independently [14], making its current tracking control simpler than the FLFB topology.

However, in this case all the zero-sequence injected current flow through the DC-bus capacitors. So, in order to compensate the source neutral current, the DC-bus capacitor of the filter is split into two series connected capacitors in order to create a mid point that is directly connected to the mains neutral [7]. This current gives rise to voltage unbalance between the two capacitors C_1 and C_2 in the DC-bus especially when the compensated currents are highly distorted and unbalanced. The DC-bus voltage control is generally included in the process of current reference identification, because it provides additional active current that the active filter must inject or absorb in or from the main to achieve DC-bus voltage regulation. Due to this effect, the source currents after compensation will depend strongly on the efficiency DC-bus control. For the TLSC topology, two control loops are generally performed to control respectively the DC-bus voltage absolute value and unbalance.

To mitigate the oscillation between the voltage V_{C1} and V_{C2} across the capacitors C_1 and C_2 of the DC-bus, some ideas are proposed in the literature. The fuzzy logic control is already performed successfully for active filter control.

The present paper proposes a fuzzy logic control in order to overcome eventual inconvenient of the usual methods. Two fuzzy logic controllers performe respectively the total bus voltage and the unbalance between the two capacitors.

The filter presented by a PWM converter is controlled with conventional hysteresis regulator.

The active power filter operates as a controlled current source generating the load harmonic current. As a result, the current supplied from the mains at the point of common coupling will be sinusoidal. The harmonic current detection is a very important; it determines the performance of active power filter in a certain extent [4]. This filter is based on an extension of the instantaneous power theory that considers the existence of zero-sequence phase current components in un unbalanced three phase four wire electrical distribution system feeding three single non-linear loads.

CONTROL STRATEGY. Conventional instantaneous powers theory

Active power filter can be used with different control strategies. One of the most widely used is based on the conventional instantaneous real and imaginary powers theory initiated by Akagi.

Phase voltage imports the phase-locked loop (PLL), PLL exports the sine and cosine signal circuit which produce sinusoidal signals in phase.

Figure 2 presents supply voltage waveforms before using PLL, and figure 3 presents it after the use of PLL.

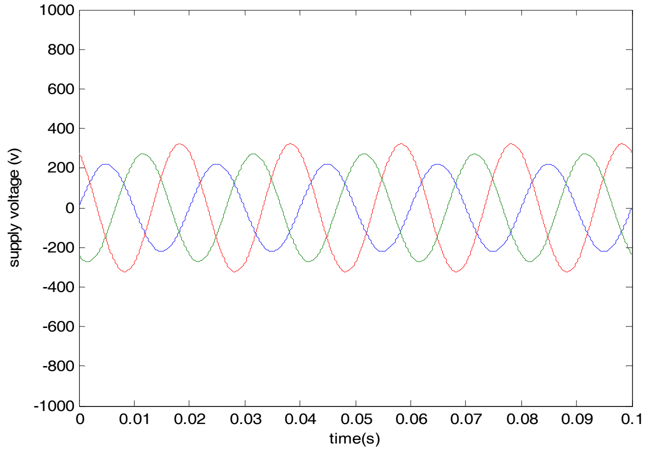

Figure 2. Supply voltage waveforms without PLL

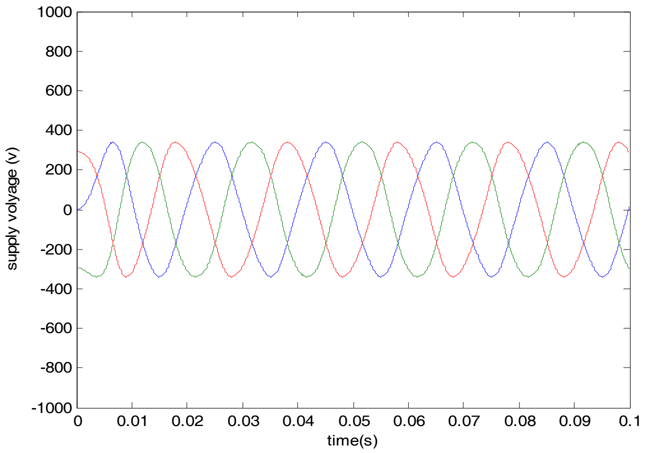

Figure 3. Supply voltage waveforms with PLL

This theory is based on a-b-c phase reference currents computation by transferring three phase voltage and current signal into corresponding α-β-0 components. Simply, the basic p-q theory consist of an algebraic transformation, known as Clarke transformation, of the sensed three-phase source voltage (V_{sa}, V_{sb}, V_{sc})

and load currents (I_{La}, I_{Lb}, I_{Lc}) from a-b-c coordinates to the α-β-0 coordinates is shown in (1) and (2) .

