# Hybrid shunt active filter: Impact of the network's impedance on the filtering characteristic

C. BENOUDJAFER, C.BENACHAIBA, A.SAIDI

Faculty of the sciences and technology, Béchar University B.P 417 BECHAR (08000), ALGERIA

benoudjafer.cherif@mail.univ-bechar.

*Abstract:* - The filtering system is an indispensible way to cancel all harmonics which are generated by the nonlinear load.
In this paper, we will study the impact of the network's impedance on the filtering characteristic in two cases:
In the first one, we will treat the behavior of the passive filter alone in relation to the short circuit power.
The second part, we'll study a hybrid active filters in relation to the short circuit power.
The obtained results are very interesting and show the importance of this electrical characteristic on the behavior of the active and/or passive filtering system.

*Keywords:* -Compensation, Harmonics, Power Quality, Hybrid Shunt Active Filter, Shunt Active Filter, Passive Filter, THD

## 1 Introduction

Harmonic pollution and reactive power in the power system are the important power quality problems, in the last years, there has been an increase of non-linear loads as electronic devices in the electric power distribution networks. The current harmonics consumed by these loads flowing through the line impedances introduce distorted voltages, and the significant harmonics are extended to the rest of the network. There are some possibilities to improve the power quality in power systems. So, when the current harmonics are known, the passive filters resonant with the main harmonic frequencies are a usual solution. One of its advantages is the lower cost of the filter. However, there are some disadvantages, mainly which the filter does not eliminate another harmonics, and resonance problems with the system impedances can appear. Recent development of signal processing and power converters allows using the power active filters to improve the electrical power quality [1-6]. The main disadvantage is the price. It is possible to combine passive and active filters to get both advantages. Many proposals have been realized, This feature makes hybrid power filter as an appropriate solution for the harmonic problem in high power application where the active power filter cannot be used alone [7].The objective of this work is to verify the behavior of the network's impedance on the filtering systems.

## 2 Passive filters

The passive harmonics filters are composed of passive elements: resistor (R), inductor (L) and capacitor (C). The common types of passive harmonic filter include single-tuned and double tuned filters, second-order, third-order and C-type damped filters. The double-tuned filter is equivalent to two single-tuned filters connected in parallel with each other, so that only single-tuned filter and other three types of damped filters are presented here. The ideal circuits of the presented four types of filters are shown in Fig. 1 in which both third-order and C-type damped filters have two capacitors with one in series with resistor and inductor, respectively. Two capacitors of third-order damped filter have typical same capacitance In µF) for simplifying design and unifying stock.[8]

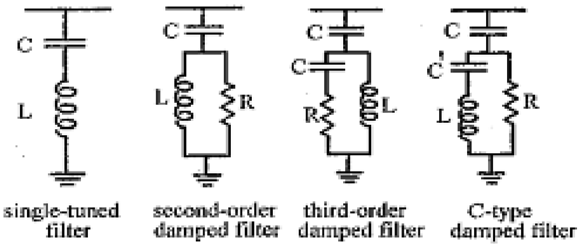



Fig.1. Typical passive harmonic filters

The capacitor C' and inductor L of C-type damped filter are designed to yield series resonance at fundamental frequency for reducing the fundamental power loss. Because single-tuned resonant filter only comprises LC components, its investment cost and power loss are lower than that of damped filters with same capacity, and easily to design. However, its performance of harmonic filtering is where general aimed to the harmonics with frequency slightly higher than the resonant frequency of filter. At high frequency, the single-tuned filter is inefficient in harmonic filtering because of the impedance of filter increasing with frequency monotonously. The low frequency harmonics will be magnified by single-tuned filter due to the impedance of filter becoming capacitive. So the single-tuned filter is only suitable to the system with simple harmonic situations, (i.e. not many large harmonics distributed on wide frequency range). On the other hand, the damped filters impedance approaches to the value of resistance at high frequency, so that they have a better performance of harmonic filtering at high frequency. The phenomenon of enlargement of low frequency harmonics will be mitigated even eliminated by the damped filters with proper parameters. Hence, the damped filters are suitable for reducing complex harmonics, i.e. many large harmonics distributed on wide frequency range. Although the above descriptions show that the damped filters are better than single-tuned filter from the viewpoint of harmonic filtering, the damped filters are usually used in cooperation with tuned filters for reducing investment and power loss, in which the tuned filters are used for filtering primary harmonics and the damped filters are used for filtering secondary harmonics.

