Proceedings of the Sixth IASTED International Conference
EUROPEAN POWER AND ENERGY SYSTEMS
June 26–28, 2006, Rhodes, Greece

ATTENUATION OF THE HARMONICS AND COMPENSATION OF REACTIVE POWER BY ACTIVE FILTERING

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ABSTRACT

The improvement of the intrinsic parameters of the electro-energy systems and the improvement of the devices of power electronics which can influence each type of adjustment are a major concern in the analysis and the identification of several criteria of the evaluation of the quality of distributed energy. This quality is dependent on the fed loads which are in many cases nonlinear because of the thorough use of the static inverters of power electronics. This increased use is due to the industrial development of automation. The static inverters do not absorb sinusoidal currents and generally consume reactive power. These two phenomena produce some disturbances like the dysfunction of the equipment in the worst cases. In this article, our interest is the attenuation of these two phenomena by the method of active filtering. We create antagonistic currents to the disturbing currents in order to annihilate them.

KEY WORDS

nonlinear loads, reactive power, static inverters, harmonics, active filtering,

1. INTRODUCTION

The nonlinear loads absorb a current which does not have the same form of wave as the voltage which is applied to them. Moreover current fluctuations are not proportional to the variations of the voltage. It is the case of the majority of the apparatuses using power electronic sets, in particular the rectifiers (but also variators, gas-discharge lamps, apparatuses with electric arcs etc...). The nonlinear loads can disturb the operation of the other devices connected to the network by the injection of harmonic currents. The losses they induce are added to the losses resulting from the fundamental one. These additional losses caused by the presence of the harmonic currents reduce the efficiency, accentuate the ageing of the equipment such as the motors, the transformers and by precaution lead even to an oversizing of the lines. In addition to this degradation, the harmonic currents deform the voltages of the network upstream via the short circuit impedance [1]. The study relates to the description as well as the choice of many various types of power electronics devices.

2. ATTENUATION OF THE HARMONICS

It is necessary to choose a structure proven as being slightly polluting on the one hand and a converter equipped with a suitable control making it possible to relieve the structure of the converter on the other hand. The increase of the index of pulsation using a rectifier with 12 diodes called "twelve-phase" bridge which one is carried out by connecting two Grätz bridge rectifiers in parallel to fed with the common continuous bus. The disadvantage of this solution it is the recourse to a transformer with two of different couplings. The reinforcement of the short-circuit power and the reduction in the total network impedance upstream of a nonlinear load make it possible to reduce the voltage drop created by the harmonics of current, and to decrease the harmonic rate of distortion in the voltage at the connection point. On the other hand, the harmonic currents are not attenuated [2].

3. FILTERING

A simple solution would be the filtering which consists in "trapping" the harmonic currents in LC circuits in tune on the rows of harmonics to be filtered. A filter can thus include a series of "steps" which correspond to a row of harmonic. Rows 5 and 7 are usually the most filtered because they are the most disturbing. The installation of a filter can be considered for one load or for whole of loads [2].

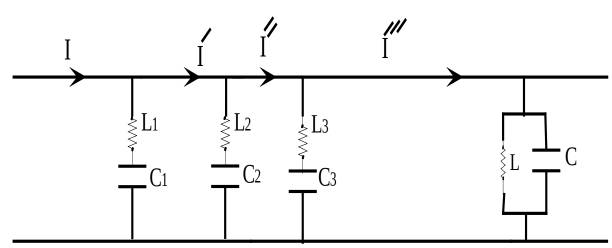

Fig. 1. Association of filters tuned to selected harmonics

The advanced solution is another mode of filtering based on the principle of the active filtering of harmonics and the use of the power electronics to voluntarily produce harmonic components which eliminate the harmonic components of the nonlinear loads. The active filter can be connected to the network in series or in parallel according to its acts on the voltages or on the harmonic currents. It is composed of an element of the storage of energy, of a converter, of a filter and a control block. The active compensator must provide the deforming power D and the reactive power Q. Thus, the network has to only provide the active power. There are three topologies of filtering according to whether the connection with the network is in series or in parallel or a combination of the two precedents called mixed or universal topology.

