ELECTRONIC BALLAST TO SUPPLY HPS LAMPS WITH LOW FREQUENCY SQUARE WAVEFORM IN PUBLIC LIGHTING SYSTEMS

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Abstract – This paper presents a topology that integrates the inverter stage and the power control stage for supplying high-pressure sodium lamps applied to public lighting system. The topology consists of a bidirectional flyback converter operating in discontinuous conduction mode (DCM), in order to supply the lamp with a low frequency square waveform and avoid the acoustic resonance phenomenon. The aim of this work is to integrate the inverter stage and the lamp power control, thus reducing the components and the ballast final cost. A DC voltage is used to supply the proposed topology, once electronic ballast requires a power factor correction stage to be applied to the public lighting system, due to the lamp power demand. Some experimental results are presented to validate the proposed topology.

***Keywords* – acoustic resonance phenomenon, bidirectional flyback, electronic ballasts, high-pressure sodium (HPS) lamps, public lighting.**

I. INTRODUCTION

The public lighting corresponds about 7% of the national demand and 3.3% of all electric energy consumption in Brazil [1]. For this reason the implementation of more efficient lamps and ballasts represents fundamental importance for energy saving.

The high-pressure mercury lamps are usually used in Brazilian public lighting systems. Although these lamps bring long useful life, the presented energy efficacy is low, when compared to the high-pressure sodium lamps (HPS).

The useful life of HPS lamps is about 24000h, which guarantee low maintenance costs, and its high luminous efficacy brings a significant energy saving. These lamps radiate light of yellowish color, due to sodium, what results a low color rendering index. However, this characteristic is not the most relevant one, when considering open-air environments, where the color rendering index is not a problem. These characteristics become the HPS lamp an excellent option for using in public lighting system.

The negative incremental resistance characteristic becomes unfeasible the direct connection of HPS lamp to the main. The using of a device (ballast) capable of controlling the lamp current is needed, in order to guarantee a stable operation [2].

The HPS lamps are usually fed by electromagnetic ballasts. However, these devices present some unpleased characteristics, as low efficiency, sparkling, audible noise and decreasing of the lamp useful life [3]. Besides, they are large and weighty.

With the purpose of overcome these problems, researches have been developed electronic ballasts for supplying high-pressure discharge lamps.

The using of electronic ballasts to feed low-pressure discharge lamps, as fluorescents lamps, is already a reality. However, the development of electronic ballasts to supply high-pressure discharge lamps, for instance the HPS lamps, presents some particularities. The most relevant characteristic of these lamps is the acoustic resonance phenomenon, which makes impossible the using of conventional electronic ballasts for supplying them.

II. ACOUSTIC RESONANCE PHENOMENON

The acoustic resonance phenomenon occurs in a discharge lamp when its operation frequency is close to the lamp natural frequencies, making the pressure waves diffuse and causing the disturb in discharge course [4]. However, that disturb becomes visible when the energy related to the resonance frequency is big enough, although the effects of the acoustic resonance are detected even when there are not visible modifications in the discharge course. For this reason, the identification of the phenomenon through the visual inspection is not suitable [5], [6].

The light color changing, instability of the discharge course, inconstancy of the shine intensity and, in extreme situation, the break of the discharge tube, are some results caused by the acoustic resonance phenomenon.

The acoustic resonance phenomenon occurs in high frequency range, as shown in figure 1. In extra-high frequency range, at megahertz lamp operation, the acoustic resonance phenomenon does not occur [7]. However, parasitic inductances and capacitances should be taken into account in the design, what becomes it more complicated. The soft switching technique must be required to reduce the switching power losses and the EMI emission [8].

The DC lamp current operation is another option to avoid acoustic resonance occurrence, but it causes the deterioration in one of the lamp electrodes, which causes a drastic reduction of its useful life.

The using of low frequencies to supply the lamp enables a stable operation without the drawback presented by DC lamp current. It explains the great demand for electromagnetic ballasts, which feed the lamp with the low frequency of the main (50/60 hertz).

