A 10kW, THREE PHASE SYSTEM WITH HIGH POWER FACTOR AND LUMINOSITY CONTROL, FOR A GROUP OF FLUORESCENT LAMPS

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***Abstract* – This article presents the study and implementation of an illumination system of 10kW. This system centralizes the rectifier with high power factor, processing all the energy and giving it to the bus CC. From the bus CC, there are ten converters CC – CC of 1kW each – connected, which are able to regulate and also vary the voltage, which is given to the group of inverters. An inverter to each fluorescent lamp of 40W is used, altogether with the resonant filter. The control of luminosity is obtained through the variation of the voltage given to the inverters.**

The system is able to feed 250 fluorescent lamps of 40W, being the act in the control of the luminosity done in each of the CC-CC converters, in other words, to each group of 25 lamps. In this paper, it is presented to each circuit that is part of the system: methodology and example of project, simulation and experimental results.

1 INTRODUCTION

It is necessary that the usage of the electrical energy in the country come to be more rational at every time. The illumination systems are responsible to a great part of the consumption of electrical energy, thus it is relevant all the effort in order to use more efficient ways of illumination.

It is known that the fluorescent lamps are more efficient if they are compared to the incandescent ones. The fluorescent lamp is a low-pressure discharge lamp, in which the light if predominantly produced by dust-fluorescent activated by the ultraviolet energy of the discharge. The lamp, generally in the shape of a long tubular bulb, with an electrode in each extreme, has mercury steam under low pressure, with a small amount of inert gas to facilitate the escape. The internal surface of the bulb is covered with a fluorescent dust or phosphorus, whose composition determines the amount and color of the emitted light.

The discharge lamps need a reactor to their functioning. The more used are the magnetic ones due to their simplicity and low cost. There are, however, a series of disadvantages in the usage of this kind of reactor, such as high weight and volume, low power factor and low revenue among others. To minimize these problems, the electronics reactors were developed. They possess small volume and weight, they can be projected to present a high factor of power, and they possess high revenue and enable the control of the luminosity of the lamp. As disadvantages, they present a high cost, more complex circuits and less reliability.

Currently, solutions are searched to raise the power factor and minimize the harmonic distortion rate in electronic systems. The evolution of the components used in the power electronics, allied to the techniques of conception of converters has significantly contributed to it. This study restores the usage of passive techniques, in which there is an emphasis on the robustness and simplicity, altogether with the static converters.

It is presented a new conception in illumination systems joining all the characteristics mentioned above. The figure 1 illustrates the diagram in blocks of the system.

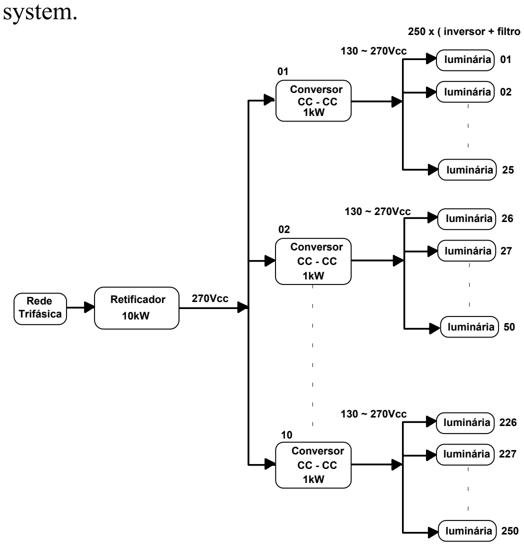

Fig. 1 – Proposed structure.

2 THREE PHASE RECTIFIER OF 10kW USING THE LIT

The high power electronics systems generally use a three-phase rectification to the CA-CC conversion. Therefore, it is relevant the study of the techniques that improve the performance of the three phase converters, regarding the power factor.

In [12] Clemens Niermann uses the characteristics of the multiple pulses three phase rectification systems and, using the line-side interphase transformer (LIT), create a passive solution of relative low volume and excellent characteristics.

2.1 Advantages and Disadvantages between the passive and active techniques to the correction of the power factor

Advantages of the active techniques:

- Power factor practically unitary;
- Good regulation of the exit voltage;
- Small volume and weight.

Disadvantages of the active techniques:

- High number of components;
- Less reliability;
- Higher cost.

Advantages of the passive techniques:

- Higher robustness;
- Higher reliability;
- Less number of components;

Disadvantages of the passive techniques:

- Higher volume and weight;
- Doesn't have regulation of the exit voltage.

