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Comparison of Instantaneous Reactive and Notch Filter Algorithms Seven Level Parallel Active Filter

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ABSTRACT

This work focused on the association of a seven level Neutral Point Clamped inverter and a parallel active filter. In order to test the efficiency of the 7 level parallel active filter, two reference current generating algorithms are used. The instantaneous reactive power algorithm and the notch filter algorithm. In this study, the instantaneous reactive power method and the notch filter method are presented. Than a section which gives a recall of the NPC multilevel inverter and PWM strategy. A comparison between the two reference current generating algorithms is made. The subjects of comparison are the total harmonic distortion (THD) and the fundamental value of the source current. The obtained simulation results have proved that the instantaneous reactive power technique is better than the notch filter technique. Simulations are carried out by PSIM program.

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1. INTRODUCTION

The growing use in industry of energy conversion static devices called static converters causes increasingly disturbance problems at electricity network level [1]. Thus, there is an increase of harmonic content and current imbalance, in addition to a significant consumption of reactive power. These harmonics are spread from the load towards the network and create harmonic voltage drops added to the fundamental component of the voltage supplied by the electrical network. The result is a voltage assigned with a harmonic content, which on occasion, will lead to serious problems of electromagnetic compatibility, and hence, disastrous impacts on electrical equipments, which can range from an excessive overheating, or an abrupt shutdown of rotating machines, till the complete breaking down of these equipments.

To deal with these challenges, the use of the active filter becomes primordial [2], [3]. Even the active filter is not meeting the growing needs of industry; this has led to seek adequate solutions. One way to address the problem is to increase the level voltage. However, the voltage withstand of semiconductors may result in the degradation of its static and dynamic performances. This constraint has led to the replacement of the conventional inverter by a multilevel inverter that has significant benefits such as lower THD, higher efficiency and lower common mode noises (CM) [4]. This combination gave birth to multilevel active filters.

The paper starts with a presentation of the parallel active filter and the Neutral point clamped (NPC) multilevel inverter [5]. Presentation of the instantaneous reactive power algorithm and the notch filter algorithm is given on the ensuing section, followed by a recall of PWM strategy. Finally a discussion of the simulated results is presented.

2. STRUCTURE OF THE PARALLEL MULTILEVEL ACTIVE FILTER OR SHUNT

The multilevel parallel active filter is composed of two parts, namely a power section and a control section. The power part is constituted of a multilevel inverter, a coupling filter and a capacitor as a power source. The control part is used to monitor the switching of semiconductor components.
By means of appropriate control strategies, we can generate harmonic signals at the inverter output in order to compensate those present in the electricity network [6].

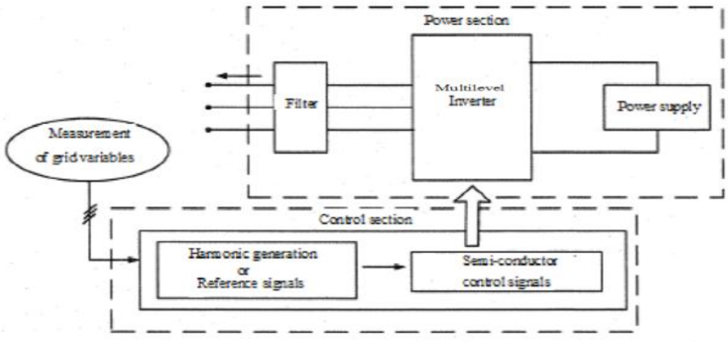

Figure 1. General structure of a parallel active filter

3. NEUTRAL POINT CLAMPED (NPC) MULTILEVEL INVERTER

The NPC inverter was proposed by Baker [7], [8]. This inverter allows having an uneven level of voltage. This topology facilitates the intermediate voltage balance, since only the total voltage is connected to an active source, while the other sources are reduced to simple capacitors, which allows a better power distribution.
The direct input voltage distribution on the various series switches is ensured by the diodes (clamped) connected to capacitive middle points.
The number of levels is computed by the following formula [9]:
N=P-1
N: number of voltage levels;
P: number of complementary switches per phase.
The Figure 2 represents the structure of one-leg NPC multilevel inverter of 7 levels.

