Experimental comparative study of FeedBack Linearized Controller and Proportional Integral (PI) Controller of the DC bus voltage of . three phase shunt Active Power Filter

Ismail Ghadbane, Mohamed Toufik Benchouia

Abstract –In This paper we present experimental comparative study of FeedBack Linearized and Proportional Integral (PI) Controller of the DC bus voltage of three phase shunt Active Power Filter (APF). The FeedBack Linearized and PI controllers are introduced to improve tracking performance characteristics, power quality and minimized consumption of the reactive power. The algorithm used to identify the reference currents is based on the Self Tuning Filter (STF). The firing pulses of the IGBTs inverter are generated using a hysteresis current controller; which is implemented on an analogue card. Finally, the above study, under steady state and transient conditions, is illustrated with signal-flow graphs and corresponding analysis. This study was verified by experimental tests on hardware prototype based on dSPACE-1104. The experimental results show the feasibility and the effectiveness of the designed active filter, associated with FeedBack Linearized and PI controllers and are capability in meeting the IEEE 519-1992 recommended harmonic standard limits.

Keywords – Harmonics, Shunt Active Filter, Feedback, Total Harmonic Distortion.

I. INTRODUCTION

The standard norms imposed by utilities force the users to comply with the harmonics injected into the network. Also, an adequate reactive power support is important to improve the electrical grid stability.

Some of the power quality problems can be solved by utilizing shunt active power filters [1]-[11]. However, the cost of shunt active filters is relatively high and they are not preferable for a large-scale system since the power rating of the shunt active filter is directly proportional to the load current to be compensated [12]-[21]. In addition, their compensation performance is better only under current harmonics type of loads than the voltage harmonics type. To reduce the system cost, a shunt hybrid power filter has been proposed and used [22]-[25]. Power electronics devices have been widely used in recent years; while they are convenient in use they cause several power pollutions just like electrical harmonics and low power factor. In high power systems, most electrical devices use three-phase symmetrical power system. But in medium and small power system, single-phase electronic equipments are widely used in domestic, educational and commercial appliances, such as computers, communication equipments and electronic lighting ballasts, etc. These equipments normally have a diode rectifier to convert ac electricity to dc and filter by a huge capacitor. These equipments behave like nonlinear loads, generating harmonics and cause electromagnetic compatibility problems. For the devices with an alternative input such as: rectifiers, Ac voltage controllers, indirect frequency converters..., the wave shape of the absorptive current of the network is non-sinusoidal. In addition to the fundamental component, this waveform presents harmonic contents which are, in certain cases, very important. These harmonics are propagated from the load towards the network and generate harmonic voltage drops which are added to the fundamental component of the voltage delivered by the network. The result is a form of affected wave, which contains also of harmonic contents; this affected wave can, as mentioned before, cause serious problems of electromagnetic compatibility. Many solutions have been studied in the literature to mitigate the harmonic problems, such as filtering (passive, active, and hybrid) with various topologies (shunt, series or both) [6] Industrial and domestic equipments actually use a large variety of power electronic circuits such as switch mode power converters, adjustable speed drives, rectifiers and dimmers. These ones lead to significant energy savings and productivity benefits. But unfortunately, they also present non-linear impedance to the supply network and destroying equipments and disturbances of communication equipments and precision instruments [1]. So, it is necessary to develop techniques to reduce all the harmonics as it is recommended in the IEEE 519-1992. The first approach consists in the design of LC filters. But, passive filters are not well adapted as they do not take into account the time variation of the loads and the network [1], [2]. They can also lead to resonance phenomena. The Active Power Filter (APF) can solve the problems of harmonic and reactive power simultaneously. The theories and applications of Active Power Filters have become more popular and have attracted great attention since two decades ago. Since its introduction some twenty years ago, the Active Power Filter (APF) presents a good solution for disturbance treatment, particularly for harmonic currents and/or voltages. APF is an up-to-date solution to power quality problems. The shunt APF allows the compensation of current harmonics and unbalance, together with the power factor correction, and can be a much better solution than the conventional approach (capacitors and passive filters)

The performance of the APF is determined by the kind of control used. It is more emphasized when the voltages of electrical network contain harmonics and/or are unbalanced. Moreover, the Self Tuning Filter STF is proposed for extracting harmonic currents instead of classical harmonics extraction based on High Pass or Low Pass Filters [4], [5]. The three phase currents/voltages are detected using current/voltage sensors. The inverter currents are controlled by using hysteresis comparators,. The hysteresis control is characterized by its simplicity and its intrinsic speed.. [1][3][7]

