Harmonics generated by Compact Fluorescent Lights: Diagnostic and Shunt Active Filtering.

H.HOUASSINE, S.MOULAHOUM and N.KABACHE
Research Laboratory on Electrical Engineering and Automatics (L.R.E.A)
University Of Médéa, ALGERIA
hamza_houassine@yahoo.fr

Abstract— nonlinear loads greatly used in the industry, such as power converters, fluorescent lamps and adjustable speed motor drives, is expected to grow rapidly. All of these loads inject harmonic currents to the grid. This paper presents the diagnostic and the active filtering of the harmonic distortion generated by the compact fluorescent lamps (CFL)by conducting measurement tests and the comparison of these results with the simulations based on the CFL's electronic model. The Instantaneous active and reactive power theory, called p-q theory, is used to design the control strategy for extracting reference currents for the shunt active power filter. The active filter control scheme has been verified and its performance has been evaluated under different load conditions through a set of simulation tests. Also, the tuning of the active power filter is performed to improve the quality of the electrical power supply by harmonic compensation and power factor improvement.

Keywords-CFL, Shunt active power filter (SAPF), harmonics distortion, P-Q theory.

I Introduction

Power system harmonics are integer multiples of the fundamental power system frequency. Power system harmonics are created by non-linear devices connected to the power system such as variable-frequency drives, dc-adjustable speed drives, and switch-mode power supplies like fluorescent lamps. High levels of power system harmonics can create voltage distortion and power quality problems [1-4]. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. That has increased the vulnerability of such equipment to power quality problems [5].

Some loads cause the current to vary disproportionately with the voltage during each cyclic period. These are classified as nonlinear loads, and the current has a non-sinusoidal waveform [2].When there is significant impedance in the path from the power source to a nonlinear load, these current distortions will also produce distortions in the voltage waveform at the load. However, in most cases where the power delivery system is operational correctly under normal conditions, the voltage distortions will be quite small and can usually be ignored [6].

One of the obvious ways to use electricity more efficiently is by using energy efficient lighting such as Compact Fluorescent Lamps (CFL) to replace conventional incandescent lamps. The electronic ballasts of CFLs are nonlinear, and hence a current waveform is rich in harmonics. This harmonic current flowing in the grid causes a power quality issue and a voltage wave form distortion.

In the past the harmonics injected into the network by CFLs has been ignored as each CFL's injection is very small [7]. The combined effect however, of the widespread adoption of CFLs can be just as detrimental as one large harmonic source.

Traditionally, mechanically switched capacitors and passive filters are usually employed to reduce harmonics, to compensate the reactive power and improve the power factor. However, the use of passive filters has many disadvantages they are bulky, load dependent and can also cause resonance problems to the system. In order to solve these problems, Active power filters APFs have been considered as a possible solution to mitigate harmonic because they have excellent compensation characteristics. They are developed to eliminate the harmonic currents and compensate for reactive power, simultaneously.

Active filters avoid the disadvantages of passive filters by using a switch mode power electronic converter to supply harmonic currents equal to those in the load currents. Different active power filters topologies have been presented in the technical literature [8-9].Moreover, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non-linear load and the active power filter as an ideal resistor [10]

Control strategies for reference current generation may be put into two categories: time-domain and frequency-domain. One of the well know time-domain methods was proposed by Akagi [4], [5], called instantaneous active and reactive power theory (or p-q theory). Most APFs have been designed on the basis of this theory to calculate the desired compensation current. However, this method only works correctly in the case when three phase grid voltages are balanced and undistorted

The control technique applied in this paper is based on the p-q theory, proposed by Akagi et al. [11].In literature, several works can be found on control strategies for active power filters based on instantaneous power theory [12-13].

This paper presents experimental and simulation results that evaluate the harmonic distortion. The diagnostic and the filtering of harmonics generated by the electronic ballasts on the distribution power system will be studied based on theoretic models of the Compact Fluorescent Lights. Since the CFLs are being very used in the grid, the system suffers from the problem of harmonics and reactive power. Shunt active power filter has been used for the compensation and improvement of power quality .The performance of the shunt active power filter, with nonlinear Load CFLs, is analyzed. The instantaneous Reactive Power theory of the active filter will be analyzed and discussed for CFLs load. The presented system is able to compensating current harmonics and improve power factor under balanced and unbalanced grid voltages. The total harmonic distortion THD and power factor are calculated for different load before and after filtering.

II. COMPACT FLUORESCENT LIGHTS PRESENTATION

A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent lamp; some types fit into light fixtures formerly used for incandescent lamps. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and the compact electronic ballast in the base of the lamp.

Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use less power (one fifth to one third) and have a longer rated life (eight to fifteen times). In most countries, a CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime. Like all fluorescent lamps, CFLs contain mercury, which complicates their disposal. In many countries, governments have established recycling schemes for CFLs and glass generally.

CFLs radiate a light spectrum that is different from that of incandescent lamps. Improved phosphor formulations have improved the perceived color of the light emitted by CFLs, such that some sources rate the best "soft white" CFLs as subjectively similar in color to standard incandescent lamps.

III. HARMONICS GENERATED BY THE CFLS

Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components.

In this section, we present the simulation and the experiment of a lamp’s model (CFL) on a single phase(230V-50Hz), and three phase(380V-50Hz).