## 3 Transfer Functions

The first order filters have transfer functions of the form

$$H_{1p}(s) = \frac{k\omega_c}{s+\omega_c} \quad \text{or} \quad H_{1p} = \frac{k_s}{s+\omega} \qquad (1)$$

Bode Plots of first-order high-pass filters (K = 1) are shown below. The asymptotic behavior of this class of filters is:
At low frequencies, $\omega = \omega_c \ll 1$, $|H(j\omega)| \propto \omega$ (a +20dB/decade line) and $H(j\omega) = 90°$
At high frequencies, $\omega = \omega_c \gg 1$, $|H(j\omega)| \propto 1$ (a line with a slope of 0) and $H(j\omega) = 90°$

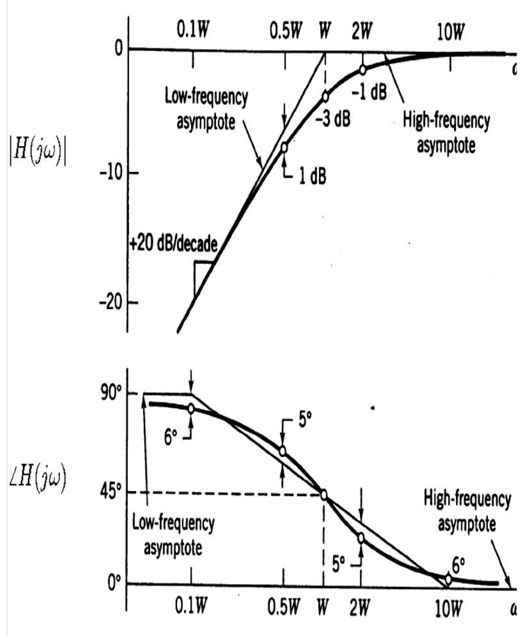



Figure 2: Bode Plots of first-order high-pass filters

The transfer function for a second-order can be written as

$$H(j\omega) = \frac{K}{1+jQ\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)} \qquad (2)$$

Bode plots of a second-order filter is shown below. Note that as Q increases, the bandwidth of the filter become smaller and the $|H(j\omega)|$ becomes more picked around $\omega_0$.

$$|H(j\omega)| = \frac{|K|}{\sqrt{1+Q^2\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)^2}} \qquad (3)$$

$$H(j\omega) = -\frac{|k|}{K}\tan^{-1}\left[Q\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)\right] \qquad (4)$$

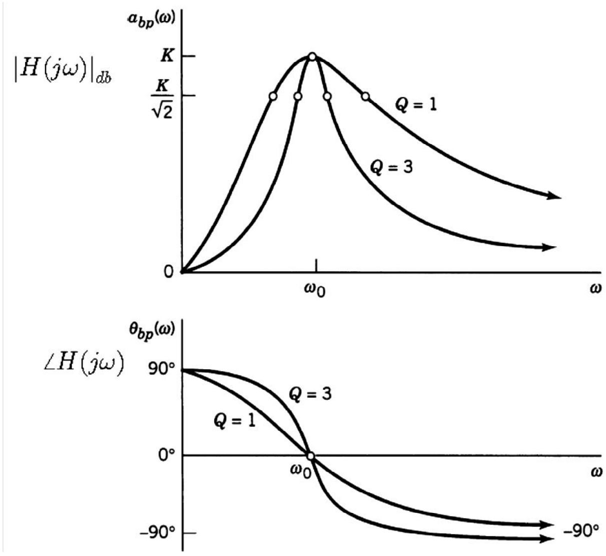



Fig 3. Bode plots of a second-order filter.

## 4 Shunt Active Filter

One of the most popular active filters is the Shunt Active Power Filter (SAPF) [3-7,9]. SAPF have been researched and developed, that they have gradually been recognized as a workable solution to the problems created by non-linear loads.

