SINGLE STAGE LOW FREQUENCY SQUARE WAVE ELECTRONIC BALLAST FOR HID LAMPS

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Abstract – **This paper presents a single power processing stage electronic ballast for HID lamps. A DC-DC buck converter that controls the current and the power of the lamp, a power factor pre-regulator based on discontinuous conduction mode boost converter and the inverter are combined in a dual fed full bridge BIBRED converter. It operates with low frequency current driving the lamp. All signals of the power stages are provided by a dedicated microcontroller. A 70W prototype without acoustic resonance and no stroboscope effect was implemented.**

KEYWORDS

HID lamps; microcontroller; ballast.

I. INTRODUCTION

Electromagnetic ballast for high intensity discharge (HID) lamp is a robust and low cost device, however it presents high weight and volume, poor power regulation and is not able to dimmer the lamp. Electronic ballasts, that have been extensively studied, can overcome the conventional solution with the following features: reduced volume and weight, operate the lamp with constant power for both lamp voltage and input voltage variation, control the luminous flux, reduce the warm-up time, work with high input power factor, improve lamp lifetime and efficiency [1].

The electronic ballast can be classified into two groups, depending on the lamp current frequency. The high frequency ballast can be build with a simple power circuit, however it requires some strategy to avoid the acoustic resonance, which sometimes limits this solution [2]. The low frequency ballast imposes a square wave current to the lamp that ensures the operation free from acoustic resonance and stroboscope effect [3 – 6], however the power circuit is more complex.

A low frequency square wave electronic ballast can be implemented by using three power-processing stages. The input one, called power factor pre-regulator (PFP) stage, is used to obtain high power factor maintaining constant the DC bus voltage. The intermediate stage is a DC-DC buck converter, operating at high frequency to control the lamp current and power. The output stage is a low frequency square wave inverter that drives the lamp.

However, three power-processing stages demand more components, which increase the overall cost and reduce the electronic system reliability. There are some alternatives to simplify the overall converter, which consist in combining the power stages described above.

This paper proposes a new single stage electronic ballast with low frequency square wave lamp current and high input power factor for HID lamps. It uses a dual fed full bridge BIBRED topology [7] fully controlled by a microcontroller device, so that the current is maintained constant during the warm-up, resulting in reduction of this phase time. After that, the control compensates both, the voltage lamp increasing and the utility line voltage variation, and the system operates with fixed power.

II. THE PROPOSED SINGLE STAGE LOW FREQUENCY SQUARE WAVE ELECTRONIC BALLAST

The Fig.1 shows the complete power stage circuit of the proposed electronic ballast, which is formed by: The input rectifier, the dual fed full bridge BIBRED and the igniter circuit. The igniter circuit uses an appropriated ratio between the coupled inductances L_{ig1} and L_{ig2}, which ensure the high voltage ignition pulses to start up the lamp. These pulses are obtained when the S_{ig} is turned on, through the resonance between C_{ig} and L_{ig1}.

The dual fed full bridge BIBRED converter can provide high power factor by controlling a square wave low frequency current. It can be obtained by an appropriated bridge signal command: the switches S_1 and S_3 operating at low frequency in a complementary mode and the switches S_2 and S_4 operating at high frequency PWM mode. By using a high value of C_o capacitor, this topology can integrate an input boost converter with an output step-down inverter [7].

The input inductance (L_{boost}) is designed in order to ensure the converter operation in discontinuous conduction, which provides high power factor. The output inductor (L_{buck}) is placed in series to the lamp and its value has to be as small as possible to ensure fast polarity changes of the lamp current. A capacitor filter is still needed to reduce the lamp ripple current, preventing the acoustic resonance [3].

The Fig. 2 shows the main waveforms of the circuit. The converter has three typical operation stages that happen in the positive (a1, b1, c1) and in the negative (a2, b2, c2) lamp current half cycles as described below:

a1 stage: During this stage S_1 and S_4 are ON, so the L_{buck} current increases linearly through C_o - S_1 –lamp - S_4, and the L_{boost} current increases linearly through V_{in} - D_{b2} - S_4, which are modulated by the input voltage.

b1 stage: S_4 is turned off. The L_{buck} current decreases linearly through S_1 - D_{S3} - lamp and L_{boost} current decreases linearly through D_{b1} - D_{S1} - Co until it becomes zero.

c1 stage: During this stage i_{Lboost} = 0 and the L_{buck} current still decreases through S_1 - D_{S3} - lamp.

