A FUZZY LOGIC BASED CONTROLLER FOR SHUNT POWER ACTIVE FILTER

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Abstract: *This paper deals with the use of shunt active filter to compensate current perturbations produced by non linear loads. To perform the identification of disturbing currents, the so called Instantaneous Active and Reactive Power Method (pq) is used. A Phase Locked Loop (PLL) circuit, locked to the fundamental frequency of the system voltage, is also introduced for eventual mains voltages perturbations.*
The output current of the Voltage Source Inverter (VSI) must track the reference currents produced by the pq algorithm. Two fuzzy logic controllers are used to regulate the DC-link capacitor voltage and to control VSI AC output currents, respectively.

Key words: *Three phase active filter, fuzzy logic controller, voltage source inverter,…*

1. Introduction

Due to the increased use of nonlinear electrical loads, such as power electronics supplies, harmonics currents are generated in the level of these loads and injected back to the grid causing its voltage distortion at harmonics currents' frequencies. The distorted voltage generates distorted currents which will be absorbed by sensitive loads and causing losses in the lines. Also, the most consuming electrical power loads are almost inductive and then they contribute to the degradation of grid power factor at the Point of Common Connection (PCC).

A shunt active filter is generally used to eliminate the reactive power and current harmonics, produced on the load side from the grid current, by injecting compensating currents.

In this paper, the method based instantaneous active and reactive power (pq) is performed for disturbing current identification [1]. Taking into account an eventual perturbation of main voltages (distorted and unbalanced main voltages conditions); a Phase Locked Loop (PLL) circuit is introduced to lock to the fundamental frequency of the system voltage [2]. In fact, the pq theory is not effective under distorted and unbalanced mains voltages conditions [3]. For controlling the inverter output current, a Fuzzy Logic based current controlled modulation is introduced. The Fuzzy Logic Controller (FLC) will replace a classical PI controller both in regulating VSI DC bus voltage and PWM VSI output currents.

2. General structure

The main circuit of the shunt active filter control, as used in the Matlab/Simulink environment, is shown by figure 1.

This structure representing the shunt power active filter is composed by :

- Three wires power network;
- Non linear load based on a rectifier;
- Reference current identification bloc based on a pq method;
- Two regulation blocs, of capacitor voltage and the inverter, based on a fuzzy logic technique;
- First order output filter;
- Active Filter consisting of a voltage source inverter (VSI) with a capacitor in its DC side.

