Harmonic Distortions Produced by Compact Fluorescent Lamps in Distribution Networks

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Abstract: - This article presents some reached excellent results in the development of an analysis methodology for the harmonic chains interference produced by compact fluorescent lamps on the distribution circuits in low voltage (127/220 V). In such a way, they are supplied by data of measurements in real circuits, before and after the installation of the compact fluorescent lamps. They also are presented the aspects related to the computational modelling. Finally, a typical distribution circuit is simulated and the results are presented comparing two distinct situations

Key-Words: - Compact Fluorescent Lamps, Harmonic Current, Power Quality, Distribution Systems

1 Introduction

In the last years, it is happening a growing expansion of the compact fluorescent lamps (CFL's) use in Brazil, motivated, above all, for the fall of the prices of the lamps and for programs of energy efficiency promoted by the dealerships of energy as well as, more recently, for the ANEEL Resolution 492/2002. Though, in spite of to the benefits related to the reduction of the electric power consumption, a lack of larger investigations is verified concerning the impacts of the use in wide climbs of CFL's, as for instance, the emission of harmonic currents, support and sensibility to the variations of short duration, among others.

Some recent studies [1, 2, 3] they accomplished investigations about harmonic penetration in nets of distribution of energy, approaching from aspects of the modelling of the residential loads, and real systems monitor. In the other hand, the support of CFL´s to energy interruptions was investigated in [4], where tests of switch off were done with intention of observing the useful life reduction of these devices.

In this way, this work has an objective establishes the bases of these equipments impact analysis methodology for the distribution systems in low tension (127/220 V). Because of that, the studies took the adoption of computation models for CFL's allow to evaluate the performance, in permanent regime, of electric circuits of low tension with great presence of CFL's. This procedure will allow extrapolating the results in order to increase the effects for the system in 13,8 kV and the substations.

Besides the benefits mentioned above, the developments can assist the agencies to take decisions and avoiding problems, such as resonances, on-heating and on-shipment of transformers, as well as alterations in the power factor of the circuits stressed by the harmonic currents originating from of CFL's.

In order to realize works, three stages were accomplished. The first, related to the laboratory tests and CFL's models. In the second stage, the campaigns of measurements were driven in field, and in the third and last stage they were made compute systems simulations to stimulate the performance after the lamps installation.

2 Modeling CFL´s

This stage was dedicated to the modelling of the compact fluorescent lamps in software of harmonic analysis. The starting point of this process was the

definition of the modelling type to be used in the studies of harmonic penetration.

The modelling technique in the frequency domain for simulations of harmonic flow offers smaller modelling difficulties that in the time domain and, as harmonic in electric power systems are considered a steady state phenomena, this technique is fully satisfactory for this study category. Besides allowing an economy of time in the modelling process, the simulation time and results analysis contribute to the adoption of the modelling in the frequency domain.

Determinate the calculation methodology, the choice of the appropriate modelling for CFL relapsed in the harmonic sources of current. This modelling is used and recommended by several authors, books and manuals of simulation software's [5, 6, 7]. In that point, we can emphasize the importance of to use the module and angle of each harmonic order, allowing possible cancellations among different no-linear loads presents in a same electric system. The Fig. 1 shows a harmonic current source, where the index n represents the harmonic order of a certain spectrum.

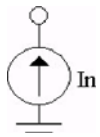


Fig. 1. Current source.

Define the model to be used, laboratory tests were carried out for determination of the amplitude and angle of each harmonic component generated by LFC. This procedure is adapted and recommended for a better precision of the computation simulations, because it represents operational conditions similar that was found in the field.

Data regarding the harmonic spectrum of the feeding current of CFL in hands, it was able to pass to the conception of the computation model.