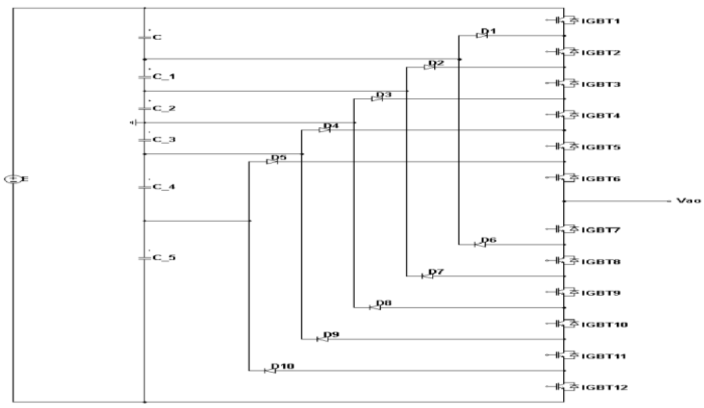

Figure 2. Power circuit of a one leg NPC seven level inverter

4. ACTIVE FILTER CONTROL

As shown in Figure 1, the control part is generally divided into two sections. The first one, which is of significant importance for the filter performances, is to generate reference harmonic signals. The second one, is the generation of control signals to open and close the semi conductors. Both parts are crucial in the active filter performance.

4.1. Generation of Reference Signals by the Instantaneous Reactive Power Algorithm

This method is based on the measure of three phase instant variables contained in the electrical grid with or without negative sequence components [9], [10]. This method is equally valid in steady and transient states. In the control algorithm, the voltage and current measurements expressed in three phase form (abc) are converted in an equivalent two phase system (αβ) using the Concordia Transform [11] which leaves the power invariant.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{3/2}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{3/2}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2}$$

The instant actual power p and the instant reactive power q can be expressed in the same manner in two phase system by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

That gives us:

$$p = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta \tag{4}$$

$$p = v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha \tag{5}$$

The instant actual power and the instant fictitious power can be expressed by the:

$$p = \overline{p} + \tilde{p} \tag{6}$$

$$q = \overline{q} + \tilde{q} \tag{7}$$

Where $\overline{p}$ and $\overline{q}$ are respectively, the components of active and reactive average powers corresponding to the fundamental load current (50 Hz), while $\tilde{p}$ and $\tilde{q}$ correspond to the alternative components linked to the harmonic current. The harmonic compensation by the active filter is done through the generation of the latter.

$$\tilde{p} = \mathrm{p}^* \quad , \quad \tilde{q} = \mathrm{q}^* \tag{8}$$

Consequently, the removal of the fundamental component in (8) is carried out using two low pass filters of second order. Figure 3 shows the low pass filter.
The reference compensation currents shall be calculated by the following formula:

$$\begin{bmatrix} i_a{}^* \\ i_b{}^* \\ i_c{}^* \end{bmatrix} = \sqrt{3/2}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_\alpha{}^* \\ i_\beta{}^* \end{bmatrix} \tag{9}$$