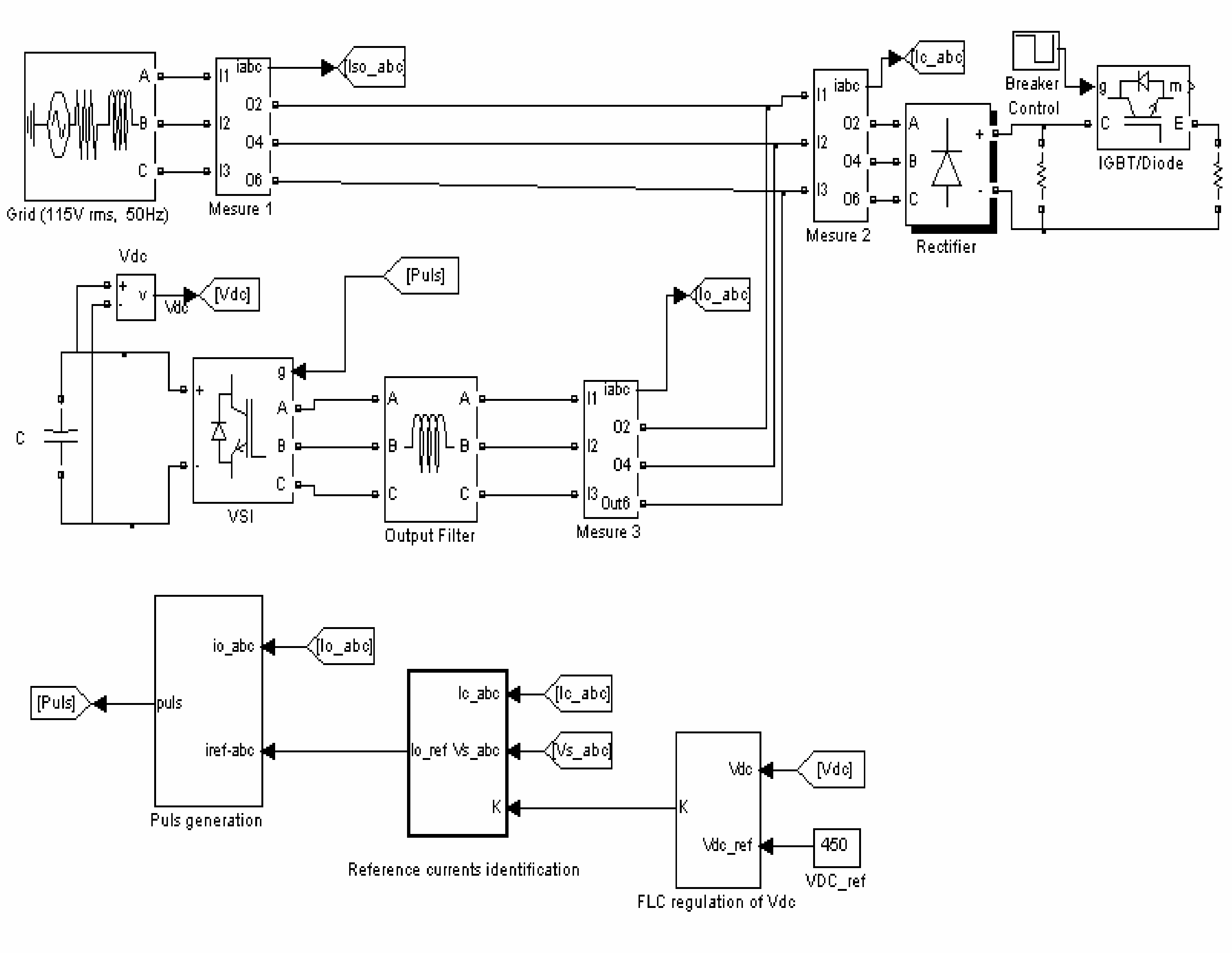

Fig. 1. General structure of the PAF control

3. Disturbing current identification

The reference current for the control of the active power filter could be calculated using also the active and reactive power analysis in a stationary α-β frame.

The instantaneous real and imaginary powers absorbed by the load are respectively, defined as follows :

$$p_l = v_\alpha \, i_\alpha + v_\beta \, i_\beta \qquad\qquad q_l = v_\alpha \, i_\beta - v_\beta \, i_\alpha$$

These powers may be decomposed into oscillatory component (harmonic power) and average component (fundamental active and reactive powers) :

$$\begin{bmatrix} p_l \\ q_l \end{bmatrix} = \begin{bmatrix} \bar{p}_l \\ \bar{q}_l \end{bmatrix} + \begin{bmatrix} \tilde{p}_l \\ \tilde{q}_l \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix}$$

The active filter, which the aim is the compensation of reactive power and elimination of harmonic components, may be used as a controlled current source and it has to supply a current wave as close as possible to reference current.

In order to generate the current reference, a balance between instantaneous powers supplied by the grid (noted p_g and q_g) and the active filter (p_f and q_f) and drained by the load is to be computed.

To obtain a sinusoidal current with unity power factor, the oscillating term of 'p' and all terms of 'q' have to be removed. In this case, power balance yields:

$$p_g = \bar{p}_l \qquad\qquad q_g = 0$$

$$p_f = p_l - p_g = \tilde{p}_l \qquad q_f = q_l - q_g = q_l$$

In normal operating condition, the active filter should be able to supply $p_f = \tilde{p}_l$ and $q_f = q_l$ and consequently capacitor voltage level is constant during the steady state and varies during transients. In order to control capacitor voltage level on the D.C. side of the inverter, is necessary to modify previous equation $p_f = \tilde{p}_l$.

A gain factor K, which is the ratio between p_g and $\bar{p}_l$ is introduced to control the proper amount of active power fed or drawn by the APF [4].

The instantaneous reference powers for the active filter are:

$$p_f^* = \tilde{p}_l + (1-\mathrm{K})\,\bar{\mathrm{p}}_l \qquad q_f^* = q_l$$

The optimum value for the k gain could be computed by a fuzzy inference system applied to the control of the D.C. voltage..

The compensation currents in α-β quantities are:

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -p_f^* \\ -q_f^* \end{bmatrix}$$

By performing the inverse transformation, three-phase compensation currents are obtained by:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}^T \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

The diagram of (p-q) algorithm, given in Fig. 2, shows the control circuit of the compensator.