II. SYSTEM CONFIGURATION

Figure 1 presents the shunt active filter topology based on a three-phase voltage source inverter, using IGBT switches, connected in parallel with the AC three-phase system through three inductors L_f. the capacitor c is used in the Dc side to smooth the Dc terminal voltage. The nonlinear load is a three-phase diode rectifier supplying a RL load. This load generates harmonic currents in the supply system. The proposed control strategy can be divided into two parts. The first part is the harmonic isolator

Ismail Ghadbane is with the Department of Electrical Engineering, M'sila University, Algeria. Mohamed Toufik Benchouia is with the Laboratory L.G.E.B., Department of Electrical Engineering, Biskra University, Algeria

(reference current generation). It consists in generating the harmonic current references and uses STF instead of HPF or LPF usually used in the classical instantaneous real and imaginary power theory, first proposed by H. Akagi [5]. This harmonic isolator will be implemented into a DSPACE system (ds1104 prototyping card) in the experimental study.

The second part is the current control of the power converter. This controller generates the suited switching pattern to drive the IGBTS of the inverter by using a modulated hysteresis current controller. In the experimental study, this controller is implemented into an analogue card.

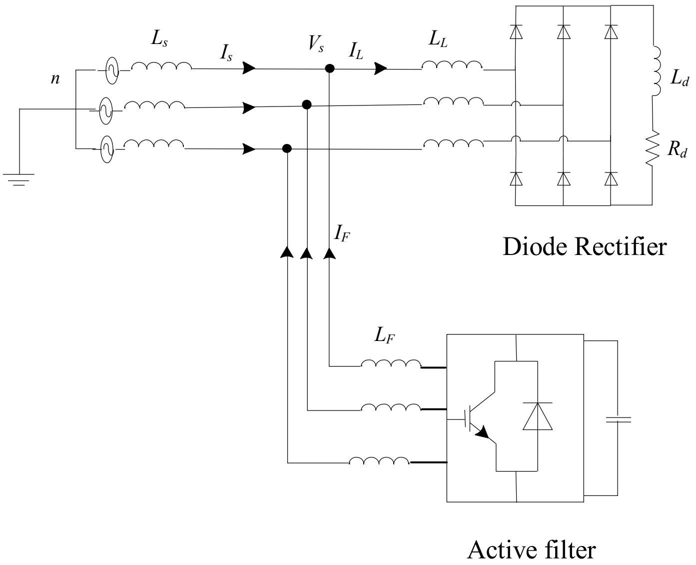

Fig 1. Power System Configuration.

Fig.2 presents the schematic diagram of the three-phase active power filter and the associated control strategy for harmonic mitigation. The filter is connected in parallel with the mains. The non-linear load is a three-phase diode rectifier feeding a RL load. As mentioned above, the control method is divided into two parts. The first one consists in the harmonic isolator implemented into a DSPACE DS1104 development board. The second part is the analogue hysteresis current controller, developed in our laboratory.

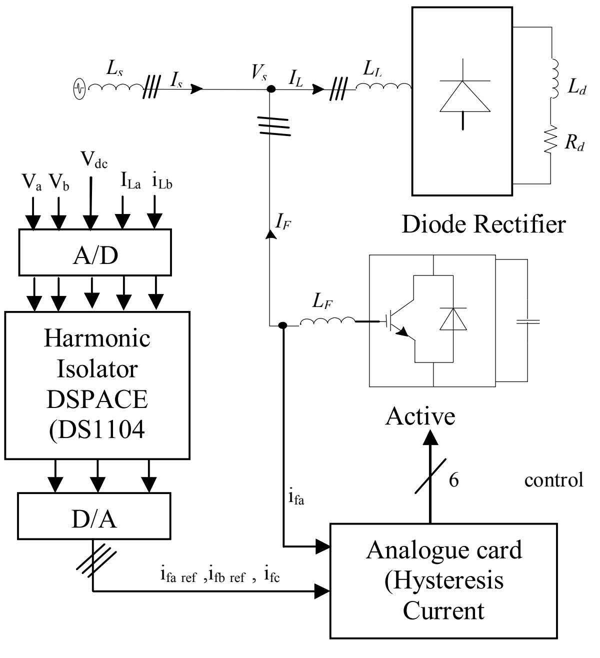

Fig 2. Experimental System

III. HARMONIC ISOLATION

Akagi [1] proposed a theory based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms called as Instantaneous Power Theory or Active- Reactive (p-q) Theory which consists of an algebraic transformation (Clarke Transformation) of the three-phase voltages in the a-b-c coordinates to the α-β coordinates, followed by the calculation of the p-q theory instantaneous power components by eliminating the DC component of the instantaneous active power (corresponding to the fundamental component of load current) using a selective Filter STF, so the harmonic components can be identified. Figure 3 shows the modified scheme for the identification of reference currents during simultaneous compensation of harmonic currents and reactive power using the method of instantaneous power by using STF