Where

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (10)$$

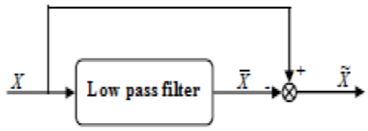

Figure 3. Low pass filter

Figure 4 shows the active filter controlled by the instantaneous power method

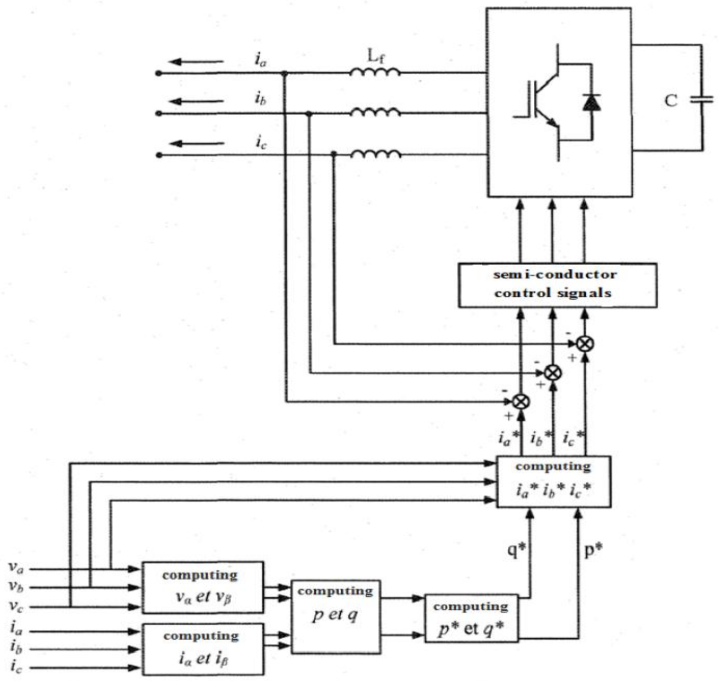

Figure 4. Active filter controlled by the instantaneous power method

4.2. Generation of Reference Signals by the Notch Filter Algorithm

The time domain control methods such as the notch filter are based on the instantaneous comparison of reference harmonic compensation signals to actual harmonic signals.

The most important stage of this algorithm is undoubtedly the removal of the fundamental component in order to generate reference harmonic signals.

In this kind of control, the load current is filtered by a band-stop filter called Notch filter [12]. The reference current thus created allows generating semiconductor control signals of the inverter. The transfer function enabling the implementation of the notch filter is based on the following [13]:

$$FT = \frac{S^2 + {\omega_0}^2}{S^2 + \frac{\omega_0}{Q} S + {\omega_0}^2} \qquad (11)$$

Figure 5 shows the active filter controlled by the notch filter method

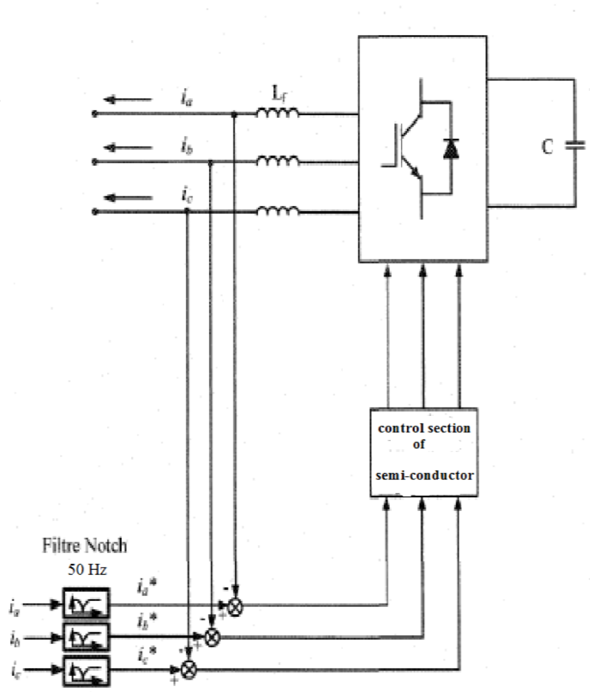

Figure 5. Active filter controlled by the notch filter method

4.3. Control Signall Generation by the Pulse width Modulation (PWM) Technique

The second step is to generate control signals for the semiconductors of active filter inverter. These control signals are obtained from the harmonic compensation signals seen in the previous section. The SPWM technique for an N level active filter, shown in Figure 7, compare the error between the reference current Iref and the filter current Ifa with (N-1) triangle waves (carriers) that have the same frequency Fp and the same amplitude Ap [14], [15].

The error passes through a corrective proportional–integral PI before to be compared to the triangle carriers. Figure 6 shows the principle of control currents by SPWM.