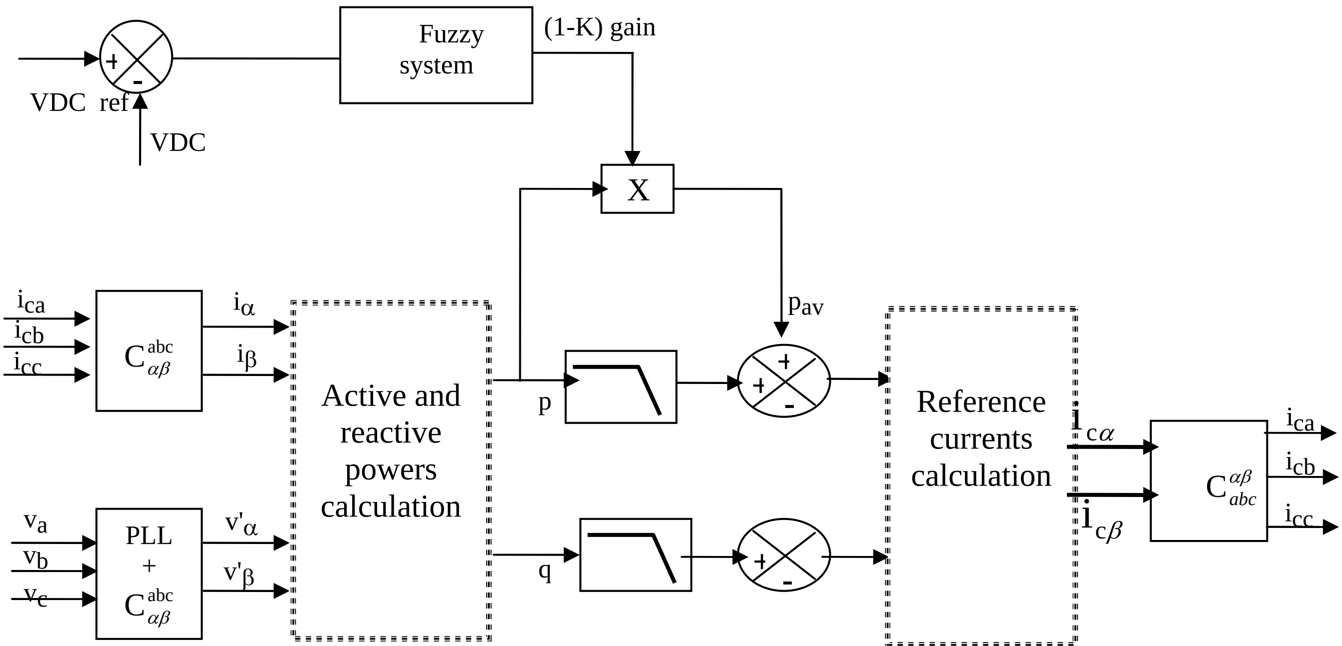

Fig. 2. Block diagram for the instantaneous active and reactive power theory

4. DC bus voltage control

The DC bus voltage control is done by using a fuzzy inference system in the object to generate the optimal gain K which determine a part of the power "(1-K) $\bar{p}$ " corresponding to the control of the DC voltage.

The aim value of K is quite near to unity; when k is above unity, more power is required from the mains than that required by the load. Power in excess is drawn by the active filter which lets the D.C. capacitor charge. The D.C. bus voltage decreases when K is below unity [5].

The optimum value of K gain is calculated by a fuzzy inference system, which receives as inputs the slope of D.C. average bus voltage and D.C. voltage error.

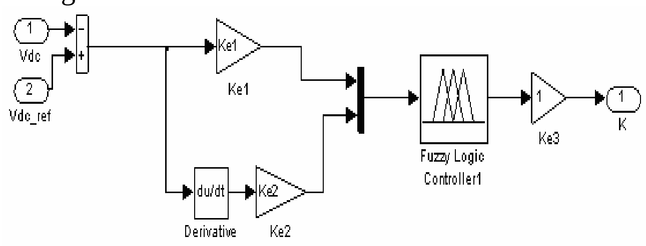

Fig. 3. K gain evaluated by Fuzzy system

Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is between -1 and 1 normalized unity.

Tacking into account that the value of K is quite near unity, we consider the range of the output weight membership function between 0.6 and 1.4.

We have chosen to characterize this fuzzy controller by seven and five sets respectively for the error and slope inputs. The output is defined by seven sets.

