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The Influence of Reactive Flow by Electronic Loads in Electricity Billing System of a Shopping Mall's Consumer Unit

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Abstract.

This paper analyzes the use of a set of electronic loads, specifically tubular and compact fluorescent lamps with electronic ballasts in a Shopping Mall, as well as its possible impact on existing rules of charging. In field measurements regarding two transformers that feed two levels of the building, using a power analyzer, was observed a capacitive reactive power flow to the source. This study inquires if this capacitive reactive flow generated by electronic loads is beneficial or detrimental to the charging system, depending on the time of the day that the electronic charge is triggered. Beyond that, this paper provokes discussions about projects of power factor correction in consumers units, that have in its bus the presence of linear and non-linear electronic loads.

Key words

Electronic Charge, Surplus Reactive Power, Demand, Reactive Flow, Charging.

1. Introduction

The quality of electricity delivered by utilities to consumers has always been an object of interest. However, until some time ago, the power quality was related mainly to the continuity of service delivered based on the availability of the system and network parameters. Therefore, it was necessary to study the state of the system to identify ways to keep the system operating with quality.

However, the growing trend of electronics provided the increasing use of electronic equipment, electrical system introducing a large number of electronic charges, so that the studies to be conducted in an electrical system can no longer disregard the influence of such charges and consequences. For example, when performing studies of power flow in a system, they always led to the use of linear elements, passive network of capacitors and inductors, for reactive compensation and control voltage level. So, analyzing the behavior of certain electronic loads, there is a reactive capacitive flow which can behave as an internal compensation system.

The reactive power compensation through electronic loads in the system would impact on its performance and also in charging of surplus of reactive, especially in predominantly inductive systems. As it is already known, large consumers are penalized by charging reactive power surplus. For example, industries that operate with a significant number of electric induction motors with power factor lower than that established by the standard. Accordingly, the flow behavior of reactive electronic loads can help to offset decreasing the amount of reactive capacitor bank to be installed.

Thus, this paper aims to study the use of a set of electronic loads, specifically CFLs and tubular to offset the demand for reactive inductive load.

For this study, field measuring were made in an edification with commercial characteristics typical of a Shopping Center, composed of several stores and a food court that uses a variety of electronic equipments. Through these measuring realized in two 1,5MVA transformers that feed two floors, being the first one the ground floor, corresponding to the administrative sector, and the second one integrating mainly commercial establishments. This article's main goal is to analyze the characteristics of the many loads present in floors of the consumer unit and its influence on the billing systems, once was found reactive flow with inductive and capacitive characteristics among certain phases of the monitored transformers. Also, this paper analyzes the behavior of voltages and currents lags, regarding the characteristic of the loads present in the edification, searching the objective of obtaining the reactive flow's profile during inductive and capacitive turns.

2. Consideration regarding surplus power factor in electrical systems

The Normative Resolution No. 414 [1] of September 9th, 2010, which establishes the general conditions of supply of electricity so updated and consolidated, says that for consumers in group A, the power factor reference "fr", inductive or capacitive, has a minimum allowed value of 0.92.

"The amounts of electric power and reactive power demand in excess of the allowable limit, apply the charges set forth in articles 96 and 97, to be added to the regular billing consumer units from Group A, including those who choose to billing with the application rate of Group B in terms of article 100.", says the Normative Resolution.

"Article 96 - For consumer unit that has the appropriate measuring equipment, including one whose owner has concluded the CUSD- Cost of the Use of the Distribution System, the values corresponding to the power and reactive power demand surplus is calculated as the following equations:

$$E_{RE} = \sum_{T=1}^{n} [EEAM_T \times \left(\frac{fr}{ft} - 1\right)] \times VR_{ERE} \quad (1)$$

$$D_{RE}(p) = \left[\max_{T=1} \left(PAM_T \times \frac{fr}{ft}\right) - PAF(p)\right] \times VR_{DRE} \quad (2)$$

Being:

E_{RE}: corresponding value to the reactive power surplus to the amount allowed by the power factor reference "fr" in the billing period in *Reais* (R$);

$EEAM_T$: amount of active power measured at each interval "T" of one (1) hour during the billing period in Megawatt-hour (MWh);

fr: power factor reference equal to 0.92;

ft: power factor of the consumer unit, calculated at each interval "T" of one (1) hour during the billing period;

VR_{ERE}: reference value equal to the rate of energy "TE" applicable to subgroup B1, in *Reais* per megawatt-hour (R$ / MWh);

$D_{RE(p)}$: value set by tariff "p", corresponding to the reactive power demand exceeding the amount allowed by the power factor reference "fr" in the billing period in *Reais* (R$);

