AN ELECTRONIC BALLAST EMPLOYING A BOOST HALF-BRIDGE TOPOLOGY

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***Abstract*—This paper presents a new proposal of an electronic ballast employing a Boost half-bridge topology. A Boost converter is used to control input power factor and a half-bridge one is used to drive the fluorescent lamp. Both stages were associated to simplify the design procedure. The proposed converter presents a simple and robust topology.**

KEYWORDS

Ballast, Boost Half-Bridge Converter, High Power Factor.

I. INTRODUCTION

Electronic ballasts have been widely used, gradually replacing the conventional magnetic ballasts due to their attractive characteristics such as high luminous efficiency, reduced size, weight, long lamp life and non-audible noise. Cost is the main disadvantage of electronic ballasts when compared with electromagnetic ballasts, but they have high weight and size due to the operation in low frequencies, implying a low power factor. One alternative to reduce electronic ballasts cost is to decrease the number of components and size of the power stage.

The proposed ballast is obtained as an adaptation from a half-bridge and a Boost converter. The Boost one is used as the input stage for power factor correction, and a resonant half-bridge inverter is used to operate the lamp. The proposed converter consist in a simple and robust topology.

II. PROPOSED CONVERTER

The proposed circuit of the Boost half-bridge ballast is shown in Fig. 1.

- *Input Inductor* L_{boost} – A boost inductor is added to the ballast, and the discontinuous current mode control causes the input current to be nearly sinusoidal;
- *Switch* M_1 – This switch controls the high frequency output and shapes the input current (PFC);
- *Switch* M_2 – This switch only controls the high-frequency output;
- *Energy storage capacitors* C_1 *and* C_2 – Both capacitors deliver energy when the input voltage is low;
- *Fluorescent Lamp* – It is considered as the load of the ballast;
- *Startup capacitor Cp* – It is used to start the lamp;
- *Resonant tank Ls and Cs* – Both Ls and Cs resonate with the lamp, so that a sinusoidal output current can be generated;
- *Input filter* C_f *and* L_f – The input filter blocks the high frequency switching noise from the ballast to the source;
- *Diode bridge* – The diode bridge rectifies the ac input voltage;
- *Diode* D_0 – Diode D_0 blocks the current from the load to the source.

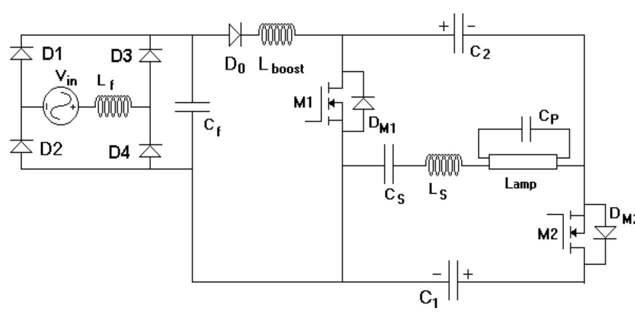


Fig. 1 – Proposed ballast.

III. PRINCIPLE OF OPERATION

The converter operation in steady state is characterized according to five distinct stages. Theoretical waveforms are shown in Fig. 7.

1st Stage [t_o, t_1] – Linear charging of L_{Boost} – This stage begins when switch M_2 is turned off and switch M_1 is turned on in a ZVS way. The input voltage is applied to inductor L_{Boost}. Consequently, current I_{Boost} increases linearly, considering that the voltage remains approximately constant during a switching period. Current in switch M1 is equal to the sum of currents I_{Boost}, and I_L, flowing through diode D_{M1} as seen in Fig. 2.

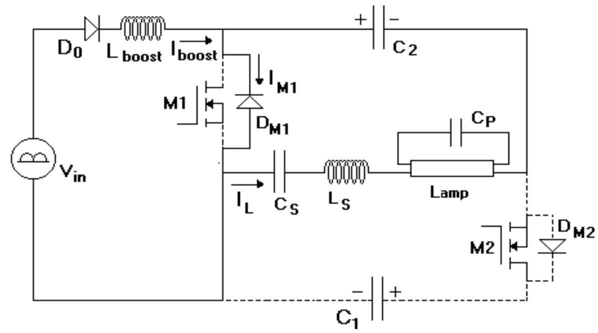


Fig. 2 – First stage.

$2^{\underline{st}}$ Stage [t_1, t_2] – Linear charging of L_{Boost}– This stage begins when part of the current in diode D_{M1} flows through switch M_1. Current I_{Boost} continues to increases linearly. The current in switch M1 is equal to the sum of currents I_{Boost} and I_L , as seen in Fig. 3.

