AN IMPROVED HIGH POWER FACTOR ELECTRONIC BALLAST WITH A SINGLE SWITCH

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***Abstract*— This paper presents a high power factor electronic ballast used in fluorescent lamps with a single power stage and a single-switch. This topology has been obtained by combining the Boost topologies and a new inverter topology with coupled inductors. The use of a single active switch allows a reduction in the number of components used in the control and power circuits. The equations used in the proposed reactor design and also in the choice of the semiconductor devices have been presented. A prototype with switching frequency equal to 50kHz has been built to startup 40W fluorescent lamps.**

KEYWORDS

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

I. INTRODUCTION

Nowadays, electronic ballasts have been widely used, gradually replacing the conventional magnetic ballasts due to their attractive characteristics such as high luminous efficacy, reduced size, weight, long lamp life and non audible noise.

This type of ballast, it can be built with characteristics of high power factor and low current harmonic distortion. Tipically, a high power factor electronic ballast is implemented using two power processing stages. The input stage is called preregulator, as it corrects the power factor and controls the voltage on the load capacitor. The second stage is responsible for the voltage inversion in the series-parallel resonant circuit, and it is called inverter stage.

Thus, in this paper it has been presented a new high power factor electronic ballast, based on a single power stage, which is obtained by the integration the inverter and the preregulator stages. However, this topology present larger current levels in the switches if compared to another similar topologies with two stages.

II. PROPOSED CONVERTER TOPOLOGY

The proposed electronic ballast (Fig. 1) consists in the combination of the Boost converter and a new inverter topology. The Boost stage is formed by diodes D5, D6, inductor L_{Boost}, capacitor $C_{1,}$ C_2 and switch M1.

The capacitor C_2 and the diode D6 are responsible for the active clamping of inductor L2, which has the purpose of minimizing the effects of leakage inductance and also providing a path for the current of the series parallel resonant circuit to flow during a certain time interval after the turned off switch M1.

The active clamping circuit employs capacitor C1, the diode D6 are responsible for the active clamping of inductor L1.

The series-parallel resonant circuit is formed by capacitors Cs and Cp, inductor L_R and the lamp equivalent resistance R_{LAMP}. The input filter is formed by inductor L_F and capacitor C_F.

The steady state operation can be described in three operating stages as follows.

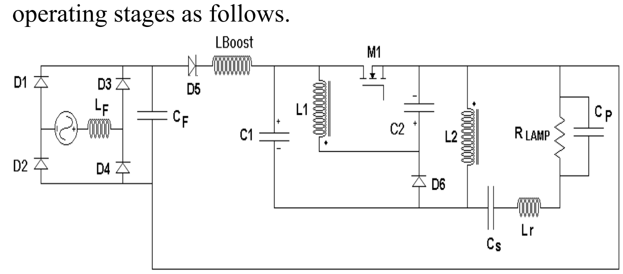


Fig. 1 – Proposed ballast.

III. PRINCIPLE OF OPERATION

The converter operation in steady state is characterized for five different stages. Theoretical waveforms are shown in Fig. 7.

1st Stage [t_0, t_1] – This stage begins with the switch M1 turning on, as the input voltage is applied to inductor L_{Boost}. Once that, the switching frequency is much greater than the line frequency, the voltage is assumed constant during the switching period. Therefore the current i_{Boost} increases linearly. The voltage on capacitor C_1 is then applied to inductor L2, the voltage on capacitor C_2 is applied to inductor L1, as the currents in both inductors are supposed to increase linearly. This fact implies in a current nonlinear variation in inductors L1 and L2, due to magnetic coupling between them., See Fig. 2.

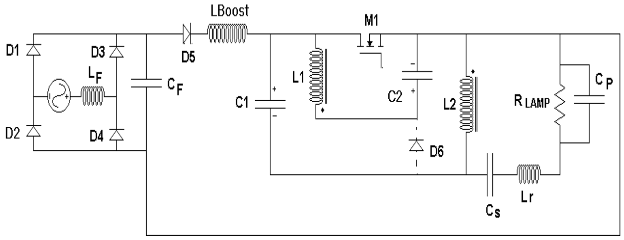


Fig. 2 – First stage operation

2nd Stage [t_1, t_2] – This stage is described by the switch M1 turning off, when the energy transference from inductor L_{Boost} to capacitor C_1 and C_2 and L1 to capacitor C_1 begins. The inductor L2 and the series parallel resonant circuit provide energy to the capacitor C_2 simultaneously. This operating stage finishes when the current L_{Boost} becomes null., See Fig. 3.