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad (2)$$

Load side instantaneous real power (pαβ), imaginary power (qαβ) and zero sequence power (p0) are calculated as in (3).

$$\begin{bmatrix} P_\alpha \\ P_\beta \\ P_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} V_\alpha & V_\beta & 0 \\ -V_\beta & V_\alpha & 0 \\ 0 & 0 & V_0 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \quad (3)$$

Instantaneous real and imaginary powers include oscillating (AC) and average (DC) components as shown in (4). pαβ and qαβ may be, split into two parts (average values and oscillating values) as:

$$p_{net} = p_{\alpha\beta} + q_{\alpha\beta} + p_0 = \bar{p}_{\alpha\beta} + \tilde{p}_{\alpha\beta} + \bar{q}_{\alpha\beta} + \tilde{q}_{\alpha\beta} \quad (4)$$

After determining the active and reactive power signals, they are smoothened by passing through a low pass filter.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \frac{1}{V_0 V_\alpha^2 + V_0 V_\beta^2} \begin{bmatrix} V_0 V_\alpha & -V_0 V_\beta & 0 \\ V_0 V_\beta & V_0 V\alpha & 0 \\ 0 & 0 & V_\alpha^2 + V_\beta^2 \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \\ p_0 \end{bmatrix} \quad (5)$$

Later, they are converted back to three phase reference currents and made available for comparison with actual currents [6].

$$\begin{bmatrix} i_{ha} \\ i_{hb} \\ i_{hc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \quad (6)$$

The neutral current is equal to:

$$i_n = \left(i_{ha} + i_{hb} + i_{hc}\right) \quad (7)$$

Multi-Variable Filter

Now a multi variable filter developed by Benhabib in 2004 is presented in order to obtain a good voltage signal without harmonics [2]. It can be presented by the following transfer function:

$$V_{xy}(t) = e^{j\omega t} \int e^{-j\omega t} U_{xy}(t)dt \quad (8)$$

After Laplace transformation, we get:

$$H(s) = \frac{V_{xy}(s)}{U_{xy}(s)} = \frac{s + j\omega}{s^2 + \omega^2} \quad (9)$$

After developing this equation, we obtain:

$$\hat{x}_\alpha = \frac{k}{s}\left[x_\alpha(s) - \hat{x}_\alpha(s)\right] - \frac{\omega}{s}\hat{x}_\beta(s) \quad (10)$$

$$\hat{x}_\beta = \frac{k}{s}\left[x_\beta(s) - \hat{x}_\beta(s)\right] + \frac{\omega}{s}\hat{x}_\alpha(s) \quad (11)$$

The scheme of this filter is illustrated in figure 4.

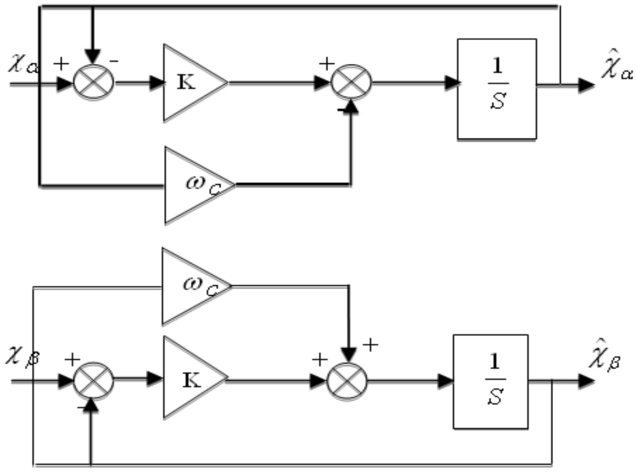

Figure 4. Multi-variable filter

Description Regulation of Capacitor Voltage

There are two types of power circuits applicable to three-phase active filters, the author prefers the voltage- source to the current-source PWM converter because it is higher in efficiency, lower in cost, and smaller in physical size than the current-source PWM converter, particularly in terms of comparison between the dc capacitor and the dc inductor .

