LOW FREQUENCY HIGH POWER FACTOR ELECTRONIC BALLAST TO SUPPLY HPS LAMPS

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Abstract – **This paper presents a high power factor electronic ballast for High Pressure Sodium Lamps (HPS). The ballast consists of a Double-Flyback and a Half-Bridge inverter. The Double-Flyback is responsible for PFC and lamp current limiting, through the use of a single switch. The inverter stage supplies the lamp in a low frequency square waveform avoiding the acoustic resonance phenomenon occurrence. Ballast project and experimental results are presented in order to verify the feasibility of the proposed topology.**

Keywords – **Acoustic Resonance Phenomenon, High Intensity Discharge Lamps, Electronic Ballasts, Power Factor Correction, Public Lighting**

I. INTRODUCTION

High Pressure Sodium (HPS) Lamps have been used in many applications. The Luminous efficacy and the typical colour characteristics make these lamps very suitable for applications where energy saving plays a more important role than requirements for colour rendering [1].

In recent years, many electronic ballasts have been developed to supply HPS lamps. The performance of discharge lamps is improved when they are supplied by electronic instead of electromagnetic systems, due to their merits of: high efficiency, low audible noise, longer useful life lamp, small size and flicker absence [2].

However, when electronic ballasts operate HPS lamps in high frequency one important phenomenon has to be considered. It is called acoustic resonance.

A. Acoustic Resonance Phenomenon

High Intensity Discharge (HID) lamps operating under high frequency current waveforms are hampered by standing pressure waves. What happens is that when the frequency imposed to the lamp is increased and an egeinfrequency is approached, pressure waves become propagational perturbing the discharge path [1].

The damping term of acoustic resonance phenomenon is directly linked with the gas pressure inside the discharge tube. Higher the pressure, lower the damping coefficient resulting in a difference of the resonance modes.

Furthermore, acoustic resonance regions change according to some lamp characteristics: lamp wattage, arc tube geometry, internal fill pressure, arc tube salts composition and lamp burning time [3]. So, driving HID lamps in a high frequency and trying to predict acoustic resonance free bands during the entire lamp life is a very hard assignment.

Changes in arc position and light color, unstable arcs, and in the worst case, leads arcs to extinguish or crash the discharge tube are some results of the acoustic resonance occurrence [4].

In this way, supply HID lamps without acoustic resonance phenomenon occurrence in a simple, robustness and efficiency way is the goal of the researchers in this area.

Drive the lamp in a low frequency square waveform using electronic ballasts is a good option to avoid acoustic resonance phenomenon occurrence and lamp re-ignition [5].

B. Proposed Electronic Ballast Overview

The typical circuit diagram of a conventional electronic ballast to supply the lamp in a low frequency square waveform is shown in Figure 1.

The circuit consists of a PFC stage, a DC/DC converter and a low frequency square wave inverter. The PFC stage is generally required for switching mode power supply to comply with the regulations, such as IEC 61000-3-2. Due to the negative incremental impedance of the HPS lamp, a DC/DC converter has to be employed working as a controlled current source. An inverter stage is used to supply the lamp with AC current [5].

Despite the advantages of electronic ballasts to supply HPS lamps in a low frequency square waveform, the number of stages needed increases the cost and the complexity of conventional electronic systems.

This work is based on a Double-Flyback Half-Bridge topology operating in a high frequency and supplying the lamp in a low frequency (150Hz) square waveform. The proposed electronic ballast presents a reduced number of active switches composing the PFC and Power control Stage.

The proposed topology attends the HPS supply requirements as is described in this paper. The proposed circuit is shown in Figure 2.