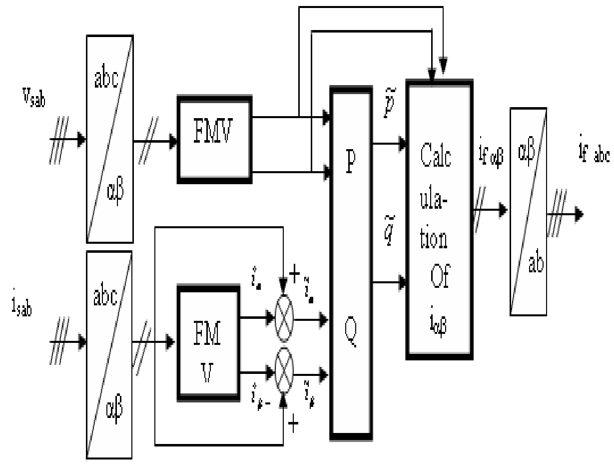

Fig. 3: The Method of Instantaneous Active and Reactive Power

This method is based on measuring the instantaneous three-phase variables present on the grid with or without zero-sequence components. This method is valid both in steady-state phase. In this control algorithm (Figure 2), measurements of voltages and currents expressed as a three phase (abc) are converted to two-phase system (α-β) is equivalent to using the transform from Concordia leaving the power invariant:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{LC} \end{bmatrix} \tag{2}$$

In the presence of harmonics, the power is composed of three parts: active (P) reactive (Q) and deformed (D) as shown by the following equation:

$$S = \sqrt{P^2 + Q^2 + D^2} \qquad (3)$$

The instantaneous active power, denoted P (t) is defined by the following equation:

$$P(t) = v_{sa} i_{sa} + v_{sb} i_{sb} + v_{sc} i_{sc} \qquad (4)$$

Can be written in the stationary reference:

$$P(t) = v_{s\alpha} i_{s\alpha} + v_{s\beta} i_{s\beta} \qquad (5)$$

Similarly, the instantaneous imaginary power can be written as follows:

$$q(t) = -\frac{1}{\sqrt{3}}[(v_{sa} - v_{sb}) i_{lc} + (v_{sb} - v_{sc}) i_{la} + (v_{sc} - v_{sa}) i_{lb} = v_{s\alpha} i_{l\beta} - v_{s\beta} i_{l\alpha} \qquad (6)$$

Q power a broader meaning than the usual reactive power. In fact, unlike the reactive power, which considers only the fundamental frequency, the imaginary power takes into account all the harmonic components of current and voltage that is why it is given a different name (imaginary power) as a unit with the volt-ampere imaginary (VAI).

The part of the relations (5) and (6), we can establish the following matrix:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{S\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} i_a \\ i_\beta \end{bmatrix} \qquad (7)$$

In the general case, each of the powers p and q has a continuous part and part alternative, which allows us to write the following expression

$$\begin{cases} P = \overline{P} + \widetilde{P} \\ q = \overline{q} + \widetilde{q} \end{cases} \qquad (8)$$

with: $\overline{P}$ Continuous power related to the fundamental component of active power and voltage, $\overline{q}$ Continuous power related to the fundamental component of reactive current and tension, $\widetilde{p}$ *and* $\widetilde{q}$ Powers of alternatives related to the sum of the components of disruptive current and voltage.

By inverting the relation (7), we can recalculate the currents in the coordinate α β as shown in the following equation

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_{s\alpha}^2 + v_{s\beta}^2} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \qquad (9)$$

Considering equations (8) and (9), we can separate the current benchmark in the three components, active and reactive at the fundamental frequency and harmonics.