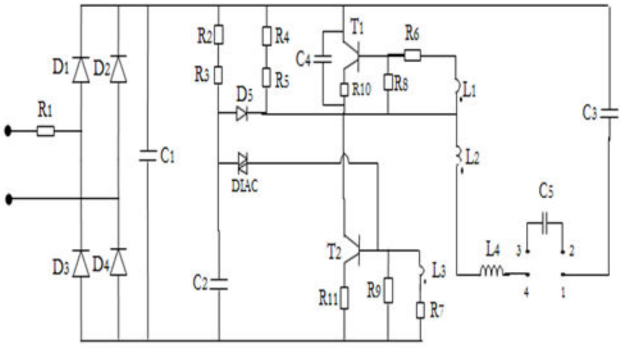

Figure 1: CFL electronic ballast block diagram

The model, shown in Figure1, is identified from the electronic ballast of the lamp. We use the harmonic analyzer to validate CFL electronic ballast block and to diagnostic the harmonic generated by the CFLs. A harmonic analyzer not only shows data on the spot but can also store data digitally which can later be retrieved using computer and a software provided by the harmonic analyzer. The experimental bench is illustrated in Fig.2.

Fig.2. Experimental bench

A. *CFLs under the single phase supply*

The applied voltage is similar to that used in experimental tests; the THD is 4.9%.The Fig.3 and Fig.4 show the experimental and simulated source voltages and their harmonic spectra respectively. The current of the lamp with its harmonic spectrum is shown in the Fig.5 and Fig.6.Comparing the simulation results of the lamp model and the experimental tests; we conclude that the model adopted for the lamp is validated. The fundamental current is about 0.075 Ampere and its THD is equal to 147%.

B. CFLs under the three phases balanced supply

In this section, the effect of CFLs on a three-phase balanced source is analyzed .The current of the lamp in each phase is shown in the figure7. The neutral current and its harmonic analysis are given in the figure 8.

The experiment and simulated results of three-phase CFLs confirm that the current in three phases are identical, but distorted. The neutral carries an important current with frequency multiple of the frequency of3rd harmonic. The fundamental of the neutral current is about 0.181 Ampere and its THD is equal to 84%.

After modeling and testing the FLCs, we concluded that these lamps are harmonic generator (non-linear loads), if used in large numbers, can affect the distribution grid power quality.

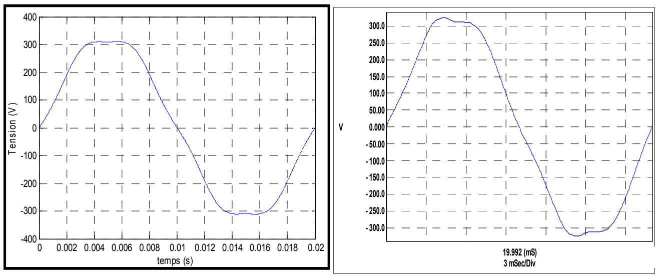

Fig.3. Source voltage : simulation(left) measure (right)

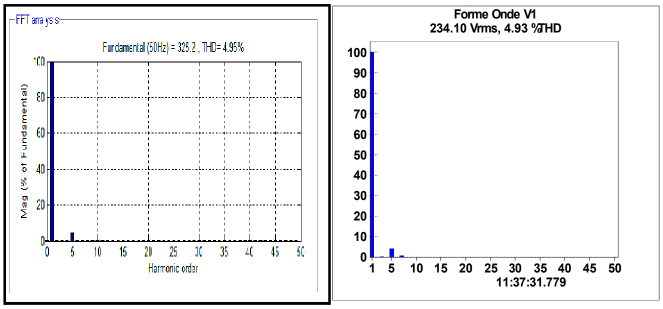

Fig.4. Harmonic spectrum of source voltage: Simulation (left) Measure (right)

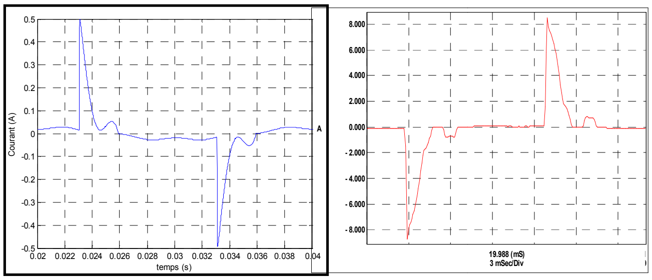

Figure 5: Source current: simulation (left) measure(right) current scale (*0.05)

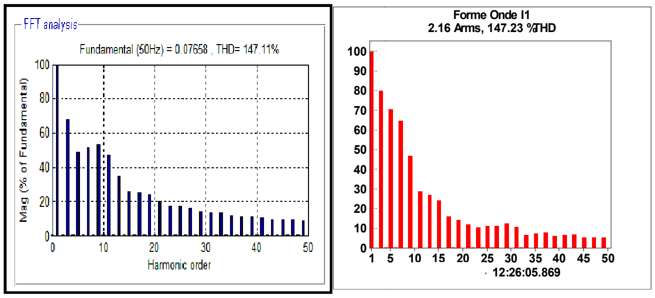

Fig.6. Harmonic spectra of source current: Simulation (left) Measure (right)

