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Power Quality Compensation Strategy for Distribution System by Parallel Active Power Filter

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***Abstract*—The increasing use of non-linear loads has led to the appearance of many disturbances in low voltage distribution networks. Active power filtering is one of the most effective solutions to these problems. First, the different perturbations of electrical networks that affect the quality of the electrical energy delivered are studied, as well as the different methods of depollution proposed, classical or modern. Then the most efficient solution of active power filtering is chosen. This work is based in the modeling and simulation of a parallel active filter that compensates for the harmonics and the reactive power created by nonlinear loads**

Keywords—Active power filter; Instantaneous active and reactive power; harmonic currents; THD; nonlinear loads

I. Introduction

Nowadays, the increasing presence of nonlinear infecting loads in the network is a major problem, generating harmonic currents that disrupt the optimal operation of the electrical installations connected on the same network. Power filters represent a viable alternative to remedy this problem. Passive filters have been used to eliminate current from harmonics and to increase the power factor. However, the use of the passive filter has many disadvantages [1-2].

So the active power filters based on power inverters have has been developed to replace the role of passive power filters; the latter injecting compensations equal but opposite to the harmonics and eliminate them.

Several filter configurations exist, in our case the active power filter is a two-level inverter where the switches are controlled by sampling reference currents calculated by the instantaneous PQ by MLI method, energy storage is provided by Vdc which maintain a voltage fixed and equal to 600V at the terminals of the arms of the inverter

To study this configuration, we will go through the following two steps:

Step 1: Presentation of the current pattern in the source before application of any filtering operation, its harmonic spectrum information is containing on the THDI.

Step 2: devoted to the study of the parallel configuration, in the case of a voltage inverter with constant power source; the power circuit, the identification block of the harmonic current and the control circuit

II. Quantification of Harmonic Disturbances

Various criteria are defined to characterize the disturbances.

The harmonic rate of distortion and the power-factor are employed to quantify respectively.

A. The harmonic rate of distortion THD

The harmonic rate of distortion THD is a very significant factor in the determination of pollution and harmonic depollution it is expressed by:

$$\mathrm{THD}\ (\%) = 100\sqrt{\sum_{k=2}^{\infty}\frac{C_K^2}{{C_1}^2}} \tag{1}$$

1) The harmonic rate of distortion in current THDI

The THDI translates the deformation of the current. For that, it must be strongly reduced in order to limit the effects of the harmonic currents. It is expressed in the form:

$$\mathrm{THDI}\ (\%) = 100\sqrt{\sum_{k=2}^{\infty}\left(\frac{I_{cK}}{I_{c1}}\right)^2} \tag{2}$$

2) The harmonic rate of distortion in voltage THDV

The harmonic distortion of the tension can be defined as being the product of the harmonic current and the impedance through which it circulates

$$\mathrm{THDV}\ (\%) = 100\sqrt{\sum_{k=2}^{\infty}\left(\frac{V_{CK}}{V_{C1}}\right)^2} = 100\sqrt{\sum_{k=2}^{\infty}\left(\frac{\left|Z_{scc}^{K}\right| I_{CK}}{V_{C1}}\right)^2} \tag{3}$$

B. The Power-factor

Normally, for a sinusoidal signal the power-factor is given by the relationship between the powers activates (P) and the apparent power (S). Thus it is expressed by the relation:

$$FP = \frac{P}{S} = \frac{V_n I_n \cos\varphi}{V_n I_n} \tag{4}$$

If there are harmonics, an additional power called the deforming power (D), given by the relation (5), appears it has as an expression:

$$D = 3V_1\sqrt{\sum_{k=2}^{50} I_k^2} \tag{5}$$

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Thus the power-factor becomes:

$$FP = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} = \cos\varphi_1 \cos\gamma \qquad (6)$$

Thus the harmonics create a deforming power which influences the power-factor.

II. EFFECTS OF HARMONIC POLLUTION

- Disturbance of the electronics components [8, 6]
- The interference with the telecommunications network.
- Progressive destruction of the electromagnetic instruments.
- Risk excitation of resonances.
- Heating of the machines and transformers.
- Heating of the cables and the equipment.