The D.C. voltage error normalized, the D.C. voltage slope normalized and the output weight membership functions are shown in Figures 4, 5 and 6.

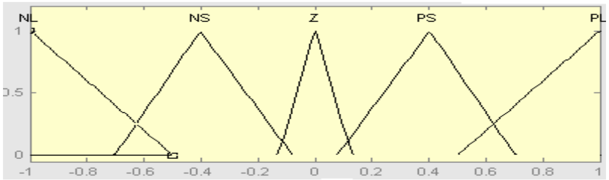

Fig. 4. D.C. voltage error normalized membership function

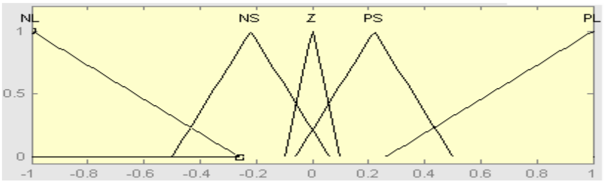

Fig. 5. D.C. voltage slope error normalized membership function

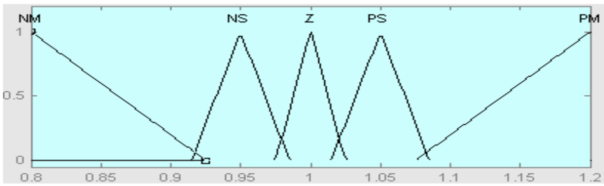

Fig. 6. Output weight membership functions for K gain value

The linguistic rules for the fuzzy logic controller are chosen, in most cases, depending only of the D.C. voltage error. These fuzzy rules, used in the object to maintain the K gain not too far from unity, are resumed in the table 1.

5. Fuzzy current control

To obtain the desired switching signals according to output inverter currents to follow the reference ones, a current control should be made by fuzzy logic controller.

The inputs variables for the necessary control action of active filter are the error and the rate change of error between the reference signal and the active filter output current.

The current control method used in this paper is related to fuzzy controller based PWM current controller. The switching signals are generated by means of comparing a carrier signal with the output of the fuzzy controller (Fig 7).

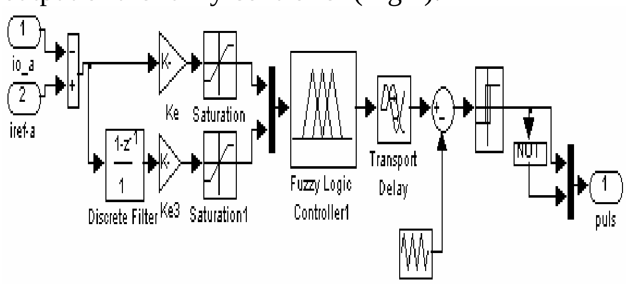

Fig. 7. PWM Fuzzy current control of each leg of the inverter

In this case, we have chosen to characterize the fuzzy controller by three fuzzy sets for each input and for the output. Their membership functions are shown in Figures 8, 9 and 10.

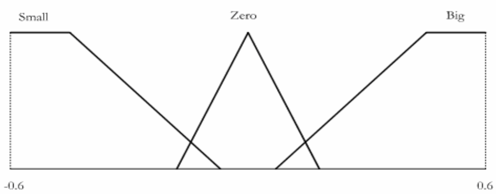

Fig. 8. D.C. voltage error normalized membership function

		D.C. voltage error				
		NL	NS	Z	PS	PM
D.C. voltage slope	NL			NS		
	NS			Z		
	Z	NM	NS	Z	PS	PM
	PS			Z		
	PL			PS		

Table 1. Fuzzy rules for D.C. voltage control

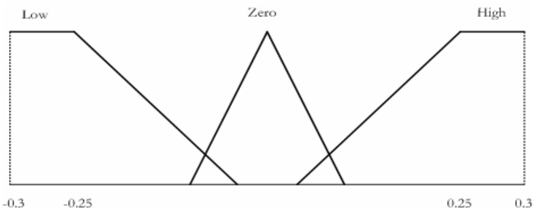

Fig. 9. D.C. voltage slope error normalized membership function

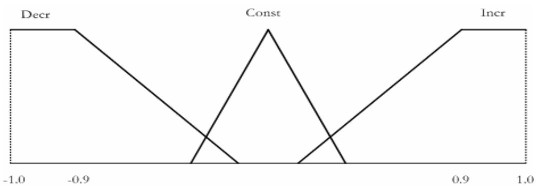

Fig. 10. Output weight membership functions for K gain value

6. Simulation results

Simulations were performed to show the effectiveness of the APF regulation by means of fuzzy controllers which control the DC bus voltage and the active filter output current to tack current reference.