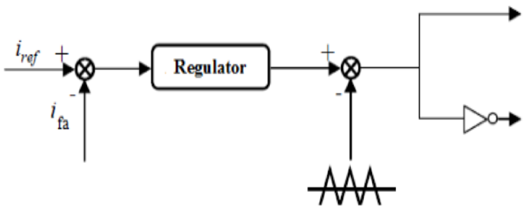

Figure 6. Principle of control currents by SPWM

5. SIMULATION RESULTS

To test the feasibility of reference current generating algorithms, we use a comparative study based on the THD and the fundamental value of the source courant Isa (A) for both reference current generating algorithms; the instantaneous reactive power and the notch filter.

The 7 level active filter simulations for both reference current generating algorithms are carried out by PSIM program. In order to get the THD level of the waveform, a Fast Fourier Transform (FFT) of PSIM program is applied to obtain the spectrum of the courant Isa (A).

The Table 1 presents the parameters of electrical network.

Table 1. Electrical network parameters

$V_{s,eff(L-L)}$ (V)	110
F(Hz)	50
R_s (Ohm)	0,5
L_s (Ohm)	0,1m
R_{ch} (Ohm)	2,5
L_{ch} (Ohm)	0,01

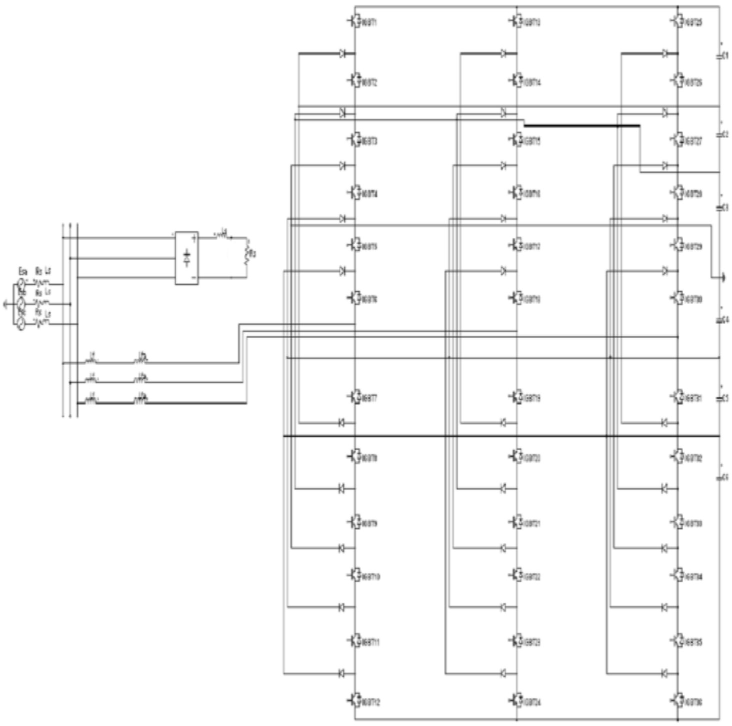

Figure 7. Seven-level active filter

5.1. Before the use of the Seven Level Active Parallel Filter

Figure 8 and Figure 9 show the current waveform Isa (A) and its harmonic spectrum for the electricity grid before compensation.

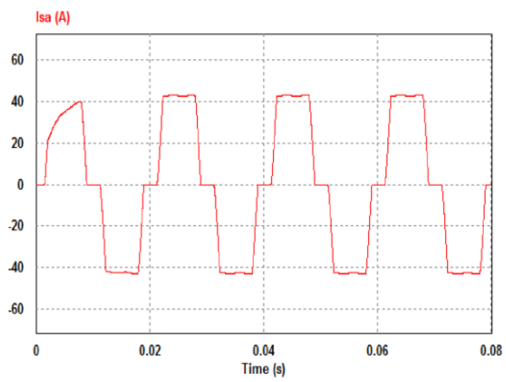

Figure 8. The source current Isa (A) before compensation

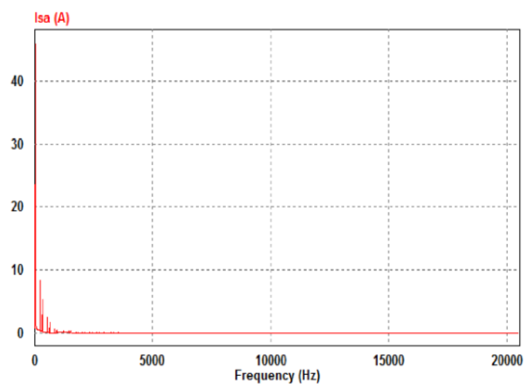

Figure 9. Current harmonic spectrum of the source before compensation

5.2. Seven-level Active Filter Simulations (Notch Filter)

Figure 10, Figure 11, Figure 12 and Figure 13 show the current waveform Ifa (A), the current waveform Isa (A), its harmonic spectrum and a closer look for the 7-level active filter.