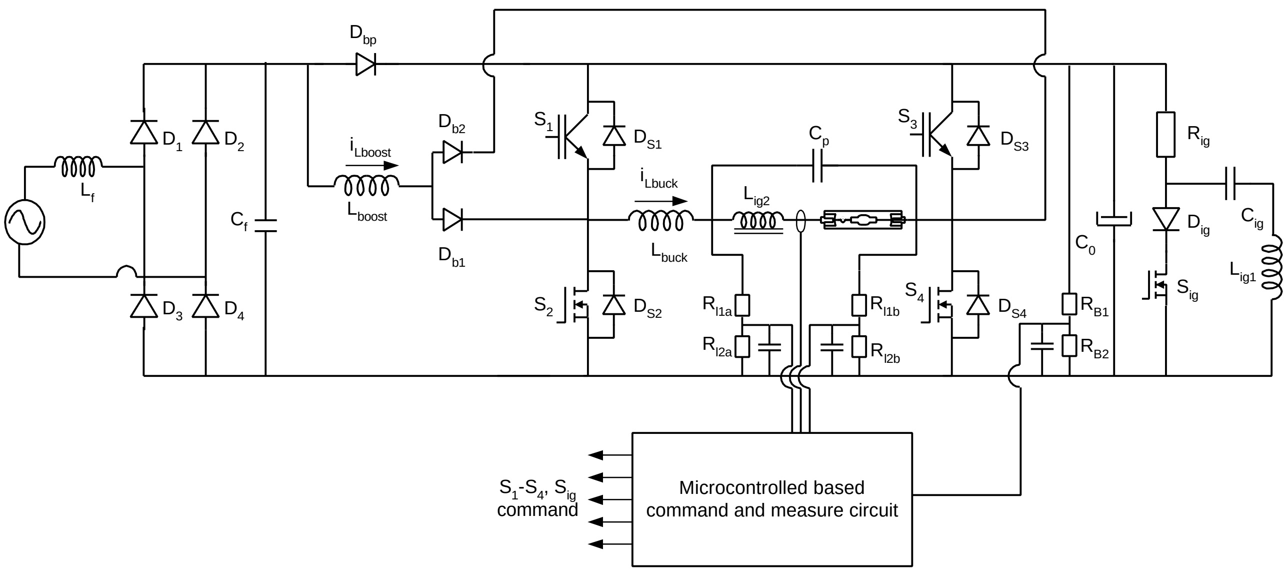

Fig. 1– The proposed electronic ballast circuit

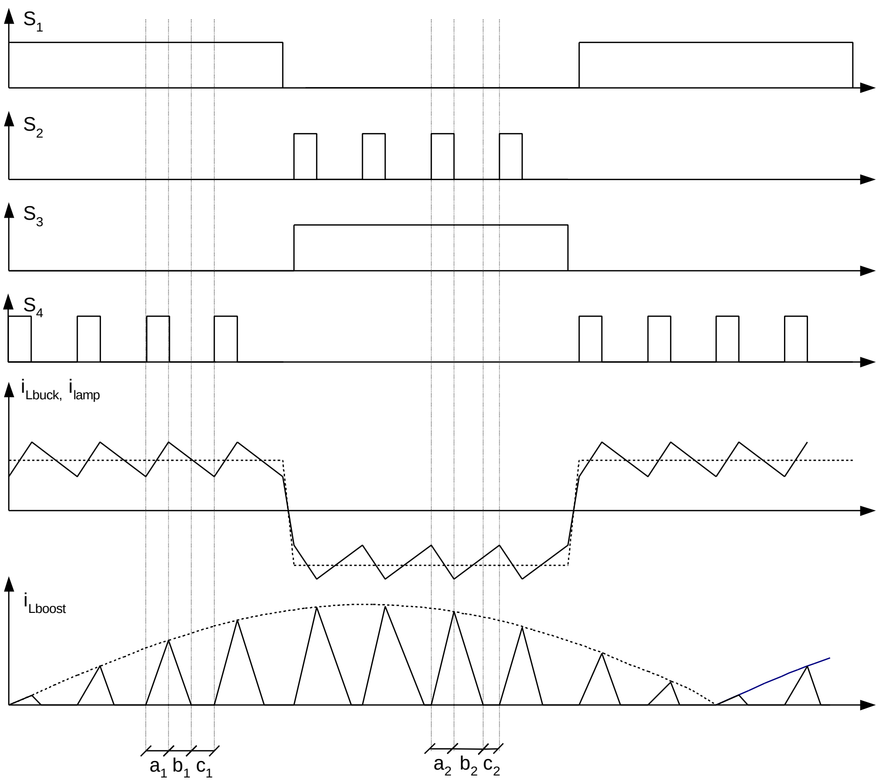

Fig. 2 – The main waveforms of the proposed electronic ballast.

These stages repeat until the switches S_1 and S_4 are turned off. After the dead time, S_2 and S_3 switches start to operate and the lamp current inverts resulting in the a2, b2 and c2 stages, which are similar to a1, b1 and c1.

III. THE CONTROL SYSTEM

A dedicated device performs the control signals of all structure (using high performance RISC CPU microcontroller PIC16F873, from Microchip).

The control tasks of this device will be described below:

Ignition sequence: The ignition pulses occur only if the lamp is off, regarding to a sequence of short time interval ignition trial (less than 0.5 second) followed by a long time of interrupted interval (up to 10 seconds). During the trial interval the lower switches of the bridge work with a limited maximum duty cycle and the igniter switch is maintained on after the ignition pulse. These facts help to maintain the DC bus voltage in