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CURRENT HARMONIC COMPENSATION IN THE ELECTRICAL NETWORK USING VOLTAGE SHUNT ACTIVE FILTER CONTROLLED BY HYSTERISIS

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KEYWORDS: Electrical network, harmonics, three-phase rectifier, voltage active filter, control by hysterisis.

ABSTRACT

This paper presents a study on voltage active filter, controlled by hysterisis and placed in parallel on an electrical network polluted by a three-phase rectifier.

Firstly, we gave the power circuit of the active filter and his control strategy. In a second time, we developed the method of instantaneous active and reactive powers for identifying the reference currents of the filter.

We then provided the results of the simulation for a polluting load of 400KVA. These results show a good compensation of current harmonics and a good reduction of total harmonic distortion (from 29% before filtering to 4% after filtering). Also, these results clearly reflect the effectiveness of our active filter to meet IEEE-S19 recommendations on harmonic levels.

Finally, to see the effects on compensation of harmonics, we conducted a study of total harmonic distortion depending on certain parameters of the system "electrical network - active filter - polluting load".

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INTRODUCTION

In recent years, the number of static converters connected to the electrical network is constantly growing. This poses serious problems for distributors of electric power, for whom these converters are polluting sources. Indeed, these converters absorb non-sinusoidal currents even if they are powered by sinusoidal voltages. They therefore act as generators of harmonic currents that can deform the mains voltage and lead to harmful effects on the network itself and its environment.

- Supplementary losses in transformers, AC generators and motors ;
- Supplementary losses in transformers, AC generators and motors ;
- Dielectric losses and rapid aging in the power capacitors ;
- Disruption in telecommunication networks ;
- Dysfunction of certain electrical equipment's, etc.

Passive filters, that are traditionally used to compensate harmonics, are increasingly abandoned in favor of active power filters, designed around the inverters.

In this context, this article presents the study of a voltage shunt active filter capable of compensating current harmonics injected into an electrical network by a polluting load (thyristor rectifier).

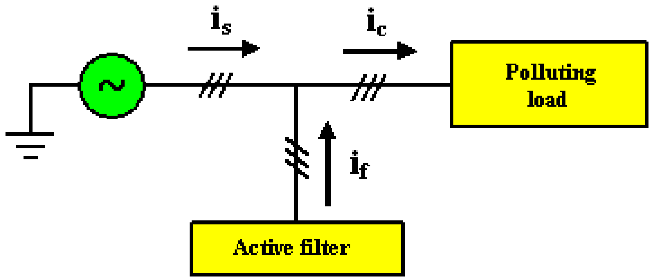

Figure 1: Principle of harmonic compensation by a shunt active filter

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POWER CIRCUIT OF THE ACTIVE FILTER

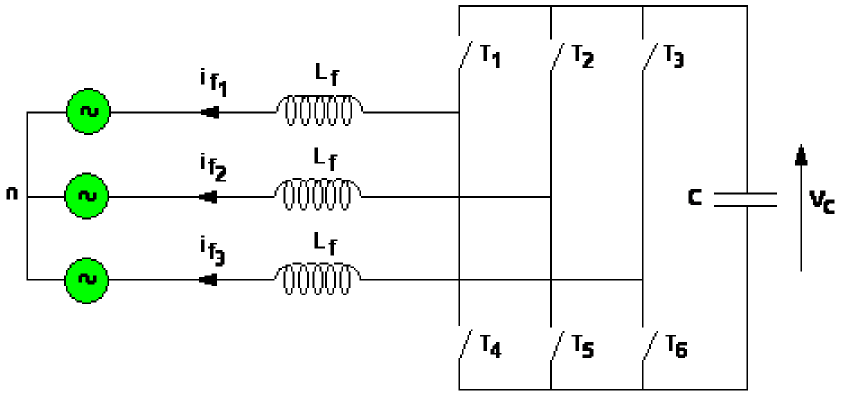

Figure 2: Scheme of power circuit

We insert an inductance as input filter of first order between the inverter and the network.

The capacitor acts as a DC voltage source. The voltage (Vc) at its terminals is maintained at a near constant value through appropriate regulation.