Proportional Integrator Controller

In many industrial applications, a PI controller is generally used to regulate the DC bus voltage of shunt active power filters. The regulation of the continuous voltage at the boundaries of the capacitor being ensured by a regulator made up of a low-pass filter of time constant and proportional regulator with Kc as a gain, which makes it possible to compensate losses in the inverter [3]. Since converter consumes an instantaneous active power given by:

$$Pc = \frac{d}{dt}\left(\frac{1}{2} C V_{dc}^2\right) \quad (12)$$

For small change in V_{dc}^* around its reference, this equation can be linearized as:

$$Pc = C V_{dc} \frac{d}{dt}\left(V_{dc}\right) \quad (13)$$

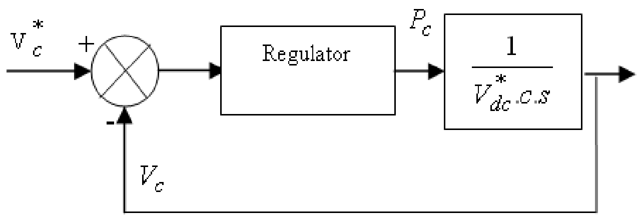

Figure 5. DC Voltage control bloc diagram

For stabilizing the DC voltage, a proportional controller is used, response of it is calculated by:

$$\Delta V_{C12} = K_p\left(V_c^* - \left(V_{c1} + V_{c2}\right)\right) \quad (14)$$

where V_{C1}, V_{C2} are voltages on capacitor C_1 and C_2, Kp gain of voltage controller, Vc is DC voltage reference, where*

$$C = K\left(1 - e^{-Ts/\tau}\right) \qquad (15)$$

$$d = -e^{Ts/\tau} \qquad (16)$$

In recurrence notation, we have:

$$P_c(K) = C\varepsilon(K-1) - dP_C(K-1) \qquad (17)$$

FUZZY LOGIC CONTROL OF DC-BUS VOLTAGE

In recent years, fuzzy logic controllers have generated a great deal of interest in certain applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity [13]. In this part of paper, the error signal caused by the filter losses has been computed firstly. Then this error signal has been compensated using the fuzzy logic controller.

Mamdani fuzzy system has been used in the fuzzy controller. The fuzzy controller is characterized for the following: - Seven fuzzy sets for each input - Seven fuzzy sets for the output-Triangular membership functions Defuzzyfication using the "centroid' method. Figure 4 shows a schematic block diagram of fuzzy inference system or fuzzy controller.

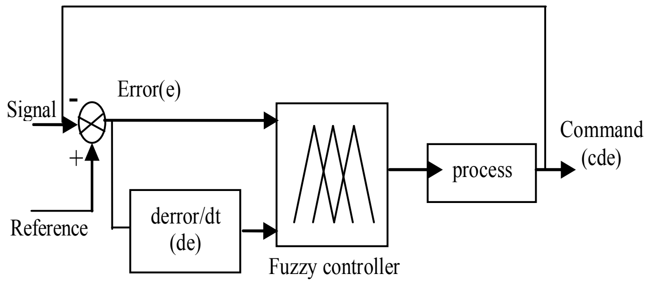

Figure 6. Fuzzy controller synoptic diagram

Figure 6 shows a schematic block diagram of fuzzy inference system or fuzzy controller. In our application two fuzzy logic controllers are implemented to control the DC-bus voltage.

SIMULATION RESULTS

The performance of the proposed method is examined with an active filter simulation model using the instantaneous power theory and the results are compared with a multi-variable filter.