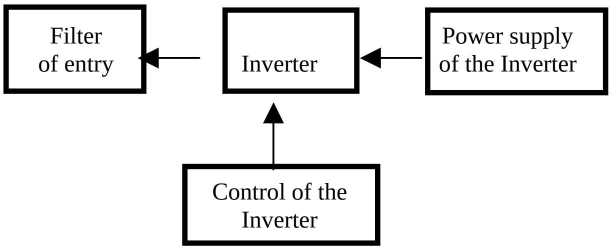

Fig. 2. Principle of active filtering

The parallel active filter behaves like a generator of harmonic currents which compensate the harmonics produced by the nonlinear load by generating harmonics with the same row and amplitude but whose phases are in opposition (Fig.3).

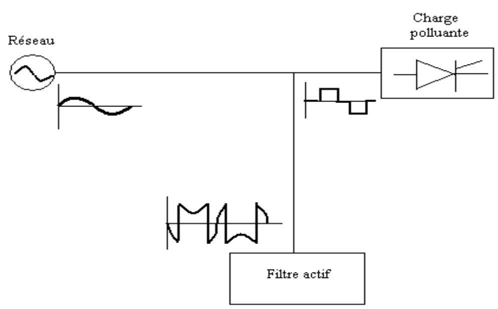

Fig. 3. Principle of operation of a parallel active filter

This can be carried out while investing much more in the advanced control making it possible to make the converter less pollutant, even with a basic structure. Among the converters used in the power supply of the electric machines at variable speed, the inverter is mostly used as a frequency converter (fig. 4). The active filter consists of a voltage inverter connected in parallel with the network, supplied by a continuous voltage source. At the exit of the inverter, one connects an inductance of smoothing [3].

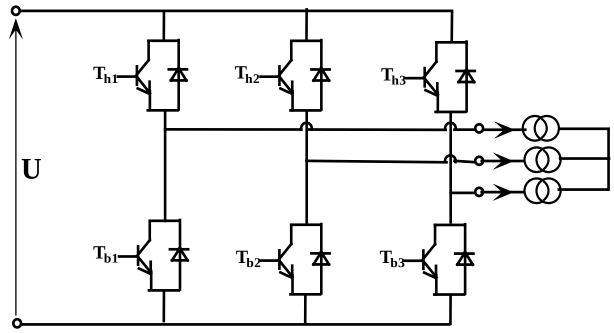

Fig. 4. Set in bridge of a three-phase inverter

The control imposes currents with phases are near as possible to the fixed reference. The control can be obtained by a control of hysteresis type or PWM type. The hysteresis control of the currents is characterized by a variable frequency of modulation. This variation will be higher that the value of hysteresis is lower [6] The principle of this method is based upon the control of the switches of the inverter so that the variations of the output current of each phase of the inverter is limited in a band which confines the current references (Fig. 5).

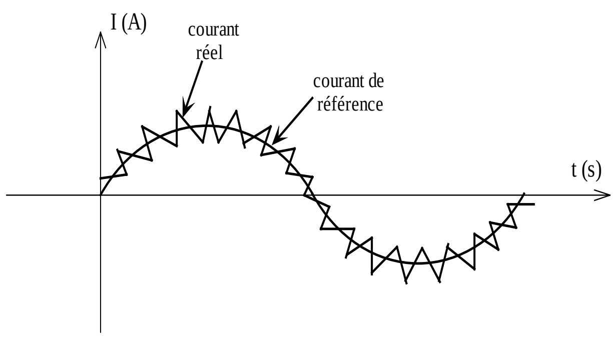

Fig. 5. Limitation of the current around the reference

This control is obtained by a permanent comparison between the real currents and the references of currents. The output of the comparators is connected to the logic control of the inverter so that it imposes a commutation of the switches when the current deviates from the hysteresis value of its reference (Fig. 6).