The switches are reversible in current. They are formed by controllable semiconductor components to the closing and opening (IGBT in anti-parallel with a diode).

In practice, the two switches of the same arm are controlled in a complementary manner: the conduction of one causes the locking of the other.

CONTROL STRATEGY OF THE ACTIVE FILTER

To control the active filter, we must first identify the harmonic currents of the pollutant load. They serve as a references of currents for the active filter (i^*f_1, i^*f_2, i^*f_3). Then we must choose the active filter control mode to generate currents (if_1, if_2, if_3) that follow well their references. We use the control by hysterisis.

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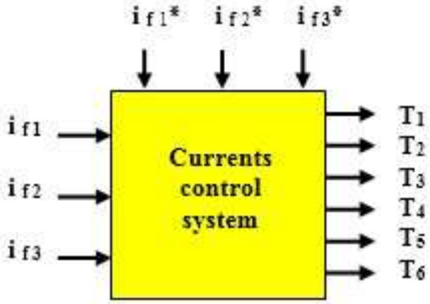

Figure 3: Synoptic diagram of the currents control

Its principle, shown schematically in figure 4, is to maintain each of the currents generated in a band framing its reference. The difference between the real current and the reference current is compared to the hysteresis band. Each output of this band entails a change in configuration of the inverter switches. Failover conditions for the comparator of the phase j (j = 1, 2, 3) are then:

- from 0 to 1 if $if_j^* - if_j \geq +\Delta I$
- from 1 to 0 if $if_j^* - if_j \leq -\Delta I$

ΔI is the width of the hysteresis band.

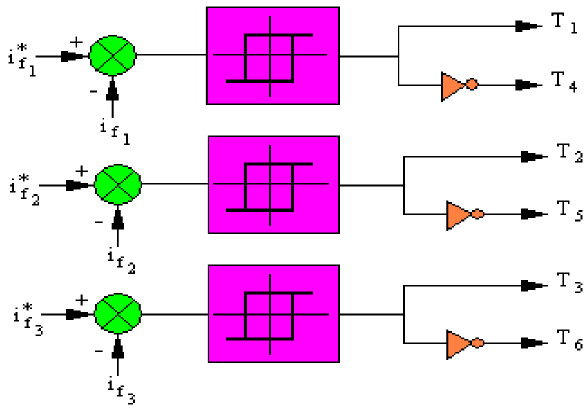

Figure 4: Synoptic diagram of currents control

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IDENTIFICATION OF REFERENCE CURRENTS OF THE ACTIVE FILTER

For the identification of reference currents, we chose the method of instantaneous active and reactive powers. Using the transformation of Concordia, we can write:

$$\begin{bmatrix} v_{c\alpha} \\ v_{c\beta} \end{bmatrix} = [C_{32}] \begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} \text{ and } \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = [C_{32}] \begin{bmatrix} i_{s1} \\ i_{s2} \\ i_{s3} \end{bmatrix} \quad (1)$$

With:

$$[C_{32}] = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$$

The instantaneous powers p and q are defined by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \quad (2)$$

Each power comprises a DC component and an AC component.

$$\begin{cases} p = \bar{p} + \tilde{p} \\ q = \bar{q} + \tilde{q} \end{cases} \quad (3)$$

$\bar{p}$ is continuous power related to the fundamental component of the active current..
$\bar{q}$ is continuous power related to the fundamental component of the reactive current..
$\tilde{p}$ and $\tilde{q}$ are alternative powers related to the sum of the harmonic components of the current.

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From equation (2) we can deduce:

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

With: $\Delta = v_{s\square}^2 + v_{s\square}^2$

Using equations (3) and (4), the components ($i_{c\alpha}$, $i_{c\beta}$) of the current i_c in reference (α,β), are given by :

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \underbrace{\frac{1}{\Delta} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix}}_{\text{active current}} + \underbrace{\frac{1}{\Delta} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix}}_{\text{reactive current}} + \underbrace{\frac{1}{\Delta} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix}}_{\text{harmonic currents}} \quad (5)$$

The three-phase currents (i_{c1} , i_{c2} , i_{c3}) are obtained from the diphase currents (i_α , i_β) by the reverse transformation of Concordia, namely :

$$\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = [C_{23}] \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \text{ with } [C_{23}] = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \quad (6)$$