For the implementation of this model, it was used a software of harmonic analysis that allowed the technique of the frequency domain. The choice relapsed on the application of harmonic flow PQF 6.0, developed by the company Quality would Engineer and Systems. This tool allows the accomplishment of several types of studies, for instance:

- Determination of the power factor and its correction;
- Load Flow and harmonic flow, determining the tension levels and harmonic currents;
- Analyse of the equipments support that operate under the harmonic presence;
- Application of ABNT rules for the evaluation of the impact of the harmonic on capacitors;
- Analysis of electric circuits in permanent regime;
- Clearance of energy consumption;
- Calculation of the electric losses with and without harmonic;
- Project of harmonic filters.

Because of it, using the amplitude and angles of the harmonic, even to 50 order, it was done the computing implementation of 15 W CFL. The values of the used electric parameters can be visualized in the Table I.

TABLE I
ELECTRIC PARAMETERS FOR THE LOAD FLOW

CFL	S (VA)	PF
15 W - Manufacturing A	13,23	0,9654 CAP

The CFL was modelled in the simulation software of simulation as a parallel load RL for the load flow, considering active power and it reactive power as constant, and for the harmonic flow it was considered as a current source for each order. The Fig. 2 illustrates the representation of the component CFL implemented in PQF.

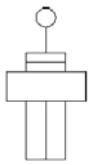
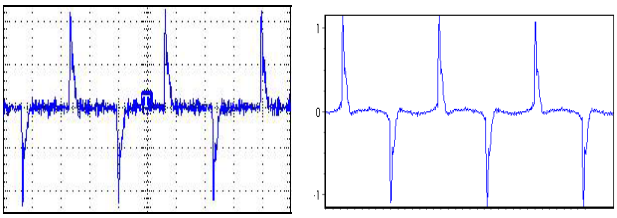


Fig. 2. CFL.

The entrance data for CFL's limit to the amount of lamps for phase and the used type, as showed by Fig. 4.

Fig. 4. CFL entrance datas.

With the implementation of the model, it happened the stage of validation. The Fig. 5 (a) and (b) they show the waveforms for the current of supply of LFC, experimental and computation, respectively.



(a) (b)

Fig. 5. Waveforms of the current for validation of the CFL model of 15 W of the manufacturer A: (a) Experimental and (b) Computation.

Through the analysis in the waveform, the used modelling perfectly assists highly to the purposes of the study being their results satisfactory and capable of representing the performance of this device in steady state situation.

3 Field Measurements

For the studies realized of the CFL's impacts in distribution systems, the main objective of this study, measurements were done, with the customers, for the quantification of the several electric parameters to be analyzed. Such parameters, jointly with the computation simulations results can indicate the main current effects of the use of CFL's in the electric systems, as well as the solutions to be implemented for the mitigation.

They will be presented in the sequence the results of the measurements accomplished in a point of the system of distribution of COPEL (Parana Energy Company - Brazil), before and after the installation of CFL's. The complete analysis of the application of CFL's in the distribution net will be developed along the second cycle of the research project.

The chosen circuit for the sampling is a residential condominium constituted by buildings of three floors with six apartments each. Such condominium, Ilha do Mel, is located in the city of Curitiba. The choice for this circuit relapsed, especially, in the fact of the residents have wakened up in accomplishing the substitution of the lamps of their residences for CFL's donated through the project. However, it should be mentioned that the adhesion was about 85%, totalling about 500 illumination points. Besides, this circuit cannot be considered of low income, once the consumers fed by this are considered, for the utility, middle class.

For the accomplishment of the measurement works, it was adopted as main strategy to monitor the entrance of energy of the condominium, in other words, the secondary of the respective transformer feeder. Also measurements were accomplished in a residence where all of the loads were working simultaneously, excluding the electric shower. This strategy is justified in the interest in evaluating the impact of the interaction of CFL's with the other loads.

The Fig. 6 and 7 show the curve of demand of the system, and the Fig. from 8 to 11 show the performance of the distortions in the waveform of the voltage and current for the entrance of the condominium along one week.