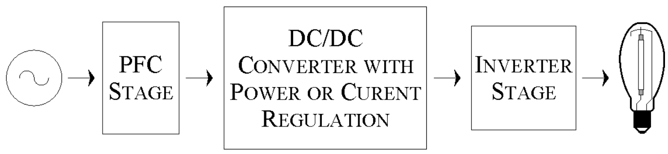

Fig. 1. Circuit diagram of conventional low frequency square wave electronic ballast

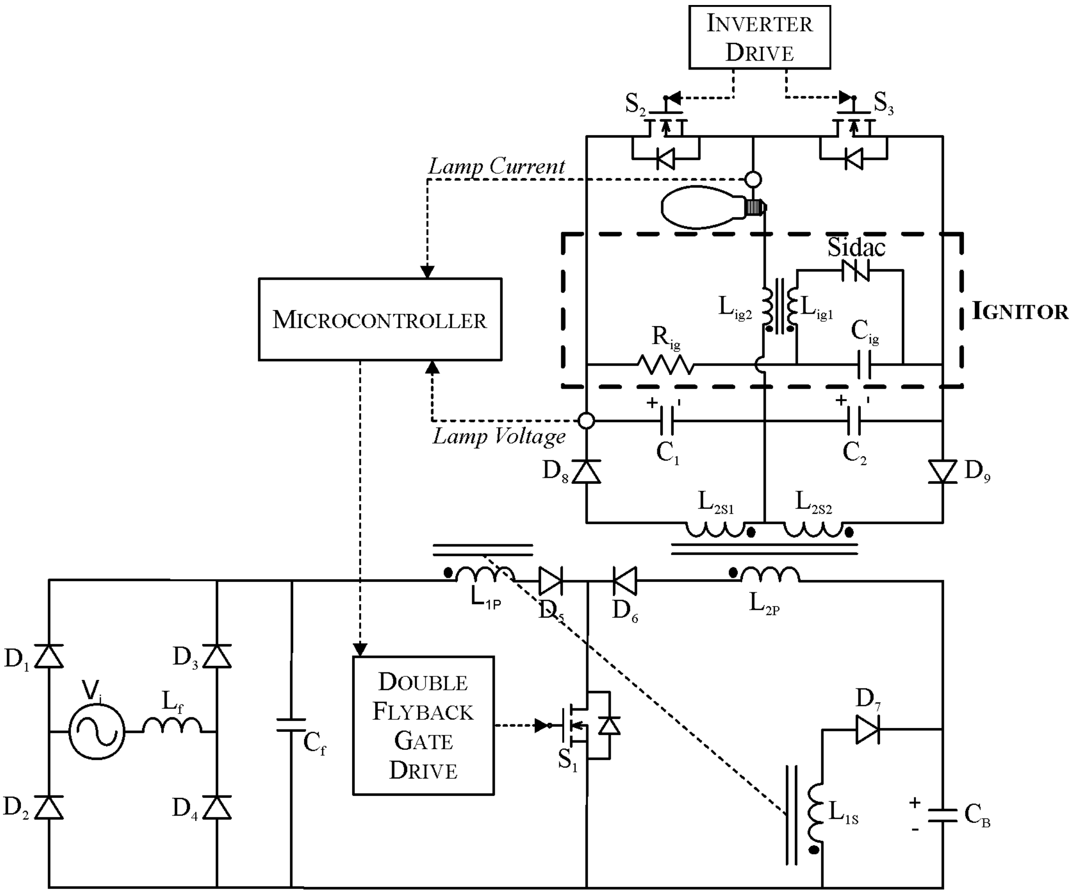

Fig. 2. Proposed Electronic Ballast

II. DOUBLE-FLYBACK HALF-BRIDGE ELECTRONIC BALLAST

The system is formed by Two Flyback converters sharing the same active switch, a low frequency Half-Bridge Inverter, a LC input filter (L_f, C_f) and an ignitor (R_{ig}, C_{ig}, Sidac, L_{ig1}, L_{ig2}).

The LC input filter is responsible for filtering high current component from converter side.

The ignitor circuit must provide a high voltage pulse to the lamp in order to begin the ignition process.

Flyback converter is employed as a power regulation stage, becoming possible the use of a Half-Bridge inverter to supply the lamp.

The operation phases of the proposed electronic ballast are described below:

A. Ignition Process

When the circuit is turned on, the Double-Flyback converter is operated at no load. Consequently, the voltage across capacitors C_1 and C_2 increases until reaching the igniter breakdown voltage (Sidac's voltage).

At this moment, the lamp is turned on with a 2-4kV voltage pulse for tens of microseconds.