The dynamic response of control strategy (and overall active power filter) is studied by switching three single phase inverter feeding unbalanced loads. The simulation results where carried out using Matlab under the following parameters:

Table 1. Parameters of simulation

f=50Hz		
V_{s1}=220 v	V_{s2}=271 v	V_{s3}=322v
R_s=1,18e-3 Ω	L_s=37,6e-6H	
R_c=4,3e-3 Ω	L_c=68,67e-6H	
R_f=5e-3 Ω	L_f=300-6H	
R_{l1}=0,2 Ω	L_{l1}=1e-3H	
R_{l2}=0,3 Ω	L_{l2}=2e-3H	
R_{l3}=0,4 Ω	L_{l3}=3e-3H	

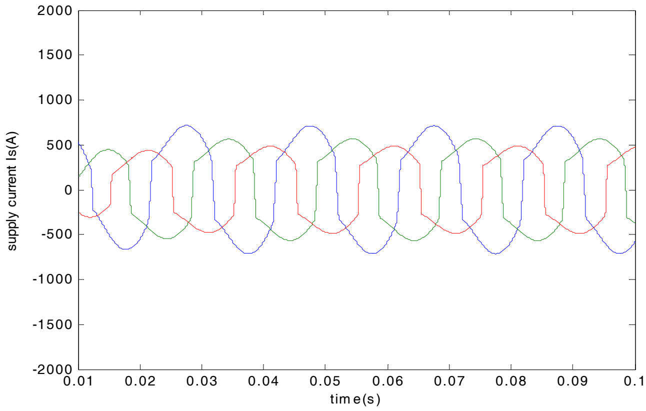

Figure 7.a Supply current wave form

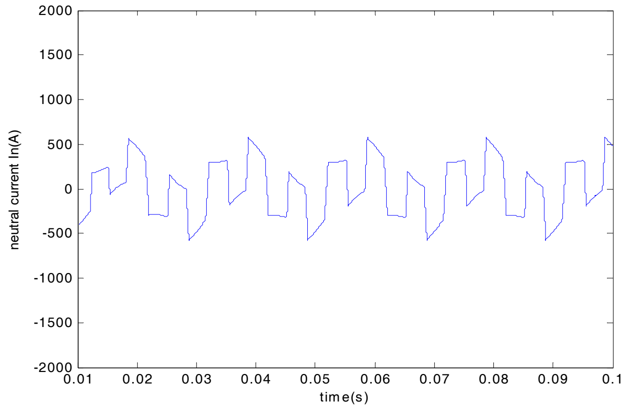

