CURRENT INVERTER STUDY FOR ELECTRONIC BALLAST APPLICATIONS DESIGNED FOR AUTOMOTIVE HID LAMP

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Abstract - This paper presents the study of a current inverter applied in an electronic ballast for high pressure discharge (HID) lamp. Normally the structure used to drive HID lamps is composed by a regulated dc/dc converter followed by an unregulated dc/ac inverter [1]. The current inverter is supposed to be a low cost solution since the component count can be lowered, improving the reliability and efficiency. Theoretical analysis is presented together with simulations and experimental results for the proposed solution. Some problems and limitations are related and comented.

KEYWORDS

Current Inverter, Xenon lamp, HID ballast.

I. INTRODUCTION

The electronic ballast area is consolidated in power electronics. Therefore, the researches in HID lamp ballast for automotive applications are still a challenge and many innovations are about to come. The Xenon lamp is a type of metal halide lamp used in cars headlight where the Xenon gas is introduced to facilitate the ignition process[2]. Actually, these lamps are used only in high end cars, but with good colors properties, high efficiency and long life are becoming a general solution for automotive lighting. The HID lamps have a different dynamic behavior which turns the ballast design more complex. Some problems arise when driving metal halide lamps, like cataphoresis and acoustic resonance [3-5]. The cataphoresis is a not equality electrode consummation when using direct current. The acoustic resonance is an instability in the arc when some particular acoustic frequencies of the discharge tube are encountered. The two stage approach avoids acoustic resonance and cataphoresis driving the lamp with a symmetrical voltage of low frequency. The main objective of this work is design a ballast using a single stage topology, increasing the efficiency and also avoiding acoustic resonance and cataphoresis. The topology must boost the battery voltage to the level necessary for lamp operation and impose a symmetrical and low frequency current waveform.

II. TOPOLOGY

The current inverter is a well-known structure [6-7] apparently never employed in this kind of application [1],[8],[9]. Fig. 1 shows the current inverter topology and it may be observed it has four switches and four diodes.

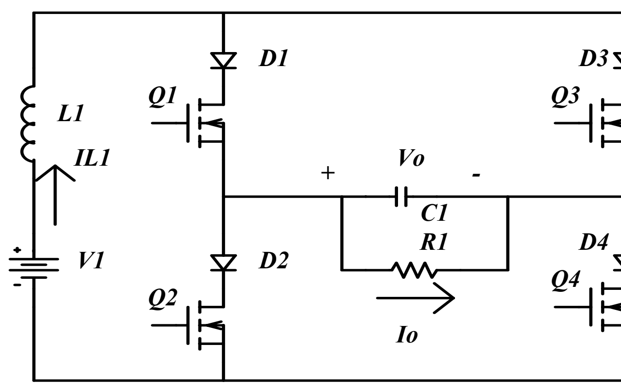

Fig. 1 – Current inverter.

The diodes in series with each Mosfet are necessary to block the reverse voltage that appears over them during the circuit operation. This is a great drawback since the number of semiconductors is directly proportional to losses and cost.

III. ANALYSIS

The modulation used in this paper is the complementary one. The switches Q_1 and Q_4 receive the conduction order together while Q_2 and Q_3 receive the turn off signal. The duty cycle (D) is defined by (1) being the ratio of conduction time of switches Q_2 and Q_3 by the switching period (T_S). The ideal voltage gain of the structure is given by (2). Considering the non-idealities of each switch, the real voltage gain can be calculated by (3), where R_S is the diode series resistor from its model and $R_{DS_{ON}}$ is the mosfet conduction resistance. Fig. 2 shows the equivalent circuit during each operation mode.

