INTERNATIONAL CONFERENCE ON SYSTEMS AND PROCESSING INFORMATION
May 12-14, 2013, Guelma, Algeria

COMPARATIVE STUDY OF BACKSTEPPING AND PROPORTIONAL INTEGRAL CONTROLLER TO COMPENSATING CURRENT HARMONICS

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ABSTRACT* – This paper presents and compares the performance of two control techniques namely backstepping and Proportional Integral PI applied to a voltage source inverter operating as an active power filter. The controller permit to compensate harmonics and reactive power generated by the non-linear load simultaneously. This work is performed in order to make an accurate comparison of backstepping controller and classical control technique such as PI controller. The backstepping controller . The obtained results show the backstepping controller is performing much better than the PI controller over a wide operating *range.

KEYWORDS – Harmonics, shunt active filter, Backstepping, total harmonic distortion

1. INTRODUCTION

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]

2. SHUNT ACTIVE FILTER STRUCTURE

Fig.1 presents the schematic diagram of the three- phase active power filter and the associated control strategy for harmonic mitigation

The power part is composed of an inverter, a filter of coupling Rf Lf and a capacitive element used as source of energy for APF. This element must provide a voltage of quasi-constant value. The fluctuation of this voltage must be weak. The other part is used for commutation control of the Semiconductor elements of the inverter in power part. By means of control strategies well adapted, it is possible to generate harmonic signals in the output of the inverter, which are used to compensate those present in the distribution network.

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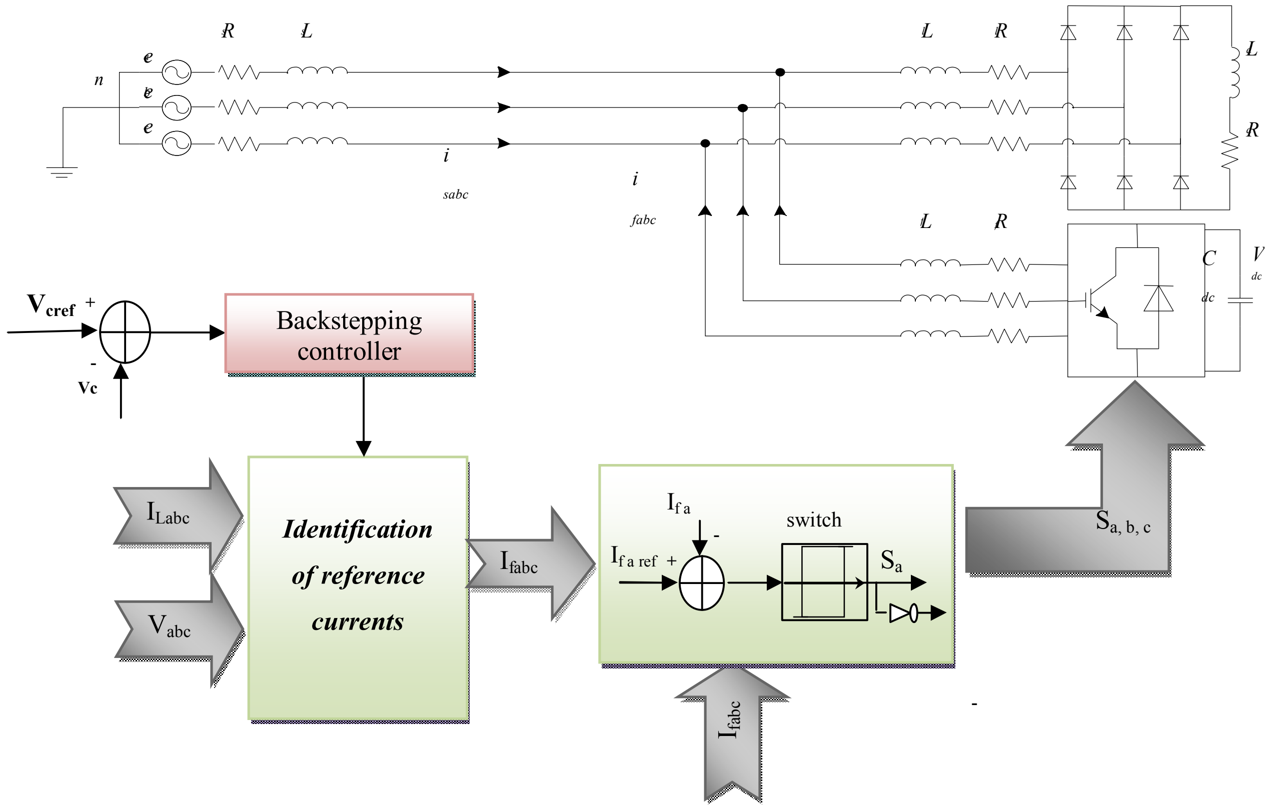