Figure 7.b Neutral current wave form

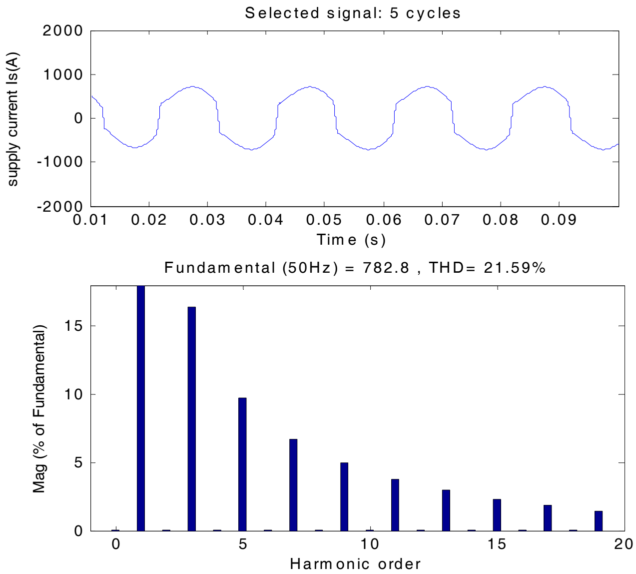

Figure 7.c Supply current wave form with TDH

Figure 7. Waves form signal before compensation

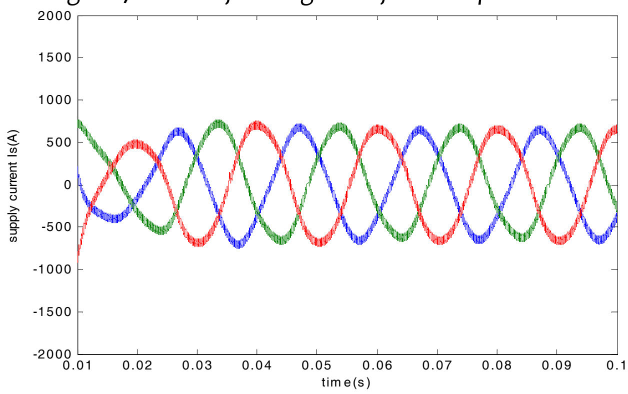

Figure 8.a Supply current wave form

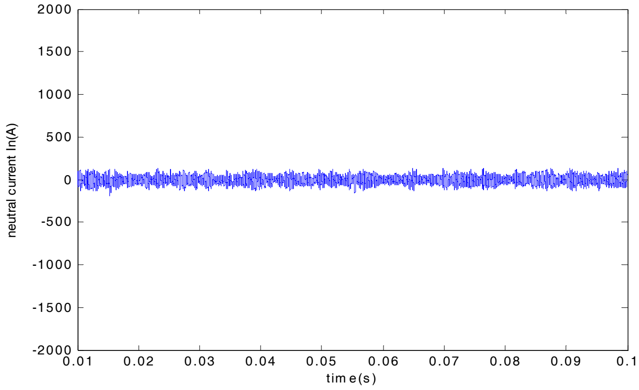

Figure 8.b Neutral current wave form

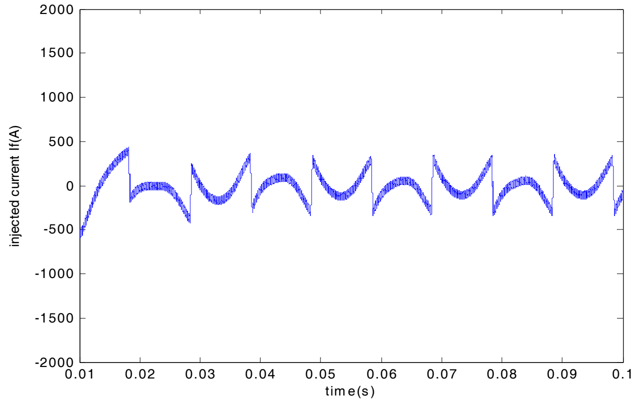

Figure 8.c Injected current wave form

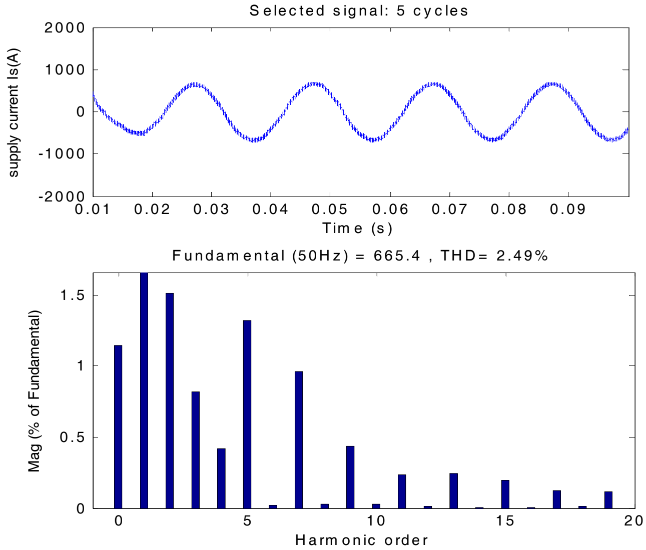

Figure 8.d Supply current wave form with THD

Figure 8. Waves form signal using instantaneous power theory and PI Controller for DC voltage