The converter drives the lamp at a low frequency square waveform. However, during the warm up phase of the lamp the output voltage can be below 20V for a few seconds and the control have to guarantee the DCM operation of the Double-Flyback converter [6]. This is done by maintaining a fixed duty cycle until the capacitor C_2 voltage (lamp voltage) reaches 50V.After that, until to reach the 70W nominal lamp power, the control is done through the duty cycle variation.

The lamp is supplied with a highest power during the warm up phase in order to decrease the necessary time to reach the lamp nominal power [7].

B. Steady State

After the ignition process takes place, the Double-Flyback Half-Bridge converter supplies the lamp. C_1 and C_2 capacitors voltage do not reach the Sidac's breakdown voltage anymore. The steady state simplified circuit is shown in Figure 3.

The Double-Flyback converter operates at 50 kHz switching frequency and is employed to guarantee a high input power factor and to limit the power delivered to the lamp.

The main switch S_1 is shared between the power factor correction stage and the power control stage. Thus, Power delivered to the lamp is controlled through duty cycle variation of switch S_1 gate drive.

The operation of the Double-Flyback converter in a high frequency allows the reduction of magnetic components size.

As the lamp is supplied in a low frequency, a Half-Bridge inverter is used to supply the load through the alternate commutation of switches S_2 and S_3. Capacitors C_1 and C_2 are DC sources of the 150 Hz inverter.

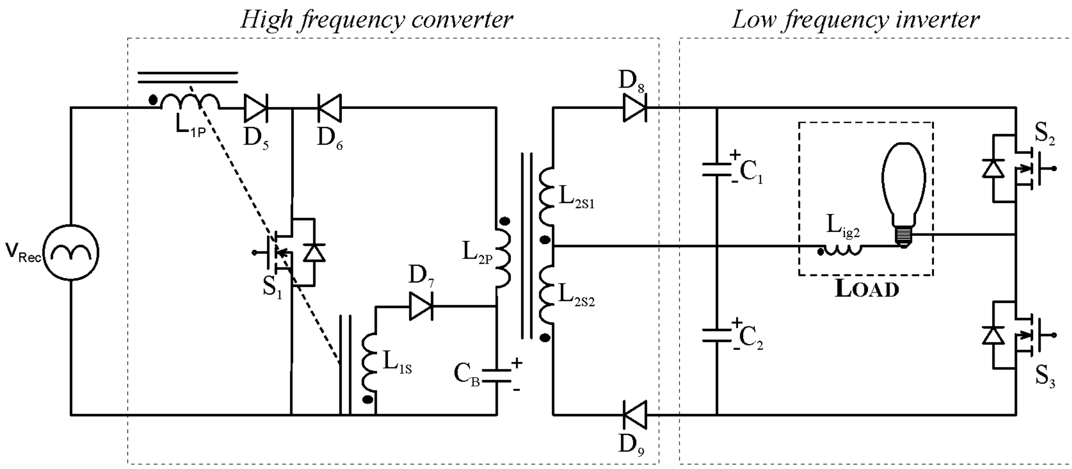

Fig. 3. Ballast power circuit at the steady state operation

The ballast load is a series combination of lamp resistance (72 Ω) and pulse transformer inductance. The reactance of pulse transformer is negligible with respect to lamp resistance in the steady state operational frequency.

C. Overvoltage Protection Method

If the lamp does not ignite or turns off during steady state operation, the voltage across C_2 capacitor rises to an out of project value, and the S_1 driver signal is disabled.