PAM_T: active power demand measured in the range of payment of one (1) hour "T" during the billing period, in kilowatt (kW);

PAF(p): billable active power demand in each tariff position "p" in the billing period in kilowatt (kW);

VR_{DRE}: reference value, in dollars per kilowatt (U.S. $ / kW), equivalent to the rate of power demand - to set off-peak tariff - applicable tariff provision to subgroups of group A for the modality tariff hourly blue and TUSD-Transport Use of the Distribution System -Consumers-free, as is in force the Supply Agreement or the CUSD, respectively;

MAX: function that identifies the maximum value of the equation, inside the corresponding parentheses, in each station HS "p";

T: indicates the range of one (1) hour in the billing period;

p: indicates set tariff peak or off-peak arrangements for hourly or billing period for the conventional binomial tariff category;

n1: number of intervals of payment "T" of the billing period for posts tariff peak and off peak;

n2: number of intervals of payment "T" for tariff set "p" in the billing period. "

Thus, although the amount to be paid is related to reactive surplus, this is proportional to the amount of active power measured in the time range concerning the measurement and the relation of the reference power with the power factor of the consumer unit factor.

For the calculation of these quantities, there is also a period of six (6) consecutive hours (at the discretion of the distributor) between 23 hours and 6 hours, in which only considers the factor power "ft" capacitive lower than 0.92, recorded in each interval of one "T". It is considered only the power factor below 0.92 inductive for the remaining period of the day, recorded in the same time.

Being these loads studied in this work of electronics and capacitive nature, there is then a direct influence on their use in the measurement of the values of excess reactive rules described in the resolution, because they, in theory, inject capacitive reactive on the bus, contribute to change in the value of the power factor recorded every hour. This raises new arguments in academia about how relevant will be this influence, according to the considerable increase of electronic loads in residential, commercial and industrial buses.

3. Considerations Regarding The Harmonic Distortion In Electrical Systems

For basic power grid, the Independent System Operator (ONS) since 2002 provides quality parameters for the voltage supplied. But from the point of view of the consumer, the constraints to be considered are (mostly) the distribution system, which are still under discussion.

The National Electric Energy Agency (ANEEL), in the document "Procedures for electricity distribution in the national electricity system – Prodist Module 8 – power quality" [2], proposes benchmarks for harmonic voltage distortion in the system distribution as shown in table I.

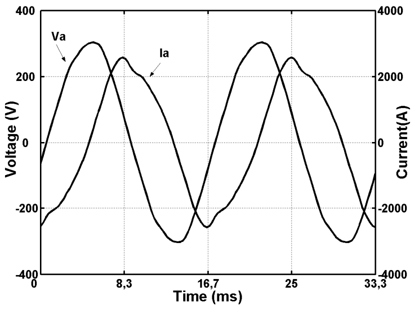
Table I. REFERENCE VALUES OF THD

Nominal Bus Voltage	Total Voltage Harmonic Distortion [%]
Vn ≤ 1 kV	10
1 kV ≤ Vn ≤ 13.8 kV	8
13.8 kV ≤ Vn ≤ 69 kV	6
69 kV ≤ Vn ≤ 138 kV	3

The compact fluorescent lamps used in the laboratory experiment exhibit nonlinear characteristics, which results in current waveforms with significant distortions. However, for the stresses in the supply of bus loads, significant harmonic distortion was not observed, remaining within the limits recommended by the rules established by ANEEL Resolution [3]. However, the measurements performed in the field, with tubular fluorescent lamps with electronic ballasts, both voltages as currents showed linear characteristics. Therefore, regardless of electronic charge be linear or non-linear, the flow of reactive behavior of the power presents similarly in the direction of the load to the source, featuring capacitive reactive power flow.

4. Analysis of field measurements

Initially were realized measurements in the ground floor of the building which is fed by a 1,5MVA transformer, using a power analyzer. Observing the graph illustrated in figure 1 is noted that "a" and "b" phases present inductive characteristics, because the voltages are lead in relation to currents, absorbing inductive reactive flow of the system. However, the phase "c" illustrated in figure 1 (c), presents the current leading in relation to voltage, injecting capacitive reactive flow in the system, improving the power factor and contributing to reduction of the surplus reactive flow on the inductive schedule, which occurs between 6:30 and 23:30 hours. In this case, the electronic loads are switched off at nighttime, so the capacitive reactive flow in the phase "c" is not harmful to surplus reactive energy on the capacitive time related to the night period, that includes 6 consecutive hours between 23:31 to 6:29 hours.