The rectifier presented joins the passive and active techniques, in order to obtain a robust circuit, with a high power factor and a good regulation of the exit voltage.

2.2 General considerations about the LIT

The LIT line-side interphase transformer, is a kind of three phase connection that divides the current into two components that dislocate among themselves, one of them in advance and the other one delayed from a determined angle (φ) in relation to the phase current. This displacement is defined through the turn relations between the roll ups LAi, LBi, LCi, belonging to the same single phase transformer, in which i=1,2,3 (see figure 2). In this way, it is possible to obtain two three-phase systems from one. Having two three phase systems, it is used two three phase rectifier bridges (bridges of Graetz) to obtain a system known as rectifier of twelve pulses. In this way, the most significant harmonic components presented in the entrance current are of the order of 12*n ± 1 to n complete.

The 2nd figure presents the rectifier circuit of twelve pulses using the LIT transformer with a filter inductor in the entrance, whose purpose is to make the entrance current not pulsed and with a sinusoidal wrapper.

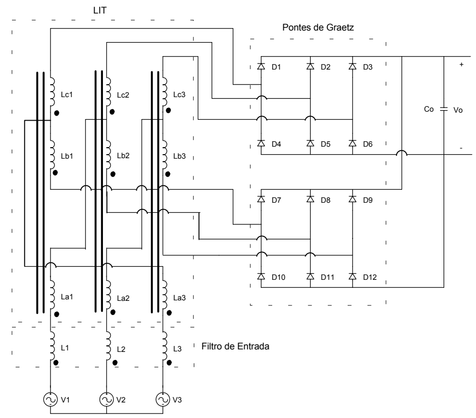

Fig. 2 – Converter of 12 pulses CA-CC with the LIT.

The LIT is constituted of three single-phase nucleuses with three turn-ups each, making the total of nine roll ups suitably interconnected.

2.3 Analytical study

Principal equations to the LIT project.

a) Roll-ups relations

- N1 is roll-ups relations between the roll-ups Lbi e Lai:

$$N_1 = \frac{\sqrt{3} - tg(\varphi)}{2.tg(\varphi)} \qquad (1)$$

- N_2 is roll-ups relations between the roll-ups Lc_i e La_i:

$$N_2 = \frac{\sqrt{3} + tg(\varphi)}{2.tg(\varphi)} \qquad (2)$$

To the converter of twelve pulses, φ = 15o, is has:

$$N_1 = 2{,}732 \quad \text{e} \quad N_2 = 3{,}732$$

b) Effective current in the winding

- Effective current in the winding La_i:

$$I_{La_i} = \frac{P_o}{3.V_i} \qquad (3)$$

- Effective current in the winding Lbi and Lci:

$$I_{Lb_i} = I_{Lc_i} = \frac{0{,}3.P_o}{V_i \cdot \sqrt{3}} \qquad (4)$$

c) Medium voltage in the exit of rectifiers

$$V_o = 2{,}12.V_i \qquad (5)$$

d) Effective voltage in the winding

- Effective voltage in the winding La_i:

$$V_{La_i} = 0{,}063.V_o \qquad (6)$$

- Effective voltage in the winding Lb_i:

$$V_{Lb_i} = 0{,}173.V_o \qquad (7)$$

- Effective voltage in the winding Lc_i:

$$V_{Lc_i} = 0,236.V_o \quad (8)$$

e) Nominal power of each single-phase transformer of the LIT

$$P_{LIT_i} = 0,1494.P_o \quad (9)$$

f) Inductance of each LIT winding and of the entrance filter

- Inductance of winding La_i:

$$La_i = \frac{324,63.10^{-6}.V_o}{I_{La_i}} \quad (10)$$

- Inductance of winding Lb_i:

$$Lb_i = \frac{2,423.10^{-3}.V_o}{I_{La_i}} \quad (11)$$

- Inductance of winding Lc_i:

$$Lc_i = \frac{4,521.10^{-3}.V_o}{I_{La_i}} \quad (12)$$

- Inductance of the entrance filter L_i:

$$L_i = \frac{2.39.10^{-2}.V_i}{f_{rede} \cdot I_{La_1}} \quad (13)$$

The equations presented in this section allow the achievement and simulation of the project of the line interphase transformer.

2.4 Experimental results

The figures 3 and 4 show that the entrance current presents low harmonic content.