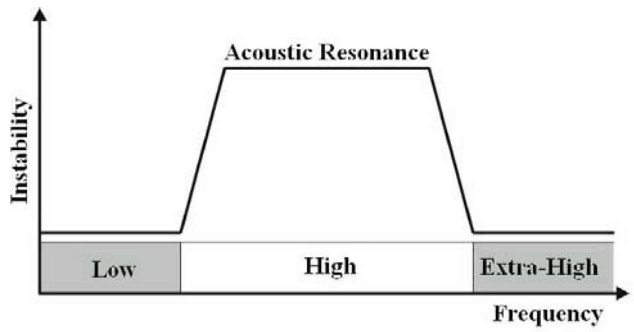


Fig. 1. HPS lamps instability behavior related to the frequency [9].

Considering the methods employed to prevent the harmful consequences of the acoustic resonance phenomenon, the option of supplying the HPS lamp with low frequency square waveform through the use of electronic ballasts seems to be the most reliable option [10]. This method presents some advantages as preventing the re-ignition process, improving the lamp useful life and the visual comfort of the lighting.

III. PROPOSED CIRCUIT

Figure 2 shows the proposed inverter, which consists of two Flyback converters sharing the same output and an igniter circuit.

The arrangement of the switches M_3 and M_4 brings a bidirectional characteristic to the topology. According to the correct operation of switches M_1, M_2, M_3 and M_4, it is possible to obtain a low frequency symmetrical square waveform applied to the lamp.

A similar topology was presented by the same authors in [11]. It was applied two flyback transformer cores and four high frequency switches to obtain a low frequency lamp voltage, instead of one transformer core, two low frequency and two high frequency switches applied in the proposed inverter.

The switches commuting signals are controlled through the use of a microcontroller, which enables the lamp power control and makes possible to obtain a network communication through the public lighting systems.

The capacitor in parallel to the lamp acts as a high frequency filter. It is designed to obtain a small output voltage ripple, avoiding the acoustic resonance occurrence due to the converter operational frequency (50kHz). Even so, its project requires some caution, in order to allow a fast inversion at the lamp voltage each low frequency period.

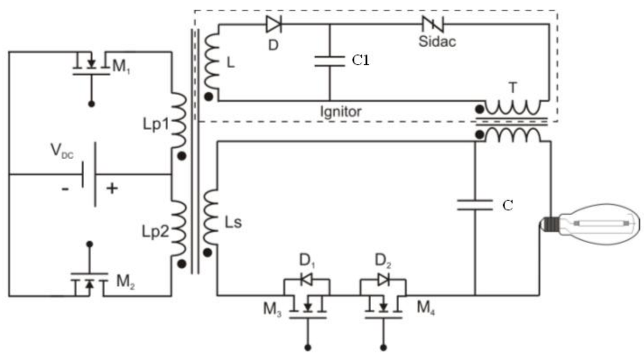


Fig. 2. Proposed topology.

The amplitude of the output voltage ripple must be kept below 20% of the square wave amplitude in order to guarantee that the acoustic resonance phenomenon is below a secure threshold value [4].

IV. IGNITION PROCESS

The beginning of the ignition process denotes the alteration of the gas from a non-conducting state to a conducting state. This modification is obtained through the application of a voltage pulse with enough amplitude, width and rising time [4].

An igniter circuit of the lamp has been developed in order to supply a voltage pulse of 2.5 to 4kV (according to NBR IEC662/1997 standard) for lamp ignition.

One of the main problems of the igniter project for HPS lamp electronic ballasts is the isolation of the high voltage pulse needed to start the ignition process. It has been obtained using an output of the flyback converter.

The igniter circuit is shown in the hatched area of figure 2. Inductor L discharges its energy over capacitor C1 through diode D. When the voltage across capacitor C1 reaches the Sidac breakdown voltage, the energy is transferred from capacitor C1 to the primary side of the transformer T. The high turns ratio of this transformer brings the needed high voltage pulse to the lamp igniting process at secondary side.