In the case of a 6 thyristors rectifier, the components of powers p and q are given by:

$$\bar{p} = 3VI_1\cos\varphi_1 \qquad \bar{q} = -3VI_1\sin\varphi_1$$

$$\tilde{p} = \sum_{k=1}^{\infty} S_{p6k}\sin(6k\omega t - \varphi_{p6k}) \qquad \tilde{q} = \sum_{k=1}^{\infty} S_{q6k}\sin(6k\omega t - \varphi_{q6k})$$

With:

$$S_{p6k} = 3V\sqrt{I_{6k-1}^2 + I_{6k+1}^2 - 2I_{6k-1}I_{6k+1}\cos[(6k-1)\varphi_{6k-1} - (6k+1)\varphi_{6k+1}]}$$

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$$S_{q6k} = 3V\sqrt{I_{6k-1}^2 + I_{6k+1}^2 + 2I_{6k-1}I_{6k+1}\cos[(6k-1)\varphi_{6k-1} - (6k+1)\varphi_{6k+1}]}$$

$$\varphi_{p6k} = \mathrm{Arctg}\left(\frac{I_{6k+1}\sin(6k+1)\varphi_{p6k+1} - I_{6k-1}\sin(6k-1)\varphi_{p6k-1}}{I_{6k+1}\cos(6k+1)\varphi_{p6k+1} - I_{6k-1}\cos(6k-1)\varphi_{p6k-1}}\right)$$

$$\varphi_{q6k} = \mathrm{Arctg}\left(\frac{I_{6k+1}\sin(6k+1)\varphi_{p6k+1} + I_{6k-1}\sin(6k-1)\varphi_{p6k-1}}{I_{6k+1}\cos(6k+1)\varphi_{p6k+1} + I_{6k-1}\cos(6k-1)\varphi_{p6k-1}}\right)$$

We finds that $\tilde{p}$ and $\tilde{q}$ comprise a suite of frequency components 6 times that of network. To extract these components, we must eliminate the DC components ($\bar{p}, \bar{q}$). We use a low pass filter as shown in figure 5.

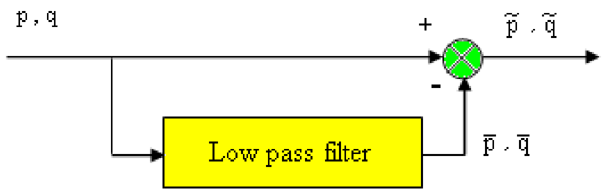

Figure 5: Low passe filter

The different steps for identifying the harmonic currents of the pollutant load serving as reference currents of the active filter are shown in figure 6.

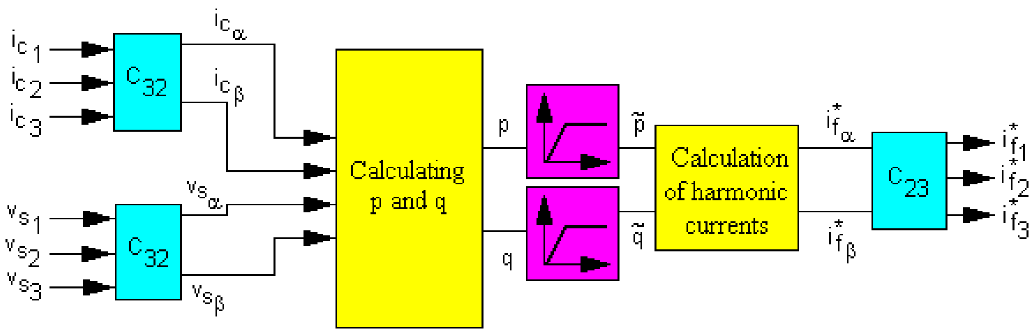

Figure 6: Synoptic diagram of identification steps of harmonic currents

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SIMULATION RESULT AND DISCUSSION

The network is modeled by the sinusoidal three-phase voltages in series with a resistor (Rs) and an inductance (Ls), representing its impedance.