Finally, it is easy to obtain the reference currents along the axes *abc* by the inverse transformation of Concordia

$$\begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \widetilde{P} \\ \widetilde{q} \end{bmatrix} \qquad (10)$$

$$\begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} \qquad (11)$$

The self tuning filter is the most important part of this control which allows to make insensible the PLL to the disturbances and filtering correctly the currents in α-β axis. Hong-Scok Song [6] had presented in his PhD work how recovered the equivalent transfer function of the integration expressed by The block diagram of the STF tuned at the pulsation ωc is shown in the figure 5. The transfer function of this filter is:

$$H(s) = \frac{\hat{i}_{a\beta}(s)}{i_{a\beta}(s)} = K \frac{(s+K) + j\omega_c}{(s+K)^2 + \omega^2_c} \qquad (12)$$

According to the α-β axes, the expressions linking the components FMV output $x_{\alpha\beta}$ to input $x_{\alpha\beta}$ components are:

$$\hat{x}_a = (\frac{K}{s}[x_a(s) - \hat{x}_a(s)] - \frac{\omega_c}{s}\hat{x}_\beta(s)) \qquad (13)$$

$$\hat{x}_\beta = (\frac{K}{s}[x_\beta(s) - \hat{x}_\beta(s)] - \frac{\omega_c}{s}\hat{x}_\alpha(s))$$

We obtain the following block diagram for STF

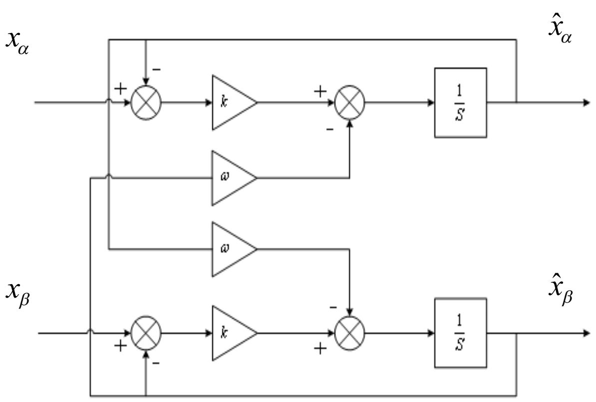

Fig 4. Self Tuning Filter

IV. NON-LINEAR CONTROLLER SYNTHESIS

The dynamic equations of the active filter in the stationary reference are given by:

$$\begin{cases} \dfrac{dV_{dc}}{dt} = \dfrac{p^*_{dc}}{C_{dc}V_{dc}} \\ \dfrac{di_{fa}}{dt} = -\dfrac{R_f}{L_f} i_{fa} + \dfrac{V_{fa} - V_{s\alpha}}{L_f} \\ \dfrac{di_{f\beta}}{dt} = -\dfrac{R_f}{L_f} i_{fa} + \dfrac{V_{f\beta} - V_{s\beta}}{L_f} \end{cases} \quad (14)$$

In this control strategy, we have three outputs to regulate.

I- *Subsystem 1*

The equation describing this subsystem is:

$$\frac{dV_{dc}}{dt} = \frac{p^*_{dc}}{C_{dc}V_{dc}} \quad (15)$$

The first sub-system of order 1, is characterized by its state, $x = V_{dc}$ and its control: $u = P_{dc}$ We can write the equation as follows:

$$\dot{x} = f(x) + g(x)u \quad (16)$$

$$f(x) = 0 \quad and \quad g(x) = \frac{1}{C_{dc}V_{dc}}$$

II-*Subsystem 2:*

The equation describing this subsystem is:

$$\begin{cases} \dfrac{di_{fa}}{dt} = -\dfrac{R_f}{L_f} i_{fa} + \dfrac{V_{fa} - V_{s\alpha}}{L_f} \\ \dfrac{di_{f\beta}}{dt} = -\dfrac{R_f}{L_f} i_{fa} + \dfrac{V_{f\beta} - V_{s\beta}}{L_f} \end{cases} \quad (17)$$

The second sub-system of order 2, is characterized by its vector state $x = \begin{bmatrix} i_{f\alpha} & i_{f\beta} \end{bmatrix}^t$ and vector control is

$u = \begin{bmatrix} v^*_{f\alpha} & v^*_{f\beta} \end{bmatrix}^t$ We can write the system of equations (17) under the form: $\dot{x} = f(x) + g(x)u$ When :

$$f(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \end{bmatrix} = \begin{bmatrix} -\dfrac{R_f}{L_f} i_{fa} - \dfrac{1}{L_f} v_{s\alpha} \\ -\dfrac{R_f}{L_f} i_{f\beta} - \dfrac{1}{L_f} v_{s\beta} \end{bmatrix} and\, g(x) = \begin{bmatrix} \dfrac{1}{L_f} & 0 \\ 0 & \dfrac{1}{L_f} \end{bmatrix} \quad (18)$$

Now we will apply the state feedback control on models (17) and (18)

V. DC VOLTAGE CONTROLLERS SYNTHESIS

The voltage regulation V_{dc} is provided by the subsystem1. To achieve this object requires we must choose $y=V_{dc}$ as output, then, we seek its relative degree.