accepted level if the lamp do not star-up, due to the power consumption on R_{ig}. During the interrupted interval the duty cycle of S_2 and S_4 switches is forced to be zero to stop Co charge.

Lamp current and DC bus voltage control: The Fig. 3 shows the block diagram of this control. After the start-up and during the warm-up phase the lamp current is kept constant at a pre-established value through a digital PI control acting over the duty cycle of S_2 and S_4 switches.

When the lamp reaches the nominal power the reference current is constantly calculated taking in account the lamp voltage to ensure the fixed rated power. To avoid over current and unstable function during the operation the PI controller gain is changed in a schedule way.

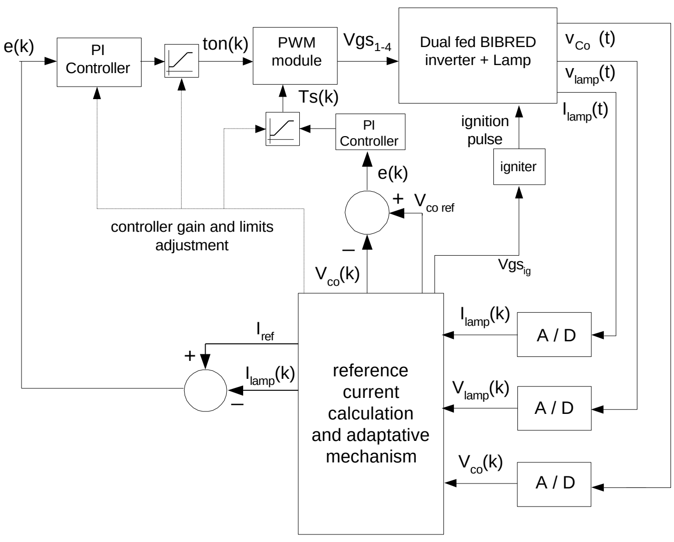

Fig. 3 – Block diagram of control.

A digital PI control, acting over the switching frequency maintains the DC bus voltage constant independent of lamp voltage or utility line voltage variations. This controlled voltage assures the discontinuous conduction mode in L_{boost}, providing high power factor.