V. OPERATION STAGES

The proposed ballast operation stages are shown in figure 3 and figure 4, and described as follows:

A. First Stage

The M_4 switch is turned on during this stage, which corresponds to the positive half cycle of the lamp voltage waveform. A high frequency modulation is provided by the M_1 switch at the same time, as shown in figure 3.

Figure 3 (a) shows the interval when the energy is transferred into the transformer by M_1. During this interval there is no current in the secondary side of the transformer due to the reverse bias of D_3, even though the gate signal on M_4 is maintained.

Figure 3 (b) shows the transfer of this energy to the load, which happens when M_1 is turned off and M_4 assumes the load current.

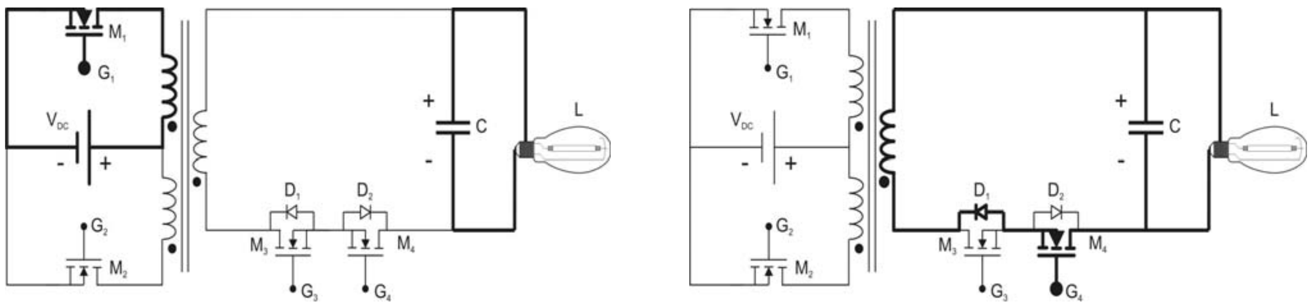
B. Second Stage

The second stage corresponds to the negative half cycle of the lamp voltage, as shown in figure 4.

In this stage, the switches M_1 and M_4 are kept off, the switch M_3 is turned on and the high frequency modulation is provided by M_2 switch.

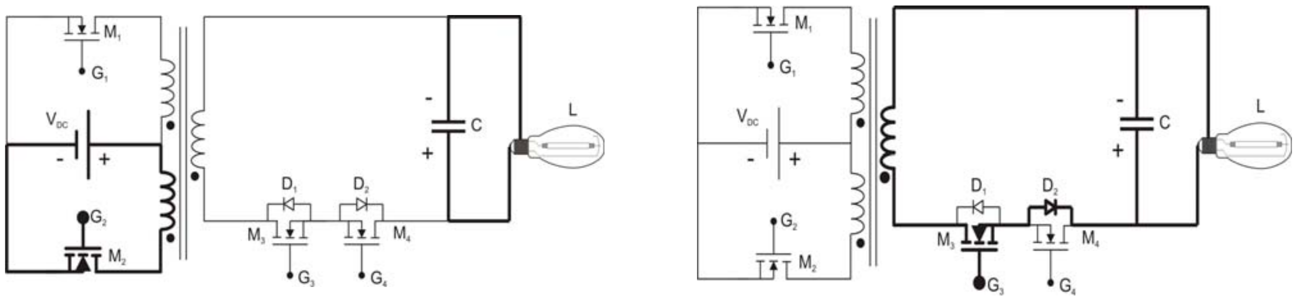
Figure 4 (a) shows the interval when the switch M_2 is turned on and the energy is transferred into the transformer. The gate signal of the switch M_3 is maintained during this interval, even though it does not have any drain current due to the blocking provided by D_3.

Figure 4 (b) shows the transfer of this energy to the load, which happens when M_2 is turned off and M_3 assumes the load current.



(a) (b)

Fig.3. Positive lamp voltage semi-cycle.



(a) (b)

Fig.4. Negative lamp voltage semi-cycle.

In this stage, the lamp is supplied with the same energy of the first stage, but its voltage polarity is inverted, what results in a symmetrical square lamp voltage supply.