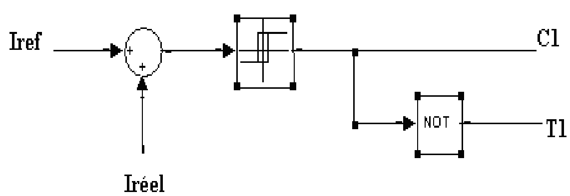

Fig. 6. Principle of control of the current by hysteresis

The method of control of the currents by Pulse Width Modulation (PWM) starting from a source of continuous constant voltage consists in imposing on the outlet side of the inverter crenels of the voltage so that the fundamental one of the voltage is nearest possible to the reference of sinusoidal voltage [4]. The voltage or current source inverters with PWM control are reversible. One can thus make them function in reverse of their usual operating, i.e. as rectifiers. In this case, it is the network which imposes the amplitude and the frequency on the alternate side. In fact, it imposes the frequency of the currents of reference which represent the alternating currents to obtain. The study concerns the modelling of the total system, namely the supply system, the polluting load and the active filter. The control part is made up of the block of reference and that the control of the current. To control the output current by the inverter, the hysteresis control is used. It is based upon the control of the switches of the inverter so that the variation of the current, in each phase, is limited in a band including the references of the currents (Fig. 5). The used inverter is a voltage source inverter connected to the network by coupling inductances that play the role of a filter. The controlled switches K_1 to K_6 (MOSFET transistors) of the inverter have, in antiparallel connected, each one a diode to ensure the continuity of the current in each phase during various commutations (Fig. 7). The Simulation by using Matlab makes it possible to get the results which are the forms of the current and the voltage like their harmonic spectra, before and after active filtering.

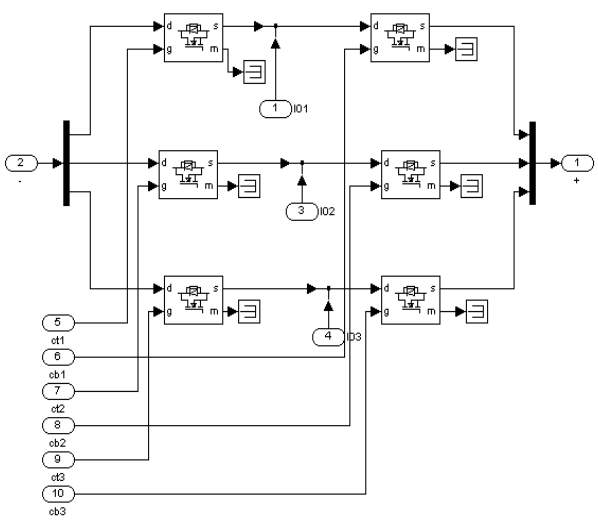

Fig. 7. Diagram of the inverter established in simulation

The inductances L_1 L_2, L_3 transform the set (continues source + inverter) into current source and carry out the smoothed currents. For the power supply of the inverter, one uses a source of continuous voltage. It is an electromotive force independent from the network to cleanse. One uses as a polluting load a three-phase gradator. It is known that this kind of static inverter presents in loads current strongly polluted. Moreover its fundamental is out of phase compared to the tension of source, which causes a strong consumption of reactive power and thus a bad power-factor. The role of the block of reference is to produce the signal being useful for the command of the switches of the inverter. As we want simultaneously to decrease the deforming power (D) and to compensate the reactive power (Q), the inverter must inject a reactive current and a harmonic current of opposed direction to those generated by the polluting load.

If we define I_s as being the active component of the fundamental of the current, I_r as being the reactive component of the fundamental of the current and I_h as being the harmonic current, then one can write:

$$I_{ch} = I_s + I_r + I_h \quad \Rightarrow \quad I_s = I_{ch} - (I_r + I_h)$$
$$I_s = I_{ch} + I_{injected} \quad \Rightarrow \quad I_{injected} = -(I_r + I_h)$$