III. ELECTRONIC BALLAST PROJECT

A. Input Filter

It is designed to attenuate the high frequency switching component of the converter side guaranteeing a high input power factor. The capacitor and inductor are calculated below.

$$C_f = \sqrt{\frac{1}{4.\varepsilon^2.\mathrm{Re}q^2.\omega c^2}} \tag{1}$$

$$L_f = \frac{1}{\omega c^2.C_f} \tag{2}$$

Where:

ε - Damping constant
Req - Converter equivalent resistance
ωc - Corner frequency

B. Power Factor Correction Stage

1) Flyback Coupled Inductors

The primary and secondary inductances are defined as:

$$L_p = \frac{V_{in}{}^2.D^2}{4.P_{out}.Fs}.\eta \tag{3}$$

$$L_s = \frac{L_p}{\left(\dfrac{V_{in}.D}{V_{out}(1-D)}\right)^2} \tag{4}$$

Where:

V_{in} - Maximum input voltage
D - Duty cycle
P_{out} - Output Power
Fs - Switching frequency
η - Efficiency
V_{out} - Bus voltage (C_B)

2) RMS Input Current

$$Ief = \frac{\sqrt{\pi}.V_{in}.D^2}{4.L_p.Fs} \tag{5}$$

3) L_{1p} Input Peak Current

$$Ipk = \frac{V_{in}.D}{L_p.Fs} \tag{6}$$

C. Power Control Stage

The main equations are the same of the Power factor correction stage project. The differences are pointed in (7) and (8).

1) Primary Flyback Inductor Inductance

$$L_p = \frac{V_{in}{}^2.D^2}{2.P_{out}.Fs}.\eta \tag{7}$$

2) RMS Primary input Current

$$Ief = Ipk.\sqrt{\frac{D}{3}} \qquad (8)$$

D. Half Bridge Inverter

1) Switch Voltage

$$V_{S2} = V_{S3} = 2.V_L \qquad (9)$$

Where:

V_L - Output capacitor (C_1 or C_2) voltage

2) Switch Current

$$I_{S2} = I_{S3} = \frac{1}{2}.\left(\frac{V_L}{R}\right) \qquad (10)$$

Where:

R - Lamp resistance

IV. EXPERIMENTAL RESULTS

The ballast design specifications are the follows:

- Main Voltage: 220V RMS, 60Hz
- Lamp: 70W OSRAM VIALOX® NAV® E LONGLIFE (Steady state, R = 72Ω)
- Double-Flyback converter frequency: 50kHz
- Half-Bridge Inverter Frequency: 150Hz

In order to prove the feasibility of the proposed topology a prototype was assembled and the experimental results obtained are presented in Figures 4, 5, 6, 7, 8 and 9.

Figure 4 shows the lamp low frequency square voltage and current waveforms.

Figure 5 shows the input voltage and current for the proposed system, which presents a Power Factor = 0.98 and a THD = 5.08%

Figure 6 demonstrates the reduced voltage ripple in capacitor C_B, bringing on a small influence in the luminous flux variation of the HPS lamp.

Voltage and Current in the main switch S_1 and the low frequency current are shown in Figure 7 and 8, respectively.

Current waveform in Figure 7 demonstrates the operation in a discontinuous conduction mode of the Double-Flyback converter.

The envelopment of the Double-Flyback primary currents is shown in Figure 8.

The current in the inductor L_{2P}, due to the Flyback power control side, is presented in Figure 9.

Experimental results were obtained through the scope Tektronix TDS430A and analyzed through Mathcad software.

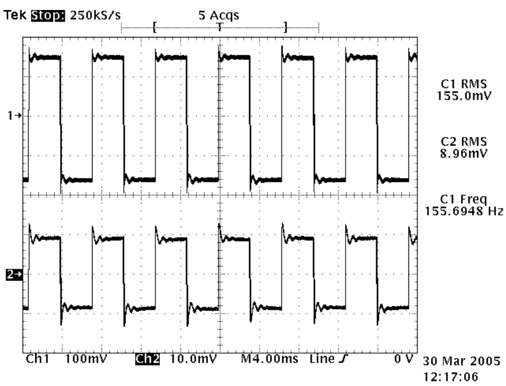

Fig. 4. Lamp voltage (top trace) and lamp Current (bottom trace). (50V/div, 1A/div, 4ms)