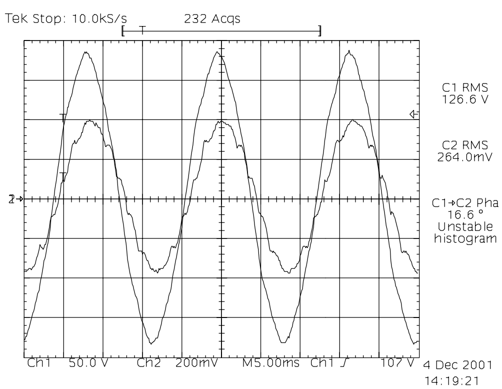

Fig. 3 – Voltage and current in one of the phases.

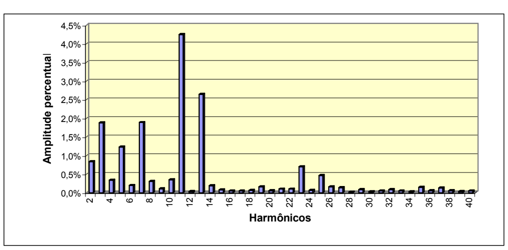

Fig. 4 – Harmonic analysis of the entrance current.

3 BUCK CONVERTER OF 1kW

This converter is an interface between the three-phase rectifier of 10kW and the inverters. It has the function of regulation the voltage of the bus CC and also allows the control of the voltage of the bus, with the purpose of varying the luminosity of the group of lamps feed by this converter. This control of the bus voltage if done through an isolated external voltage varying between 0 and 10Vcc. The basic architecture of the circuit is presented in the figure 5 below.

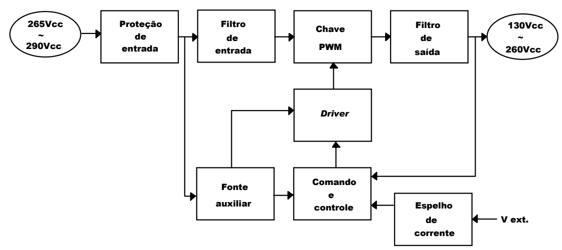

Fig. 5 – Diagram of the blocks of the converter CC – CC.

The circuit is based in the structure of the BUCK converter, commanded by the integrated circuit UC3525.

Because of the system in which the converter in inserted is modularized, it was opted to put the entrance and exit filters. In this way, the installation of the converter far from the rectifier and from the inverters is possible.

The external voltage that appears in the diagram of the blocks, represents the acting through a sensor or manual, to the control of the exit voltage and, consequently, of the luminosity of the group of lamps.

It is used a driver circuit to provide the necessary isolation to the command of the switch and, at the same time, its protection.

3.1 Experimental results

In the figures 6 to 10, it is presented wave forms obtained directly from the circuit submitted to testing. Observing the figures 6 and 7, it is noticed the importance of the usage of the driver. Besides turning the signal applied to the gate of the switch better defined in relation to its shape, the levels of voltage are of +15V when in command and of –5V when in blocked. The application of a negative voltage when it is desired to block the switch, besides accelerating the blockage, it also avoids the entrance in a non-desired conduction.

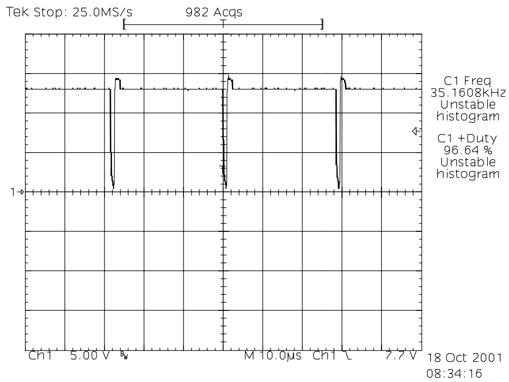

Fig. 6 - Pulses de command in the driver entrance.

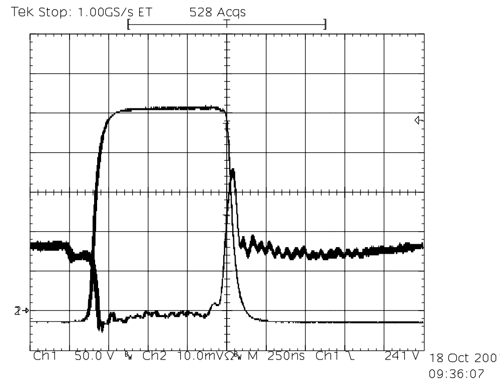

Fig. 9 - Detail of the commutation in the switch mosfet.