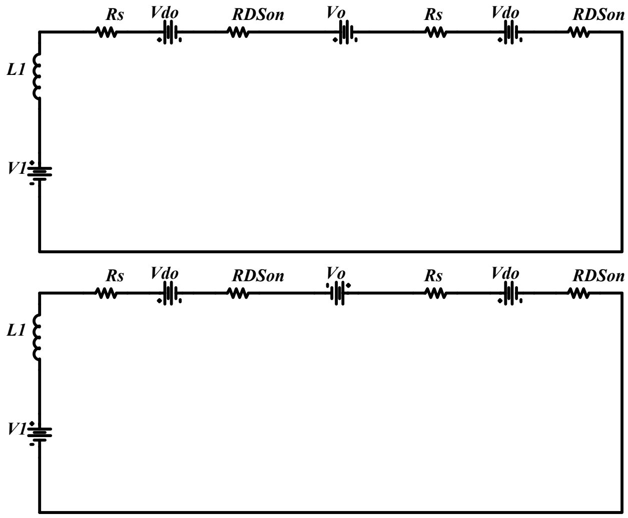

Fig. 2 – Operations modes for the converter.

$$D = \frac{t_{cond}(Q_2, Q_3)}{T_s} \tag{1}$$

$$q = \frac{V_o}{V_1} = \frac{1}{1-2D} \tag{2}$$

$$q = \frac{V_o}{V_1} = \frac{(1-2D)R_1}{2(R_S + R_{DS_{ON}}) + R_1(1-2D)^2 + 0.5} \tag{3}$$

Fig. 3 shows the variation of the voltage gain for several values of switch's resistances.

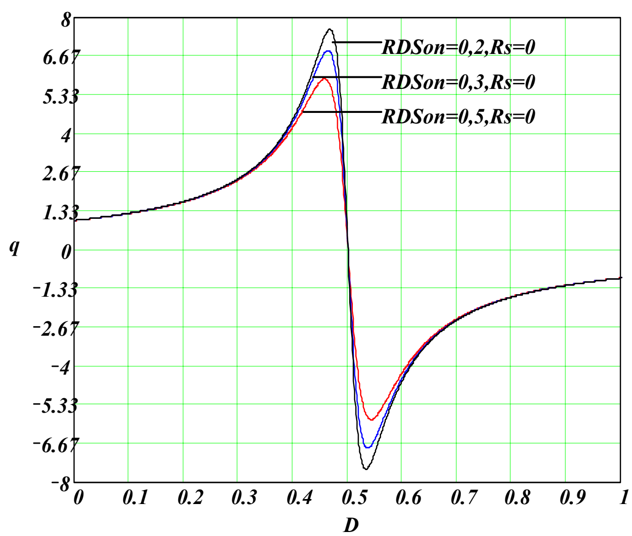

Fig. 3 – Gain considering real components.

Fig. 4 shows the converter characteristic considering the ideal voltage gain, showing the continuous conduction region, discontinuous conduction region and the limit between them.

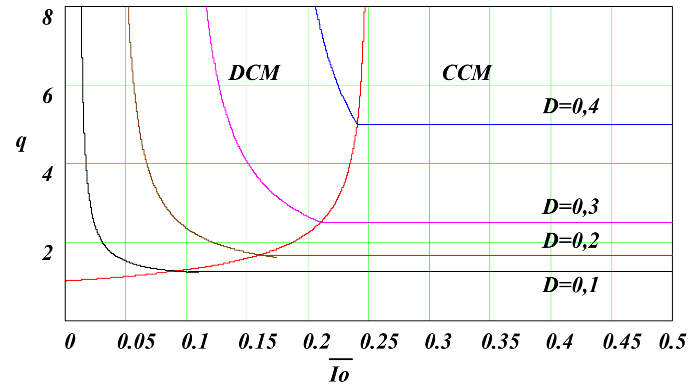

Fig 4 – Characteristic of the converter.