The loads responsible for the propagation of harmonic pollution are the nonlinear loads which include the static inverters and the transformers; the use of these loads is irreplaceable. Therefore, it is imperative to go to seek the solutions with the problems of harmonics elsewhere without having to eliminate these loads.

III. PARALLEL ACTIVE FILTER

A. *Active filter structure*

The active filters are structures which operate in a zero active power mode. They use a controllable source to introduce the voltage or current into the network, thus presenting a waveform that compensates for the harmonics.

Depending on how they are connected to the network, the active filters can be either series or parallel [3]. A serial-parallel or parallel-serial combination structure and hybrid active-passive structures are also found.

B. *Parallel active filter structure*

The structure is made up of a three-phase inverter of voltage connected to the network through a filter of inductive connection (of type L). Continuous side of the inverter one has a system of storage of energy in the form of a source of continuous tension which provides energy necessary to the compensation [7].

The quite detailed structure is represented by figure I [5]

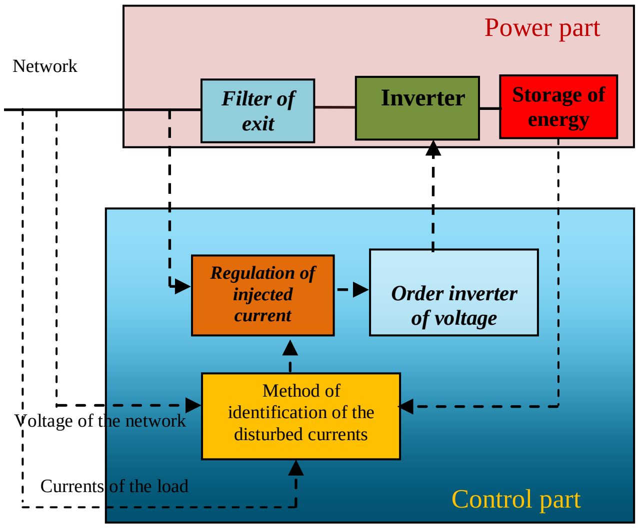

FIG.I GENERAL STRUCTURE OF THE PARALLEL ACTIVE FILTER

- The voltage inverter

The three-phase inverter with structure of voltage is composed of three arms with reversible switches while running, ordered with closing and the opening, produced starting from one-way switches (GTO or IGBT) and of a diode in anti-parallel.

- System of energy storage [9]

The storage of the energy on the continuous side is often done by a system voltage storage represented by source of tension continues Vdc [2].

- Exit Filter

The exit filter used for our work is passive filter, especially L filter.

- Identification Method of the disturbed currents

The method of identification the most used is that called method of the real and imaginary instantaneous powers [1,3]

In three-phase circuits, instantaneous currents and voltages are converted to instantaneous space vectors. In instantaneous power theory, the instantaneous three-phase currents and voltages are calculated as following equations. These space vectors are easily converted into the α–β orthogonal coordinates [6].

This method offers the advantage of choosing the disturbance to be compensated with precision, speed and eased establishment. For all these reasons we adopted this method of identification represented by figure I for our study.