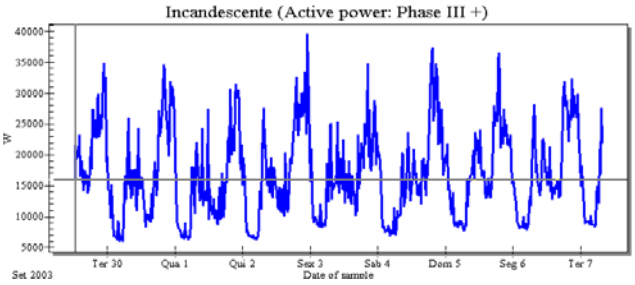


Fig. 6. Active power with predominance of incandescent lamps.

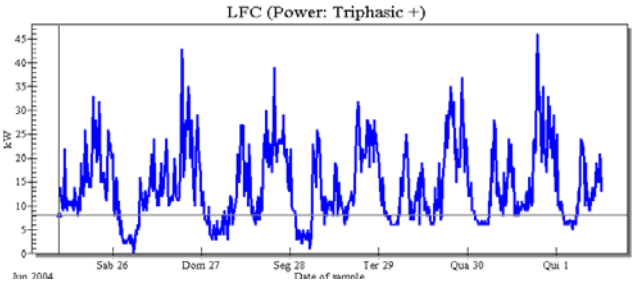


Fig. 7. Active power with predominance of incandescent CFL.

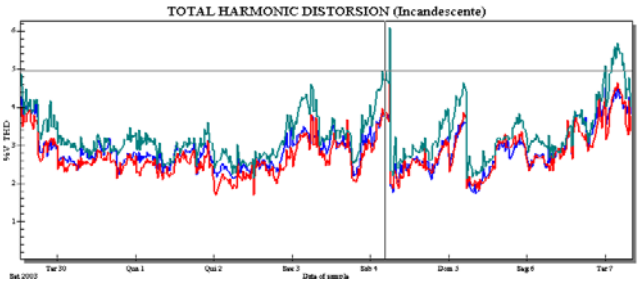


Fig. 8. Total harmonic distortion of voltage with predominance of incandescent lamps.

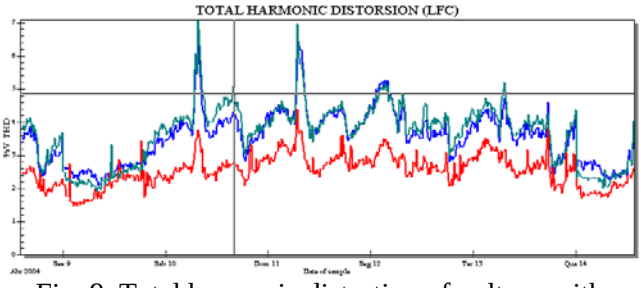


Fig. 9. Total harmonic distortion of voltage with predominance of CFL's

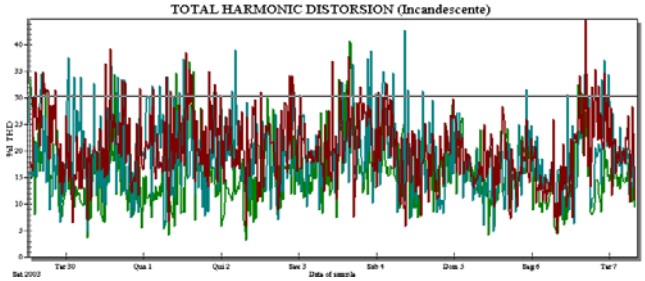


Fig. 10. Total harmonic distortion of current with predominance of incandescent lamps.

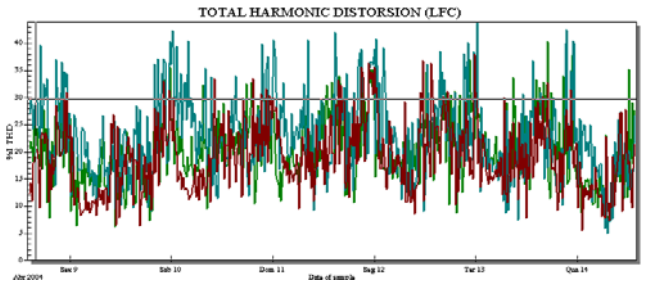


Fig.11. Total harmonic distortion of current with CFL predominance.