The pollutant load is a 6 thyristors rectifier feeding an inductive load (Rd-Ld). At its input, the resistance (Rc) and the inductance (Lc) represent the short-circuit impedance of an adapter transformer.

The thyristors of rectifier and the semiconductors of inverter are modeled by perfect switches entirely controllable.

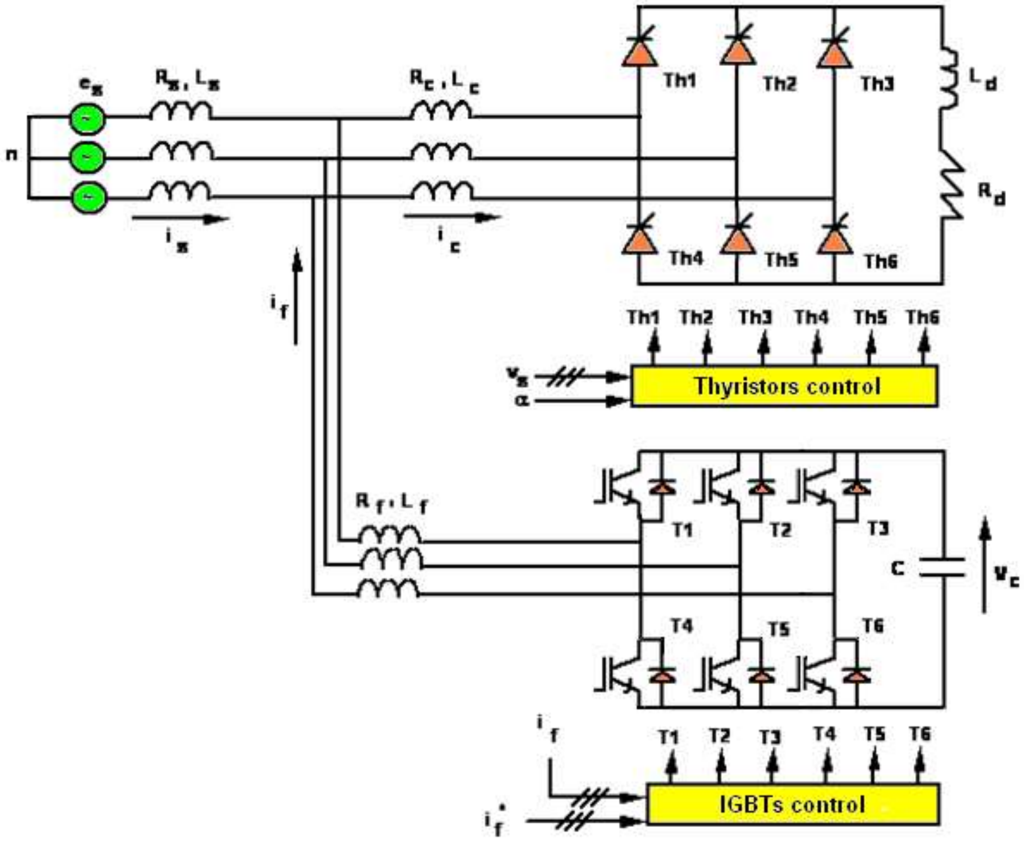

Figure 7: Block diagram of the system to simulate

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We present here the simulation results for the following parameters:

Network	$V_S = 220V$	$f = 50Hz$	$R_S = 0{,}5m\Omega$	$L_S = 15\mu H$	
Rectifier	$R_d = 0{,}6\Omega$	$L_d = 2mH$	$R_c = 1{,}2\Omega$	$L_c = 50\mu H$	□□= 30°
Active filter	$R_f = 5m\Omega$	$L_f = 150\mu H$	$C = 8{,}8mF$		

The figure 8 shows the current waveform absorbed by the rectifier, generated by the active filter and in the network. We find that the current (i_S) is almost sinusoidal.