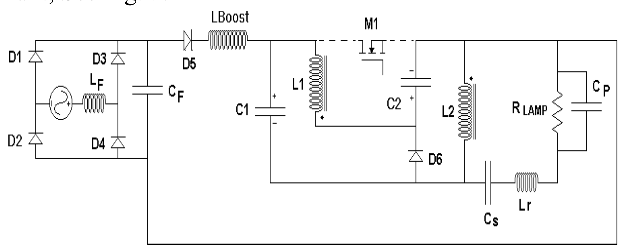


Fig. 3 – Second stage operation

3rd Stage [t_2, t_3] – During this stage the inductor L1 transfer energy to capacitor C_1. The inductor L2 and the series parallel resonant circuit continue to provide energy to the capacitor C_2 simultaneously. It finishes when switch M1 is turned on again, coinciding with the instant in which the current in L1 becomes null., See Fig. 4.

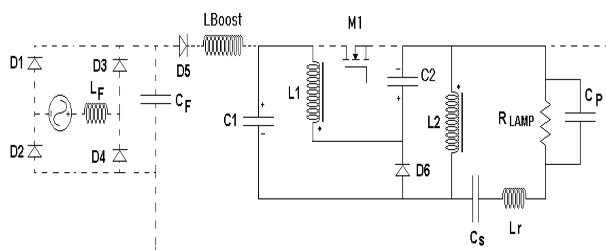


Fig. 4 – Third stage operation

IV. PROJECT CONSIDERATIONS

A. Boost Converter Design

The 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 in the inductor L_{Boost} current, the output voltage must be greater than the input peak voltage, where output voltage is the sum of voltage on capacitors C_1 and C_2.

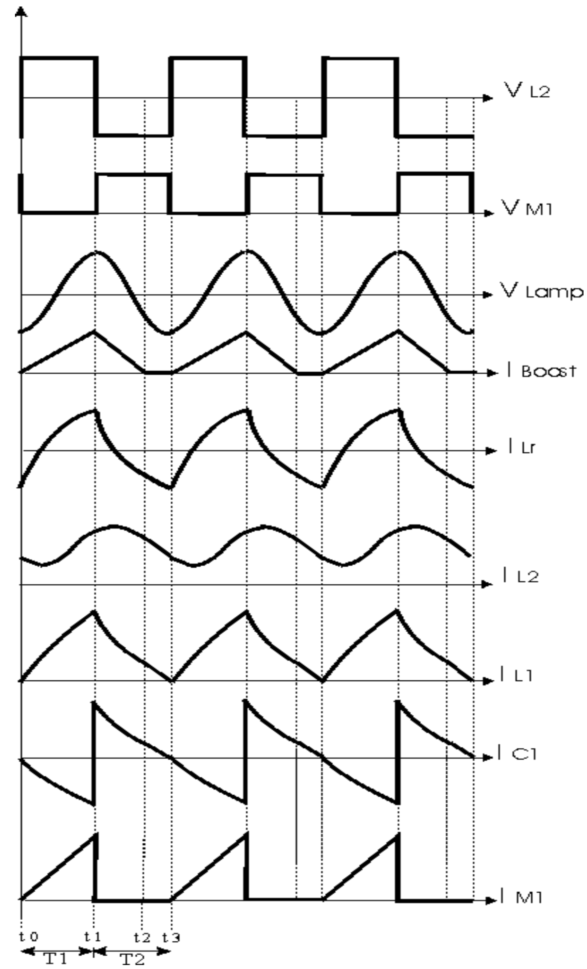


Fig. 5– Theoretical waveforms

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 voltage on the Capacitors C_1 and C_2 increases, 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 $V_{ac(peak)}+\Delta V$.

The 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 represent $C_1$and C_2 they 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.

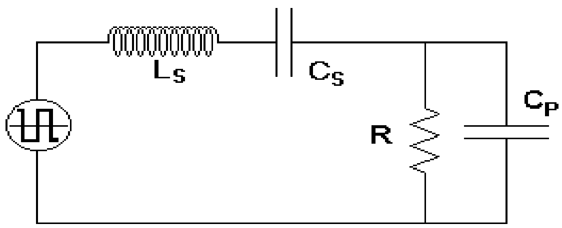


Fig. 6 – Representation of the series-parallel resonant circuit.

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.

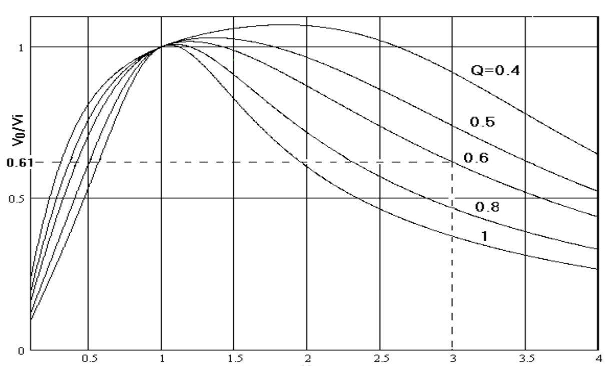


Fig. 7 – Voltage gain versus frequency ratio(ω_S/ω_0) for Cp/Cs=0.094.