Figure 5 shows the command signal of four switches, where G_1 represents the gate drive of switch M_1, G_2 represents the gate drive of switch M_2 and so on.

In the first stage, M_1 is commuted with a high frequency signal (50 kHz) and M_4 is kept on, while M_2 and M_3 are both kept off.

In the second stage, M_2 is commuted with a high frequency (50 kHz) and M_3 is kept on, while M_1 and M_4 are both kept off.

It is important to notice that M_3 and M_4 switches do not commutate in a high frequency. Therefore, it is possible to apply low frequency switches, such as bipolar transistors, to the secondary side of the flyback converter.

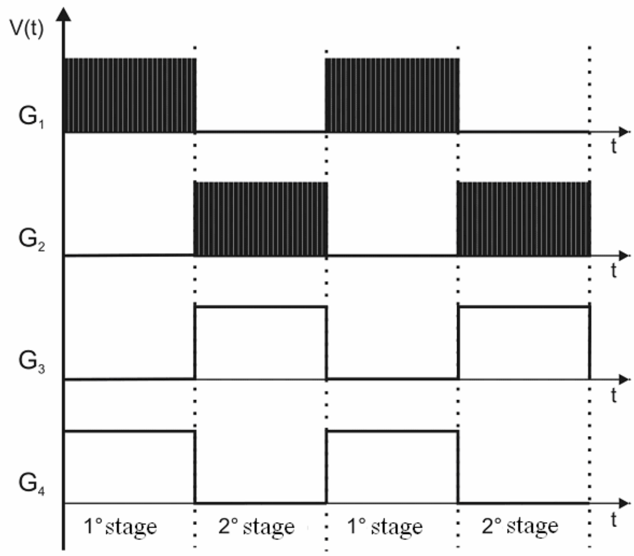


Fig. 5. Gate drives.

VI. INVERTER DESIGN

The inverter design has been done to supply a 70W high-pressure sodium lamp with a low frequency (400Hz) square voltage. The converter parameters are shown in table I.

The primary inductances of the flyback transformer are solved as shown in (1).

$$L_{p1} = L_{p2} = \frac{V_{DC}{}^2 . D^2}{2 . P_{out} . Fs} . \eta = 170 \mu H \tag{1}$$

Where:

L_{p1} and L_{p2}	- primary inductances,
V_{DC}	- input DC voltage,
D	- duty cycle,
P_{out}	- lamp power,
Fs	- switching frequency,
η	- efficiency.

The secondary inductance L_S of the coupling that supplies the lamp is calculated as shown in (2).

TABLE I
Summarized Parameters

Parameters	***Values***
Input Voltage	V_{DC} = 100 Vdc
Output Voltage	Vout = 72 V
Lamp Current	Iout = 0,98 A
Lamp Frequency	F_{LAMP} = 400 Hz
Switching Frequency	Fs = 50 kHz
Maximum Duty Cycle	Dmax = 0,4

$$L_s = \frac{L_p}{\left(\dfrac{V_{in}.D}{V_{out}\left(1-D\right)}\right)^2} = 204\mu H \qquad (2)$$

The output capacitor C is obtained through (3), considering a 15% lamp voltage ripple in order to avoid the acoustic resonance phenomenon occurrence.

$$C = \frac{Iout \cdot D}{Fs \cdot Vout \cdot \alpha} = 726nF \qquad (3)$$

Where *Iout* is the lamp output current and *Vout* is the lamp voltage.

It has been built a prototype using the components described in table II, in order to obtain experimental results to validate the proposed inverter.

VII. EXPERIMENTAL RESULTS

In order to prove the viability of the proposed inverter, some experimental results are shown.

Figure 6 shows the gate signal of the switches M_1 and M_2, commutated with a high frequency. The gate signals of M_1 and M_4 are shown in figure 7 and detailed in figure 8, which allow the visualization of M_1 high frequency operation and the M_4 low frequency commuting.

Figure 9 shows the voltage and current in the L_{P1} primary winding of the flyback transformer during a positive half cycle of the lamp voltage, and figure 10 shows the voltage in the switch M_4 and the current in the secondary side of the flyback, during the same lamp voltage half cycle.