From the data and extracted graphs of the measurements can be made some verification. For obtaining of the typical values (representative) of the monitor period, the known statistical treatment was used, P95, for the case of the harmonic distortions, so much of voltage and current. It can be observed that:

- The substitution of the lamps did not produce great reduction in the performance of the curve of demand of the measured circuit;
- The harmonic distortion of voltage increased in 20,3%, along one week, passing of THDV(P95%) = 3,99% with predominance of incandescent lamps, for THDV(P95%) = 4,80%;
- The current distortion increased in 13,8%, passing of DHTI(P95%) = 28,2%, for DHTI(P95%) = 32,09%.

Through the graphs and presented values it can be verified that the harmonic distortion increased substantially after the change of the incandescent lamps for CFL's. It was expected once the measurements accomplished in a single residence had shown that the current distortion had increased of DHTI (%) = 10,4, for DHTI (%) = 35,7, with a reduction about 51% of the demand of active power. It is worth to emphasize that these values represent the situation in that all of the loads are in operation except for the shower.

4 Computing Simulations

The compute simulations are an important tool to stimulate the performance of the systems electric front to modifications, insert of new loads, installation of capacitors banks and harmonic filters, among others. In this way, as form of evaluating the impact of the substitution of incandescent lamps for compact fluorescent lamps in certain circuits of distribution systems, some simulations were done, using the model of CFL previously presented.

2.1 Residential condominium

Initially, the residential condominium model in the measurement stages. The following simulation strategy was adopted:

- The shipment data used as base for the simulations were obtained through the average of the measured values for the schedule between the 17:00 and 18:00 hours;
- The values of THDV (%) and THDI (%) used to compare were P95 (%) for the same period;
- The feeder transformer of the circuit is of 75 kVA;
- The total load of illumination considered for the simulated cases was of 125 lamps, totaling 9000 incandescent W and 2250 W of CFL's.

Using the average of the values obtained in the end of the afternoon, it is due to the fact that on this schedule it is still low the incidence of electric showers. It is worth to also mention, that the system was considered balanced.

The harmonic currents present in the situation previous to the change of the illumination were considered as current injections. It was considered that the contribution of each bar of the circuit was identical.

The load due to the illumination, an use factor was used same to 0,25, for the established schedule, multiplied by the total number of illumination points in that there was change of lamps, in other words, 500 points.

The figure 12 display the diagram unifilar of the system in study, where each bus represents a building of 12 apartments.

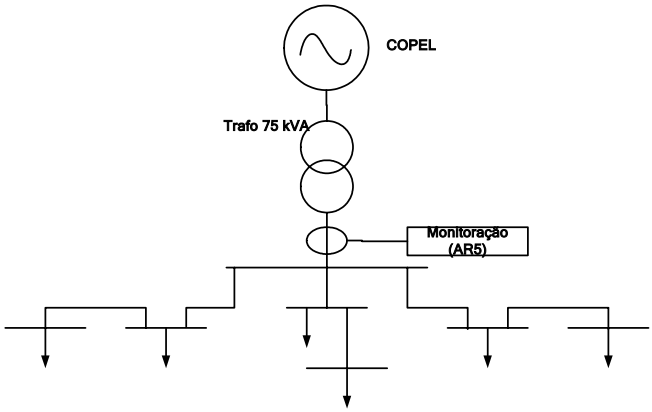


Fig.12.Unifilar diagram of Ilha do Mel

Once established the guidelines for accomplishment of the computational studies, simulations were accomplished as showed in table II:

TABLE II
SIMULATED CASES

Simulated	Lamps
Case A	125 Incandescent lamps – 60 W
Case B	125 LFC – 15 W

The Table III makes a parallel between the simulated cases and the field measurements for the secondary of the feeder transformer of the circuit.