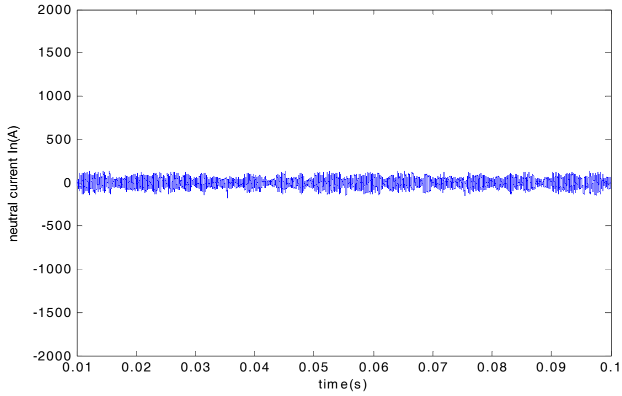

Figure 9.b Neutral current wave form

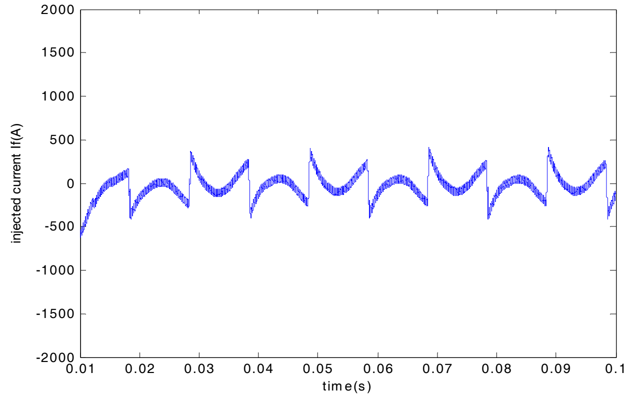

Figure 9.c Injected current wave form

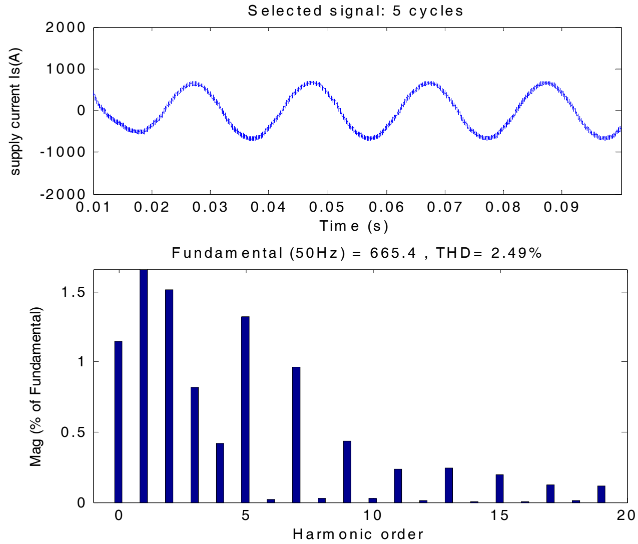

Figure 9.d Supply current wave form with THD

Figure 9. Waves form signal using multi variable filter and PI Controller for DC voltage