IV. DESIGN EQUATIONS

DC bus voltage definition

The full bridge BIBRED converter integrates a buck and a boost converter. So, the buck relation gives the duty cycle of PWM switches:

$$D = \frac{V_{Lamp}}{V_{C0}} \tag{1}$$

In addiction, to ensure the discontinuous conduction mode of the boost part, the duty cycle must to be:

$$D < \frac{V_{C0} \quad V_{AC\max}}{V_{C0}} \tag{2}$$

The DC bus voltage expression can be obtained substituting equation (1) into (2).

$$V_{C0} > V_{lamp} + V_{AC\max} \tag{3}$$

The boost inductance

The boost inductance can be obtained from equations (4), (5) and (6) below, as described in [8]. Using the equations (1), (4), (5) and (6) the boost inductance can be re-written as equation (7).

$$M = \frac{V_{C0}}{V_{AC\max}} \tag{4}$$

$$L_{par} = \frac{0,48}{M \quad 0,92} \tag{5}$$

$$L_{boost} = \frac{V_{C0}^{\;2} \quad D^2 \quad T_s \quad L_{par}}{2 \quad M \quad P_{lamp}} \tag{6}$$

$$L_{boost} = \frac{V_{lamp}^{\;2} \quad 0,48}{2 \quad f_s \quad \frac{V_{C0}}{V_{AC\max}} \quad P_{lamp} \quad \frac{V_{C0}}{V_{AC\max}} \quad 0,92 \div} \tag{7}$$

The buck inductance

The buck inductance is designed by using the equation (8) below, where *DI%* is the perceptual ripple current in this inductor, which can be defined around to 50%.

$$L_{buck} = \frac{V_{C0} \quad D \quad (1 \quad D)}{f_s \quad I\% \quad P_{lamp}/V_{lamp}} \qquad (8)$$

V. EXPERIMENTAL RESULTS

A laboratory prototype has been implemented, and some results will be showed below. The electronic ballast specifications are:

- RMS AC mains voltage: 220V, 60Hz;
- DC bus voltage: 430V;
- Output power: 70W (high pressure sodium lamp)
- Inverter switching frequency: 150Hz;
- PWM rated switching frequency: 40kHz.

The main results are shown below. The Fig. 4 shows the gate commands of S1-S4 switches.

The Fig. 5 shows the input voltage and current can be seen, which present THD = 25% and power factor of 0,97.

The Fig. 6 shows the output results of the proposed electronic ballast. The square wave lamp voltage and lamp current are shown, that ensure the lamp operates free from acoustic resonance.

The Fig. 7 shows the changes on the switch frequency to maintain the DC bus voltage constant. The frequency was limited between 35kHz to 60kHz.

The Fig. 8 shows the lamp current and lamp power behavior during warm-up phase and for lamp voltage changes. This result was obtained involving the lamp with an aluminum paper to force its temperature and voltage to rise like during the lamp lifetime.

Since the lamp current decreases when the voltage to rises like during the lamp lifetime, the prototype efficiency varies from 85 to 88% for lamp voltage changes between 80 to 110V.

The Fig.9 shows the Ballast efficiency curve.

VI. CONCLUSION

A single power processing stage electronic ballast for HID lamp was implemented, with high input power factor. The low frequency square wave current assures the operation free of acoustic resonance and stroboscope effect. The lamp current and the DC link voltage are controlled by a dedicate microcontroller. Besides that, the use of a microcontroller becomes simple the circuitry and the control task, allowing to compensate the increase of the voltage lamp during lamp lifetime and the utility line variation. The single stage demand less components, that reduces the overall cost and increases the electronic system reliability and efficiency.

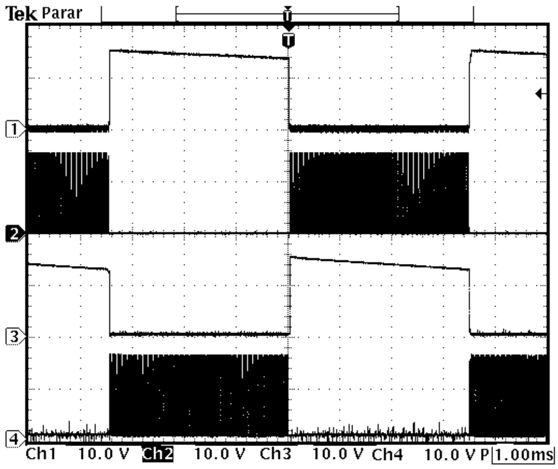

Fig.4 - Gate commands (10V/div, 1ms/div)