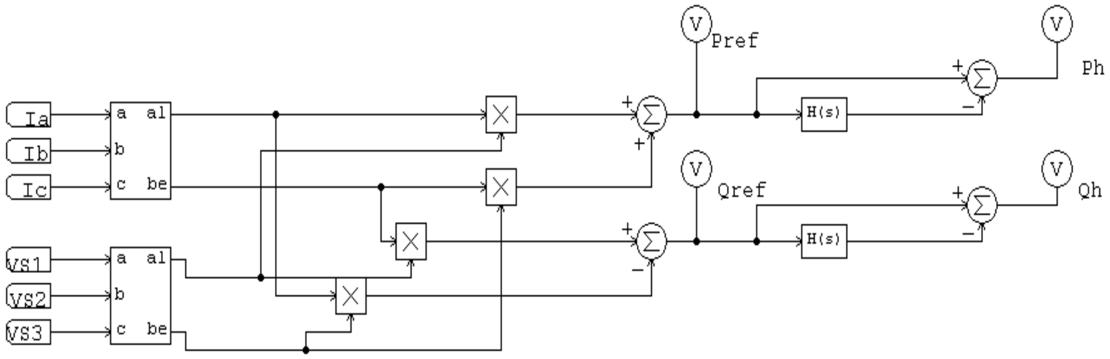

FIG. II. BUILDING BLOCK OF CALCULATION OF THE POWERS OF REFERENCE

The essential goal of this procedure is the reduction of the size of the system to be solved. Indeed, instead of having a system of six equations, one will have only to solve a system of four equations given by the two expressions (7), (8).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (8)$$

Only the three-phase three-wire system is considered, the three-phase currents can be expressed in terms of harmonic positive, negative and zero sequence currents.

Conventional instantaneous power is calculated as follows:

$$p = v\alpha i\alpha + v\beta i\beta \quad (9)$$

- α, β : are orthogonal coordinates.
- vα,iα: are on α axis.
- vβ, iβ: are on β axis.

In fact, instantaneous real power (p) is equal to following equation:

$$p = vaia + vbib + vcic \quad (10)$$

The expressions of the Instantaneous real and imaginary load powers are given by the matrices system (11)

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} i_\alpha & i_\beta \\ -i_\alpha & i_\beta \end{bmatrix} \cdot \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \quad (11)$$

Where p_L and q_L contain harmonic component (oscillatory) and dc component terms and can be written as:

$$p_L = p_L c + p_L h$$
$$q_L = q_L c + q_L h \quad (12)$$

The stage which follows consists in eliminating the continuous components in order to preserve only the alternate components relating to the required harmonic components. This is feasible by simple use of a filter passes low second order [4].

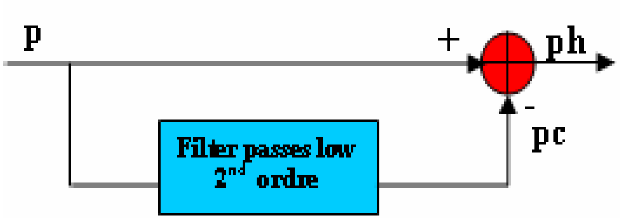

FIG.III. REPRESANTATION OF THE POWERS SEPARATION

Squaring currents of reference, I α_{ref} and Iβ_{ref} are given by the equation

$$\begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} = \frac{1}{\left| v_\alpha^2 + v_\beta^2 \right|} \cdot \begin{bmatrix} v_\beta & -v_\beta \\ v_\alpha & v_\beta \end{bmatrix} \cdot \begin{bmatrix} p_{Lh} \\ q_{Lh} \end{bmatrix} \quad (13)$$

By a simple use of the transformation of Concordia reverses [66] definite by the equation below (14), one arrives at the current of reference iref presented in the figure IV the currents of reference are given by the equation:

$$\begin{bmatrix} i_{aref} \\ i_{bref} \\ i_{cref} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{\alpha ref} \\ i_{\beta ref} \end{bmatrix} \quad (14)$$