Figure.1 -Network and shunt active filter presentation

3-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

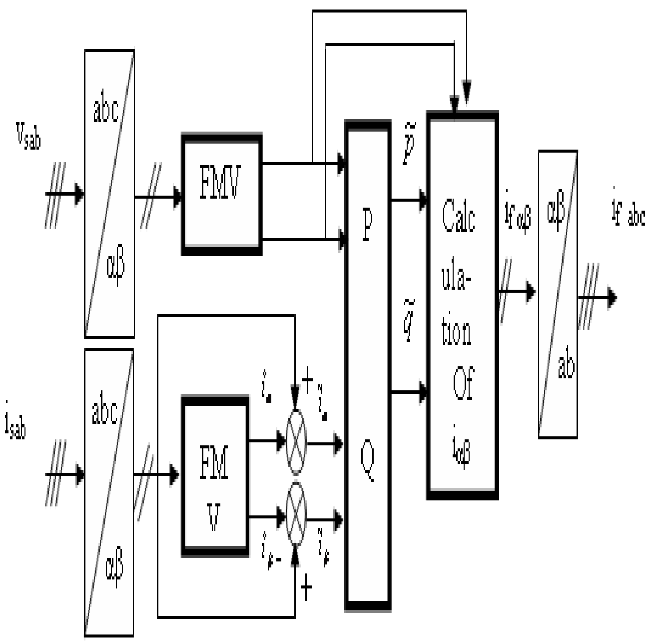

Figure. 2: The method of instantaneous active and reactive power

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:

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

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

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:

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

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

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

Can be written in the stationary reference:

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

Similarly the instantaneous imaginary power can be written as follows:

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

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 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:

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

n 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

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

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 Equation

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

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

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

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

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

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:

$$H(s) = \frac{\hat{i}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = K \frac{(s+K) + j\omega_c}{(s+K)^2 + \omega_c^2} \quad (12)$$

According to the α-β axes, the expressions linking the components FMV output . to input $\hat{x}_{\alpha\beta}$ xαβ components are:

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

We obtain the following block diagram for STF

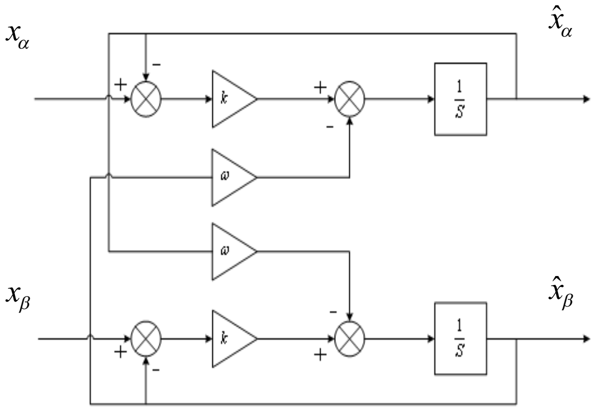

Figure.3 - block diagram for STF

4 . BACKSTEPPING CONTROLLER SYNTHESIS

The PI controller requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances, etc. Recently, backstepping controllers have received a great deal of interests in APF. When deriving a control law using backstepping many variations can be done. Among other opportunities this enables the designer to benefit from useful non-linearities. With useful means that the nonlinear terms naturally stabilizes the system[9] [10].