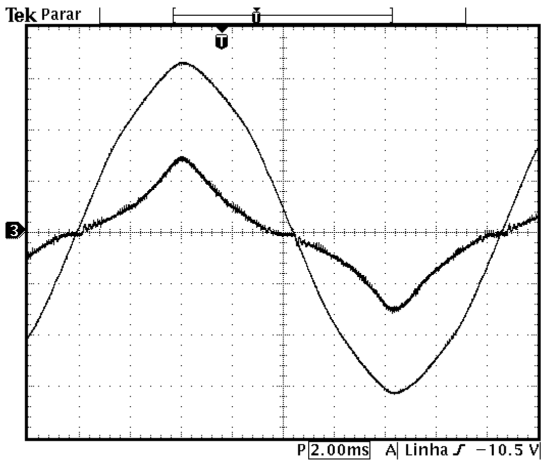

Fig. 5 – Input voltage (100V/div) and current (0,5A/div); time scale: 2.0ms/div.

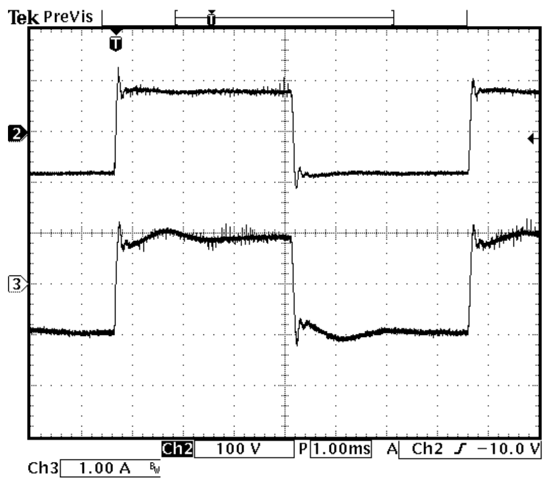

Fig. 6 – Lamp voltage (top trace – 50V/div) and lamp current (bottom trace – 1A/div); time scale: 1ms/div.

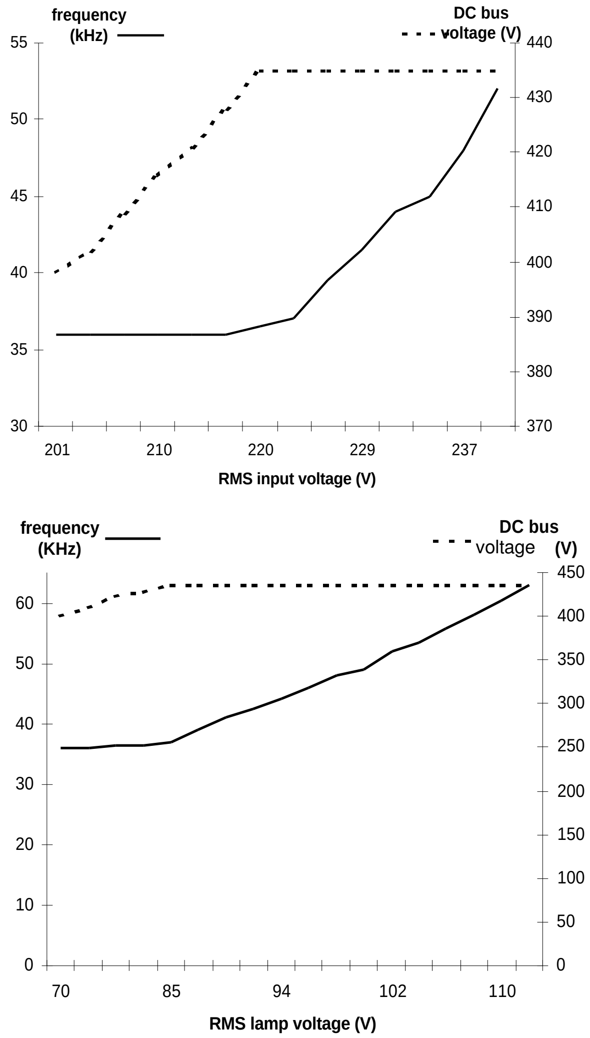

Fig. 7 – Switch frequency changes for DC voltage control. Up: input voltage variation. Down: lamp voltage variation