$$\begin{aligned} y &= V_{dc} = h(x) \\ \nabla h &= \frac{\partial h}{\partial x} = \frac{\partial V_{dc}}{\partial V_{dc}} = 1 \end{aligned} \quad (19)$$

Its derivative is given by:

$$\dot{y} = \frac{\partial h}{\partial x}\dot{X} = \frac{\partial h}{\partial X} = (f(x) + g(x)u) \quad (20)$$

And as Lie derivatives, we write:

$$\dot{y} = L_f h(X) + L_g h(X)u \quad (21)$$

With:

$$L_f h(X) = 0 \quad , \; L_g h(X) = \frac{1}{C_{dc}V_{dc}}$$

It follows that:

$$\dot{y} = \frac{1}{C_{dc}V_{dc}} P^*_{dc} \quad (22)$$

The law of order is expressed by:

$$P_{dc}^{*} = \frac{1}{L_g h(x)}(-L_f h(x) + v) = C_{dc} V_{dc} v \quad (23)$$

$$v = k_v (V_{dc}^{*} - V_{dc}) + \frac{d}{dt} V_{dc}^{*} \quad (24)$$

$$v = k_v (V_{dc}^{*} - V_{dc}) \quad (25)$$

6. PI DC Voltage Control

Fig. 5 shows the block diagram of the proposed PI control scheme for the active power filter.

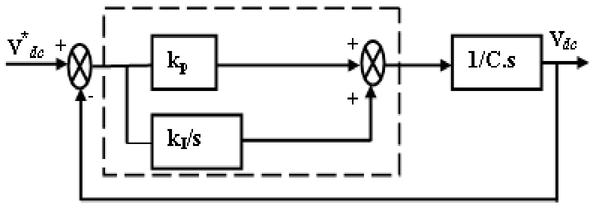

Fig. 5. Scheme with PI controller of the DC-link voltage.

The DC side capacitor voltage is sensed and compared with a reference voltage. This error e =V*dc −Vdc at the nth sampling instant is used as input for PI controller. Its transfer function is represented as where, KP =0.5 is the proportional constant that determines the dynamic response of the DC-side voltage control and KI =50 is the integration constant that determines it's settling time. The proportional integral controller is eliminating steady state error in the DC-side voltage. The PI controller for the DC-link voltage sets the amplitude of the active current of the APF inverter to regulate the DC-link voltage based on its reference value covering the inverter losses. Subtracting the measured load current, the reference value of the APF current is obtained.

$$H(s) = K_P + \frac{K_I}{s} \quad (26)$$

The DC-link capacitor will be charged or discharged by the difference of the active load current and grid current, forcing the PI controller to change its output correspondingly, until both active currents are equal. In this way, the APF will compensate all non active components of the load current and regulate the DC-link voltage of the APF.

VII. EXPERIMENTAL RESULTS

The complete active filter system is composed mainly of a three-phase source, a nonlinear load, a hysteresis current and a PI and/or Non linear controller. We study the robustness of the non linear and PI controllers using experimental results for different operating modes. The test bench used for the experiment is presented in Fig. 6. The input step-down transformer (10.60KVA) is connected to the mains (380 V line to line) and delivers a lumped voltage of 220 V. The three-phase parallel active filter is achieved with a voltage source inverter. This VSI contains a three-phase IGBT 1200V, 50A (SKM 50 GB 123D). To ensure the dead time of control signals and the insulation, developed cards based on the IXDP630 component and specialized circuits (SKHI 22) are used.

The performances of non linear controller of the DC bus voltage of three phase shunt active power filter are compared to conventional PI regulator by extensive experimentation for various operating conditions and parameters variation.

First experimentation is done on fixed load, we observe that the DC-voltage is regulated well around the reference V*dc = 420 V. The mains current has a sinusoidal form and in phase with supply voltage (see Fig.7), witch minimizes the reactive power consumed by the inverter. It is confirmed for the two controllers in permanent response.

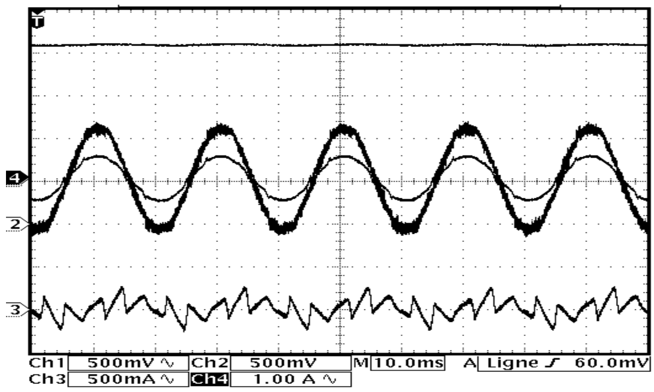

Fig. 6. Experimental results with AFC: filter current i_F (A), source current i_S (A) , source voltage Vs (V) and DC voltage V_{dc} (V). Ch3 and Ch4 scale: 5 A/div; Ch2 scale: 100 V/div; Ch1 scale: 80 V/div; Time scale: 10 ms/div.