As the control forces the inverter to follow the current of reference, then:

$$I_{ref} = -(I_h + I_r)$$

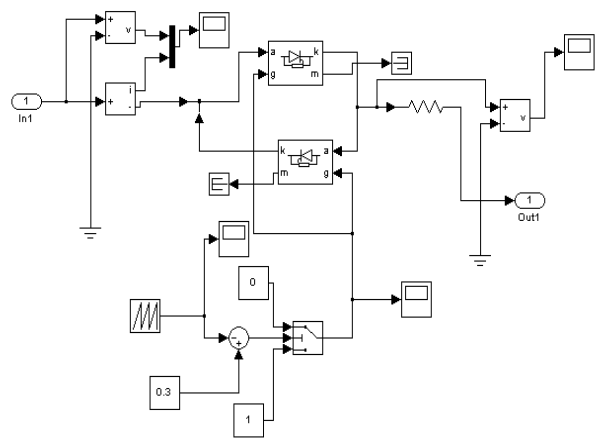

Fig. 8. Diagram of a phase of the polluting load

For the development of the reference signal starting from the harmonic current and the reactive current, one uses the diagram block (Fig. 9) which receives the current of load I_{ch}.

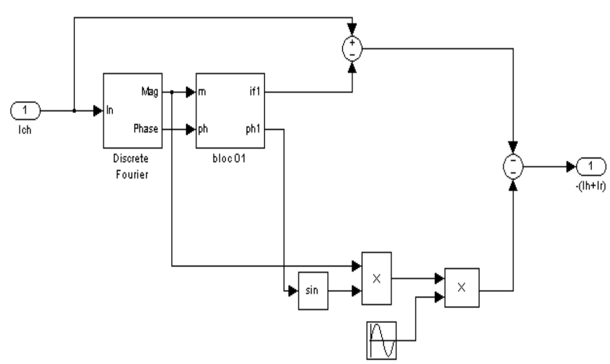

Fig. 9. Block diagram of the current of reference

Block 01 of figure 9 which reconstitutes the fundamental current starting from the amplitude and the detected phase by the module of discretization is clarified in figure 10. To obtain the signal of the harmonic current, we make the subtraction between the current of load and its fundamental.

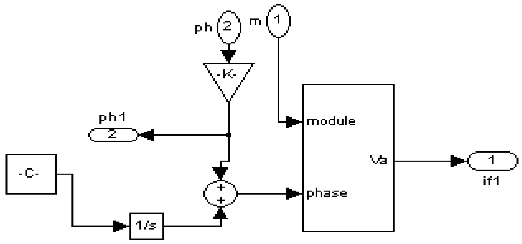

Fig. 10. Block of reconstitution of the fundamental one

The signal of the reactive current is obtained as follows:

$$\vec{I}_{ch}=\vec{I}_a+\vec{I}_r$$

The amplitude of the reactive current is expressed according to the amplitude of the fundamental current of load as follows:

$$I_{rm}=I_{fm}Sin\varphi$$

and its expression is:

$$I_r=I_{rm}Sin\left(\omega t-\pi/2\right)$$

The reference signal is given from:

$$I_{ref}=-I_h=I_r$$

The block control compares the output current of the inverter with the reference, using a comparator with hysteresis whose exit is related to the control circuit of the switches.

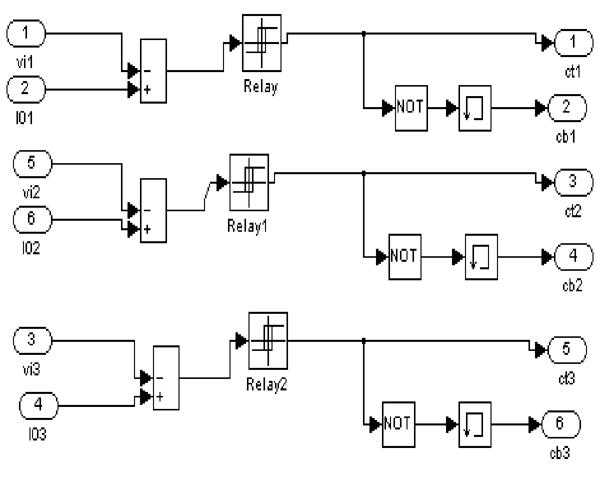

Fig. 11. Block control of the switches

4. RESULTS

We carried out the simulation of the set consisting of the three-phase source, the polluting load and the parallel active filter. The total diagram of this system for the experimentation is given in figure 12. For the model, we used the following parameters:

Load R=10 Ω and firing angle α = 90° for the gradator
Source V_{eff} = 230V and f =50Hz for the voltage
R=5 Ω and L=1mH for the line
E=580V for the continuous source of inverter and L=5mH for the smoothing inductance.