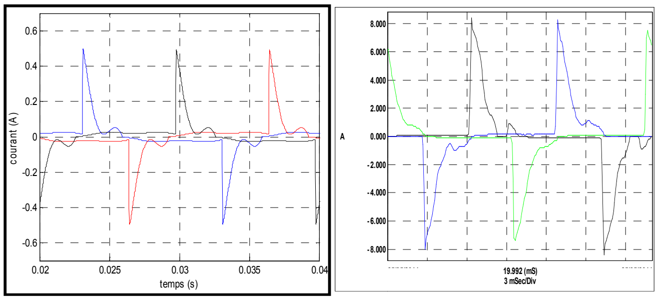

Fig.7. Three phase CFLs current
(left) Simulation, (right) Experimentation with current scale (*0.05)

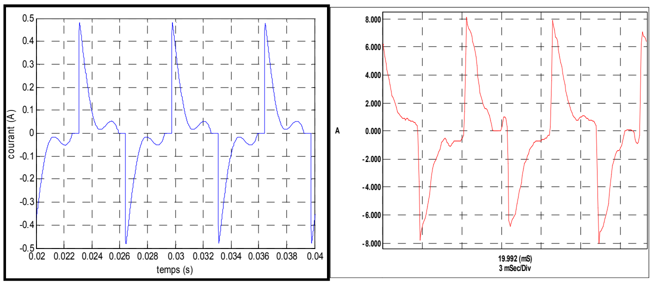

Fig.8. Current in neural conductor
(left) Simulation, (right) Experimentation with current scale (*0.05)

III. SHUNT ACTIVE POWER FILTER

The main aim of the SAPF is to compensate for the harmonics dynamically. The SAPF overcomes the drawbacks of passive filters by using the switching mode power converter to perform the harmonic current elimination. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the nonlinear load and the active power filter as an ideal resistor

The shunt active power filter acts as a current generator that compensated the load current, in such a way that the source current drained from the network will become sinusoidal and in phase with the voltage. As is convention, APFs are operated as a current source that is parallel with the non-linear loads. The power converter of an APF is controlled to generate a compensation current i_f, which is equal to the harmonics and reactive current.

Figure 9 shows a block diagram of PAF. The parallel active filter generates the reference current i_f that compensates the load current i_L in order to guarantee sinusoidal current i_S drawn from the grid. Therefore, parallel active filter injects an equal-but-opposite harmonic compensating current i_f to cancel the harmonic contents of the line current i_s. So, the current $\mathrm{i_s}$ *is* the result of summing the load current i_L and the opposite filter current i_f:

$$i_s = i_L - i_f \tag{1}$$

Instantaneous reactive power theory, developed by Akagi et al [11], is used to control the parallel active power filter SAPF. This theory, known as p-q Theory, consists of a Clarke transformation of three-phase voltages and load currents from the a-b-c coordinates to the α-β-0coordinates:

$$\text{Source Voltages:}\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{2}$$

$$\text{Load currents:}\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{3}$$

This transformation may be viewed as a projection of the three- phase quantities onto a stationary two-axis reference frame. One advantage of applying the α-β-0 transformation is the separation of zero-sequence components into the zero sequence axis. Naturally, the α and β axis do not have any contribution from zero-sequence components. If the three phase system has not neutral conductor, no zero sequence current components are present and can be eliminated in the above equations [14], simplifying them. In this situation the p-q instantaneous power components are calculated by using load currents and source voltages as:

$$\begin{bmatrix} \mathrm{P} \\ \mathrm{q} \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix}\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{4}$$

In general, each of the active and reactive powers is composed of continuous and alternating terms. The continuous term corresponds to the fundamentals of current and voltage. The alternating part represents power related to the sum of the harmonic components of current and voltage. Normally only the average value of the instantaneous power is desirable and the other power components can be compensated using a parallel active filter.

Hence, the load currents components can be obtained from direct and alternative powers as follow:

$$\begin{bmatrix} \mathrm{i_{L\alpha}} \\ \mathrm{i_{L\beta}} \end{bmatrix} = \frac{1}{\mathrm{V_{s\alpha}}^2+\mathrm{V_{s\beta}}^2}\begin{bmatrix} \mathrm{V_{s\alpha}} & -\mathrm{V_{s\beta}} \\ \mathrm{V_{s\beta}} & \mathrm{V_{s\alpha}} \end{bmatrix}\begin{bmatrix} \mathrm{P} \\ \mathrm{q} \end{bmatrix} \tag{5}$$

In general, when the load is nonlinear the real and imaginary powers can be divided in average components$\overline{\mathrm{P}}$and $\bar{\mathrm{q}}$and oscillating components$\widetilde{\mathrm{P}}$and $\tilde{\mathrm{q}}$,as shown below.