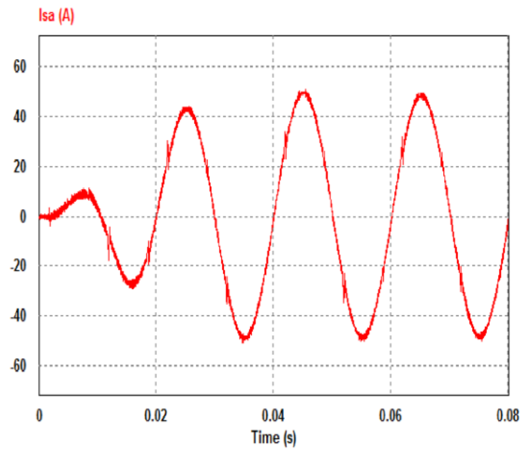

Figure 10. Source current Isa (A)

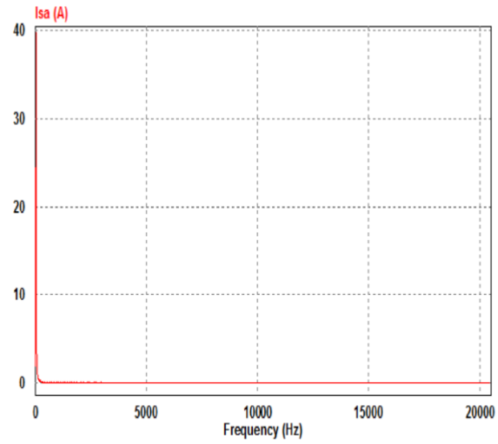

Figure 11. Harmonic spectrum of the source current Isa (A) after compensation

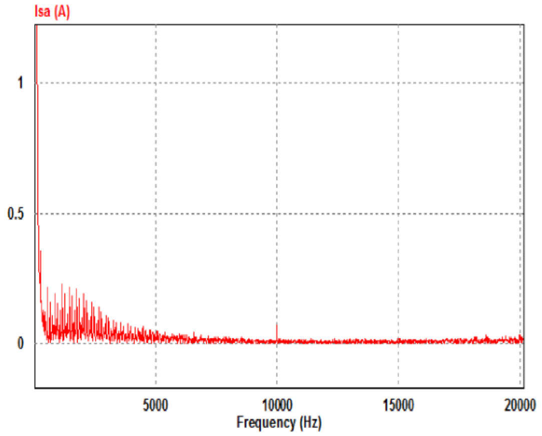

Figure 12. Closer look for Harmonic spectrum of the source of courant Isa (A)

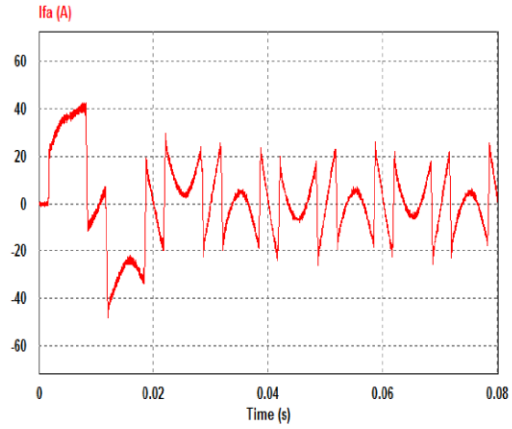

Figure 13. Filter current Ifa (A)

After applying the active parallel filter by using the notch filter as a reference current generating technique, there has been a significant improvement of the signal pattern of Isa (A), as shown in Figure 10. Thus, Isa (A) has been cleared at a satisfactory level. This is supported by the harmonic spectrum of Figure 12, with a THD distortion before compensation current injection was 22.82% and 2.86% after compensation current injection.