The passives components of the converter can be determined using (4) and (5).

$$L_1 = \frac{(V_1 + V_O)D}{\Delta I \cdot f_s} \tag{4}$$

$$C_1 = \frac{(I_{L_1} - I_o)(1-D)}{f_s \Delta V_c} \tag{5}$$

IV. Ignition

The ignition circuit is based on the spark gap component. The topology has a boost characteristic. In discontinuous conduction mode the voltage over capacitor C_1 tends to be very high. When the spark gap breakdown voltage is reached, the necessary high voltage (approximately 20kV) to ionize the lamp appears across the secondary of the pulse elevator transformer (T_p). This boost characteristic is very useful during the ignition process. Fig. 5 shows the circuit with the ignition circuit.

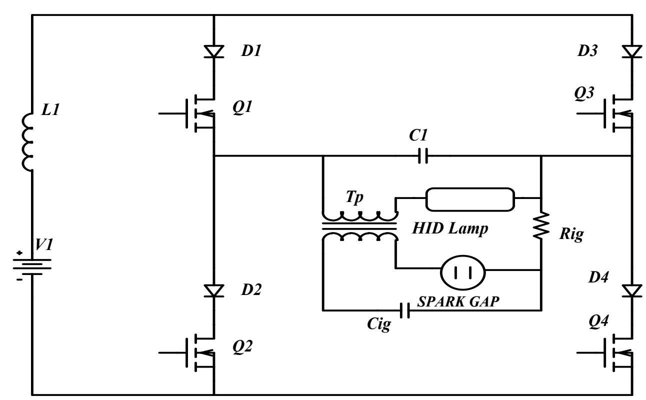

Fig. 5 – Circuit with starter.

After the high voltage pulse is applied over the lamp, a high peak current must flow through the lamp to maintain the discharge path. So, the pulse transformer leakage and magnetizing inductances must be low to provide a low impedance path to that current.

V. SIMULATION RESULTS

The simulations process is a good step to discovery the problems and difficulties before the experimental process. As the mathematical computations described, the problem when there are two switches and two diodes conducting at the same time are confirmed during simulations. Fig. 6 presents the results, inductor current and load voltage, with ideal components. The load voltage is approximately the ideal 85 Volts nominal lamp voltage. Fig. 7 shows the results with real components. The voltage drop in each switch contributes to reduce the load voltage decreasing the efficiency and reducing the voltage gain. The simulated efficiency using non-ideal components is approximately 53%. The slow rate response of this topology maybe observed in Fig. 8. The open loop control is not able to produce a square waveform to load voltage in a 400Hz low frequency. This figure also shows the inductor current modulated in this low frequency. Fig. 9 shows the takeover current and ignition pulse.

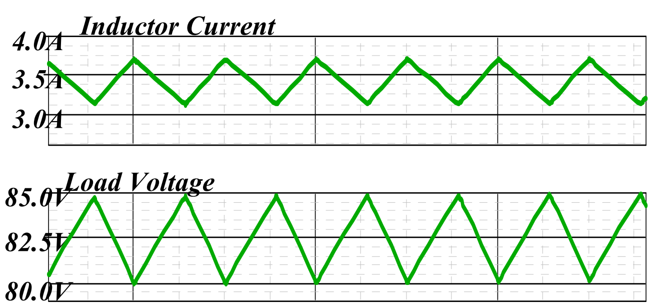

Fig. 6 – Simulations results using ideal components.

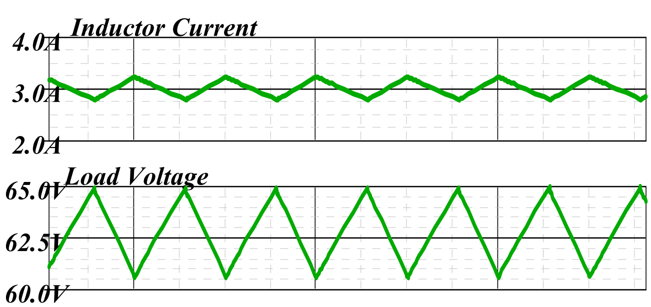

Fig. 7 – Simulations results using real components.