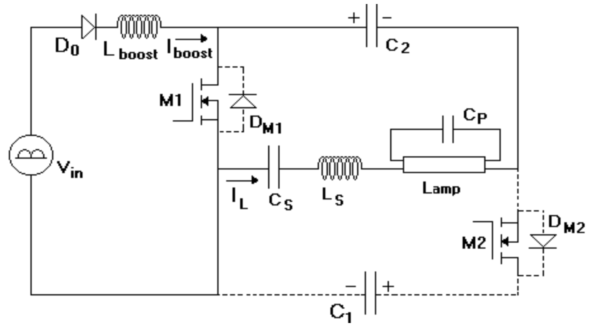


Fig. 3 – Second stage.

$3^{\underline{rd}}$ Stage [t_2, t_3] – This stage begins when switch M_1 is turned off, and consequently current I_{M1} flows through diode D_{M2}, and switch M_2 is turned on in a ZVS way. Current I_{Boost} decreases linearly and charges capacitors C1 and C2. At the instant t_3, current I_{M2} reaches zero, as seen in Fig. 4.

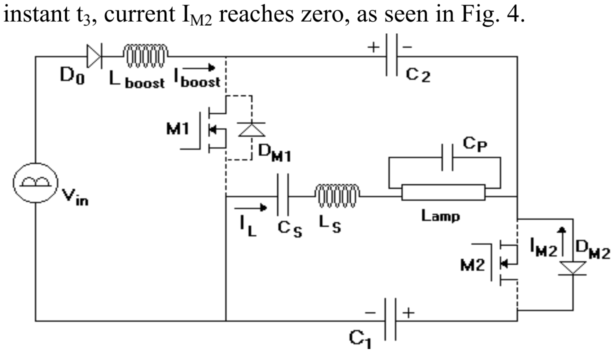


Fig. 4 – Third stage.

$4^{\underline{th}}$ Stage [t_3, t_4] – This stage begins when current I_{M2} reaches zero. During this stage, current I_{M2} flows through switch M_2. Current I_{Boost} decreases linearly until it reaches zero, as seen in Fig. 5.

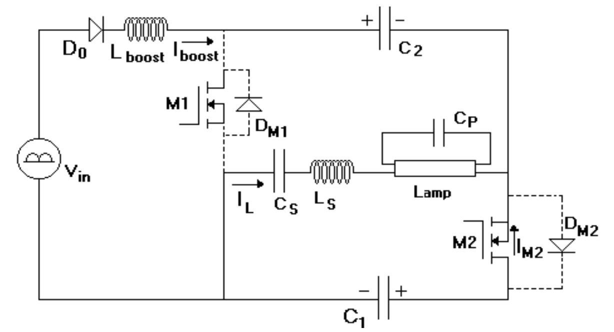


Fig. 5– Fourth stage.

$5^{\underline{th}}$ Stage [t_4, t_5] – This stage begins when current I_{Boost} reaches zero. Current I_L flows through switch M_2, as seen in Fig. 6.

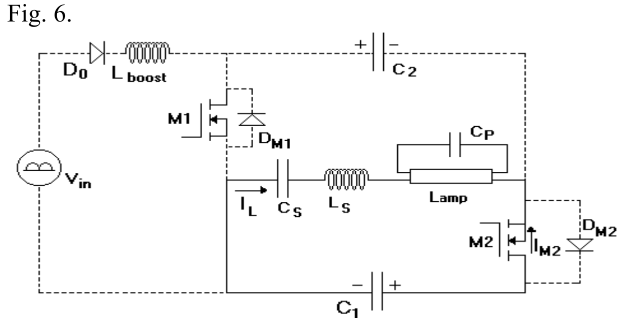


Fig. 6 – Fifth stage.