Second, to prove the dynamical response of the controllers at a transient condition, the DC side resistance is changed from RL to RL/2 at. It can be see that the voltage controlled by the feedback linearized at Fig.7 joined quickly his reference compared to the voltage regulated by the PI in Fig8, witch minimized the current harmonics.

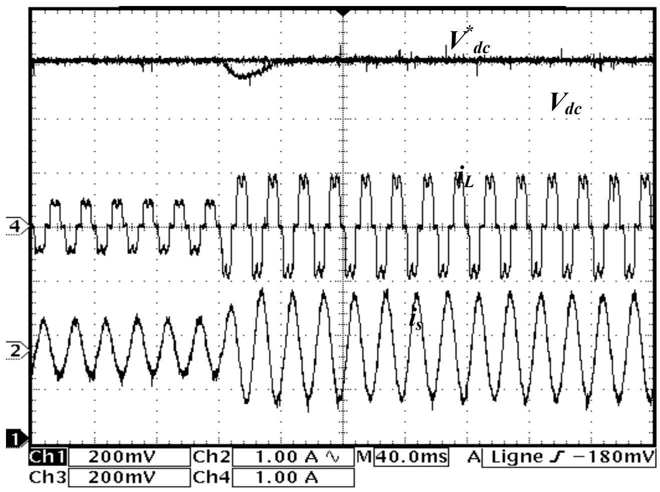

Fig. 7. Experimental APF results with Feedback linearized: load current i_L (A), source current i_S (A), DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V).Ch1 and Ch2 scale: 5 A/div; Ch3 and Ch4 scale: 40 V/div. Time scale: 40 ms/div.

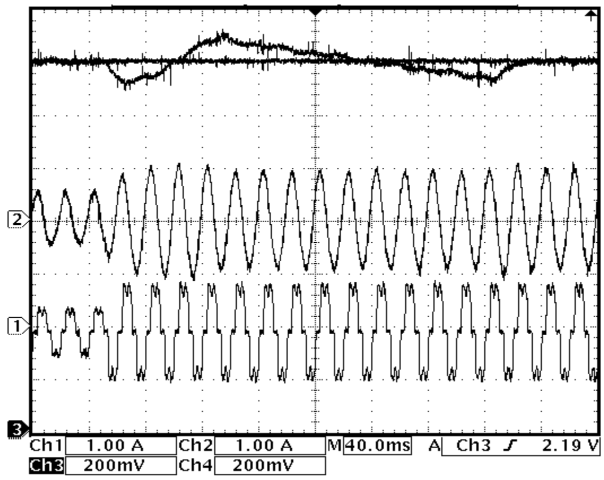

Fig. 8. Experimental APF results with PI: load current i_L (A), source current i_S (A), DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V). Ch1 and Ch2 scale: 5 A/div; Ch3 and Ch4 scale: 40 V/div. Time scale: 40 ms/div.

Finally, to confirm the effectiveness of the control of DC voltage using AFC, two tests have been performed:

First, we fixed the reference voltage at the value V^*_{dc} = 450V and the filter is switched; Fig. 9 and 11 show, the results of the DC voltage link, after a transient response due to the charging capacitor (the capacitor was been charged initially at 210V), that the DC-voltage is regulated well around the reference V^*_{dc} = 450 V. It clear that the response voltage with PI regulator in transient response is affected considerably (there is big overshoot) compared with to voltage response with the Feedback linearized controller.

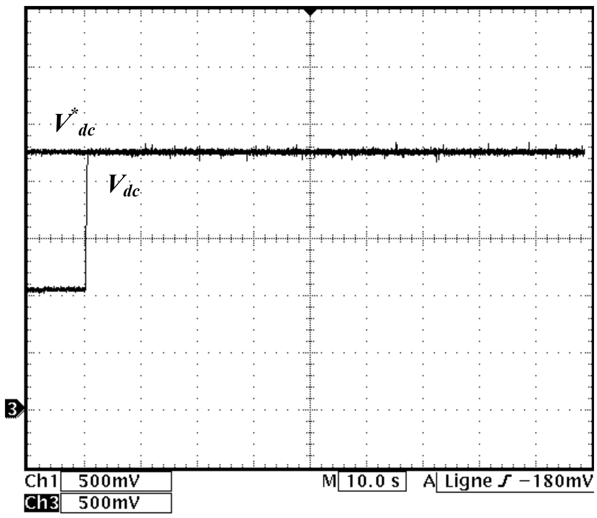

Fig.9. Experimental APF results with Feedback linearized DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V),Ch3 and Ch4 scale: 100 V/div. Evaluation of the gain G_I of AFC, Ch2 5A/div. Time scale:10s/div.