The functioning of shunt active filter is to sense the load currents and extracts the harmonic component of the load current to produce a reference current $i_c^*$, a block diagram of the system is illustrated in Fig.4. The reference current consists of the harmonic components of the load current which the active filter must supply. This reference current is fed through a controller and then the switching signal is generated to switch the power switching devices of the active filter such that the active filter will indeed produce the harmonics required by the load. Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.

Generally, the effectiveness of (SAPF) depends on three design criteria: (i) design of power inverter; (ii) use of current controller's types (iii) methods used to obtain the reference current.

In order to determine harmonic and reactive component of load current, reference source current generation is needed. Thus, reference filter current can be obtained when it is subtracted from total load current. For better filter performance, generation of reference source current should be done properly. For this purpose, several methods such as pq theory, dq-transformation, multiplication with sine function and Fourier transform have been introduced in literature [10].

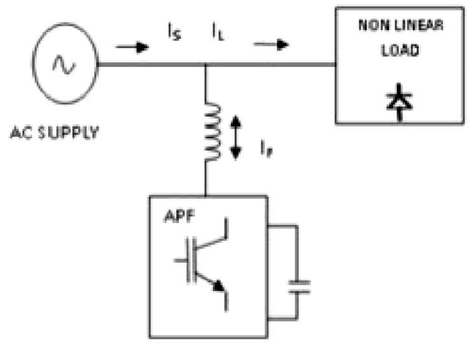



Fig. 4 Shunt active filter scheme

## 5 P-Q Theory

The concept of instantaneous reactive power theory (p-q theory) method basically consists of a variable transformation from the, b, c reference frame of the instantaneous power, voltage and current signals to the α – β reference frame [11]. The instantaneous values of voltages and currents in α – β reference coordinates can be obtained from the following equations:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [A]\begin{bmatrix} v_q \\ v_b \\ v_c \end{bmatrix}, \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = [A]\begin{bmatrix} i_q \\ i_b \\ i_c \end{bmatrix} \quad (12)$$

Where A is the transformation matrix and is equal to:

$$[A] = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (13)$$

This transformation is valid if and only if $v_a(t)+ v_b(t)+ v_c(t)= 0$ and also if the voltages are balanced and sinusoidal. The instantaneous active and reactive powers in the α − β coordinates are calculated with the following expressions

$$p(t) = v_\alpha(t)\, i_\alpha(t) + v_\beta(t) i_\beta(t) \quad (7)$$

$$q(t) = -v_\alpha(t)\, i_\alpha(t) + v_\beta(t)\, i_\beta(t) \quad (8)$$

The values of p and q can be expressed From Eqs. (3) and (4) in terms of the dc components plus the ac components, that is:

$$p = \bar{p} + \tilde{p} \tag{9}$$
$$q = \bar{q} + \tilde{q} \tag{10}$$

Where

$\bar{p}$ : is the dc component of the instantaneous power p, and is related to the conventional fundamental active current$\tilde{p}$: is the ac component of the instantaneous power p, it does not have average value, and is related to the harmonic currents caused by the ac component of the instantaneous real power.

$\bar{q}$: is the dc component of the imaginary instantaneous power q, and is related to the reactive power generated by the fundamental components of voltages and currents.

$\tilde{q}$: is the ac component of the instantaneous imaginary power q, and is related to the harmonic currents caused by the ac component of instantaneous reactive power.

In order to compensate reactive power and current harmonics generated by nonlinear loads, the reference signal of the shunt active power filter must include the values of $\tilde{p}$ and $\tilde{q}$. [6]In this case the reference currents required by the SAPF are calculated with the following expression:

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\alpha \\ v_\beta & -v_\beta \end{bmatrix} \begin{bmatrix} \tilde{p}_L \\ \tilde{q}_L \end{bmatrix} \tag{11}$$

The final compensating currents components in a, b, c reference frame are the following:

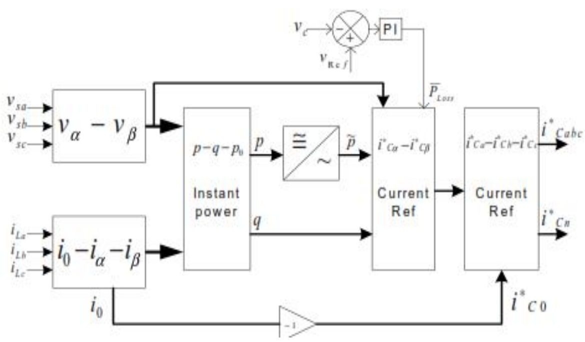



Fig.3. Block diagram for the instantaneous active and reactive power

The (SAPF) control strategy involves not only the production of currents whether to eliminate the undesired harmonics or to compensate reactive power, but also to recharge the capacitor value requested by $V_{dc}$ voltage in order to ensure suitable transit of powers to supply the inverter[9-12]. The storage capacity C absorbs the power fluctuations caused by the compensation of the reactive power, the presence of harmonics, and the active power control and also by the losses of the converter. The average voltage across the capacitor terminals must be kept at a constant value. The regulation of this voltage is made by absorbing or providing active power on the electrical network. The correction of this voltage must be done by adding the fundamental active current in the reference current of (SPAF).

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{12}$$

To realize these objectives, a controller as shown in Figure.8 is added to regulate the capacitor dc

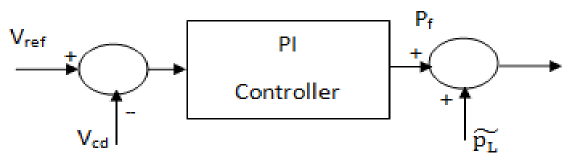



Fig.6. Control of DC Voltage

voltage of the (SAPF). In this circuit, the actual dc capacitor voltage is detected and compared with the reference value, and the error is amplified then is added to the $\tilde{p}_L$, the output of high-pass filter in Figure.8. Therefore, active power allowed into the capacitor is been changed and the dc voltage is controlled.

# 6 Simulation

### Case 1: The behavior of the passive filter

The simulated circuit is composed by three phase source which feeds a nonlinear load which is formed by a full AC-DC diode bridge with a linear load, L=60.10$^{-3}$ H, R=3.33Ω.

The passive filter is as below:

| | $H_5$ | $H_7$ |
|---|---|---|
| $X_C$ | 8.4028 | 24.7042 |
| $X_L$ | 0.3361 | 0.5042 |

| | | |
|---|---|---|
| R | 0.0168 | 0.0353 |
| L | $2.1397 .10^{-4}$ | $2.926 .10^{-4}$ |
| C | $7.5763 .10^{-5}$ | $1.8407\ 10^{-4}$ |

According to the obtained results, we can conclude that the power of the electrical network influences strongly, the characteristic of the passive filter filtering.

For a network less power full whom the value of its inductor which is equal to $10^{-3}$H, the passive filters linked respectively on the harmonics range h=5 et h=7 have eliminated target harmonics currents.

The measured T.H.D according to the load level and the source are respectively 22.7% and to 4.87% .

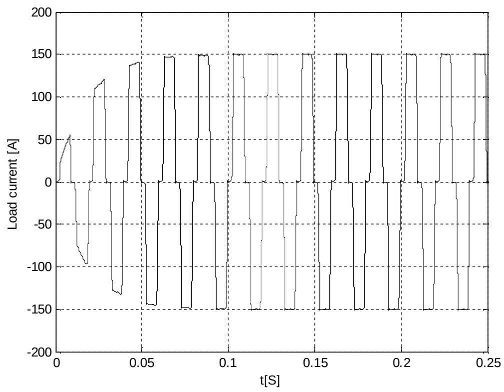



Fig.7. Load current with L=$10^{-3}$ H

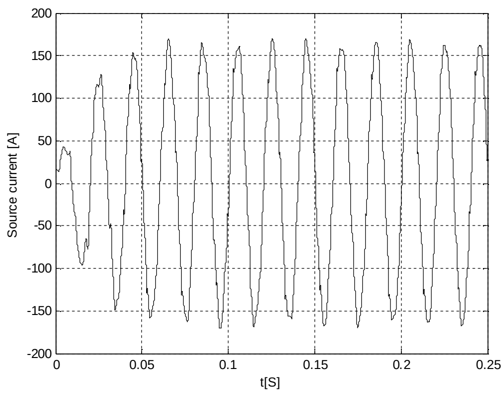



Fig.8. Source current with L=$10^{-3}$ H

These last results (Fig.9 and 10) show clearly that the action of filters is distinguished.