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \underbrace{\frac{1}{\Delta}\begin{bmatrix} V_{s\alpha} & -V_{s\beta} \\ V_{s\beta} & V_{s\alpha} \end{bmatrix}\begin{bmatrix} \overline{\mathrm{P}} \\ 0 \end{bmatrix}}_{\text{active current}} + \underbrace{\frac{1}{\Delta}\begin{bmatrix} V_{s\alpha} & -V_{s\beta} \\ V_{s\beta} & V_{s\alpha} \end{bmatrix}\begin{bmatrix} 0 \\ \bar{\mathrm{q}} \end{bmatrix}}_{\text{reactive current}} + \underbrace{\frac{1}{\Delta}\begin{bmatrix} V_{s\alpha} & -V_{s\beta} \\ V_{s\beta} & V_{s\alpha} \end{bmatrix}\begin{bmatrix} \widetilde{\mathrm{P}} \\ \tilde{\mathrm{q}} \end{bmatrix}}_{\text{harmonic current}} \tag{6}$$

In order to calculate the reference currents that the active filter should inject, it is necessary to separate the desired average power components$\overline{\mathrm{P}}$and $\bar{\mathrm{q}}$from the undesired oscillating harmonic power components $\widetilde{\mathrm{P}}$and $\tilde{\mathrm{q}}$. A low-pass filter with feed-forward structure can be used to separate continuous and alternating terms of active and reactive instantaneous power as shown in the figure 12. Reactive power can be filtered but the power factor doesn't be corrected. So, to work with power factor close to unity the reactive power $\tilde{\mathrm{q}}$can be used to generate reference currents. Hence, the compensation of both harmonic and reactive current can be guaranteed by APF. However, a well-known method of reactive power compensation is to use shunt connected switched capacitors or passive filters with the APF that will decrease the cost of the filter [16].

However, the p-q theory does not guarantee balanced compensated currents if the system voltage itself is unbalanced (i.e. it contains a fundamental negative-sequence component). Unbalanced grid voltages will reduce the harmonic detection performance. This drawback may be overcome by two solutions. The first solution is to use a filter to eliminate the harmonics components in the voltages. The filter has a magnitude and phase response that is similar to those of a general band-pass filter. The self-tuning filter (STF) was used in order to estimate the phase angle of PWM converter outputs [17-18]. Therefore, the STF can be used to filter the distorted α-β components in order to extract the sinusoidal and symmetrical voltage from the distorted and asymmetrical grid voltage. The transfer function is obtained from the integration of the synchronous reference. The transfer function is defined as:

$$\mathrm{STF(s)} = \frac{\widetilde{V_{s\alpha\beta}}}{V_{s\alpha\beta}} = \mathrm{K}\frac{(\mathrm{S+K})+\mathrm{j}\omega}{(\mathrm{S+K})^2+(\omega)^2} \tag{7}$$

This technique works well if the harmonics components are at high frequencies and the filter do not change the voltage angular phases.

The second method is based on the use of a phase-locked- loop circuit (PLL circuit), which is used to detect the fundamental positive-sequence component of the voltage. This technique is another option to guarantee the decoupling of the current and the distorted voltages.

Harmonic components of $\mathrm{i_{L\alpha}}$ and $\mathrm{i_{L\beta}}$ are the reference currents of parallel active power filter. Finally, inverse α-β-0transformation block calculates the current references by:

$$\begin{bmatrix} i_{fa}* \\ i_{fb}* \\ i_{fc}* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{f\alpha}* \\ i_{f\beta}* \end{bmatrix} \tag{8}$$

The active power filter must be able to generate an output current that follows the respective reference current which contain the harmonic and reactive component required by the load

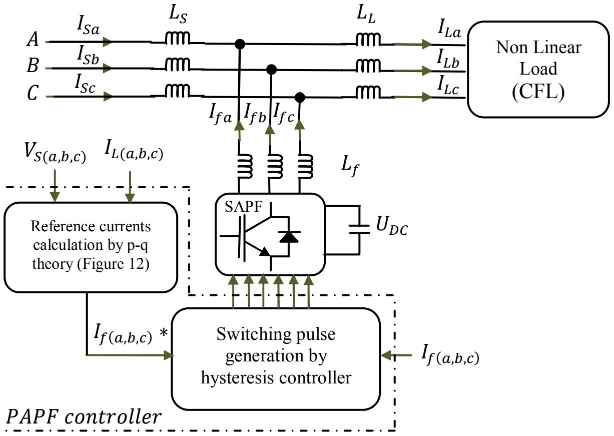

Figure 9: Parallel active power filter structure

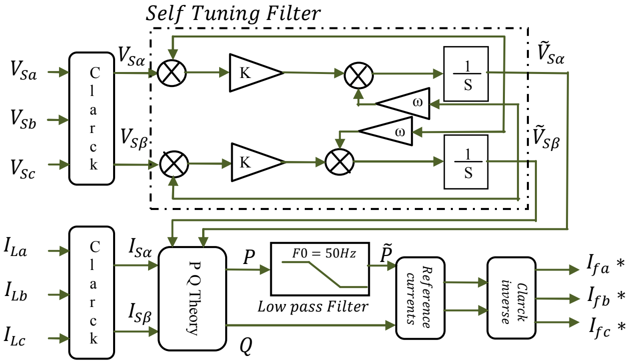

Figure 10: The P-Q theory applied to calculate SAPF reference currents in case of balanced or unbalanced grid voltages

The inputs of the parallel active filter controller are the network voltages, load currents and real filter currents as shown in the figur9.

The current references are applied to the PWM current control i.e. hysteresis band controller. The switching signals used in parallel active power filter control algorithm are generated by comparing filter reference currents and actual filter currents and using hysteresis band current control algorithm. The hysteresis band current control technique has proven to be most suitable for applications of current controlled voltage source inverters. The hysteresis band current control is characterized by unconditioned stability, very fast response, and good accuracy [15].The hysteresis band current control scheme is composed of a hysteresis around the reference filter current. The hysteresis band current controller decides the switching pattern of active power filter. The switching logic of transistors is given as:

$$\begin{aligned} i_{fa} < i_{fa}^{*} - \Delta i_f \ &\rightarrow \text{Ta on and Ta}'\text{off} \\ i_{fa} > i_{fa}^{*} + \Delta i_f \ &\rightarrow \text{Ta off and Ta}'\text{on} \end{aligned} \tag{9}$$

The switching functions of transistors T_B, T_B', T_C and T_C' for phases B and C are determined similarly.