TABLE III
COMPARATIVE ANALYSIS

Analyzed Parameters	Measurement 1 Incandescent	Case A Incandescent	Measurement 2 CFL	Case B CFL
THDV(%)	3,06	3,09	4,20	4,10
THDI(%)	21,53	24,75	31,10	34,17
P(kW)	15,15	15,10	11,28	10,31
S (kVA)	17,85	18,70	13,50	13,16
I rms (A)	54,90	51,86	38,61	34,71

The only difference among the two modeled cases was the substitution of the load regarding the incandescent illumination for the model of CFL previously described.

It is noticed by the values presented in the Table III that the differences between the simulations and the measurements, in what is treated to the active and apparent power, it can be explained by the difference of treatment of the data, as on the part of the measurement equipment as on the part of the software.

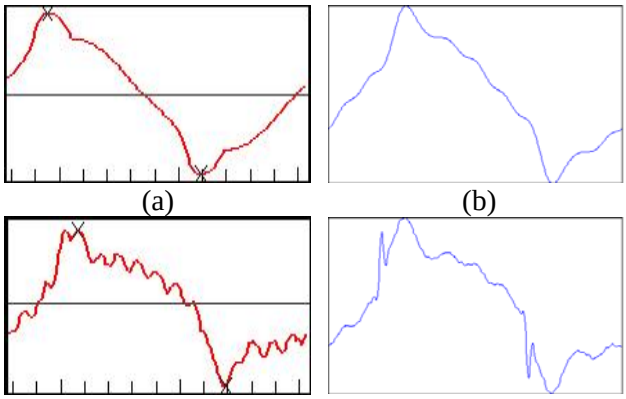


Fig.13. Waveforms of the current. (a) Measurement 1; (b) Case A; (c) Measurement 2; (d) Case B

In spite of to the differences in the values of the power, it can be verified that the modeling of the investigated system assisted from a satisfactory way to the proposed objectives, which is, to esteem the impact of the substitution of incandescent lamps for compact fluorescent lamps, once the aspects were not considered regarding the conductive threads and possible losses happened along the installation.

The Fig. 14 makes a parallel of the distortion of voltage of the simulated cases with the measurements.

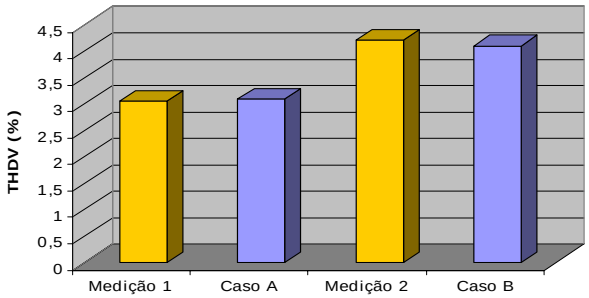


Fig.14. Total harmonic distortion of the voltage

2.2 Distribution circuit

In way to assist the expectations in knowing the impact of CFL's in a circuit of low income, where CFL's are distributed broadly through the programs of energy efficiency of the utilities, it took place the simulation of a representative circuit of a neighborhood of low income where, commonly, 60% of the load in the houses are incandescent lamps.

Because of that, in the driven studies, simulate a situation in that the change of 6 lamps was accomplished in each bar (it posts) of the circuit, that would correspond her/it a total of 258 illumination points, for a transformer of 100 kVA, with about 80% of shipment.