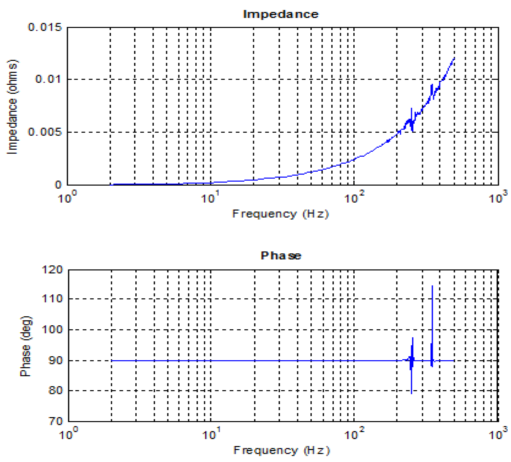



Fig.9.Impedance plot for $L = 10^{-3}H$

We can notice on the Fig. 11 that the first peak of the impedance of the system is at the frequency equal to 214 Hz and the second peak is at 332 Hz. This points show the frequencies which cause the parallel resonance.

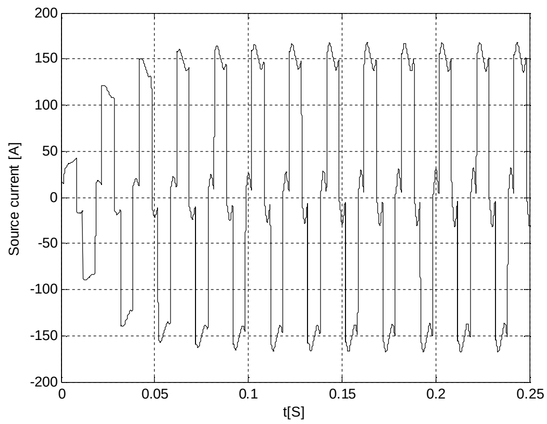



Fig. 10 Source current with L=$10^{-5}$ H

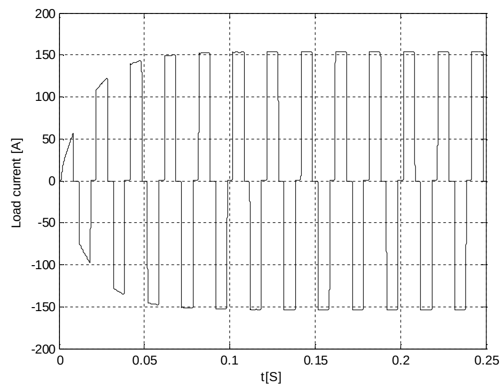



Fig.11 Load current with =$10^{-5}$ H

While, for the powerful network whom the value of its inductor which is equal to $10^{-5}$H, the characteristic of filtering is totally inefficient (Fig 12and 13) since the T.H.D have remained the same for the currents T.H.D of the load is 29.63% while the current source is 29.07%.