IV. SIMULATION RESULTS OF SAPF

The performances of the parallel active power filter are simulated using *MATLAB* software. *Simulink* and *Sim Power Systems block* sets are used for implementing the global system (CFL and SAPF). The performances are studied for different operating conditions for balanced and unbalanced grid voltages and for both the balanced and unbalanced load conditions.

Two test cases were mounted to investigate the performance of the shunt active filter. A three-phase diode bridge converter is used as non-linear load. The second load is the CFL lights.

At first, Simulation results are given here for non-linear load under balanced grid voltages. A three-phase diode bridge rectifier is used as a nonlinear load and an unbalanced inductive linear load R-L is connected to the no linear load at t=0.12s (R_A=40Ω, R_B=20Ω, R_C=30Ω, L_A=L_B=L_C=0.06 H). Figures13to 16 show the source current i_S, the load current i_L and the filter current i_f before and after active filter connection (at t=0.06s the SAPF is connected). It may be noted that, before filter connection, the source current waveform is non-sinusoidal because of which its THD is as 23.77% and its fundamental value is 27 A, Harmonic distortion of the source current drawn by the grid is observed. However, after filter connection, the source current has a THD of1.93% with load 1 with a fundamental value of 27,6A. The fundamental value remains approximately the same when the filter is connected which prove that the filter injects only the harmonic currents and the grid injects the fundamental component of the load current. When the load 2 is connected the THD decrease to 1.53% because the added load is a linear one. Figure 17shows the current and the voltage of the phase A, as can be seen, the voltage and the current are in phase and the power factor is equal to unity. However, if the active filter doesn't compensate reactive power (Figure 16), this last can be compensated separately by a shunt connected switched capacitors.

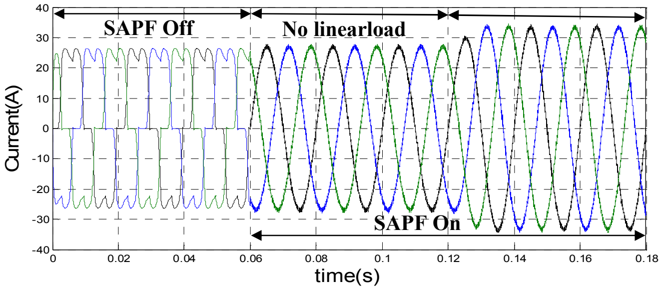

Figure 11: Source currents before and after Parallel active filter connection

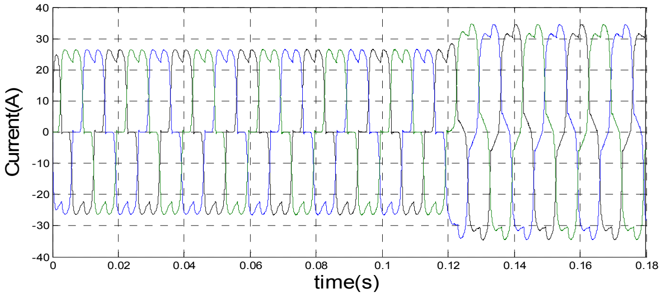

Figure 12: Load currents before and after Parallel active filter connection

The simulation results clearly demonstrate that the SAPF is able to successfully reduce the significant amount of THD in source current and a PF close to unity. The results have been analyzed on the basis of THD and PF

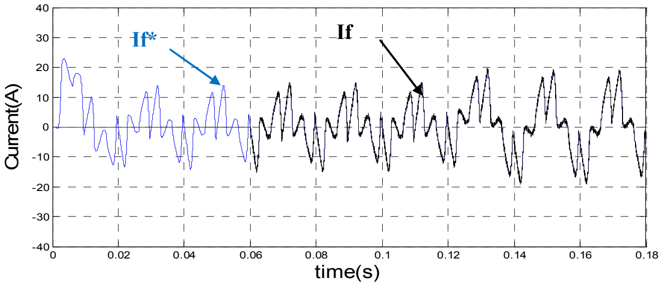

Figure 13: Real and reference filter currents after Parallel active filter connection (blue: reference filter current, black: real filter current)

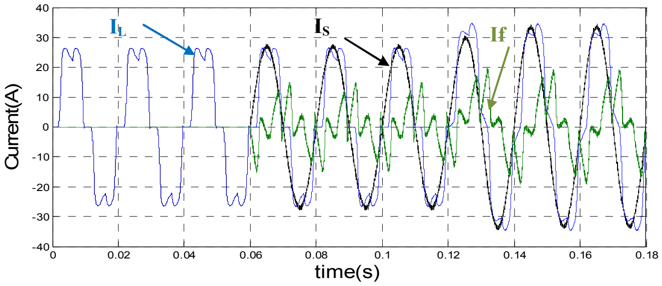

Figure 14: Source current, load current and filter current before and after active filter connection (black: source current, green: filter current, blue: load current)