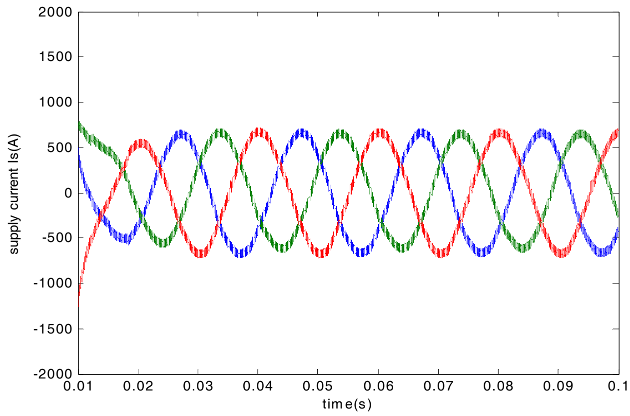

Figure 9.a Supply current wave form

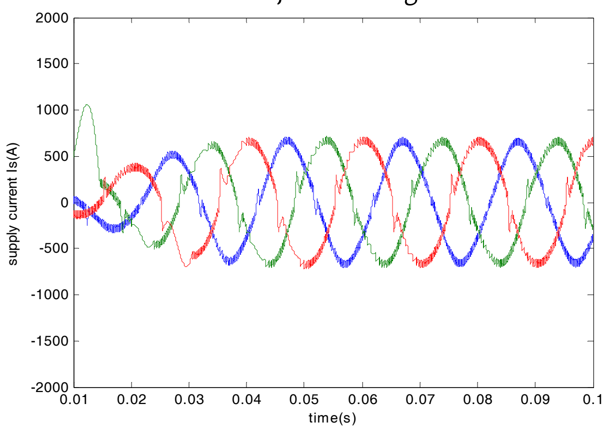

Figure 10.a Supply current wave form

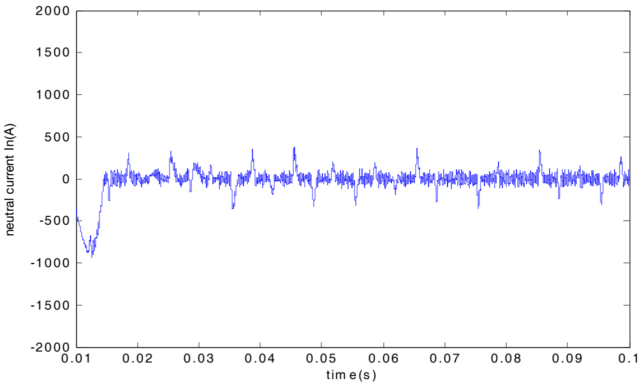

Figure 10.b Neutral current wave form

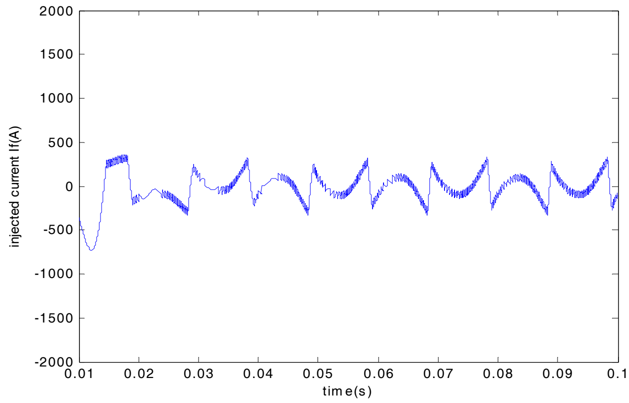

Figure 10.c Injected current wave form

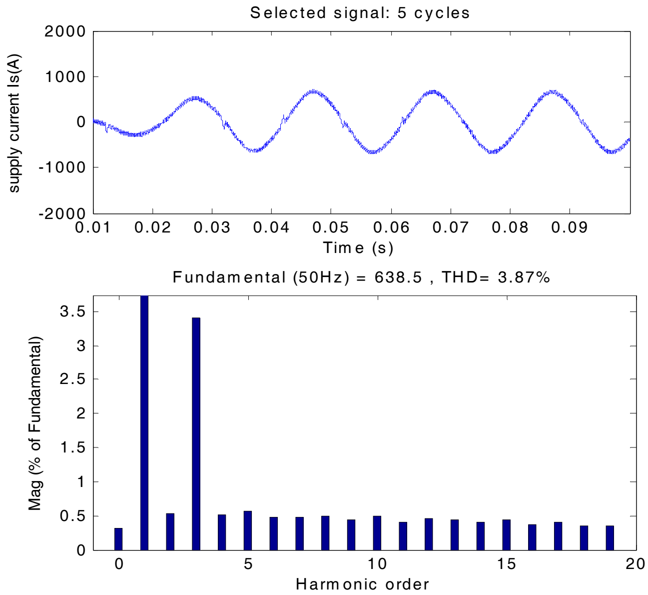

Figure 10.d Supply current wave form with THD

Figure 10. Waves form signal using instantaneous power theory and fuzzy logic Controller for DC voltage