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.

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

V. EXPERIMENTAL RESULTS

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

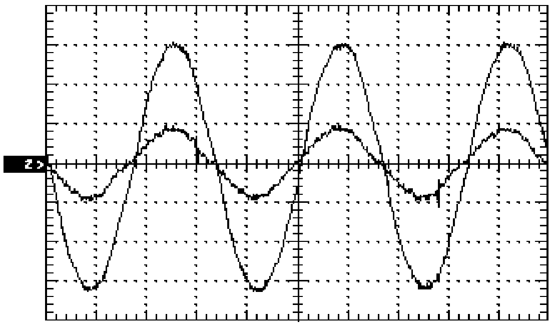
TABLE I
Parameter set

Design Features	
$V_{in(rms)}$ = 110V	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}=1.2mH C_1= C_2=100μF
Series Parallel Resonant Circuit	C_S =100nF Ls=1.54mH C_P=9.4nF
Inverter	L1=1.2mH L1=1.2mH
Input Filter	L_F=1.4mH C_F=660nF
Semiconductors	
Switch	IRF840
Diodes	UF4007 1N4007

TABLE II
Results obtained experimentally

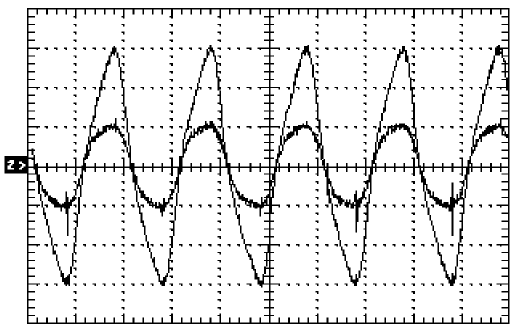
Experimental Results	
Power Factor (PF)	0.992
Total Harmonic Distortion (THD)	8.36%
Pin	39.8W
Pout	32.4 W
Efficiency (η)	94.2%
Crest Factor	1.6

Figs. 11 to 18 show some relevant experimental results.



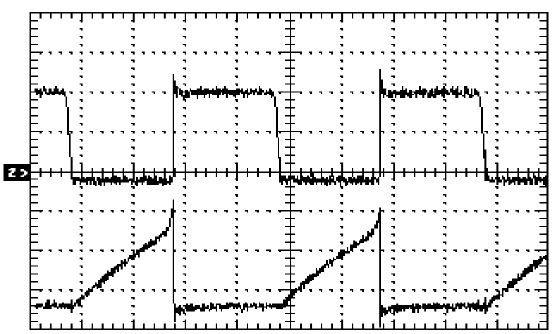
CH1 50V CH2 500mA 5ms

Fig. 8 - Input voltage and current.



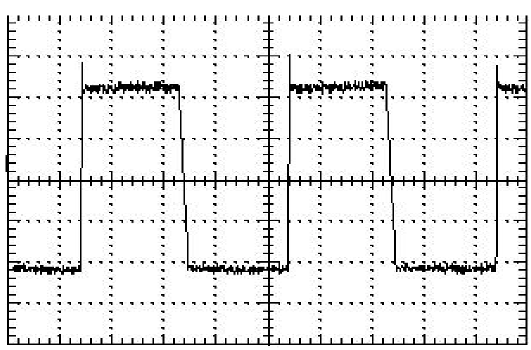
CH1 50V CH2 500mA 10μs

Fig. 9 Voltage on the lamp and current in the series parallel circuit.



CH1 200V CH2 2A 5μs

Fig. 10 .Voltage and current in switch M1.



CH1 200V 5μs

Fig. 11 – Voltage on inductor L2.

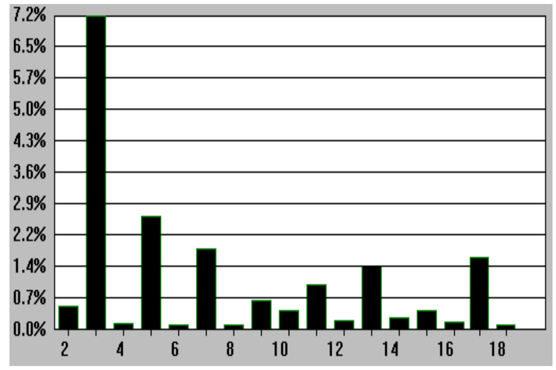


Fig. 12 - Harmonic magnitude as a % of the fundamental amplitude

VI. 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 small switches when compared another topologies of ballasts presented in literature, considering the same input voltage. The Proposed converter presented a simple and robust topology. The operations characteristics of the proposed ballast were verified through experimental results.

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