During simulation, we carried out the voltage of the source and the current of load without the connection of the active filter. Then we carried out the analysis of the current load to establish its harmonic spectrum. The voltage of source is represented in Figure 13.

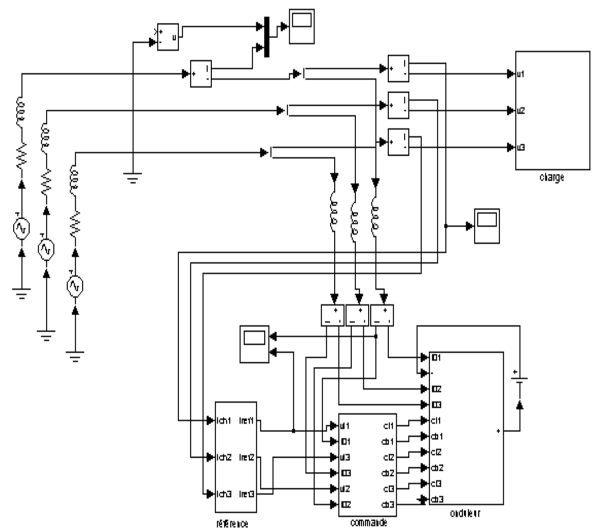

Fig. 12. Representation of the global diagram

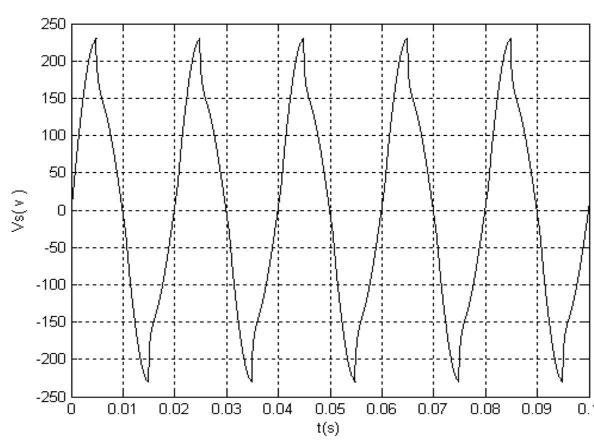

Fig. 13. Voltage of source before filtering

The current of load also obtained before the installation of the active filter is given in figure 14 and its harmonic spectrum in figure 15. The results obtained for the simulation of the system without the active filter present deformed waves of tension and current, which is the foreseeable sight nature of the load used.

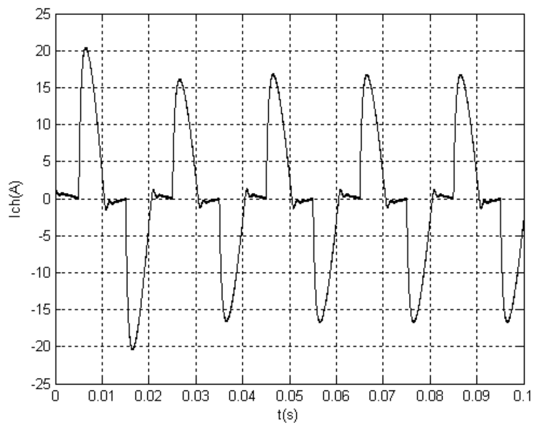

Fig. 14. Courant of load before filtering

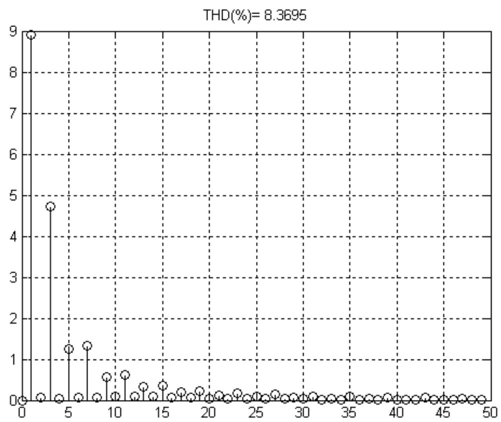

Fig. 15. Harmonic spectrum of the current of load

In order to check the effectiveness of the active filter that we developed, we simulated the system by including the inverter and its control. We initially enhanced the signal of the harmonic current, the signal of the reactive current as well as the signal of the current of reference.