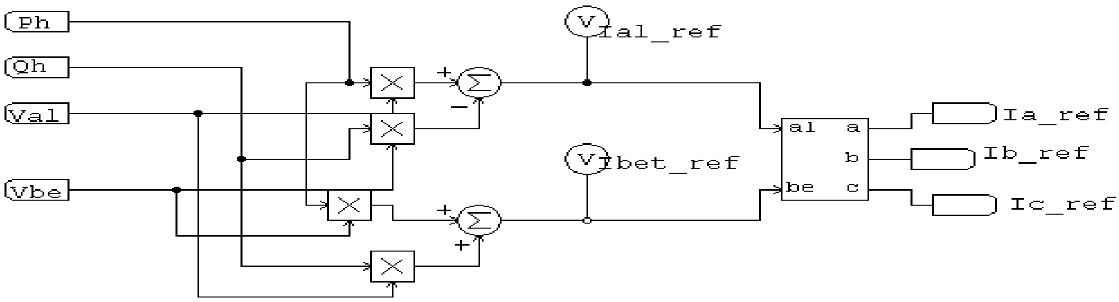

FIG IV SHOWS THE COMBINED PACE OF THE THREE CURRENTS IAREF, IBREF, ICREF

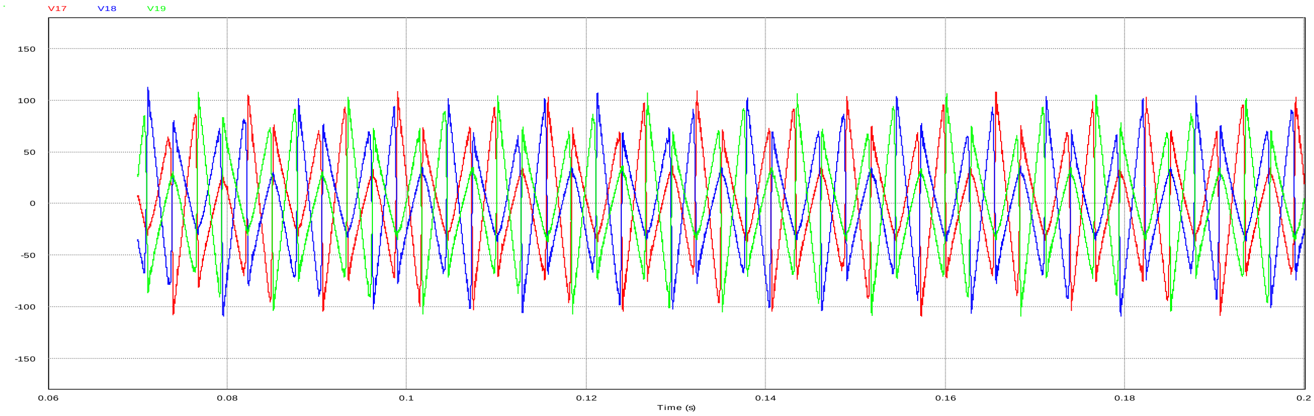

FIG V THE THREE CURRENT OF REFERENCE IAREF, IBREF, ICREF

After having identified the harmonic currents, we will pass now to the regulation of the current reference.

• The ordering of the inverter

The technique of order by MLI solves the problem of the control of the frequency of operation. This technique of order implements initially a regulator which determines the reference voltage standard of the inverter (modulating). The general diagram is given by figure VI:

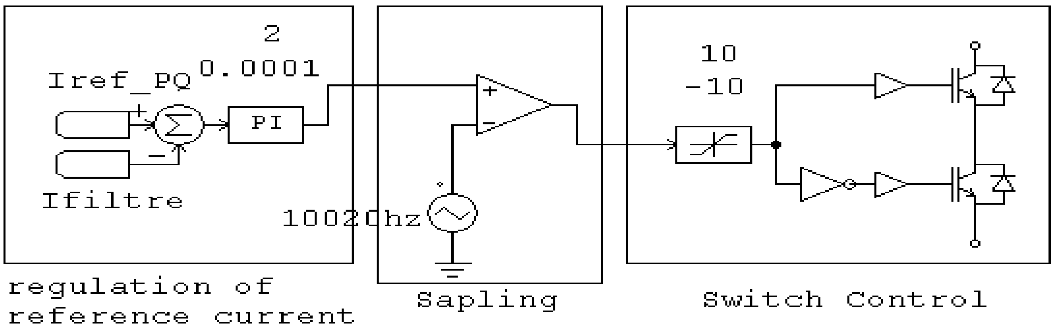

Fig.VI Principle order of the currents by MLI

IV. SIMULATION

In model presented by figure VII, three various parts can be distinct:

A. Network

Constituted of a direct balanced three-phase system of tensions having 220 V for effective value, shifted between them by 120, having a null impedance with a frequency

F = 60Hz.

B. The polluting load

It is a bridge with six thyristor feeding a continuous load RL. The load continues an inductance L equalizes to 3 mH in series with a resistance R equalizes to 0.5 Ω.

C. Active Filter parallel with two levels

It is a three-phase inverter of tension on two levels, place in parallel with the network.