5.3. Seven-level active filter simulations (instantaneous reactive power)

Figure 14, Figure 15, Figure16 and Figure 17 show the current waveform Ifa (A), the current waveform Isa (A), its harmonic spectrum and a closer look for the 7-level active filter.
After applying the active parallel filter by using the instantaneous reactive power as a reference current generating technique, there has been a significant improvement of the signal pattern of Isa (A), as shown in Figure 14.

Thus, Isa (A) has been cleared at a satisfactory level. This is supported by the harmonic spectrum of Fig. 16, with a THD distorsion before compensation current injection was 22.82% and 1.73% after compensation current injection.

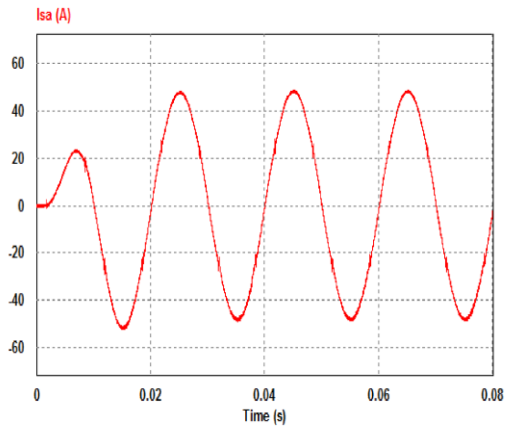

Figure 14. Source current Isa (A)

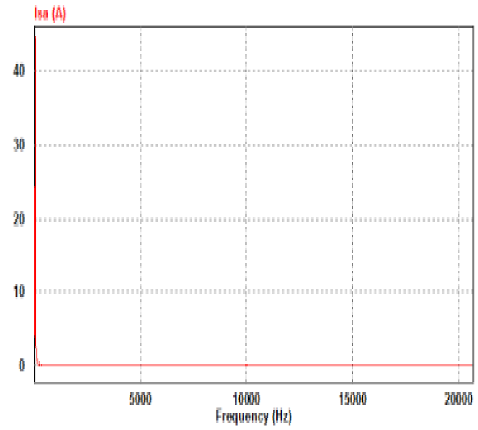

Figure 15. Harmonic spectrum of the source current Isa (A) afer compensation

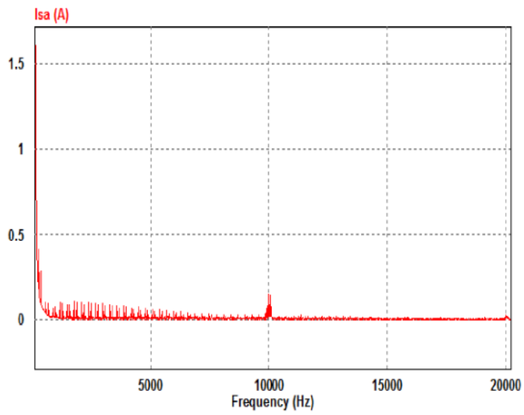

Figure 16. Closer look for Harmonic spectrum of the source of courant Isa (A)

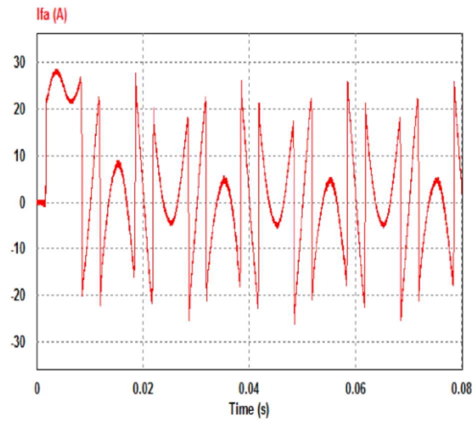

Figure 17. Filter currant Ifa (A)

6. ANALYSIS OF THE RESULTS

Figure 18 and figure 19 show the overlay of source current Isa (A) and the filter current Ifa (A) for both reference current generating algorithms in order to better appreciate the difference.