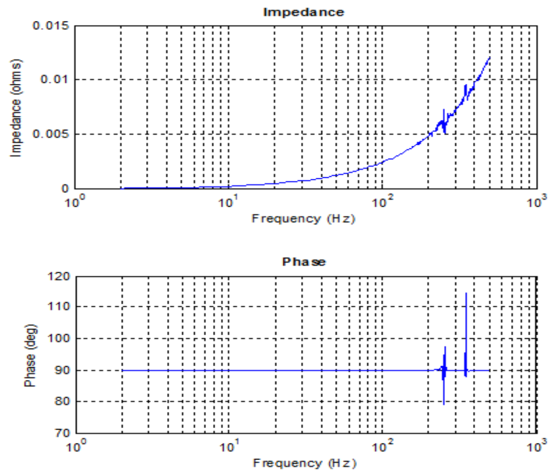


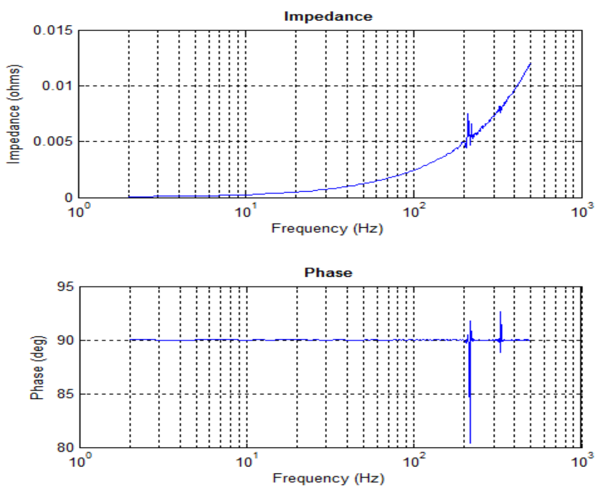

Fig.12.Impedance plot for L=$10^{-5}$ H

Even with L=$10^{-5}$ H (Fig. 14), some frequencies cause the parallel resonance in the system. The first peak appeared at f=256 Hz which corresponds to 79.02° and the second peak at f=350 Hz with 114.3°.

**Case 2: The behavior of hybrid active filter**

In the case of an hybrid active filtering system composed of an active filter and two passives filters linked on the frequencies of range h=5 and h=7

The impact of the short circuit power according to the studied networks, is without effect, for the values of the source current T.H.D that are 3.1% and 4.15% respectively for less and more powerful network (Fig 13-16).



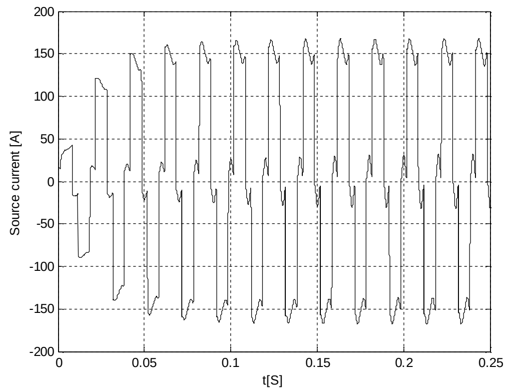




Fig.13.Source current with L=$10^{-3}$ H

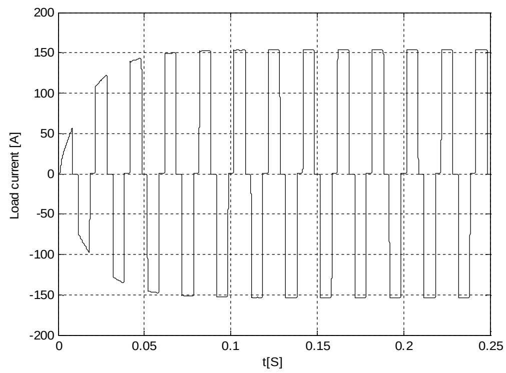



Fig.14.load current with L=$10^{-3}$ H

The obtained results show perfectly, the efficiency of parallel active filter compensating the fragility of passive filter vis-à-vis the electrical network characteristic.

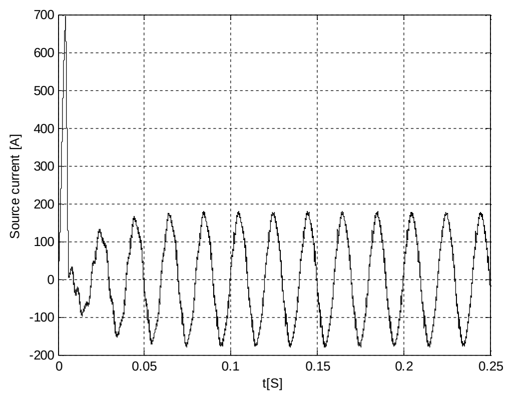



Fig.15. Source current with L=$10^{-5}$ H

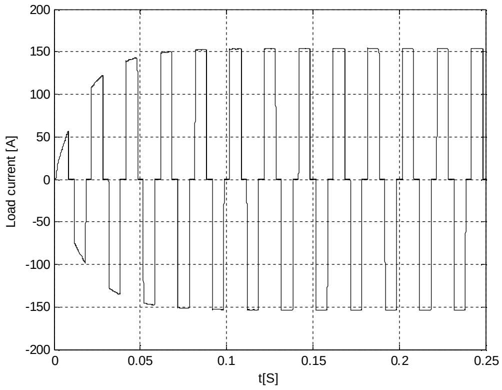



Fig.16. Load current with =$10^{-5}$ H

## 7 Conclusion

This simulation allows us to highlight the decisive role of the short circuit impedance of the electrical network, the filtering characteristic.