The inverter is characterized by a tension VDC equal to 600V. The filter of exit of the active filter is an inductance of Lf filtering Lf =5mh

D. Network model, Polluting Load and Active Filter

Figure VII shows the model of the unit network, polluting charge and active filter parallel with two levels.

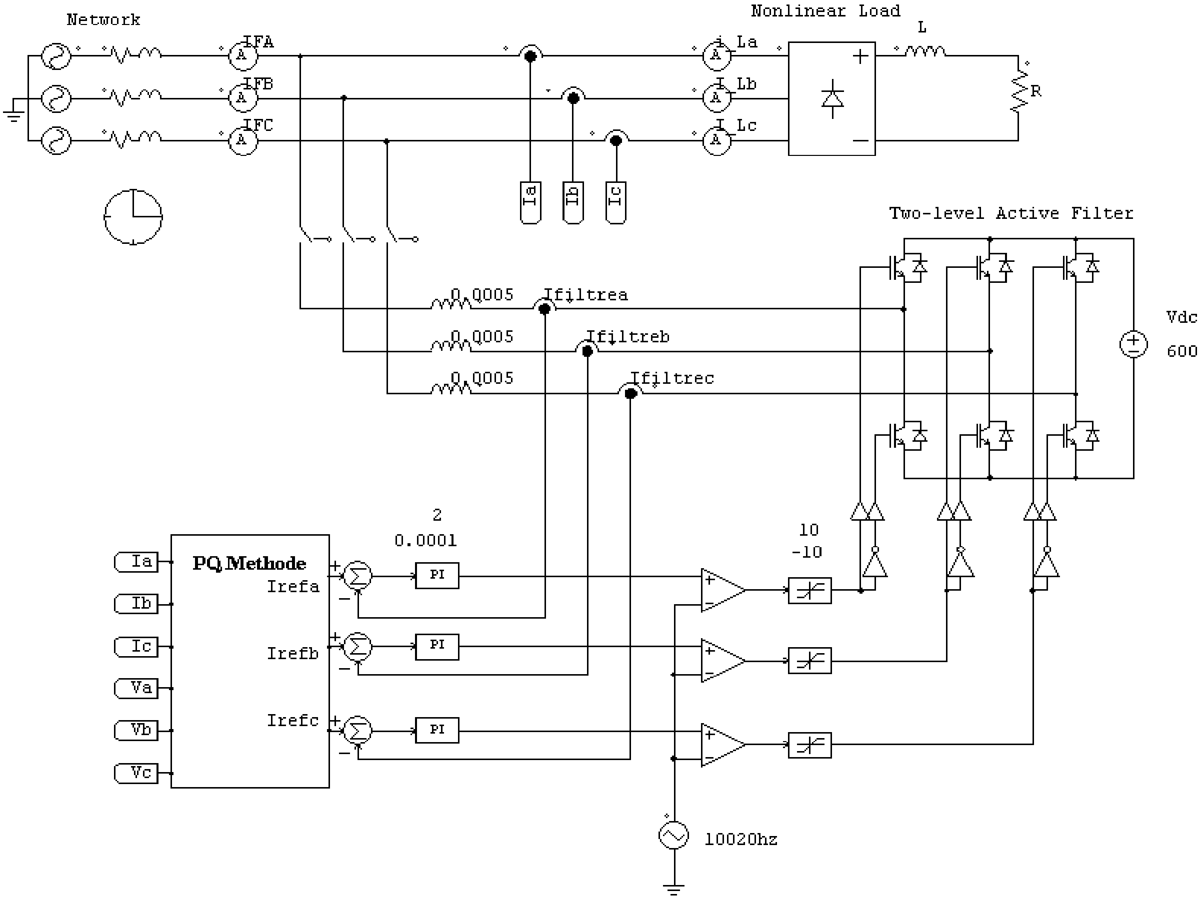

FIG.VII. MODEL OF THE NETWORK UNIT POLLUTING LOAD AND PARALLEL ACTIVE FILTER WITH TWO LEVELS

The first figures (VIII.A and VIII.B) illustrate the polluted current, followed by their harmonic specter corresponding and the corresponding THDI