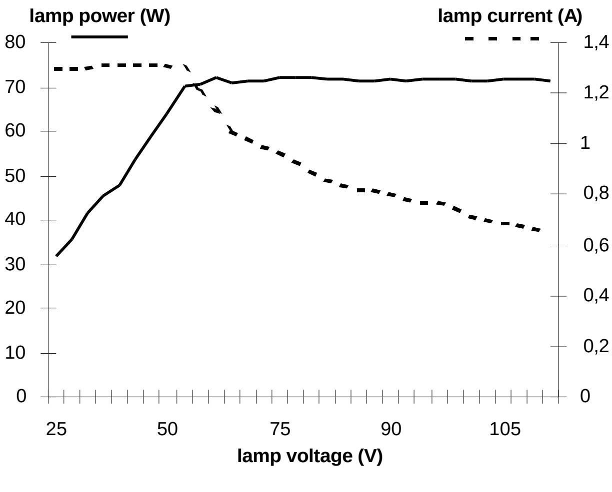

Fig. 8 – Lamp power and lamp current for lamp voltage variation.

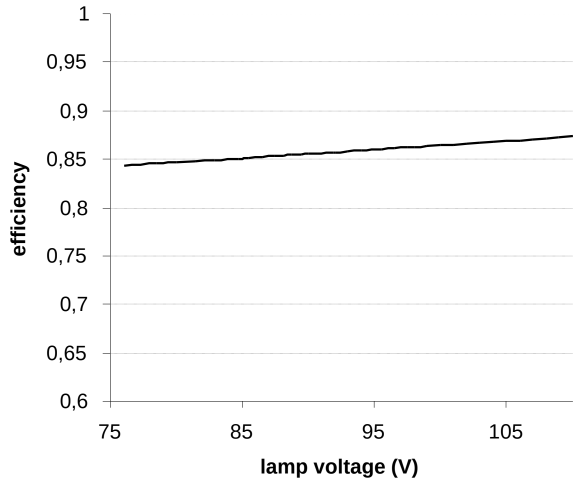

Fig.9 - Ballast efficiency curve

REFERENCES

[1] Richard Redl and Jon D. P, "A New High Frequency and High-Efficiency Electronic Ballast for HID Lamps: Topology, Analysis, Design, and Experimental Results", in Applied Power Electronics Conference – APEC, 1999.

[2] Wei Yan, Y. K. E. Ho, S. Y. R. Hui, "Investigation on Methods of Eliminating Acoustic Ressonance in Small Wattage High Intensity Discharge (HID) Lamps" in Proc. IEEE Industry Application Society Annual Meeting – IAS, 2000.

[3] H. Nishimura, H. Nagase, K. Uchihashi, T. Shiomi and M. Fukuhara, "A New Electronic Ballast for HID Lamps", Journal of the Illuminating Engineering Society, Summer 1988, pp.70-76.

[4] Tokushi Yamauchi and Tsutomu Shiomi, " A Novel Charge Pump Power Factor Correction Electronic Ballast For High Intensity Discharge Lamps" in Proc. IEEE Power Electronics Specialists Conference 1998, pp. 1761-1767.

[5] Márcio A. Có, Cássius Z. Resende, Domingos S.L. Simonetti and José L. F. Vieira, "Microcontrolled Electronic Gear For Low Wattage Metal Halide (Mh) And High-Pressure Sodium (Hps) Lamps" in Proc. IEEE Industry Application Society Annual Meeting – IAS, 2002.

[6] Miaosen Shen, and Zhaoming Quian, and Fang Z. Peng, "A Novel Two-Stage Acoustic Resonance Free Electronic Ballast For HID Lamps", in Proc. IEEE Industry Application Society Annual Meeting – IAS, 2002.

[7] M. A.Johnston and R.W.Erickson, "Reduction Of Voltage Stress In The Full Bridge BIBRED By Duty Ratio And Phase Shift Control", in Proc. IEEE, 1994.

[8] Simonetti, D. S. L.; Vieira, J. L.; Sousa, "G. Modeling of the high-power-factor discontinuous boost rectifiers". IEEE Transaction on Industrial Applications, Vol. 46, No.4 , p.788-795, August 1999.