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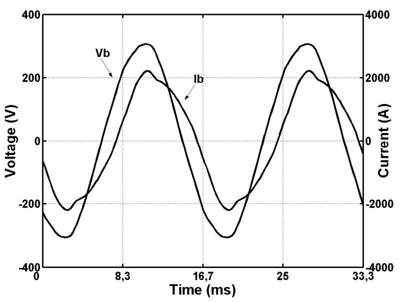

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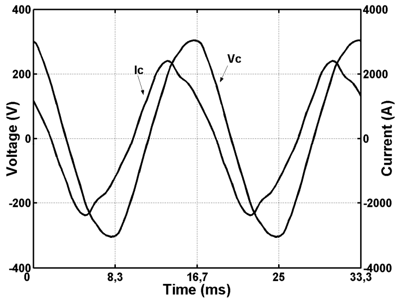
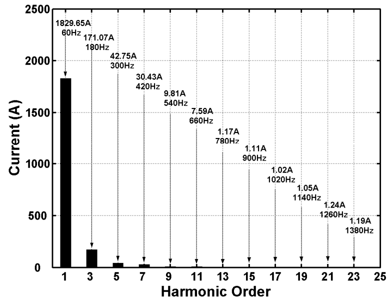


(c)

Figure 1. (a) Phase "a" voltage and current waveforms in the ground floor transformer, (b) Phase "b" voltage and current waveforms in the ground floor transformer, (c) Phase "c" voltage and current waveforms in the ground floor transformer.

Beyond of voltage and current waveforms were also analyzed the current harmonic spectrum of each phase. On the figure 2 it is noticed the most significant presence of the third harmonic.



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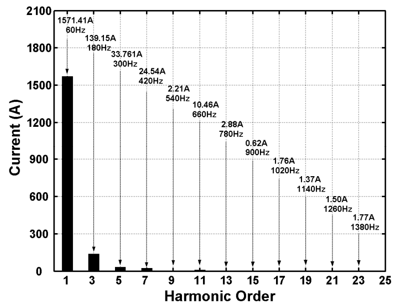

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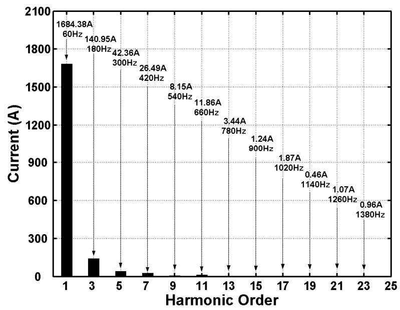

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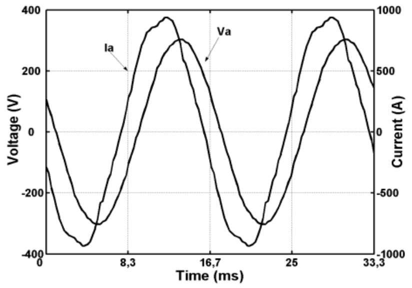
Figure 2.(a) Phase "a" current harmonic spectrum in the ground floor transformer, (b) Phase "b" current harmonic spectrum in the ground floor transformer, (c) Phase "c" current harmonic spectrum in the ground floor transformer.

There were realized measurements in the first floor which is feed by a 1,5MVA transformer, using a power analyzer. The figure 3 shows the behavior of voltages and currents in the phases "a", "b" and "c".



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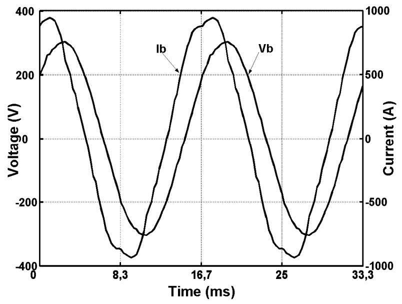

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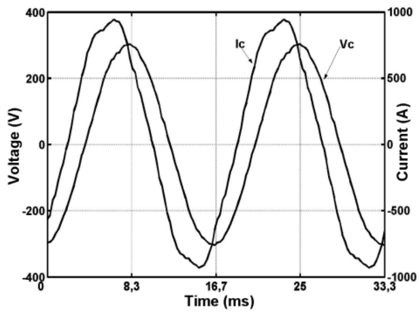

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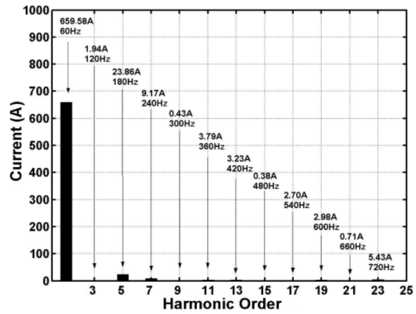
Figure 3. (a) Phase "a" voltage and current waveforms in the first floor transformer, (b) Phase "b" voltage and current waveforms in the first floor transformer, (c) Phase "c" voltage and current waveforms in the first floor transformer.