In the first step, new variables are introduced. The first virtual variable z1 is the control error defined as:

$$Z_1 = V_{dc}^* - V_{dc} \qquad (14)$$

Its derivative is:

$$\dot{Z}_1 = \dot{V}_{dc} - \dot{V}_{dc} \qquad (15)$$

$$Z_1 = V_{dc}^* - \frac{P_{dc}^*}{V_{dc} C_{dc}} \qquad (16)$$

The Lyapunov function is chosen as:

$$V_1 = \frac{1}{2} Z_1^2 \qquad (17)$$

Its derivative is :

$$\dot{V}_1 = Z_1 \dot{Z}_1 = Z_1 \left[\dot{V}_{DC}^* - \frac{P_{DC}^*}{V_{DC} C_{DC}} \right] \qquad (18)$$

For the derivative of the Lyapunov function is negative, we must choose between the term brackets as:

Where we can write the command as:

$$P_{dc}^* = V_{dc} C_{dc} (\dot{V}_{dc}^* + k_1 z_1) \qquad (20)$$

In case the reference voltage is chosen as a constant, its derivative will be zero and command will be:

$$P_{dc}^* = k_1 V_{dc} C_{dc} z_1 \qquad (21)$$

5.Control strategy

The control signals needed in semiconductors commutation are carried out from the technique of hysteresis band current control, which is the most suitable for all the applications of current controlled voltage source inverter in active power filters. This method has the advantages of good stability, fast response time and good precision. Fig.3 shows the principle of the hysteresis band current controller for three phase system. The hysteresis band current controller decides the switching pattern of APF. Each violation of this band gives an order of commutation.

This control system is also characterized by a variable frequency of commutation. The hysteresis techniques have also a few undesirable features such as uneven switching frequency that causes acoustic noise and difficulty in designing input filter [1].

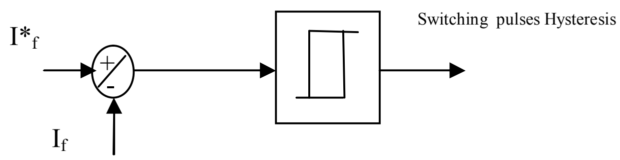

Figure.4 - Hysteresis band current controller

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6 . Simulation results and discussions

Some simulation results using model in Matlab-Simulink and SimPower System Blockset are presented. The harmonic current and reactive power compensated by APF implemented in three- phase power systems with the utility power supply voltage of 100V and current source three-phase diode-bridge rectifier with R-L loads as the current compensation object. The design specifications and the circuit parameters used in the simulation are parameters are used for simulation: V_S = 50 V (rms), R_S = 0.1 Ω, L_S = 0.566 mH, R_C = 0.01 Ω, L_C = 1 mH, R_{d1} = 26.25 Ω and R_{d2} = 17 Ω, L_d= 1 mH, V_{dr} = 140 V, C = 1100 µF, HB (hysteresis band) =0.1

To study the performance of the APF, first simulation is done on fixed load (R_{L1} & L_L) and the filter is switched on at 0.12s.