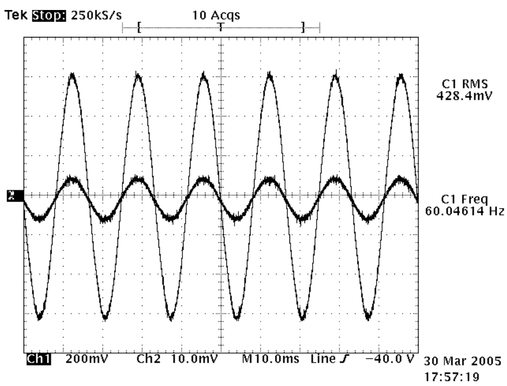

Fig. 5. Input voltage and current. (100V/div, 1A/div, 10ms)

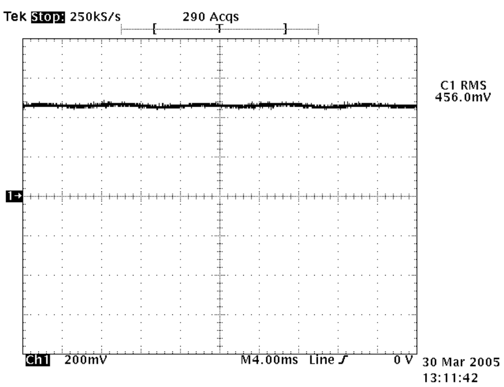

Fig. 6. Voltage in Capacitor C_B. (100V/div, 4ms)

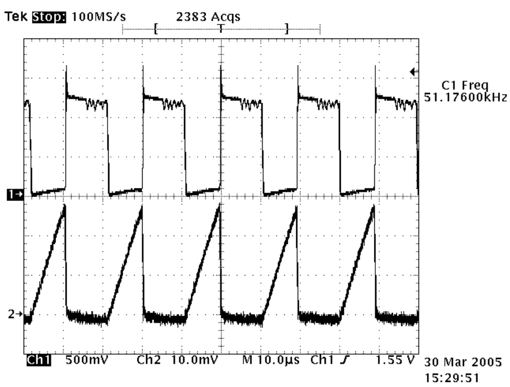

Fig. 7. Swicth voltage (top trace) and current (bottom trace). (250V/div, 2A/div, 10µs)

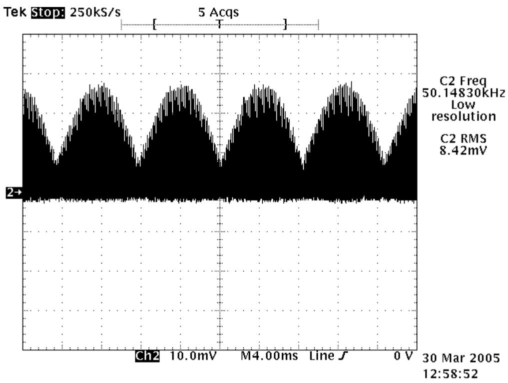

Fig. 8. Switch current (2A/div, 4ms)

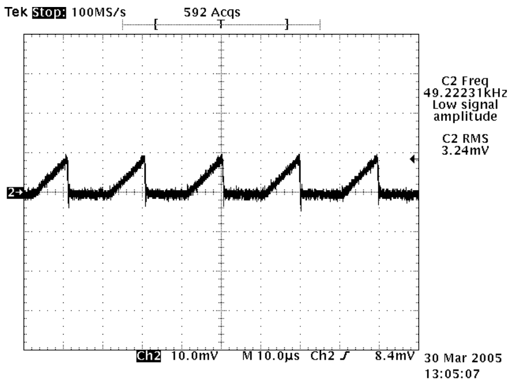

Fig. 9. Flyback primary side current (L_{2P}) of the Power control stage. (2A/div, 10µs)

V. CONCLUSION

This paper presents a high power factor electronic ballast topology to supply HPS lamps employing a single switch for Power factor correction and power control stages. This solution takes the advantage of low cost and simplicity.

Moreover, the use of the Flyback converter in the power control stage becomes possible to employ a half-bridge as the inverter stage. It reduces the number of active switches when compared to full-bridge inverters generally used.

Power switch S_1 shared between the two Flyback converters do not need an insulated gate drive circuit, simplifying the implemented topology. However, its losses are increased due to inherent sharing characteristics.

A laboratory prototype has been built in order to verify the electronic ballast feasibility. Obtained experimental results are in agreement with the proposed idea.

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