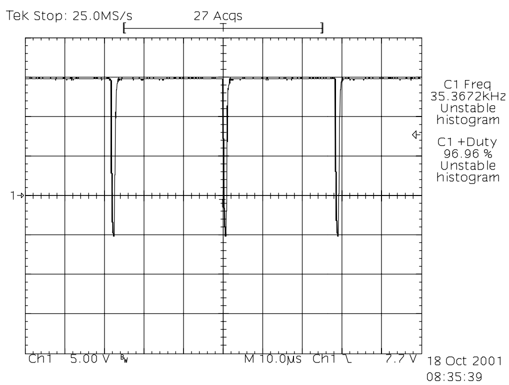

Fig. 7 - - Pulses in the exit of the driver (VGS).

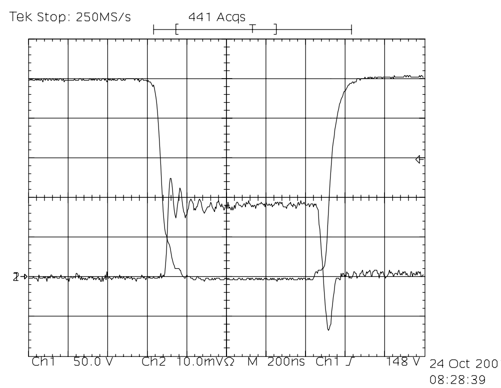

Fig. 10 – Detail of the commutation in the diode.

Through the figure 8 it is noticeable the operation of the converter in nominal power.

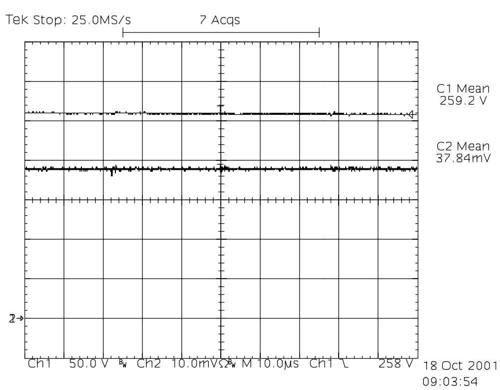

Fig. 8 - Voltage and current in the charge.

The figures 9 and 10 show the commutation of the switches of the converter; it is noticeable the details of the dissipative commutation in the switch and in the diode.

3.2 Assay of efficiency

Using a digital wattmeter, label YOKOGAWA, model WT130, it was obtained:

- Power given to the converter = 1018W;
- Power given to the charge= 1000W.

Thus, the revenue of the step of the power is of 98,2%.

- Power dissipated through the auxiliary FONTE= 5,3W.

The total revenue of the converter is of 97,7%.

4 HALF BRIDGE INVERTER AND RESSONANT FILTER TO A FLUORESCCENT LAMP OF 40W

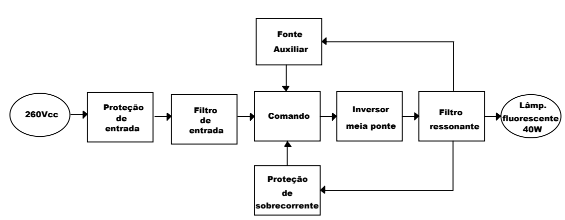

Fig. 11 – Diagram of the blocks of the inverter.

4.1 Experimental results

In the figures 12 to 15, it is presented forms of wave obtained directly in the circuit submitted to testing. The figure 12 shows the sinusoidal shape of the voltage and of the current given to the lamp.

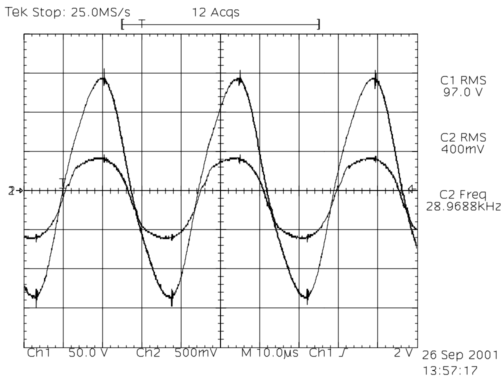

Fig. 12 - Voltage and current in the lamp.

In the figure 13 it is observable the command voltages and drain/source of the switches.

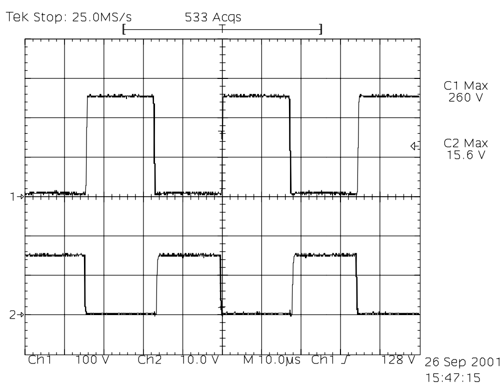

Fig. 13 - Voltage drain/source and gate/source above the mosfet.