Finally, figure 11 shows the lamp voltage and current obtained through the use of the implemented inverter.

TABLE II
Components List

Component	***Specification***
Lp1 and Lp2 inductances	170μH
Ls inductance	204μH
Transformer core	EE 42/15 (IP12) – Thornton
M_1, M_2, M_3 e M_4 switches	IRFBE30 MOSFET
C output capacitor	680nF/250V

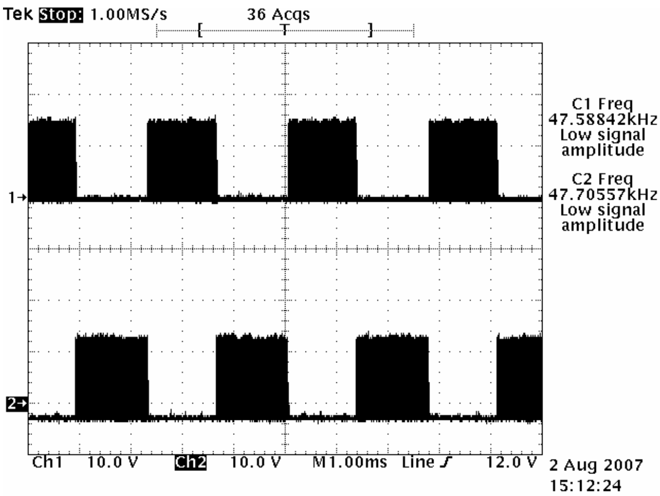


Fig. 6. M_1 and M_2 gate signals (10V/div).

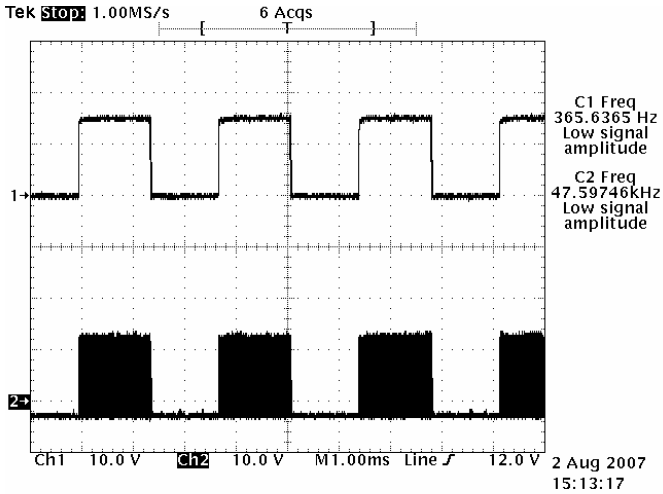


Fig. 7. M_1 and M_4 gate signals (10V/div).

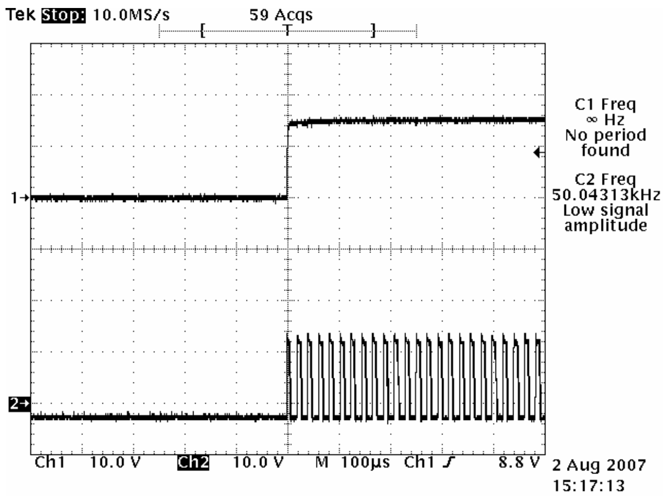


Fig. 8. Detail of the M_1 and M_4 gate signals (10V/div).