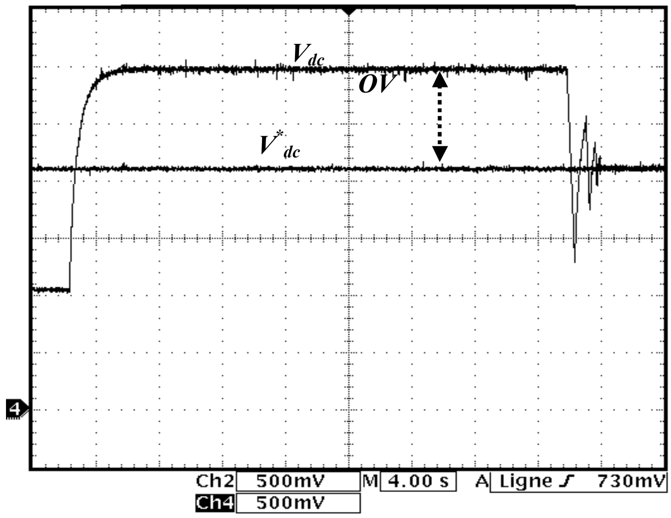

Fig. 10.Experimental APF results with PI: DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V),Ch2 and Ch4 scale: 100 V/div. Time scale: 4 s/div.

Second, a double change of the reference is shown 450-300 and 450V. It can be noted that after the transient response, the DC voltage regulated by the SMC follows its reference, there is no overshoot and the settling time is very small (see Fig. 11. and 12.). However the results obtained by the PI controller show oscillations around V^*_{dc} and a voltage overshoot in transient response.

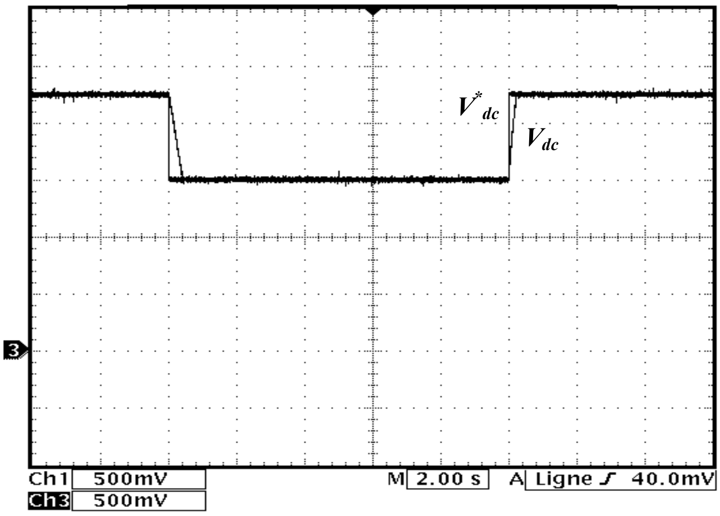

Fig.12. Experimental APF results with Feedback linearized: DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V),Ch3 and Ch4 scale: 100 V/div,Time scale: 2s/div.

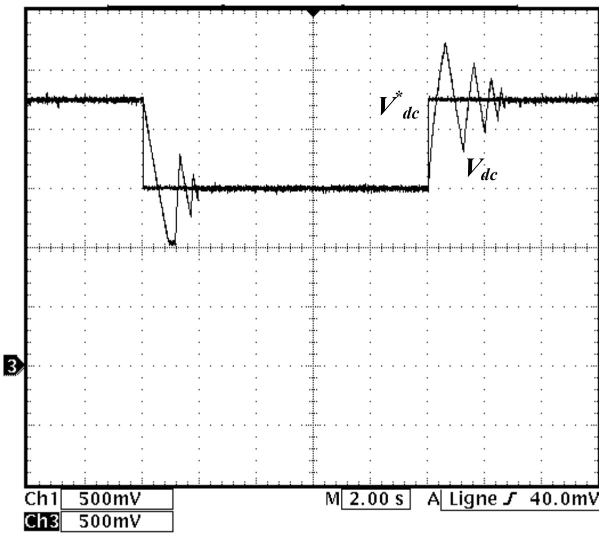

Fig.12. Experimental APF results with PI: DC voltage V_{dc} (V) and DC reference voltage V^*_{dc} (V),Ch1 and Ch3 scale: 100 V/div, Time scale: 2s/div.