The figure 14 shows the voltage applied to the lamp during its switching on.

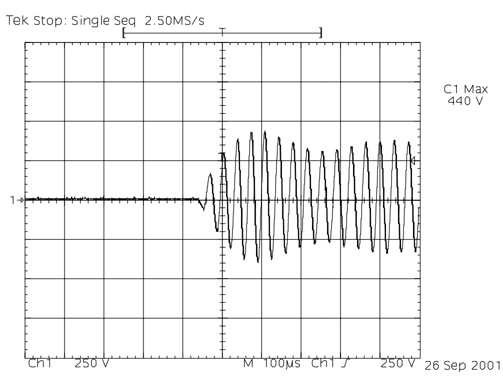

Fig. 14 - Transitory of starting (ignition voltage of the lamp).

The figure 15 shows the waving in the entrance current.

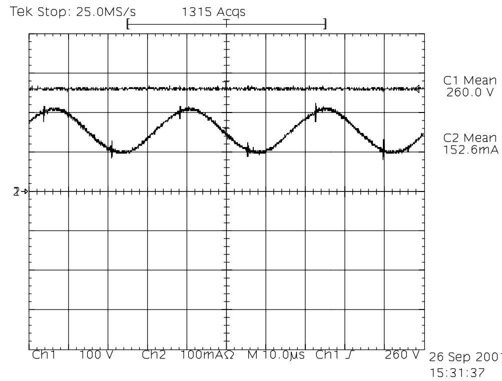

Fig. 15 – Voltage and current in the entrance of the inverters.

4.2 Assay of efficiency

Using a digital wattmeter YOKOGAWA model WT130, it was obtained:

- Power given to the inverter = 40,9 W;
- Power given to the lamp = 37 W.

Thus the revenue of the circuit is of 90,5 %.
Utilizando-se um wattímetro digital YOKOGAWA

4.3 Attempt of the control of the power.

The graphic in the figure 16 shows the behavior of the power given to the lamp, in relation of the variation of the voltage of the bus CC. In this way, obtaining the control of the luminosity of the lamp.

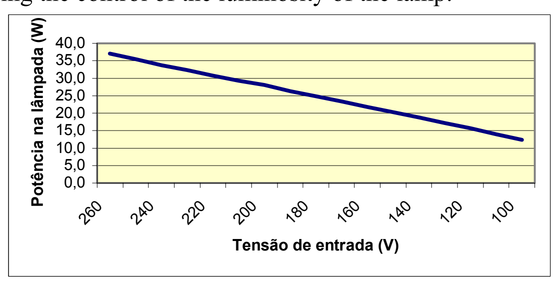

Fig. 16 - — Graphic of the power given to the lamp in relation to the entrance voltage.

5 CONCLUSIONS

This paper presented the study and practical implementation of an illumination system, composed of a three phase rectifier of 10kW with higher power factor based on the LIT, converters of the BUCK kind of 1kW with the control of the voltage in the exit, through an external isolated source, and of the inverters with their respective resonant filters to fluorescent lamps of 40kW.

The rectifier of twelve pulses studied here is a simple and robust structure, besides processing only 15% of the power of the charge in each single phase nucleus of the LIT, what leaves it with a relatively low volume and weight. It still presents a low harmonic content in the entrance current.

The results obtained in the study, simulation and implementation of the rectifier of twelve pulses with the LIT, demonstrates the viability of the usage of this kind of structure in applications where it is desirable robustness and high factor of power. The equationing of the LIT allows its dimensioning to other powers.

The BUCK converter, used as an interface between the rectifier of twelve pulses and in the inverters, is used to regulate the voltage CC and to control the amplitude of this voltage, though an external isolated voltage. The variation of this voltage given to the invertors allows the control of the luminosity.

A more simple system can be obtained kinking directly the inverters to the rectifier of twelve pulses. In this way, it is lost the regulation and the control of the luminosity.

In relation to the inverters, it was searched a circuit of small volume and easy reproducibility. After some phases of improvement of the initial circuit, it was come to a circuit that answers to the needs of the system of illumination proposed. The forms of waves obtained experimentally are very similar to those obtained through a simulator, proving the methodology used.

The attempts related to the rising of temperature and revenue was showed to be satisfactory.

The system presented itself as an innovative solution in relation to illumination.

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