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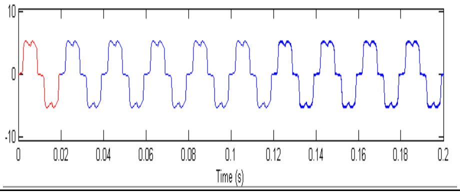
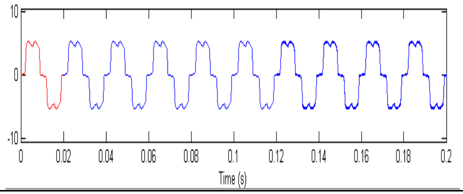
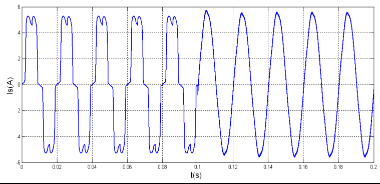
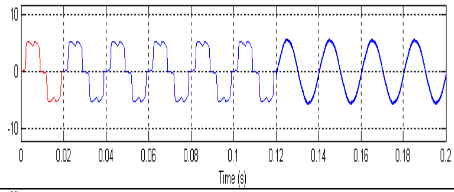
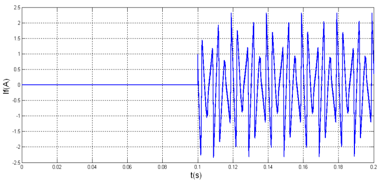
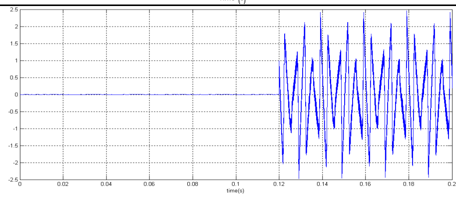
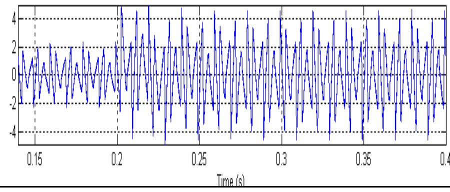
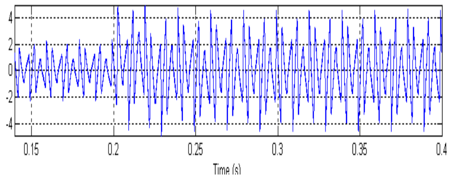
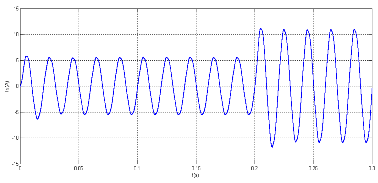
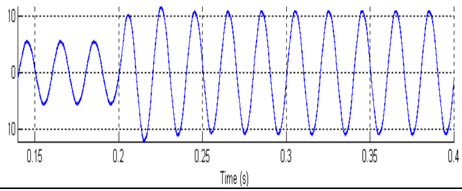
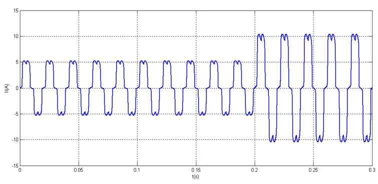
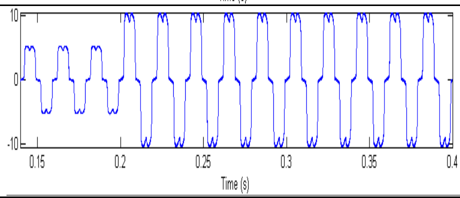
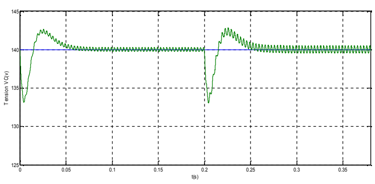
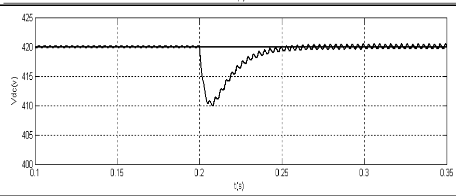
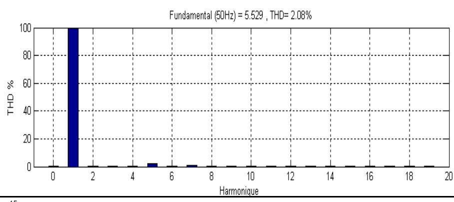
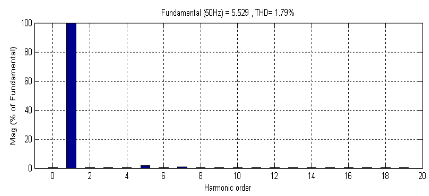
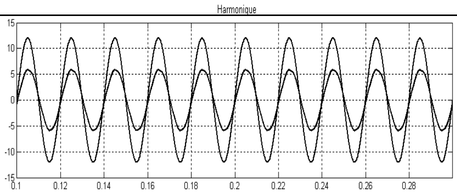
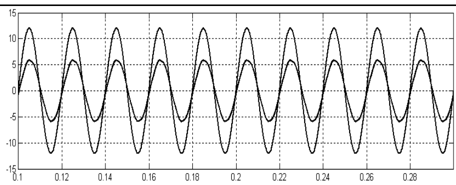
Reference	With PI	With Backstepping
Load current		
Supply current during the change of the load		
compensator current		
Compensator Current during the change of the load		
Supply current during the change of the load		
Load current during the change of the load		
dc bus during the change of the load		
Harmonics spectra of line current		
SUPPLY voltage and current		