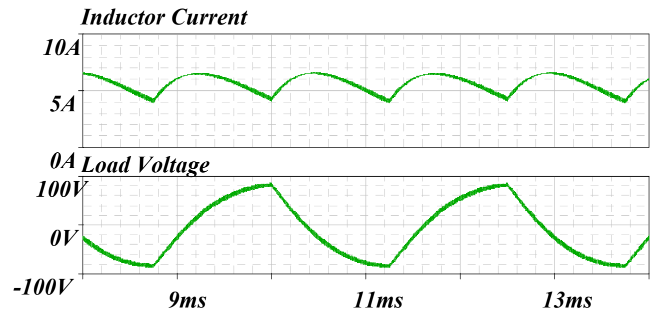

Fig. 8 – Takeover Current and ignition pulse.

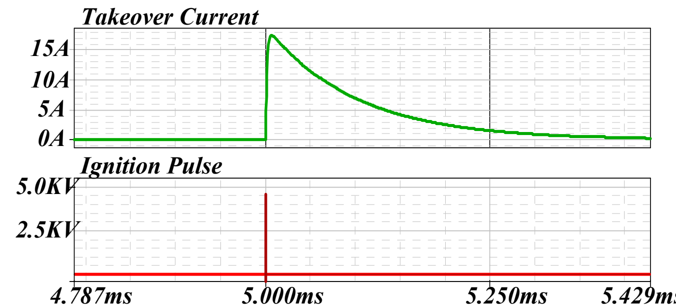

Fig. 9 – Takeover Current and ignition pulse.

VI. EXPERIMENTAL RESULTS

In the experimental process a prototype was designed and built. The results were performed using a microcontrolled based system. The chip chosen was the microchip 16F873A. The load used was a resistor of 250Ω. The effective duty cycle was approximately 43%. Fig. 10 is a schematic of the implemented circuit. As the driver components are the same in the four switches gate command circuit, the references were omitted for simplification. The lamp was replaced by a resistor with the same steady state impedance. Fig. 11 shows the inductor current ripple in 50kHz. Fig. 12 the load voltage ripple also in 50kHz. As the lamp is better drove in low frequency to avoid acoustic resonance, Fig. 13 shows the inductor current when the load voltage is alternated and frequency is 374Hz. In fig. 14 the slow rate response of the load voltage can be observed.