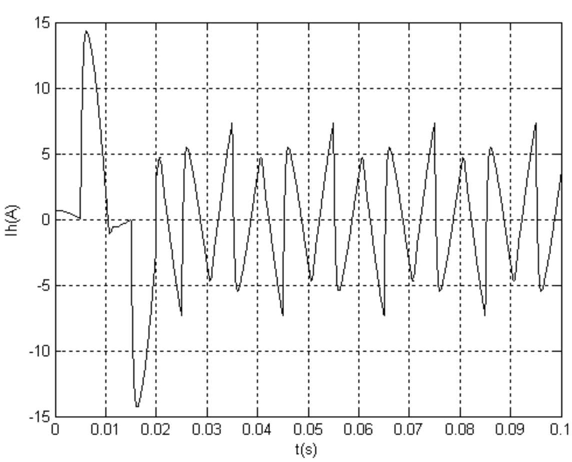

Fig. 16. Signal of the harmonic current of the load

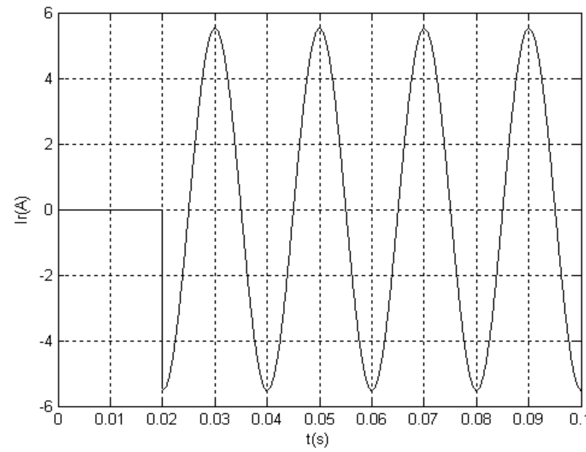

Fig. 17. Signal of reactive current

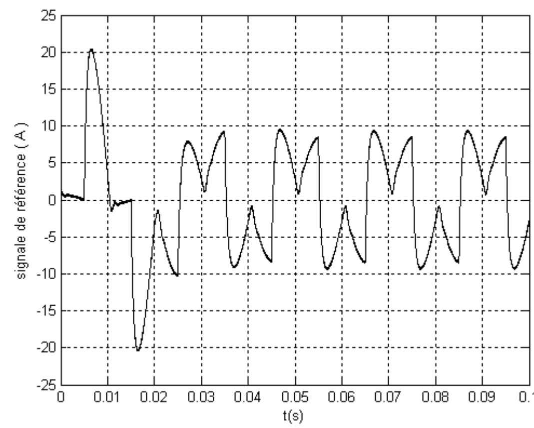

Fig. 18. Signal of the reference current

Upon presentation of these results the block of reference answers well by the development of the various currents, especially the reference current (Fig. 18). Thereafter, we enhanced the injected current by the inverter (Fig. 19), the voltage of source and the current of source as shown in Fig. 20 and Fig. 21a.