7 .Comparative study:

7.1.Influence parameters on the THD by different technique:

The performances of the active filter depend on the type of order implemented as well as parameters of the system.¶In this part, We will study the influence on the THD of the following parameters:¶ inductance of Lf and band of hysteresis

7.2.Variation of the inductance of decoupling

This paragraph illustrates the influence of the inductance of decoupling on the THD of the current of source.For that, we fix the reference voltage standard *Vdc* (140V).The following figure shows that an increase in this inductance generates a reduction in the THD

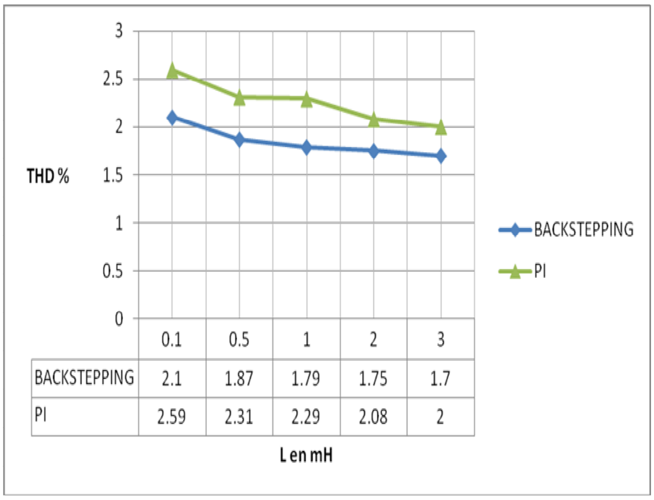


Figure. 5. Influence *Lf inductance* on the THD

C..*Variation of the bandwidth of hysteresis*

Figure VI. presents the influence of the bandwidth of hysteresis on the THD of the currents of source. a control by hysteresis at variable frequency where the THD increases appreciably with the increase in the band of hysteresis

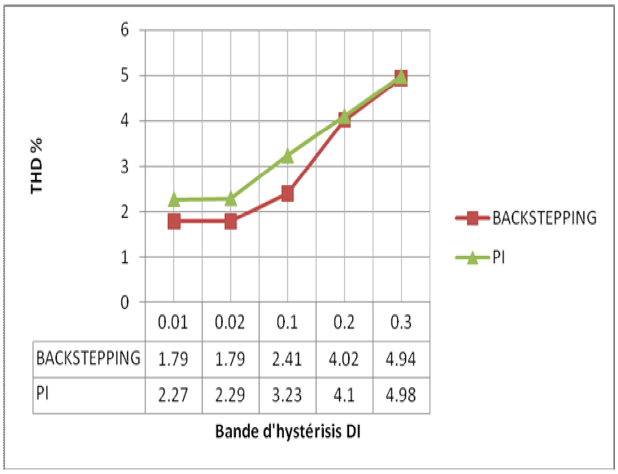


Figure. 6. Influence de la bande d'hystérésis sur le THD

8. Conclusion

In this work, we have shown the effectiveness of the shunt active power filtering especially with the application of backstepping 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.. 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 simulation results have demonstrated and conformed the effectiveness of using backstepping controller in the filter control

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