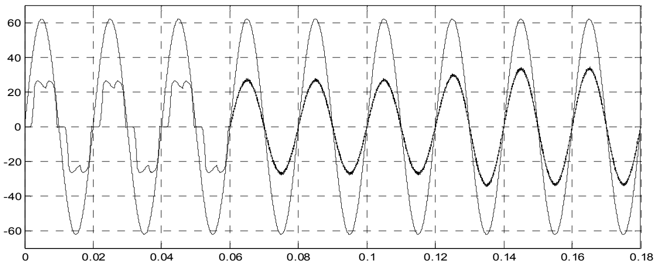

Figure 15: Voltage and current in phase a: with reactive power compensation (grid voltage scale divided by 5)

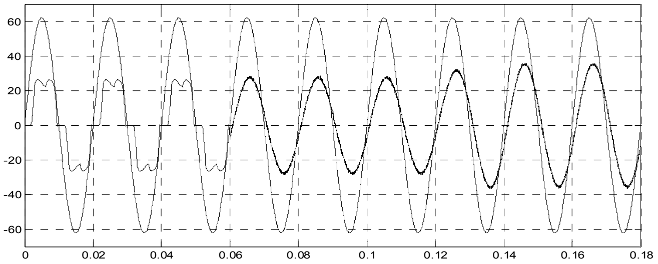

Figure16: Voltage and current in phase a without reactive power compensation(grid voltage scale divided by 5)

The Fig. 17 shows the unbalanced source voltages, these voltages contain unbalance of 18% (Vas=260V, Vbs=220V, Vcs=180V). Fig. 18 shows the source current before and after basic shunt active filter connection. As can be seen from this figure, the unbalance cannot be fully compensated by the shunt active filter, and hence, unbalance and distorted currents are still present in the source currents. This drawback does not happen, since there is a self-tuning filter to compensate the non-linear load currents.

The connection of the shunt active filter associated to self-tuning filter (Fig. 19) confirms the high performance of the proposed control algorithm. It may be noted that the compensated currents become almost sinusoidal and balanced after the start of the shunt active filter, even under a strong level of unbalance and with high contents of harmonics.

The same results under distorted grid voltages (THD of V_A= 10.80 % THD of V_B=11.72 % THD of V_C=7.85 %) are given in Fig. 22 to Fig. 24. SAPF control algorithm has ability to compensate both harmonics and reactive power of the load [4,5].

THD calculation results are summarized in Table I and table II. Both source voltage and current are sinusoidal and in phase. Hence, reactive power and harmonics are fully compensated. The source supplies only the constant power demanded by the load.

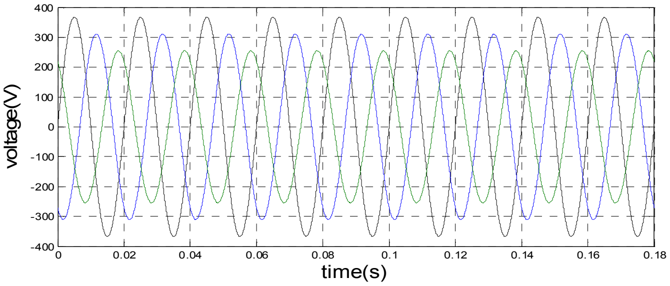

Figure 17: Unbalanced grid voltages

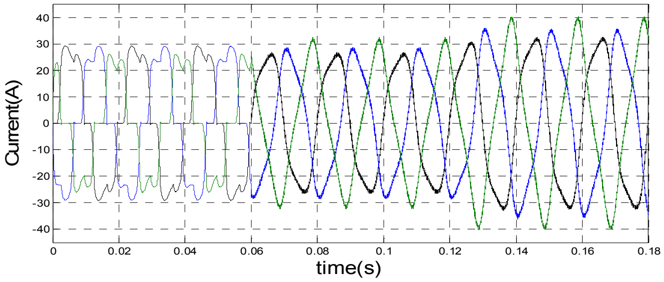

Figure 18: Source currents before and after Parallel active filter connection in case of unbalanced grid voltages

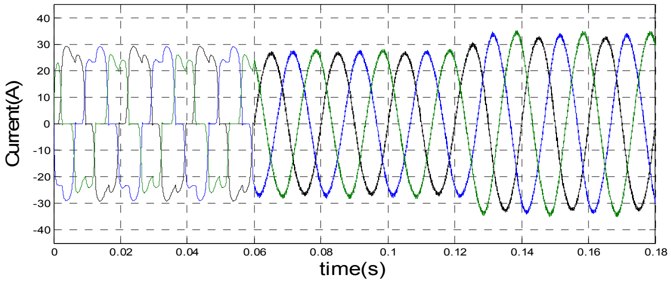

Figure 19: Source currents before and after Parallel active filter connection in case of unbalanced grid voltage and unbalanced linear load by adding Self tuning filter