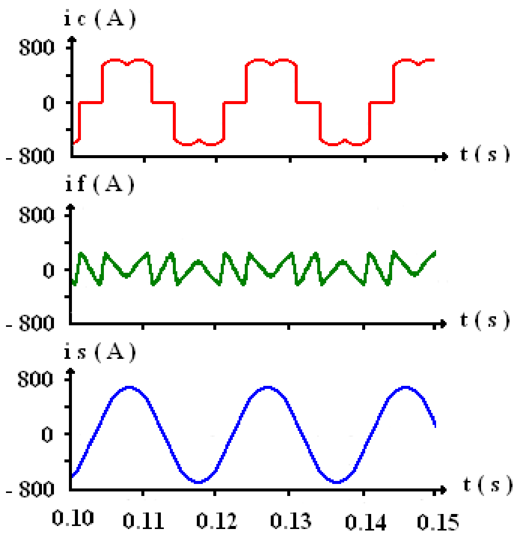

Figure 8: The rectifier current (i_c), the active filter current (i_f) and the current in the network (i_s)

The figure 9 presents the spectra of currents in the network before and after filtering. We remark that the harmonics are greatly attenuated. The total harmonic distortion is also greatly reduced. He goes from 29% before filtering to 4% after filtering.

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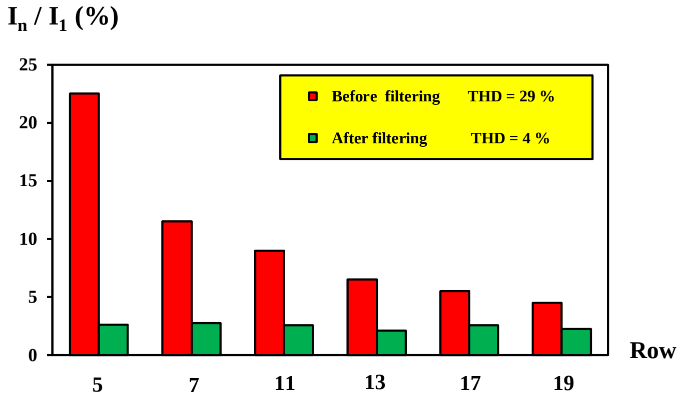

Figure 9: Spectra of currents in the network before and after filtering

To see the effects on the harmonic compensation, we studied the influence of certain parameters of electrical network, of active filter and of pollutant load on current total harmonic distortion.

Influence of the Hysteresis Band Width

The figure 10 presents the total harmonic distortion variation depending of the hysteresis band width. The results show that the THD is optimal to $\Delta I \approx 75A$.

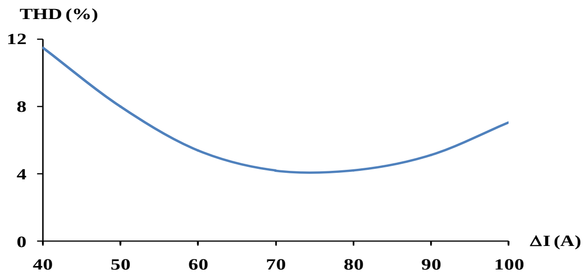

Figure 10: Total harmonic distortion depending of ΔI

Influence of the thyristors ignition angle

The figure 11 shows the total harmonic distortion evolution depending of the thyristors ignition angle. We remark that the compensation becomes less effective when □ increases. This can be explained by the fact that when □ increases,

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the commutation in the rectifier is more rapid and consequently the currents generated by the active filter have difficulties to follow their references.

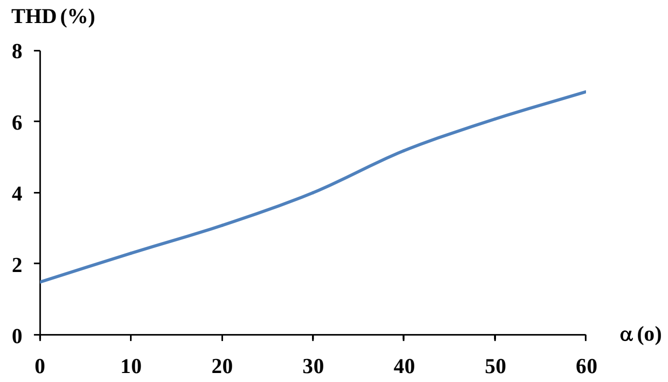

Figure 11: Total harmonic distortion depending of α

Influence of the rectifier current

The figure 12 shows the total harmonic distortion variation depending of the rectifier current. We find that the compensation becomes more effective when I_d decreases. Indeed, when I_d decreases, thyristors switching time is reduced, which improves the controllability of the currents.