A nonlinear load, consisting of a three phase diode based rectifier and an RL load in its DC side, is fed by sinusoidal and symmetrical mains phase voltages (115 Vrms, 50 Hz).

Figures 11 and 12 show the load's current without compensation (only one phase current is represented for the clearness) and its harmonics spectrum, respectively. It is shown clearly that the Total Harmonic Distortion (THD) is relatively high.

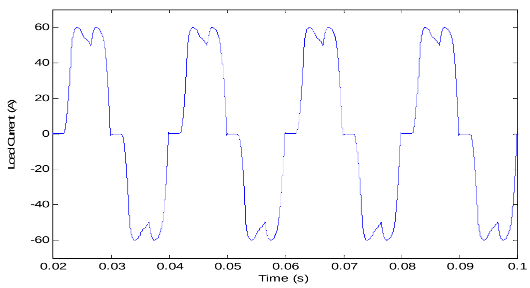

Fig. 11. Load current before compensation

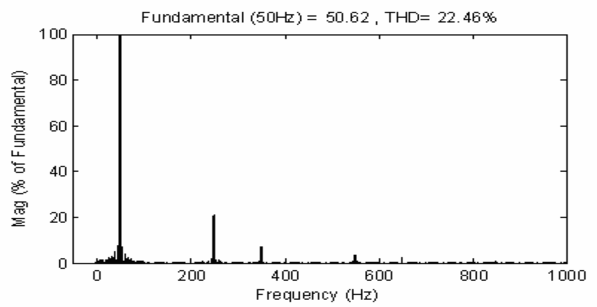

Fig. 12. Load current spectrum before compensation

The simulation results of the proposed control algorithm are presented in next figures. Thus, figure 13-a shows that the source current becomes closely sinusoidal and in phase with source voltage; the source power factor is then near unity. The THD is reduced from 22.4% to 0.7% as represented in figure 13-b.

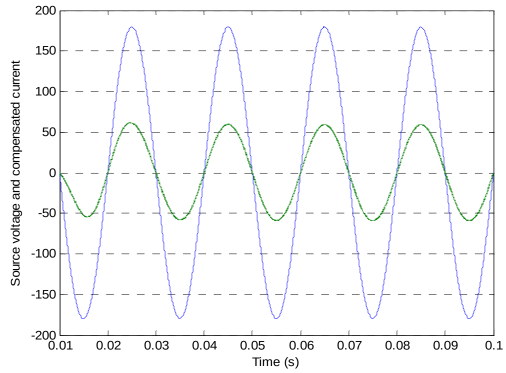

Fig. 13-a. Source voltage and compensated current

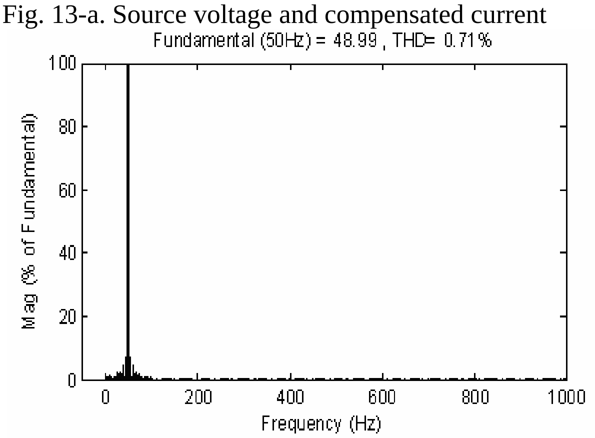

Fig. 13-b. Grid current spectrum after compensation

In figure 13-c, the VSI generated current tracks closely the reference current. Figure 13-d shows that the DC-link capacitor voltage is well regulated. In figure 13-e, the K gain progress rapidly to be close to 1.