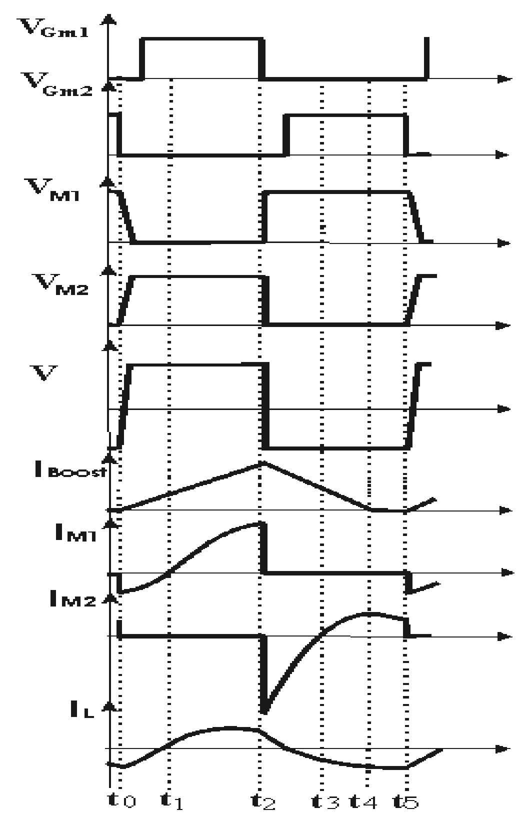


Fig. 7 – Theoretical waveforms.

IV. SELF-OSCILLATING CIRCUIT

IC IR2153 is used to operate switches M1 and M2. It has been chosen due to the low cost and simplicity of implementation. IR2153 usually controls half-bridge topologies, and in this case it is necessary to insert a pulse transformer to isolate one of the switches.

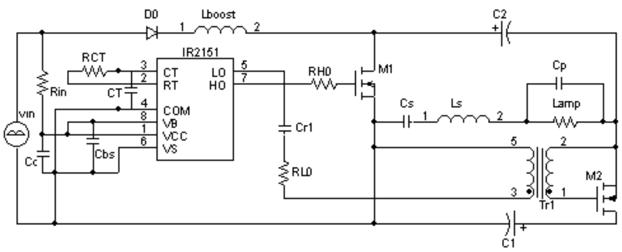


Fig. 8 – Control circuit.

V. DESIGN ASSUMPTIONS

A. Boost Converter Design

Inductance L_{Boost} is given by (1), where V_{ac_p} is the input peak voltage, f_S is the switching frequency, P_{in} is the input power and D is the duty cycle.

$$L_{Boost} = \frac{D^2 \cdot V_{ac_p}{}^2}{2 \cdot f_S \cdot P_{in}} \qquad (1)$$

In order to assure the discontinuity of the current in inductor L_{Boost}, the output voltage must be greater than the peak input voltage, where the output voltage is the sum of the voltages on capacitors C_1 and C_2.

This condition is obtained when the series-parallel resonant filter is designed so that the lamp provides its rated power when the voltage is $V_{ac(peak)}+\Delta V$.

As the voltages on the capacitors C_1 and C_2 increase, the output power also does, but the input power remains the same. The system will only achieve the equilibrium condition when the output power equals the input power. Therefore if the output filter is designed in order to provide the rated power when the voltage is equal to $V_{ac(peak)}+\Delta V$, the voltage on the capacitor will be equal to about $V_{ac(peak)}+\Delta V$.

Capacitance C is provided in (2), where f_L is the line frequency, and Vc is the desirable voltage ripple on the capacitor. Capacitor C can represent C_1 or C_2, as both them have the same value.

$$C = \frac{Vc}{4 \cdot \pi \cdot f_L \cdot R_{Lamp} \cdot Vc_{(ripple)}} \qquad (2)$$

B. Series Parallel Resonant Circuit Design

At the lamp startup, a high voltage is necessary in order to ionize the gas that is inside the lamp. Therefore, the resonant circuit is designed so that its natural frequency of oscillation is approximately equal to the commutation frequency, causing high voltages on the lamp. Before the lamp starts, it can be considered as an infinite resistance, and LS, CS and CP constitute the resonant circuit.

When the lamp starts, the resistance is not infinite anymore, and its value is less than the capacitive reactance given by C_p, and LS and Cs will define the new resonant frequency.

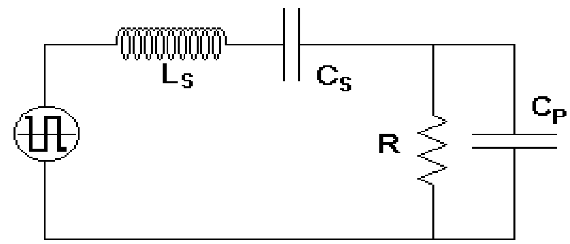


Fig. 9 – Representation of the series-parallel resonant circuit.