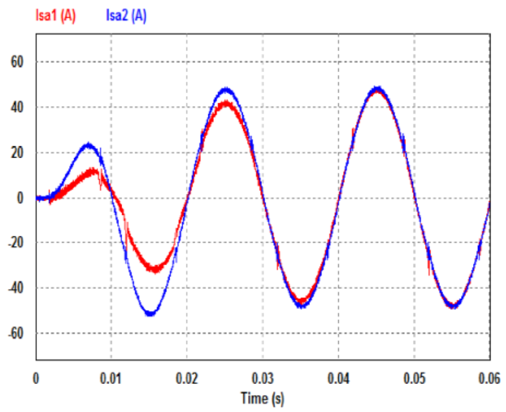

Figure 18. Source currents Isa (A) (blue for instantaneous reactive power; red for the notch filter)

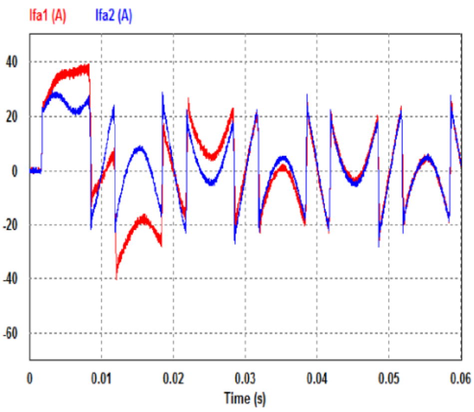

Figure 19. Filter currents Ifa(A) (blue for instantaneous reactive power ; red for notch filter)

The Table 2 below collects the THD and the fundamental values of source current obtained from simulations of both algorithms; instantaneous reactive power and notch filter.

Table 2 THD and Fundamental of source current Isa (A) for both reference current generating algorithms

	Instantaneous reactive power	Notch flter
THD (%)	1.73	2.86
Fundamental (A)	44.45	39.65

At the level of harmonic compensation at steady state, the control based on the instantaneous reactive power carries out better performances (THD of 1.73%) than those of notch filter (THD of 2.86%). We note that the control based on the instantaneous reactive power takes a little longer before reaching this value.

At transient state, the instantaneous reactive power technique achieves higher compensation performances concerning the response time which is shorter than the notch filter one. This latter is the least efficient relating to the transient response time.

It appears from Table 2, that at the level of the fundamental, the instantaneous reactive power algorithm is much better than the notch filter algorithm.

From the simulation results (Figures and Table):

The harmonic amplitudes related to the fundamental amplitude of the 41st harmonic to the 400 th harmonic have the same values (less than 0.4%) for both reference current generating techniques.

The difference between the two methods is within the 5th harmonic and the 41st harmonic.

The instantaneous reactive power: from the 5th harmonic to the 7th harmonic, the harmonic amplitude related to the harmonic fundamental varies from 0.92% to 0.62%.

And from the 8th harmonic to the 41st harmonic, the harmonic amplitude related to the fundamental amplitude is less than 0.4%.

The notch filter: from the 5th harmonic to the 29th harmonic, the harmonic amplitude related to the fundamental amplitude varies from 0.88% to 0.53%.

And from the 30th harmonic to the 41st harmonic, the harmonic amplitude related to the fundamental amplitude varies from 0.5% to 0.45%.

7. CONCLUSION

In this paper, we covered two control algorithms; the control algorithm of instantaneous reactive power and the control algorithm of notch filter for a 7 level active parallel filter. It enables us to see the inherent characteristics of each control algorithm, as well as the intricacies existing between them.

We can retain from the simulation results that the source current has been cleared at a performing level after application of the 7 level active parallel filter to our electrical network, consequently a substantial improvement of the THD for both reference current generating techniques.

Except that the instantaneous reactive power control algorithm is better than the notch filter control algorithm concerning the harmonic compensation at steady state. And at transient state, the notch filter control technique is less effective at response time level.

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