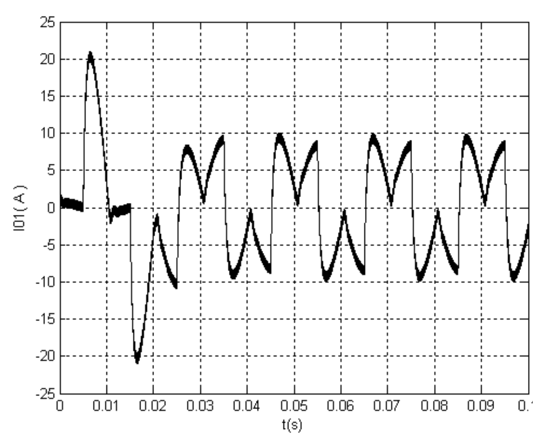

Fig. 19. Injected current by the inverter

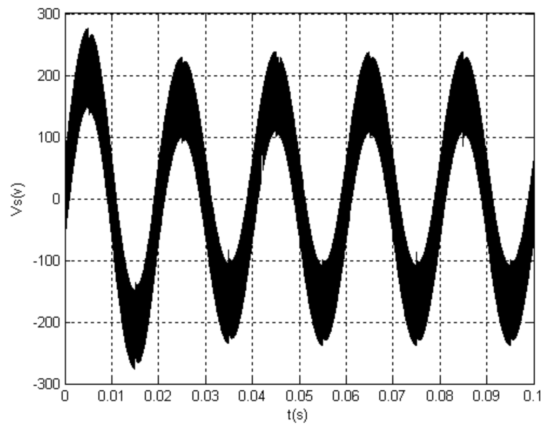

Fig. 20. Voltage of source after the filtering

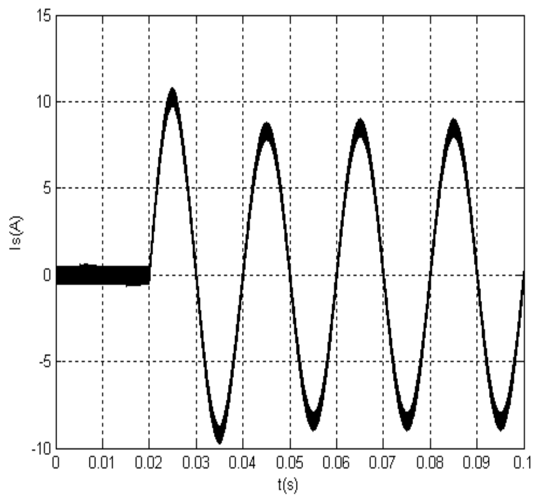

Fig. 21a. Current of source after the filtering

To estimate the effectiveness of the filter, we carried out the spectrum analysis of harmonic of the current of source after compensation (Fig. 21b) in order to see which row of harmonics are present and how important are their amplitude.

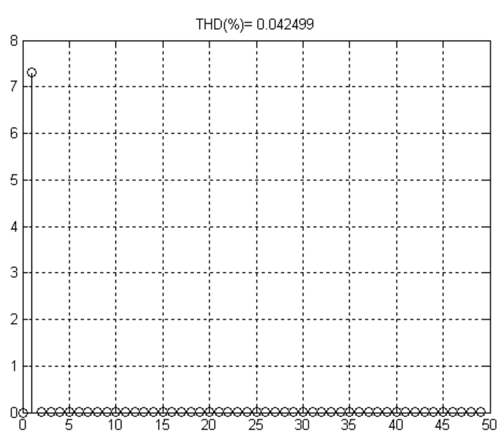

Fig. 21b. Harmonic spectrum of the current of source after filtering

5. CONCLUSION

In this study, we present one of the most significant solutions of compensation of reactive power and filtering of harmonics namely the active compensation. We started from an elementary solution which consists of the compensation from capacitor battery or by synchronous compensator. We extended the solution to the reduction in the harmonic content by the configuration of the rectifiers by increasing the index of pulsation, until to 12, by having recourse to the "dodécaphasé" bridge. Then, we simulated a rectifier with index of pulsation 6 and one rectifier with index of pulsation 12. The results showed that first harmonic which appears is the 11^{th} for "twelve-phase" bridge instead of the 5^{th} for "six-phase" [4]. To highlight the active filtering, we studied the three-phase voltage inverter which latter is the principal part of the active filter. By generating antagonistic current harmonics which will be injected in the network, it is possible to eliminate those generated by the polluting source. The inverter must be equipped with a suitable command where we chose an hysteresis control to produce the active filter. We presented the method of compensation by active filtering by using a parallel filter which makes it possible to act positively, at the same time, on the consumption of reactive power and of the rows of harmonics. For the description of the action of the filter, we simulated the output current of the source and the voltage of the source for the global system with and without filtering. The results of simulation for this application show well the significant role played by active filtering. Thus the THD of the current of source decreases from 8, 37 % to 0, 04 % after filtering, and the power-factor is brought back to the unity. These performances improve the efficiency, increase the longevity of the machines and reduce the surplus in the bill of the electric power.

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