Applying the voltage divisor concept in the frequency domain and substituting the voltage gain, *u* can be defined as the ratio between the commutation and resonance frequencies, $u = \omega / \omega_0$, where the resonance frequency is $\omega_o = 1/\sqrt{L_S C_S}$. The ratio Cps=Cp/Cs must be chosen in order to provide Cp lesser than Cs. Voltage V_0 is the voltage on the lamp, and V_i is the voltage on the series-parallel resonant circuit, as the following equation is provided:

$$Qs = \frac{\sqrt{\left(\frac{Vi}{V0}\right)^2 - \left[1 + (Cps)(1-u^2)\right]^2}}{\left(u - \frac{1}{u}\right)} \qquad (3)$$

The proposed ballast was designed to operate with high voltage gain at the startup, being necessary a low quality factor. The choice of a value for *u* is directly associated to the harmonic distortion of the current in the lamp. Equation (3) provides the most adequate quality factor.

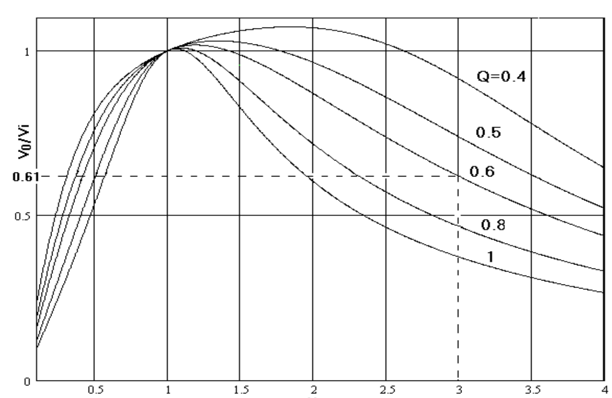


Fig. 10 – Voltage gain versus frequency ratio(ω_S/ω_0) for Cp/Cs=0.094.

Expressions (4), (5) and (6) are used to calculate the parameters of the resonant circuit. It is assumed that $R_{Lamp}=V_0{}^2/P_{out}$, where P_{out} is the power on Lamp.

$$L_S = \frac{QsR_{Lamp}}{\omega_0} \qquad (4)$$

$$C_S = \frac{1}{\omega_0^{\ 2} L_S} \qquad (5)$$

$$C_P = C_{PS} C_S \qquad (6)$$

The following expression provides the absolute value of the series-parallel resonant circuit impedance.

$$|Z_{LCC}| = \sqrt{\left(\frac{R_{Lamp}}{1+\omega_S^{\ 2}\cdot R_{Lamp}^{\ \ 2}\cdot C_p^{\ 2}}\right)^2 + \left(\omega_S\cdot L_S - \frac{1}{\omega_S\cdot C_S} + \frac{\omega_S\cdot R_{Lamp}^{\ \ 2}\cdot C_p}{1+\omega_S^{\ 2}\cdot R_{Lamp}^{\ \ 2}\cdot C_p^{\ 2}}\right)^2} \qquad (7)$$

VI. EXPERIMENTAL RESULTS

The implemented prototype was designed according to the expressions presented previously.

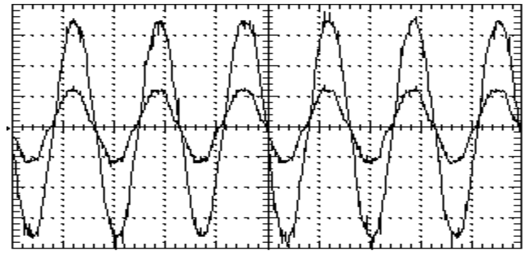
TABLE I
Parameter set

Design Features	
$V_{in(rms)}$ = 127V	P_{LAMP} = 40W
f_L = 60Hz	f_S = 50kHz
V_{C1}=V_{C2} =200V	$V_{(LAMP)}$ = 120V
Qs=0,5	u=3
Ballast Parameters	
Boost	L_{Boost}=1.59mH C_1= C_2=47μF
Series Parallel Resonant Circuit	C_S =100nF Ls=1.54mH C_P=9.4nF
Input Filter	L_F=1.4mH C_F=660nF
Semiconductors	
Switch	IRF840
Diodes	UF4007 1N4007

TABLE II
Results obtained experimentally

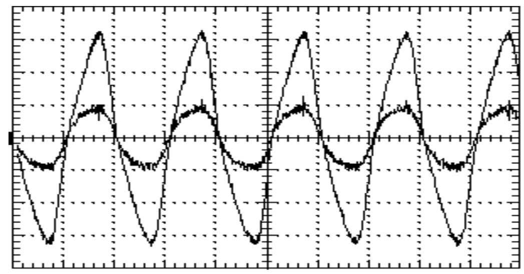
Experimental Results	
Power Factor (PF)	0.974
Total Harmonic Distortion (THD)	10.02%
Pin	39.8W
Pout	37 W
Efficiency (η)	93%
Crest Factor	1.382

Figs. 11 to 18 show some relevant experimental results.