Studying the graphs of the figure 3, it can be observed that the three phases present capacitive characteristics, considering that the currents are led in relation to voltages, injecting capacitive reactive flow into the system, improving the power factor and contributing for surplus reactive energy reduction on the inductive time. However, in the capacitive time, such fact would be really meaningful due to the three phases of this transformer being capacitive, because, as seen on the ground floor, between this break the reactive capacitive is measured, but, as in this period the electronic charges are switched off due to the stores closing, such effect is not verified.

As well as the waveforms of voltage and currents, the current harmonic spectrum of each phase were also analyzed, where it is possible to verify the most significant presence of the third harmonic, as figure 4 shows. Nevertheless, at phase "c" it is noticed the significant appearance of positive, negative and zero harmonic sequences, showing that there is a bigger presence of nonlinear loads of capacitive predominance at the referred phase. These harmonic orders of current in phase "c" contribute to the increase of the RMS current, thus the zero sequence circulating neutral can cause disturbances on the consumer unit.



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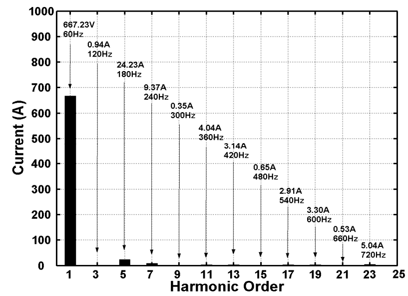

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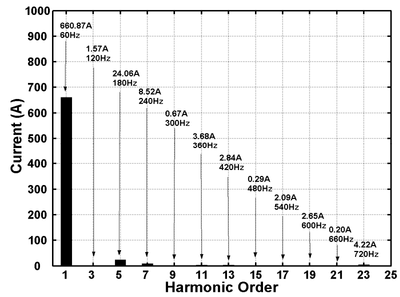

(c)

Figure 4. (a) Phase "a" current harmonic spectrum in the first floor transformer, (b) Phase "b" current harmonic spectrum in the first floor transformer, (c) Phase "c" current harmonic spectrum in the first floor transformer.

Considering the results obtained from both measurements performed in field, it can be concluded that by realizing measurements of power factor in consumer units, linear and nonlinear loads characteristics and the power factor of capacitive and inductive schedules should be analyzed, avoiding the placing of capacitor bank in buses that already have capacitive behavior.

5. CONCLUSION

In this paper was analyzed the influence of linear and nonlinear electronic loads in the charging system of consumer units from group A. In the measuring realized in field on two transformers which fed floors with different characteristics, were found inductive and capacitive loads in the respective phases. The transformer which attended the ground floor presented currents of phases "a" and "b" lagged in relation to the voltage and with power factor below of 0.92 inductive, requiring the power factor correction through the installation of capacitors banks. Notwithstanding, the phase "c" current was lead in relation to voltage, and with power factor below of 0.92 capacitive. In this case, it's not necessary the installation of capacitors bank for power factor correction in the inductive schedule. Therefore, a power factor correction project in this bus could be realized thought the installation of two monophasic capacitors banks in phases "a" and "b", to attend the legislation on inductive schedule. Regarding the first floor transformer, where all the phases are capacitive and with the power factor below 0.92 capacitive in the inductive schedule, it's not necessary a power factor correction in the bus of the secondary of the transformer, and because the loads of the first floor are switched off on the capacitive time in the night period, there will be no problems with the legislation. Therefore, regardless of the behavior of the electronic load studied in this paper be linear or nonlinear, there is an injection of reactive power on the bus, contributing to change the power of the consumer unit, and consequently influencing factor in the calculation of excess reactive power. Thus, the projects related to the installation of capacitor banks for power factor correction in buses that has the presence of linear and nonlinear electronic loads, must be accompanied by detailed studies of the behavior of the power factor in inductive and capacitive times, to avoid unnecessary costs in the Consumer Unit.

Considering that today electric utilities have made large investments in electric efficiency in low-income consumers, where are replaced specially conventional refrigerators by PROCEL seal refrigerators and thousands of incandescent bulbs with CFLs, a study about the influence of these loads in both group A and B consumers is necessary to analyze the impact of the entry of these electronic loads, both in the charging system and in the possible improvement of the electric utility system with injection of reactive power on the buses, as well as the effect of multiple frequencies on the utility bus electronic loads.

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