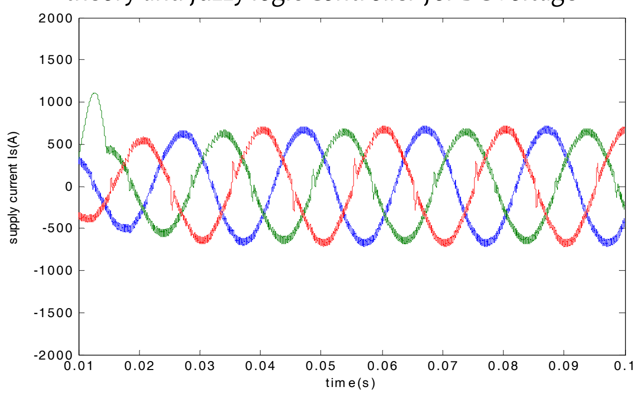

Figure 11.a Supply current wave form

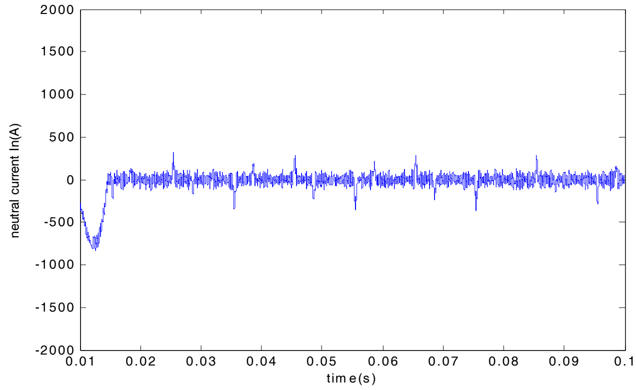

Figure 11.b Neutral current wave form

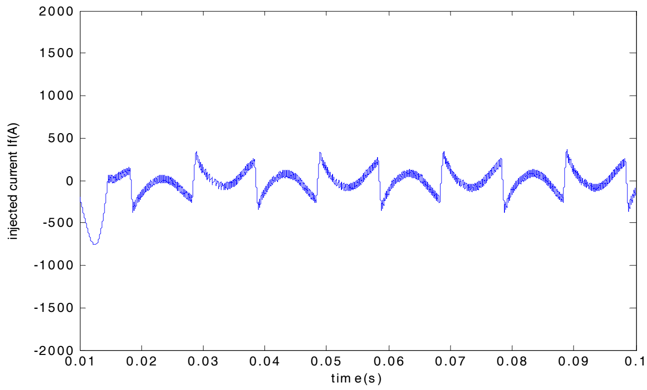

Figure 11.c Injected current wave form

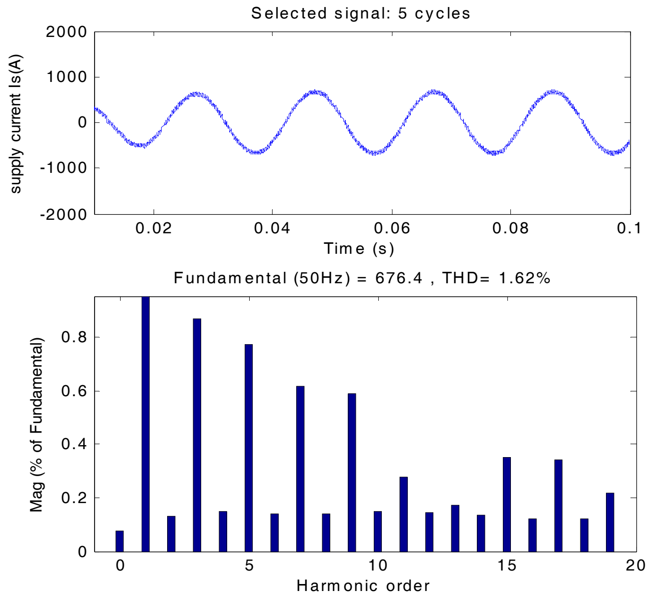

Figure 11.d Supply current wave form with THD

Figure 11. Waves form signal using multi variable filter and fuzzy logic Controller for DC voltage

INTERPRETATION

Simulation results based on MATLAB software are presented to validate the control strategy. Figures 9.a, 10.a and 11.a show that the line currents are sinusoidal and balanced after the use of the active filter. As can be seen that the THD before compensation was 21,59%, and it becomes 4,25% by using instantaneous power theory 2,49% using multi variable filter with the PI controller which is used to regulate DC bus voltage. Moreover the THD is 3, 87% by using Instantaneous Power Theory and 1,62% using a multi variable filter with fuzzy logic controller to regulate DC bus voltage. So, with all those methods, THD is less then 5% which *satisfies the CEI norms. Consequently, the obtained results have shown a better performance for multi variable filter with fuzzy logic controller to regulate DC bus voltage.*

CONCLUSIONS

A digital active filter for phase and neutral currents harmonic compensation in three phase four wire system feeding three single non-linear loads and fuzzy logic controller used in the regulation of the continuous voltage at the boundaries of the capacitor is proposed. the problem of the DC-bus voltage control of the three-phase three-leg voltage source inverter based four-wire shunt active filter control is treated. An alternative solution based on fuzzy logic control is proposed to overcome the principal inconvenient of this configuration which is unbalance between the two capacitors in that bus. The performances of the fuzzy logic control in DC-bus voltage control is verified through computer simulation. The dc link fuzzy control has better dynamic behavior than conventional PI control strategy.

Beside this, the use of a multi-Variable Filter having the advantage of extracting harmonic voltages directly from the $\alpha\beta$ *axis have improved the filtering performances of the active power filter, therefore it makes the filter more attractive for four-wire compensator implementation.*

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