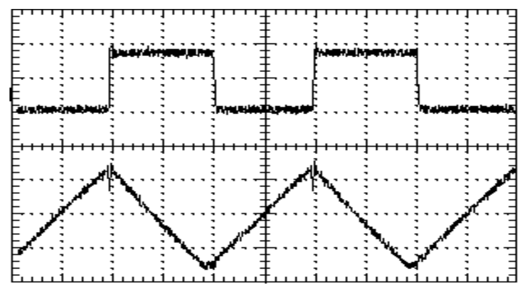
CH1 50V CH2 500mA 5ms

Fig. 11 – Input voltage and current.



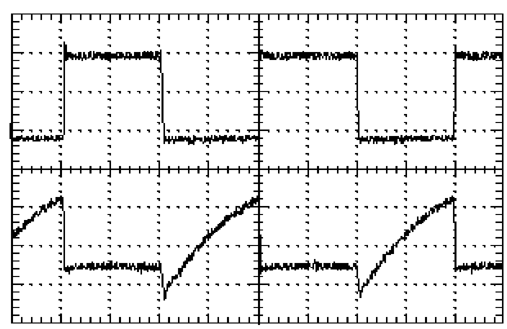
CH1 50V CH2 500mA 10μs

Fig. 12 – Voltage and current in the Lamp.



CH1 200V CH2 500mA 5μs

Fig. 13 – Voltage and current in switch M1



CH1 200V CH2 1A 5μs

Fig. 14 – Voltage and current in switch M1.

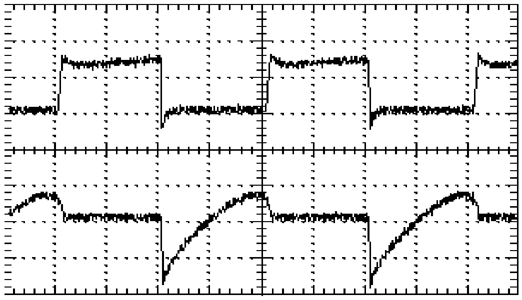


Fig. 15 – Voltage and Current in switch M2.

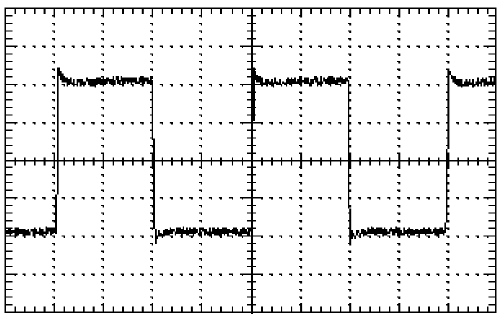


Fig. 16 – Voltage on the series-parallel resonant circuit.

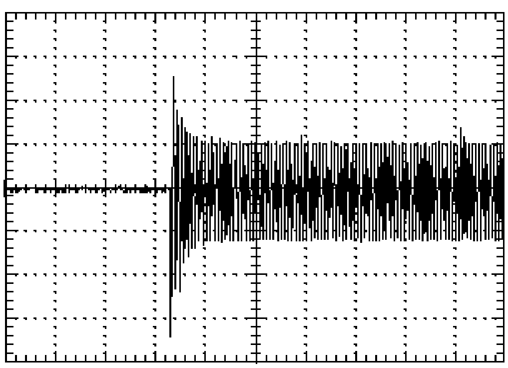


Fig. 17 – Startup pulsing voltage on the lamp.

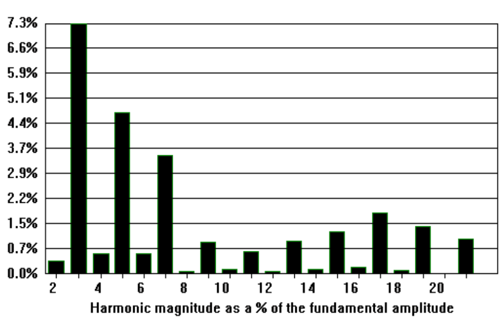


Fig. 18 – Harmonic magnitude as % of the fundamental amplitude

VII. CONCLUSION

This paper presented an electronic ballast with power factor correction in a single stage This converter presents simplicity of control, allowing the use of a reduced number of semiconductors when compared to similar topologies concerning ballasts existent in the literature, for a given input voltage. The proposed converter consists in a simple and robust topology. The operational characteristics of the proposed ballast were validated by performing several experimental results.

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