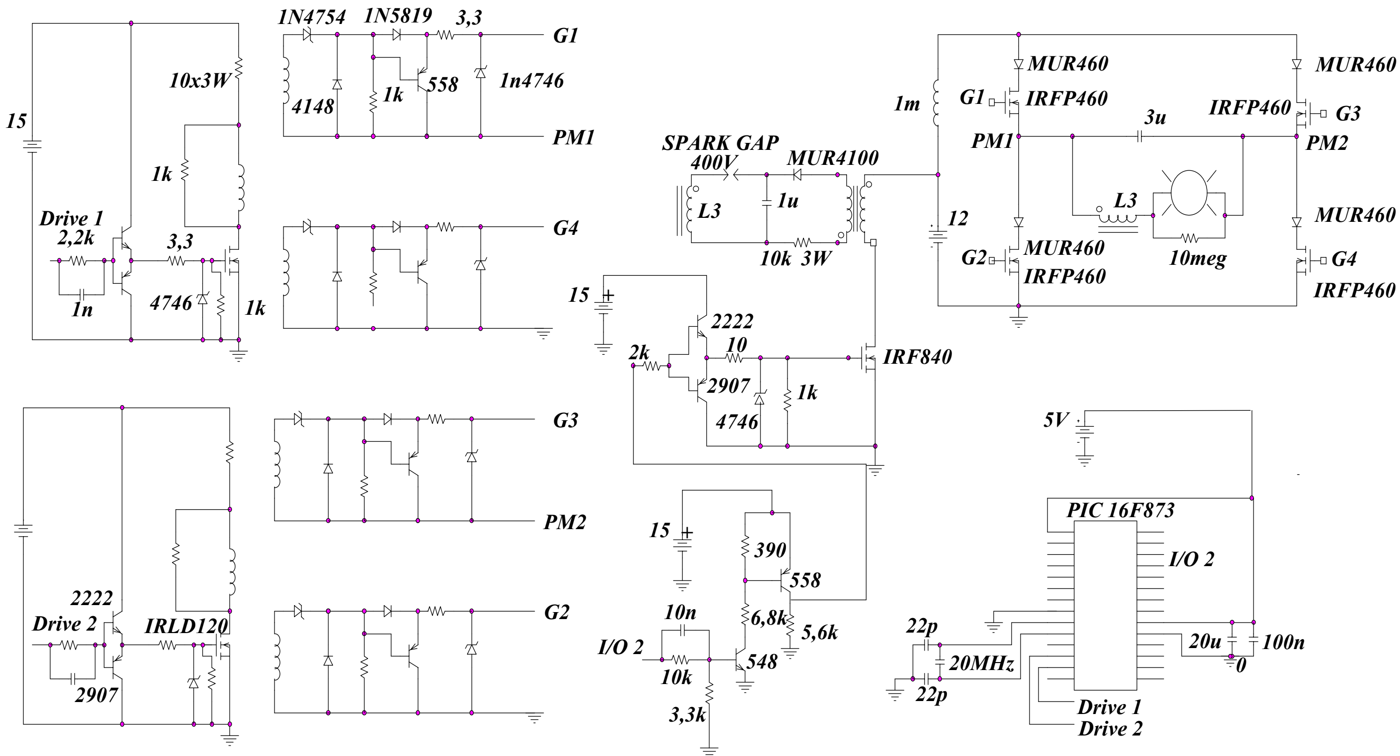

Fig. 10 – Complete implemented circuit.

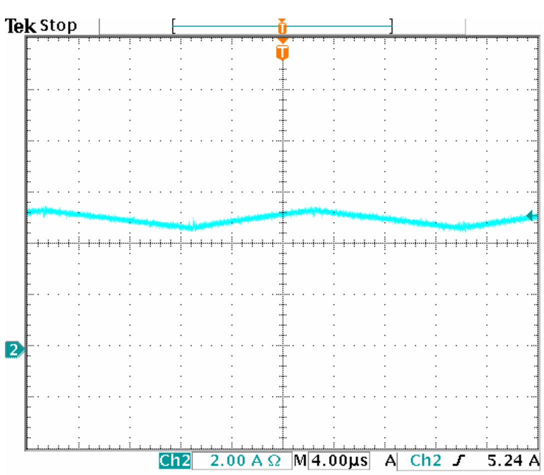

Fig. 11 – Inductor current (I :2A/div.;t:4µs/div.).

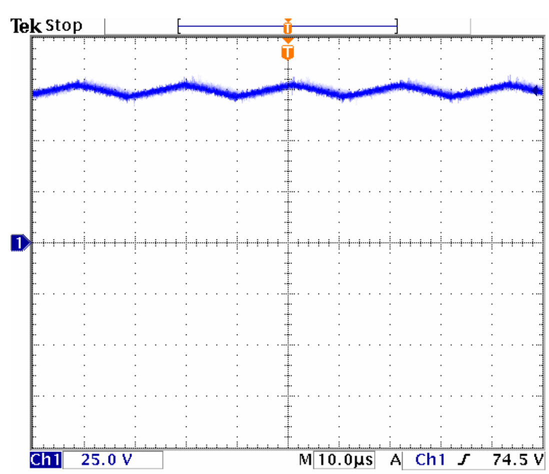

Fig. 12 – Load voltage (V:25V/div.;t:10µs/div.).