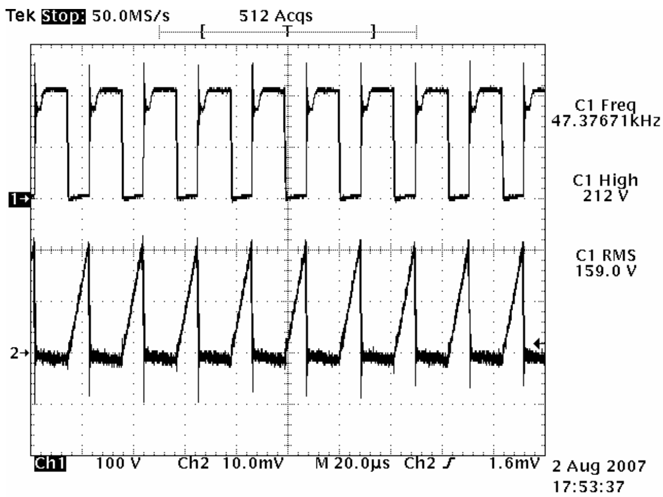


Fig. 9. Voltage and current in the primary side of the flyback transformer (100V/div and 2 A/div).

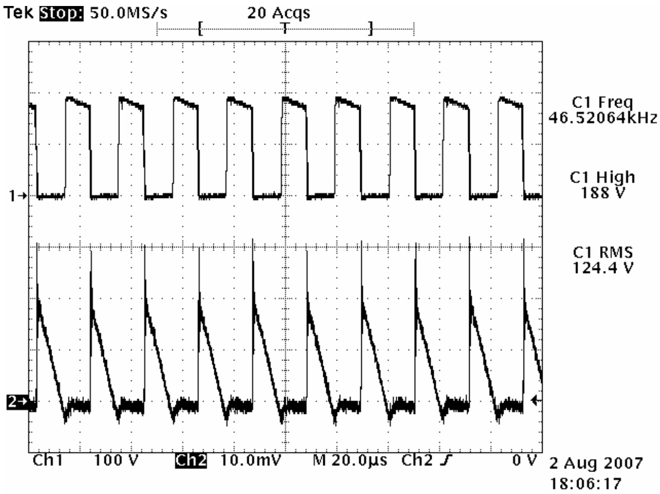


Fig. 10. Voltage in M_4 (100V/div) and current in the secondary side of the flyback (2 A/div).

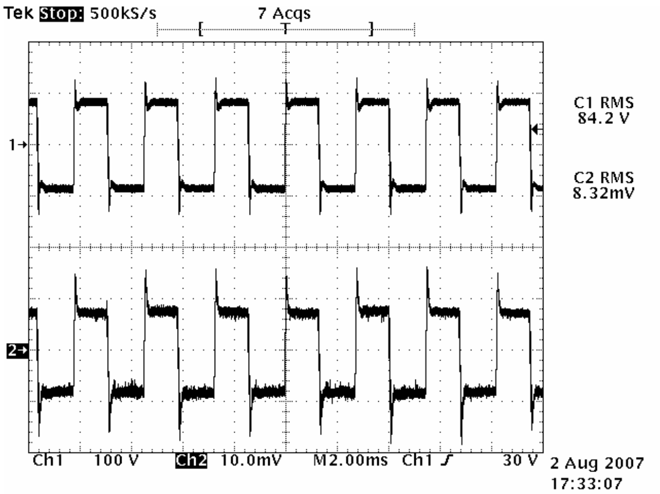


Fig. 11. Lamp voltage and current (100V/div. and 1 A/div.).

VIII. CONCLUSION

This paper presents an inverter topology based on a bidirectional flyback converter combined to an igniter circuit, which makes possible the HPS lamp ignition through a high voltage pulse.

The flyback converter supplies the lamp during the igniting process and in steady state, and makes possible the integration of the lamp power control and the inverter stage.

The implemented prototype is supplied from a DC voltage source due to the need for a power factor correction stage in electronic ballast applied to public lighting systems, because of the 70W lamp power, according to IEC61000-3-2 standard.

The lamp is supplied with a low frequency symmetrical square wave, in order to avoid the acoustic resonance phenomenon occurrence.

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