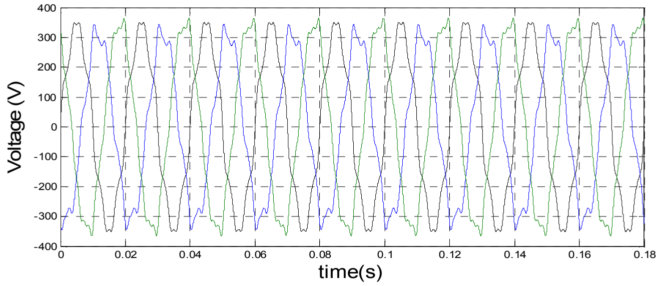

Figure 20: Unbalanced and distorted grid voltages

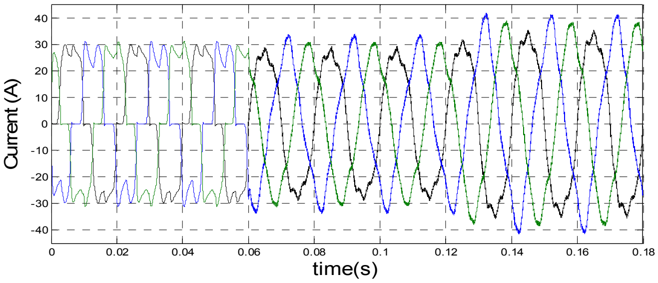

Figure 21: Source currents before and after Parallel active filter connection in case of unbalanced grid voltages

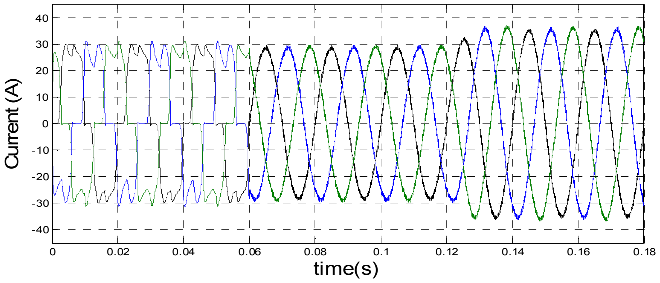

Figure 22: Source currents before and after Parallel active filter connection in case of unbalanced grid voltage and unbalanced linear load by adding Self tuning filter

TABLE I. THD value of grid currents in case of unbalanced voltages with SAPF associated to self-tuning filter

	Current in phase A	Current in phase B	Current in phase C
THD with load 1, SAPF Off	21.59 %	22.77 %	29.94 %
THD with load 1, SAPF On	12.76 %	13.10 %	12.25 %
THD with load 1+ load 2, SAPF On	13.56 %	13.71 %	12.85 %
THD with load 1, SAPF On + STF	2.45 %	2.68 %	2.43 %
THD with load 1+ load 2, SAPF On+ STF	2.59 %	2.76 %	2.58 %

TABLE II. THD value of grid currents in case of distorted voltages with SAPF associated to self-tuning filter STF

	Current in phase A	Current in phase B	Current in phase C
THD with load 1, SAPF Off	20.65 %	32.44 %	24.61 %
THD with load 1, SAPF On	11.75 %	12.55 %	7.69 %
THD with load 1+ load 2, SAPF On	11.81 %	12.25 %	7.67 %
THD with load 1, SAPF On+ STF	2.02 %	1.96 %	1.94 %
THD with load 1+ load 2, SAPF On+ STF	1.68 %	1.65 %	1.78 %

The SAPF is tested for CFL Load. Firstly, only one CFL per phase is simulated (Figures 25 to 28, left curves). The SAPF is connected at 0.1s. It can be seen that the THD in this cases is higher, it is about 147% and the fundamental current is 0.075 Ampere. The SAPF works correctly even in low values of current and high THD. After connecting SAPF, The THD is significantly reduced to 3.61%.

Same results can be obtained for a group of CFLs, as shown in Figures 25 to 28 (right curves). From the results obtained, it was found that the waveform is significantly improved. The THD changes from a value of 147% up to 1% after the incorporation of active power filter.

Figure 27 shows the currents waveform imposed by increase and decrease in load. It can be observed that the SAPF adapts its self to load variation and the currents drawn from the grid remain sinusoidal while the load changes. The THD of the source current is reduced from 115.45% to 4.02% for 15 CFLs, from 103.26% to 3% for 45 CFLs and from 92.91% to 3.68% for 75 CFLs. The fundamental values of the sources currents are respectively 0.29A, 0.86A and 1.42A

Figure 28 shows the response of the SAPF for un-balanced load. It is clearly shown that even when the CFLs load is un-balanced the source currents i_{sabc} are un-balanced and they are not purely sinusoidal. However, the THD of the source current is reduced from 102.85% to 11.7% for phase A, from 135.75% to 14% for phase B and from 112.55% to 8.7% for phase C. The fundamental values of the three phase currents are respectively 0.83A, 0.557A and 0.39A

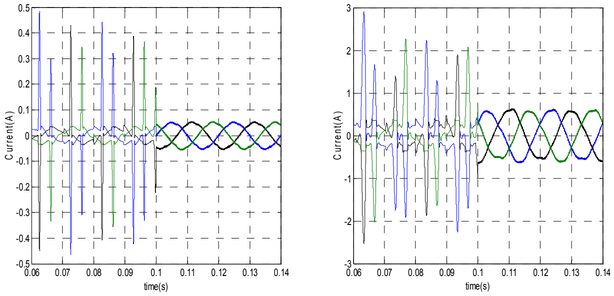

Figure 23: Source currents before and after Parallel active filter connection (left :One CFL per phase, right: 10 CFLs per phase)