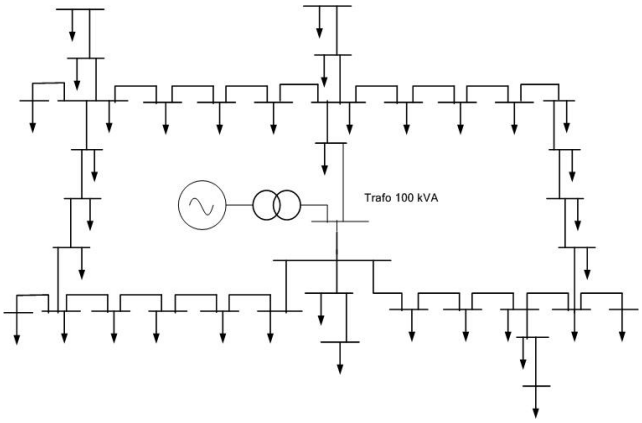


Fig.15. Unifilar Diagram - 43 bus circuit

In this way, the total load of substituted incandescent illumination was of 15,48 kW (lamps of 60 W), which corresponds to an equivalent of 3,87 kW (CFL 15 W) in fluorescent lamps. It is also important to mention that the data of impedance of cables were used regarding the cable of aluminum 2/0. The data to the simulations before and after the substitution of the lamps are in the Table IV.

TABLE IV
COMPARATIVE –43 BUS SYSTEM

Analysed Parameters	Case C	Case D
	Incandescent	CFL
THDV(%)	2,48	7,12
THDI(%)	3,03	15,91
P(kW)	79,73	74,82
FP	0,94	0,93

In the previous table, the harmonic distortion of voltage suffered a significant increase after the substitution of the lamps, extrapolating the value of 5% recommended by several international norms. The figures 16 and 17 illustrate the harmonic spectrum in the secondary of the transformer for the two proposed situations.

Through these, it is noticed that besides the elevation of the levels of the harmonic voltages already existent, there was an addition of new harmonic orders, with an expressive enlargement of the frequency spectrum.

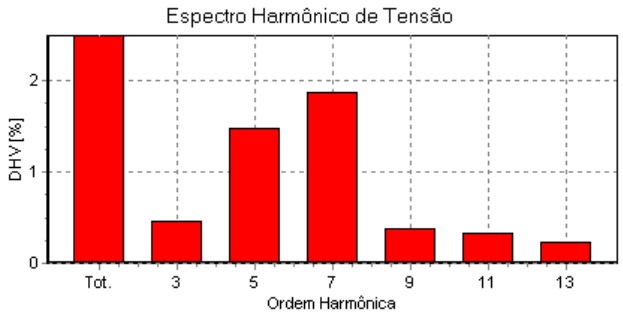


Fig. 16. Frequency spectrum – Case C

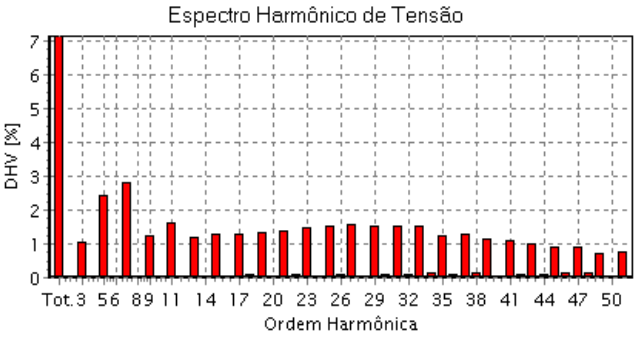


Fig. 17. Frequency spectrum – Case D

5 Conclusion

The present article tried to approach the subject of the impacts of the use in wide climbs of the compact fluorescent lamps, which have been extremely spread, above all in consumers of low income. In this way, the results obtained by this work, it proposes a discussion about the real advantages in motivating the spread of these devices. Once the agencies of energy are, on one side accomplishing his/her program of energy efficiency, but on the other hand, they can be extrapolating indexes of harmonic distortions.

Through modelings, field measurements, and computation simulations, it can be noticed that the job of CFL's elevates the harmonic levels substantially, arriving even to pass those recommended by norms. It can also be verified through the measurements in the condominium and of simulations that the reduction of active potency, in practice, it is not so significant, once we are treating with a measure very used in programs of energy efficiency. Among other reasons, to the using eventual in the residential loads.

The results shown in this study, additional investigations should be accomplished, comparing the current modelling with other using circuit elements. The technician-economical of the harmonic tensions can cause the overload of transformers and neutral conductors.

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