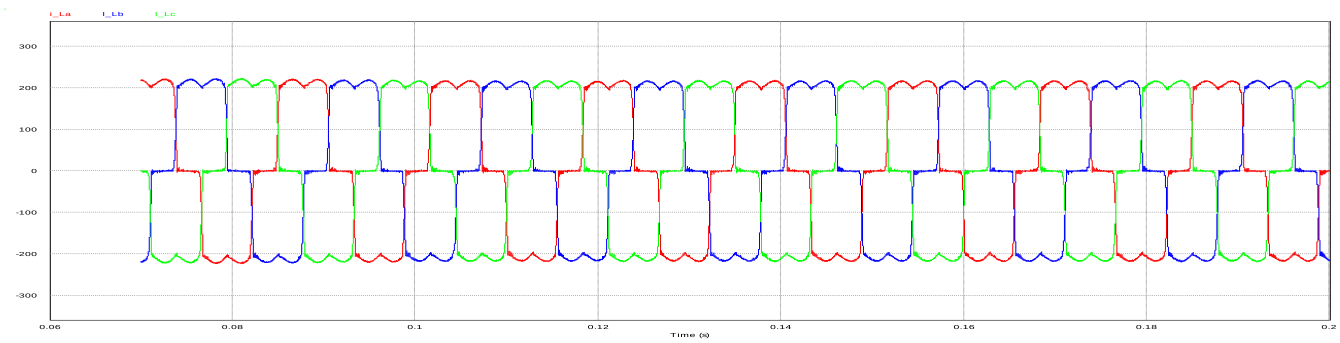

FIG.VIII.A POLLUTED LOAD CURRENT IA , IB AND IC.

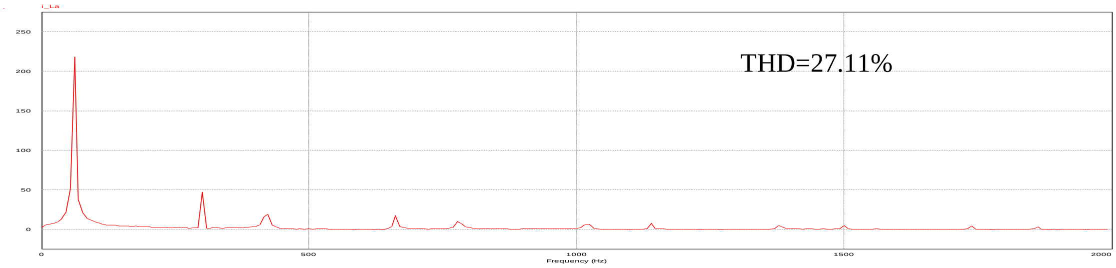

FIG.VIII.B HARMONIC SPECTRUM OF LOAD CURRENT IA

The following figures present the current of source cleansed using an active filter parallel with two levels ordered in M.L.I, follow-up of the harmonic spectrum and the corresponding THDI. One can note well a beginning of depollution seeming to be acceptable in spite of the presence of peaks due primarily to the losses by delays with commutation.
Indeed, according to the harmonic spectrum and its calculated THDI, which leaves hope for an improvement in the quality of filtering during the time which will follow; the rate of harmonic distortion of the current fell of 27.11 % to 1.28%.