The latter is very susceptible and the passive filter becomes fragile and completely loses its effectiveness for an important short circuit power.

While the insertion of A.P filter in a passive filtering system to form an hybrid filtering system much influence the filter charactestic, making it more effective in reducing the THD of the current source below the normal value.

Therfore,the filtering charactestics of the hybrid filter system remain constant vis-à-vis the change in short circuit power.

### *References*


[1] S.sellakuman ,M.vijayakumar ,V.rajendram "A dynamic hybrid shunt active filter for thee reduction of source current THD in a distribution system" ISRF journal , April 2012

[2] B. M. Bird, J. F. Marsh, and P. R. McLellan, "Harmonic reduction in multiple converters by triple-frequency current injection," Inst. Elect. Eng. Proc., vol. 116, no. 10, pp. 1730-1734, 1969.

[3] H. Sasaki and T. Machida, "A new method to eliminate ac harmonic currents by magnetic compensation-Consideration on basic design,"IEEE Trans. Power Appl. Syst., vol. PAS-90, pp. 2009-2019, 1971.

[4] A. Ametani, "Harmonic reduction in thyristor converters by harmonic current injection," IEEE Trans. Power Appl. Syst., vol. PAS-95, pp. 441-449, 1976.

[5] L. Gyugyi and E. C. Strycula, "Active ac power filters," in Proc. 1976 IEEE/IAS Annual Meeting, 1976, pp. 529-535.

[6] N. Mohan, H. A. Peterson, W. F. Long, G. R. Dreifuerst, and J. J. Vithaythil, "Active filters for a

[7] harmonic suppression," presented at the 1977 IEEEPES Winter Meeting, A77026-8, 1977.

[8] J. Uceda, F. Aldana, and P. Martinez, "Active filters for static power converters," Inst. Elect. Eng. Proc., vol. 130, pt. B, no. 5, pp. 347-354, 1983.

[9] J. Khazaie , D. Nazarpour ,M. Farsadi, M. Khalilian ,S. Badkubi "Shunt hybrid active power filter to alleviate the harmonics of VSC-HVDC in OFF-SHORE wind farms" TPE journal, June 2012.

[10] H. Akagi, S. Srianthumrong and Y. Tamai, "Comparisons in circuit configuration and filtering performance between hybrid and pure shunt active fitters", IEEE 38th Conf on Industry Applications, Vol. 2, pp. 1195-1202, October 2003.

[11] D. Rivas, L. Moran, J. Dixon and J.R. Espinoza, "Improving passive filter compensation performance with active techniques", IEEE Trans. On Industrial Electronics, Vol. 50, No. 1, pp. 161-170, Feb. 2003.

[12] Chih-Ju Chou, Chih-Wen Lio, Member,:IEEE, June-Yawn Lee, and Kune-Da Lee "Optimal Planning of Large Passive-Harmonic-Filters Set at High Voltage Level" IEEE-Trans.on power systems, vol 15 N°1,February 2000.


### Author's information


1-Benoudjafer Cherif in 2009, Magister in electotechnic from University of Bechar (Algeria) and in 2006 Engineer in Electrotechnic from University of Bechar

2-Prof. Dr. Ing. Chellali Benachaiba obtained Doctorate in Electrical Engineering from University of Science and Technology of Oran (Algeria) in 2005, Magister in Energetic Physics from University of Bechar (Algeria) in 1996 and a Diploma Engineer in Electrification from University of Boumerdes (Algeria) in 1987.

3-Saidi ahmed in 2013,licence in Electrotechnic from University of Bechar (Algeria).