APPENDIX

The experimental test bench parameters are:

Parameters Source	Voltage (V_m) = 120 V Frequency (f) = 50 Hz Resistance (R_S) = 0.42 Ω Inductance (L_S) = 2.3 mH
Parameters load	Resistance (R_l) = 45 Ω Inductance (L_l) = 1.3 mH
Parameters filter	DC link capacitor C = 110 µF DC link voltage V^*d_C = 420 Inductance (L_C) = 0.8 mH Hysteresis band Δi = 0.2 A

VIII. CONCLUSION

In this work, we have shown the effectiveness of the shunt active power filtering especially with the application of FeedBack Linearized control and with the application of the Synchronous reference frame based compensator. The THD of the source current and source voltage after compensation is well below 5%, the harmonics limit imposed by the IEEE-519 standard. Further studies will examine the opportunity of implementing a high frequency output filter with the three- phase inverter and the power factor was corrected (power supply voltage and current became in phase). This paper has discussed the control and performances of a shunt active power filter. The hardware implementation has been performed based on the reference current generation. The control of the active filter was divided in two parts, the first one realized by the DSPACE system to generate the reference currents and the second one achieved by an analogue card for the switching pattern generation, implementing a hysteresis current controller. STFs have been introduced in the proposed modified version of the p-q theory instead of classical extraction filters (high pass and/or low pass filters) for both grid voltages and load currents. The use of this filter experimentally leads to satisfactory performances since it extracts the harmonic currents at high performances. For the current controller, we implemented the hysteresis current. The experimental results have demonstrated and confirmed the effectiveness of using Feedback linearised controller in the filter control then the PI controller.

References

[1] S.Beaulieu, M. Ouhrouche " real-time modelling and simulation of an active power filter " IASTED International Conference on Power and Energy Systems PES 2007, Clearwater, Florida, U.S.A.

[2] Mohamed Abdusalam, Philippe Poure and Shahrokh Saadate "Control of Hybrid Active Filter Without Phase Locked Loop in the Feedback and Feedforward Loops" ISIE, IEEE International Symposium on Industrial Electronics, Cambridge, UK, (2008).

[3] Abdelmadjid Chaoui ,Fateh Krim Et Laurent Rambault"Filtrage Actif Triphase Pour Charges Non Lineaires " Ph.D. Thesis university of Setif 2010.

[4] Lorenzo Marconi, Fabio Ronchi, Andrea Tilli "Robust nonlinear control of shunt active filters for harmonic current compensation" Automatica 43 (2007) 252 – 263

[5] Mohamed Abdusalam, Philippe Poure and Shahrokh Saadate "Control of Hybrid Active Filter Without Phase Locked Loop in the Feedback et Feedforward Loops"

[6] Abdelmadjid Chaoui , Jean-Paul Gaubert Fateh Krim , Laurent Rambault "IP Controlled Three-Phase Shunt Active Power Filter for Power Improvement Quality " 1-4244-0136-4/06/ 2006 IEEE.

[7] M. Sc. Mariusz Malinowski "Sensorless Control Strategies for Three Phase PWM Rectifiers" Ph.D. Thesis, Warsaw University of Technology 2001.

[8] Abdelmadjid Chaoui ,Fateh Krim Et Laurent Rambault "techniques de commande predictive et floue Pour les systemes d'electronique de Puissance: application aux redresseurs a mli" Ph.D. Thesis university of setif 2010

[9] B. N. Singh, B. Singh,A. Chandra, K. Al-Haddad, "Digital implementation of fuzzy control algorithm for shunt active filter" European Transactions on Electrical Power Volume 10, Issue 6, pages 369–375, November/December 2000.

[10] K. Hasan, and K. Osman, "Globally Stable Control of Three-Phase Three Wire Shunt Active Power Filters," Elec. Eng., vol. 89, no.5, 2007, pp. 411-418.

[11] Allag, M. Y. Hammoudi, S. M. Mimoune, S. " Adaptative backstepping voltage controller design for an PWM AC-DC converter"international journal of electrical and power engineering 1 (1): 62-69, 2007

[12] V. S. C. Raviraj and P. C. Sen "Comparative Study of Proportional–Integral, Sliding Mode, and Fuzzy Logic Controllers for Power Converters" IEEE Tran Industry Vol 33, No. 2, March/Appl-1997..