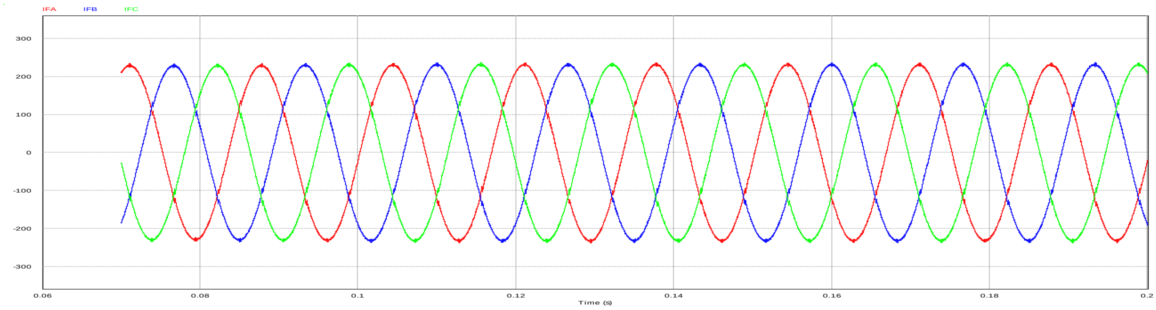

FIG. VIIII.A THE FILTERED CURRENT IA, IB, AND IC

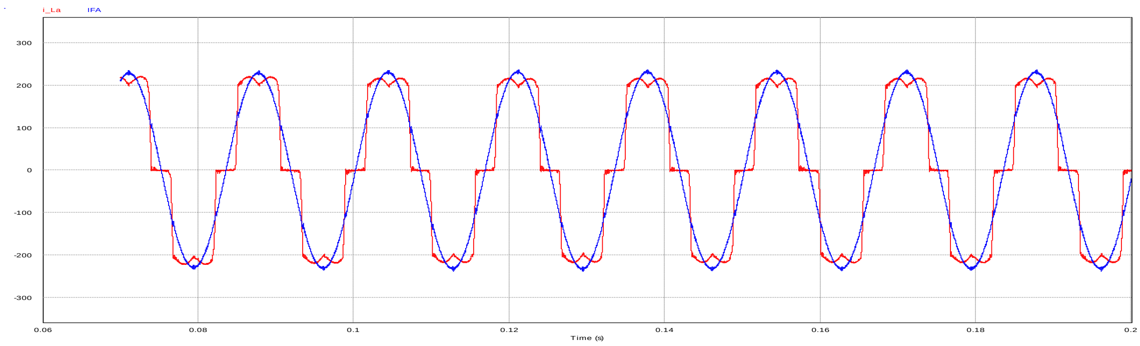

FIG. VIIII.B POLLUTED LOAD CURRENT IA AND FILTERED CURRENT IA

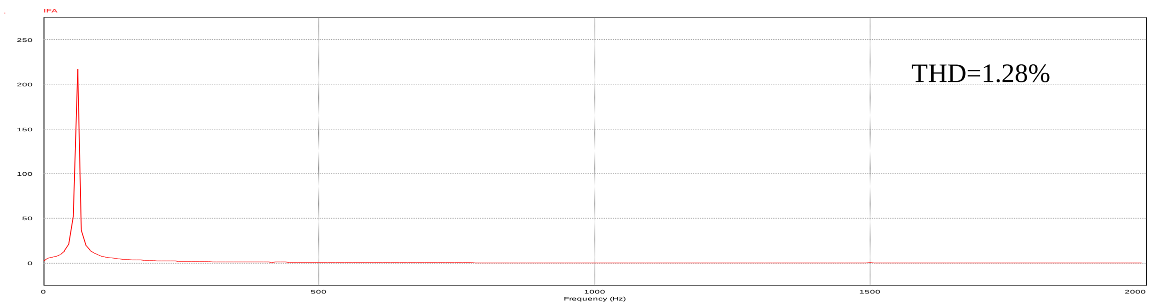

FIG. X HARMONIC SPECTRUM OF THE FILTRED CURRENT IA

V. CONCLUSION

Finally, we could present and define, in this article, the elements constituting the structure of the parallel active filter.

We could fix the choice of the elements of the part control, such as the method of identification of the disturbed currents, the ordering of the inverter and the regulation of the tension continues the element of storage, the filter of exit and the regulation of the current of the active filter.

The second part of this article is devoted to simulation of the active filter parallel with two levels, after the presentation of the order, and the fixing of the parameters of simulation, one reveled the results of the study, and the rate of harmonic distortion of the current THD fell of 27.11 % to 1.28%.

It is true that depollution did not arrive at the perfect level THD= 0%, nevertheless, we are very satisfied of the result obtained and that our objective to prove the feasibility of active filtering parallel with two levels was achieved.

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