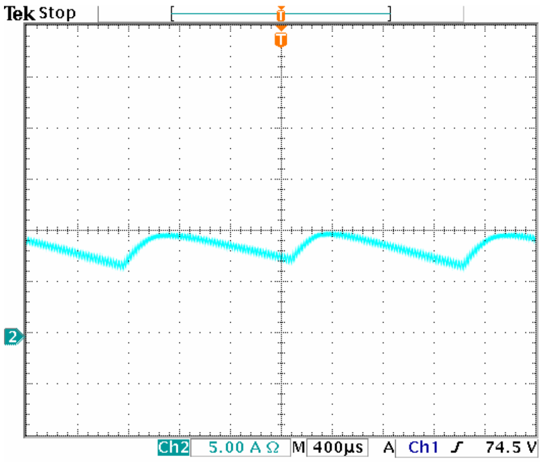

Fig. 13 – Inductor current (I :5A/div.;t:400µs/div.).

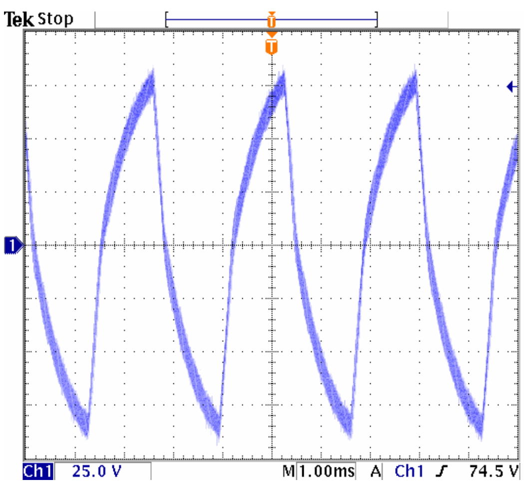

Fig. 14 – Load voltage (V:25V/div.;t:1ms/div.).

During the implementation process many difficulties were encountered. These problems are described and commented.

The input current source converter type must always provide a path to circulate the current. During the commutations there is no dead time and the command circuit should send a conduction order to both switches at the same arm during a small time to avoid destructive over voltages, reducing the effective duty cycle.

It is very complex to use a bootstrap driver with this topology. As there is only one power source, the battery, this power source must supply the driver also. When the switch Q_4 conducts, the closed voltage loop showed in Fig. 15 impose a high voltage over bootstrap capacitor.

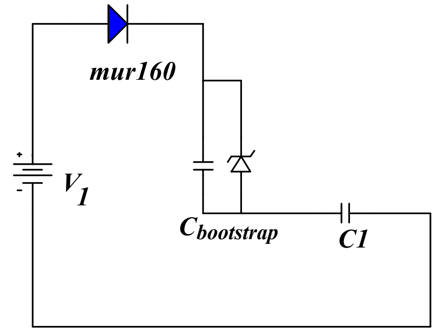

Fig. 15 – Destructive voltage over booststrap capacitor.

Due to the above exposed, the solutions to drive the bridge are pulse transformer or optocoupler. The second solution needs an auxiliary power source. The driver circuit implemented uses pulse transformers.

The necessity of a series diode with each converter switch decreases the efficiency and the voltage gain of the topology. This is a serious limitation of this topology.

As (2) express, the half duty cycle is not allowed. Therefore, during the experimental process, it was verified that duty cycles near the half, implied in an inapropriated operation of the structure. This is another limiting factor, because the voltage gain is limited at a lower value.

The plant transfer function has a slow rate response. This is a problem because the intended output voltage waveform is a square waveform. To impose this waveform the frequency must be increased to reduce the passive components and a closed loop control implementation.

VII. Conclusion

The great problem using this topology in low power systems are the losses and the voltage drop on the two switches and two diodes conducting at the same time. The solution is the use of low conduction resistances switches and a volt bi-directional switch, like the PT-IGBT, which is not usual with low current rating.

The open loop operation is complex because the slow rate response of the system. It maybe possible, but the frequency must be high.

The principal advantage is the imposed current that improve the availability and sturdiness.

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