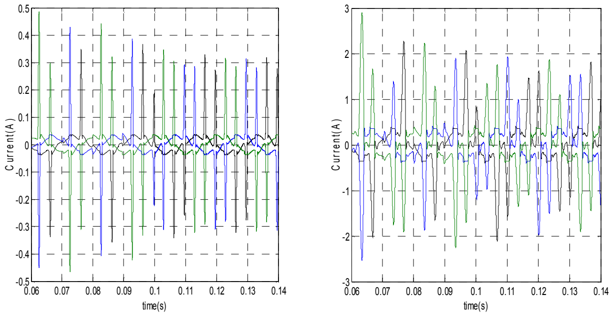

Figure 24: Load currents before and after Parallel active filter connection (left : One CFL per phase, right: 10 CFLs per phase)

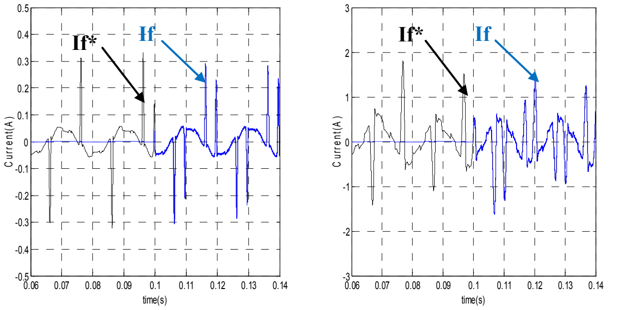

Figure 25: Real and reference filter currents before and after Parallel active filter connection (left: One CFL per phase, right: 10 CFLs per phase) (Black: reference filter current, Blue : real filter current)

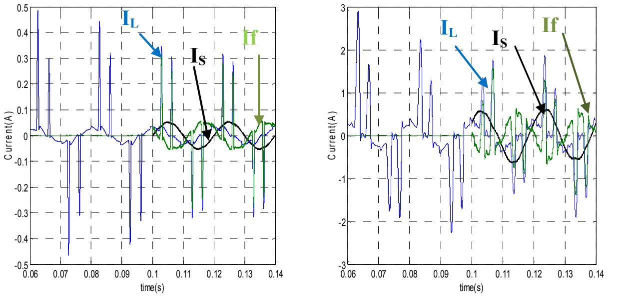

Figure 26: Source current, load current and filter current before and after Parallel active filter connection (left: One CFL per phase, right: 10 CFLs per phase) (black: source current, green: filter current, blue: load current)

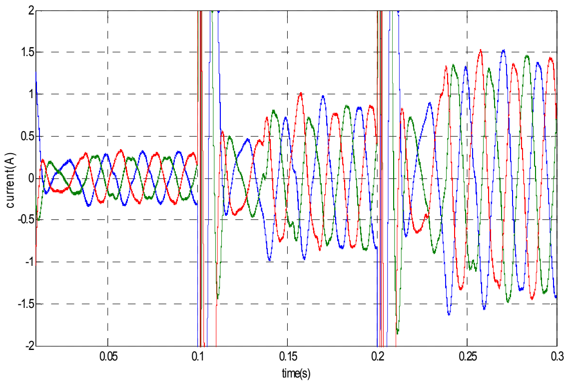

Figure 27: Response of SAPF for variable CFLs load: 15 CFLs, 45 CFLs and 75 CFLs.

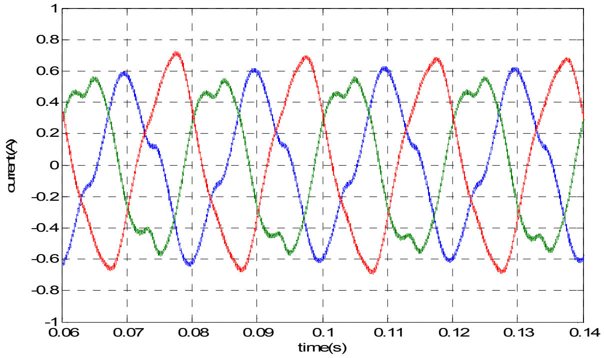

Figure 28: Response of SAPF for unbalanced CFLs load: 15 CFLs in phase A, 10 CFLs in phase B and 5 CFLs in phaseC.

V. CONCLUSION

This paper presents a solution based on shunt active power filter for harmonic current reduction with direct applicability in the electrical installations affected by harmonics caused by non linear loads like compact fluorescent lamps CFL.

The parallel active power filter is based on the instantaneous power theory proposed by Akagi and on current hysteresis band control technique of the static power converter. The active filter controller is able to determine the fundamental component of the load current even under very high distortion conditions

First, we carried out the diagnosis of lamps FCLs. The experimental and simulations tests were conducted on sinusoidal source supplying FCL lamps. These tests confirmed a significant distortion of the phase current and overloading the neutral although in the case of a three-phase system including a same number of lamps per phase.

Secondly the SAPF was presented and tested for several operating conditions are:

- SAFP is operating in the installation with balanced and unbalanced source voltages supplying a nonlinear load.
- SAFP is operating in three-phase source supplying a single FCL lamp per phase, and then the same number of lamps per phase, and finally a different number of FCL on each phase.

According to the obtained results, we concluded that incorporation of SAPF greatly improves the THD of the current sources supplying non-linear loads and sharply reduced imbalance of voltage sources and unbalanced loads current. It also permits efficient control of the power factor in installations with a consumption of reactive energy.

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