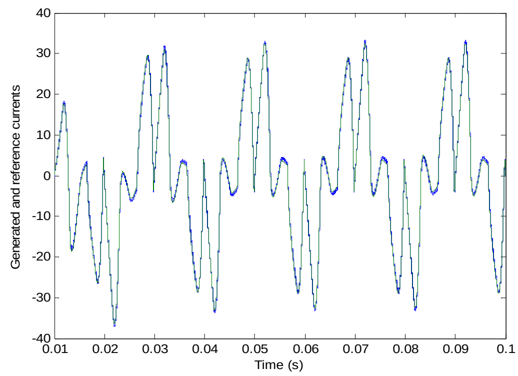

Fig. 13-c. Active filter output current

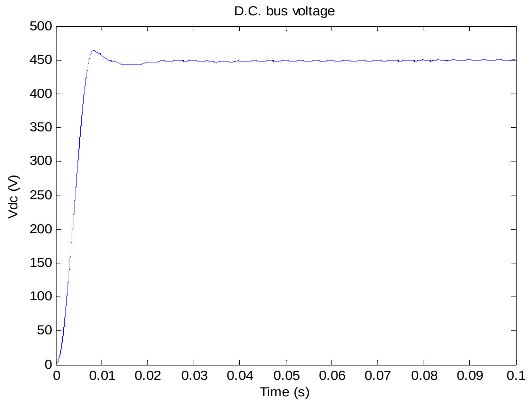

Fig. 13-d. DC voltage regulation

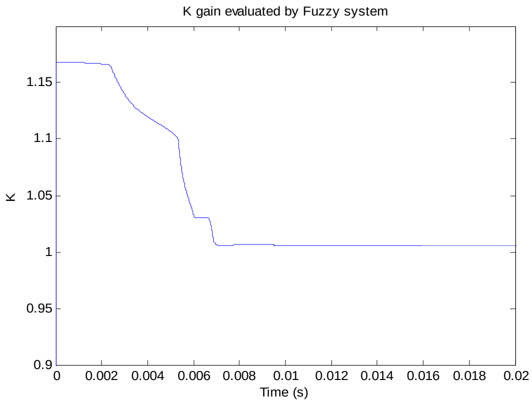

Fig. 13-e. K factor variation

To show the dynamics of the proposed control algorithm, a step change is made in the load. The result is presented in figure 14. It is obviously shown that the transient response time is nearly zero and so the dynamic of the controlled system is high.

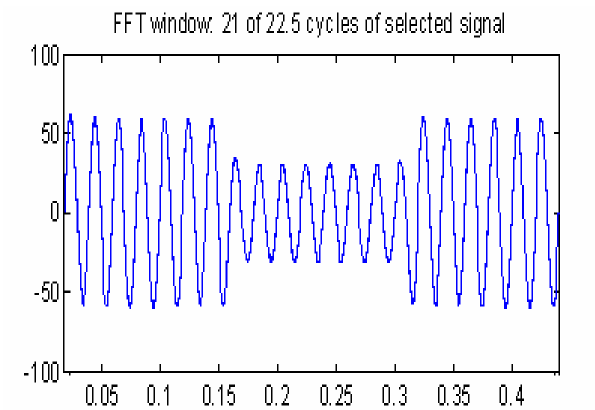

Fig. 14. Grid current transient response

7. Conclusion

We have presented, in this paper, a fully fuzzy logic control of a shunt active filter to compensate harmonics, produced in the case of a nonlinear load, and reactive power.

The reference current's identification is made by an adapted pq theory to be used in eventual voltage source perturbations. The control algorithm is adaptive; it does not take into account the system parameters like passive component values.

The first investigations, presented here, of the control algorithm prove its effectiveness and its high dynamics. It will be completed in a future work by considering a perturbed source voltage and a four wire system by unbalancing the nonlinear load.

8. References

1. Akagi, H., Kanazawa, Y., Nabae, A.: *Instantaneous reactive power compensators comprising switching devices without energy storage components.* In: IEEE Transactions on Industry Applications, Vol. IA-20, (1984), No. 3, May/June 1984, p. 625-630.
2. Abaali, H., Lamchich, M.T., Raoufi, M.: *Shunt active power filter control under non ideal voltages conditions.* In: International Journal of Information Technology, 2, (2005), No. 3, 2005, p. 164-169.
3. Aredes, M.: *Active Power Line Conditioners*, doctor engineer approved thesis D83, Berlin, 1996.
4. Liserre, M.: *Innovative control techniques of power converters for industrial automation*, doctor of philosophy degree, Politechnico di Bari, Italy, Department of Electrotechnic and Electronic, December 2001.
5. Dell'Aquila, A. Lecci, A.: *A current control for three-phase four-wire shunt active filters.* In Automatika 44 (2003), No 3-4, p. 129-135.