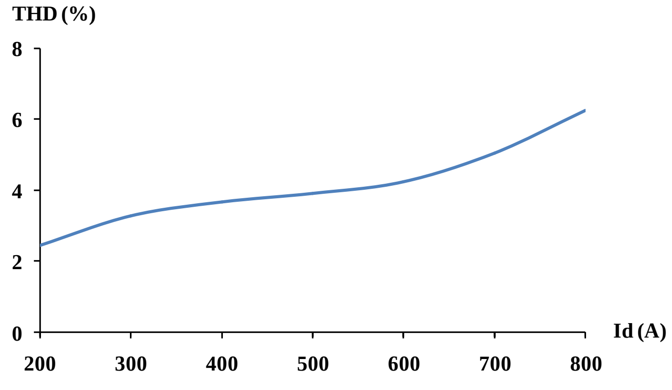

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Figure 12: Total harmonic distortion depending of I_d

Influence of network inductance

The figure 13 presents the total harmonic distortion evolution depending of the network inductance. We remark that the harmonics compensation is improved when Ls increases.

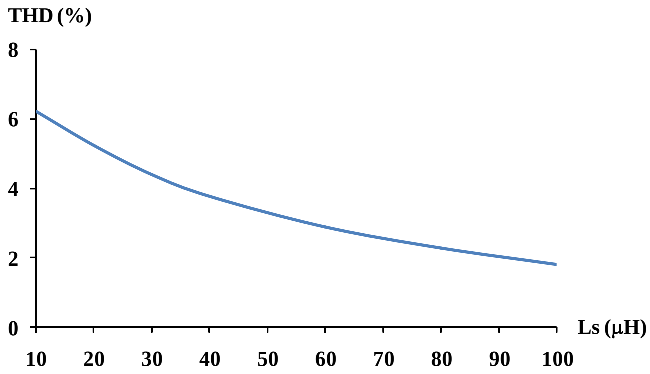

Figure 13: Total harmonic distortion depending of L_S

Influence of inductance rectifier input

The figure 14 shows the total harmonic distortion variation depending of the inductance rectifier input. We find that the harmonics compensation is improved when Lc increases.

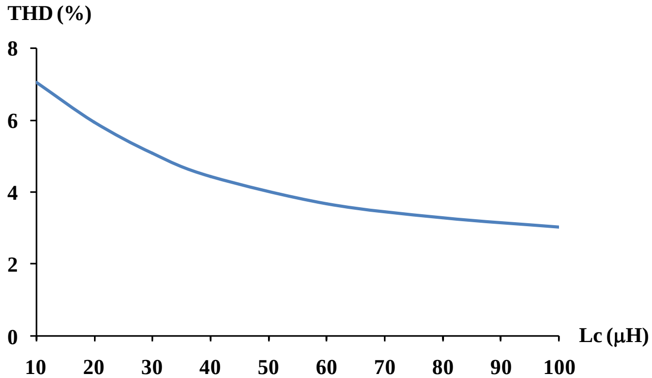

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Figure 14: Total harmonic distortion depending of L_C

CONCLUSIONS

In this paper, we gave firstly a general description of the active filter designed to compensate current harmonics injected in the network by a three-phase rectifier.

Then, we presented active filter control strategy and also identification method of the reference currents.

The simulation results showed that our active filter allows a significant reduction of harmonics. The current total harmonic distortion into the network, on the order of 29% before filtering, is reduced to 4% after filtering. We got similar results like other authors who have used other filtering algorithms and other control strategies.

We also studied the influence of certain parameters of our system on the current harmonics compensation. The results obtained showed that:

- ➔ The total harmonic distortion can be optimized by a good choice of the hysteresis band width ;
- ➔ The filtering is less effective when thyristors ignition angle (α)increases ;
- ➔ The filtering is more effective when the rectifier current (I_d) decreases ;
- ➔ The harmonic compensation is improved when the network inductance (L_s) increases ;
- ➔ The harmonic compensation is improved when the inductance rectifier input (Lc) increases.

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