Topologic study of ballast drives for a D2S-35W Lamp

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Abstract – The high intensity discharge lamp (HID) for automotive usage, more commonly known as Xenon lamp, is mainly manufactured by Philips and Osram. This lamp has a lot of peculiarities, presenting several operating stages before reaching steady-state. The electronic ballast designed to supply the lamp must satisfy some specifications to comply with each of the operating stages. The electronic ballast commercially used to supply this lamp is composed of a Flyback converter and a voltage inverter. An electronic ballast was implemented using this configuration in order to dominate this technology and learn more about the operation of Xenon lamps. Others topologies were studied and the converters performance were compared.

Keywords – electronic ballast, HID lamp, Xenon lamp.

I. INTRODUCTION

Xenon lamps, also known as metallic vapor high intensity discharge lamps, used in automobiles, are named so due to the presence of xenon gas inside the discharge tube. Its presence is necessary in order to ease the ignition process. The usage of this type of lamp has been increased lately because of its good color properties, robustness, and efficiency when compared to other lamps [1]. It is being more frequently used in the automobile industry, which is substituting the 55W halogen bulbs by the D2S-35W HID lamps in the luxury car models. However, despite the advantages stated up to this point, it is important to highlight the disadvantages of discharge lamps. The cost and the complex design of the electronic ballast are still a barrier for large scale use.

The automobile industry is a promising field for the research and development of systems for high pressure discharge lamps. If the ballasts are able to reduce the volume of automobile headlights and can be placed inside the remaining space, the demand for these systems will increase dramatically [2].

High intensity discharge lamps can be supplied by either direct or alternating current. However, it is important to remember that when using direct current, the cataphoresis phenomenon is very intense. Its occurrence reduces the life of the lamp due to an unbalanced degradation of the electrodes. This phenomenon occurs when the metallic ions of the metallic halogens inside the discharge tube are deposited on the extremities or electrodes [3].

To equalize the degradation of the electrodes, the xenon lamp is supplied by alternating current. However, when alternating current is used, the high intensity discharge lamps are susceptible to acoustic resonance. The periodic incoming power and the consequential release of energy from the collision between charged particles and neutral gases disturb the internal pressure of the discharge tube. If the frequency of the power of the lamp is increased or if the harmonics have considerable amplitudes approaching the natural resonance frequency, the pressure wave becomes resonant resulting in a disturbance in the discharge path. This phenomenon causes fluctuations in the emitted light, deformations in the arch which change its length and width and alter the electrical parameters of the lamp (voltage, current and impedance), and, in more severe cases, may extinguish the arc or may even, for certain types of lamps, cause the explosion of the tube due to a large distortion in the arc. The frequencies at which the acoustic resonance may occur depend on the dimensions of the discharge tube, the density and pressure of the gas on the inside of the discharge tube, the operating temperature of the lamp, and its orientation [4].

II. CHARACTERISTICS OF THE D2S-35W LAMP

Table I provides some electrical and physical characteristics of the D2S-35W metallic vapor lamp manufactured by Philips. Notice that the internal pressure is very high when the lamp is hot. The maximum voltage that can be applied during ignition is 23 kV. The xenon lamp, commercialized under reference number D2S-35W, specified for automotive use, illustrated in Fig. 1, has the following characteristics: quartz bulb, tungsten electrodes, axial oriented arc, 4.2 mm length arc, 1.1 mm diameter arc [5].

Fig. 1 *– Photograph of the D2S-35W lamp*

Table II summarizes the operating stages of the lamp along with the specifications of dynamic parameters and maximum and minimum values. Some parameters will be very important for designing the electronic ballast. The maximum ignition voltage of 23 kV must be respected otherwise the lamp will deteriorate faster. The rated power of 35 W should not be exceeded in order to avoid reduction in the life of lamp. The minimum transition rate of 100 mA/μs, if not respected, may cause the extinction of the arc during the polarity inversion of the lamp current [6].

***Table I** - Electrical and physical characteristics of the D2S-35W lamp.*

Power	35 W ± 0.3W
Voltage	85 V ± 17 V
Luminous Flux	3,200 lm ± 450 lm
Luminous Maintenance	1,500 h 75%
Color X	0.38 ± 0.025
Color Y	0.39 ± 0.015
Color Temperature	4,100 K
Maximum Ignition Voltage	23 kV
Maximum Ignition Current	2.6 A
Maximum Power	75 W
Minimum Life	2,500 h
Cold Lamp Internal Pressure	7 bar
Hot Lamp Internal Pressure	100 bar

Fig. 2 shows in detail the operating stages of the D2S-35W metallic vapor discharge lamp. During the pre-ignition stage, notice that a voltage of 360 V is applied across the lamp. This stage lasts approximately 30 ms. After this stage, a maximum ignition pulse of 23 kV starts the ionization process of the discharge path, allowing the take over current to flow for approximately 300 μs. After this stage, the lamp is heated until it reaches steady-state [6].

Pre-ignition – in order to guarantee the sustainability of the arc throughout this stage, a minimum voltage of 360 V must be applied across the lamp before applying the high voltage pulse of the ignition stage.

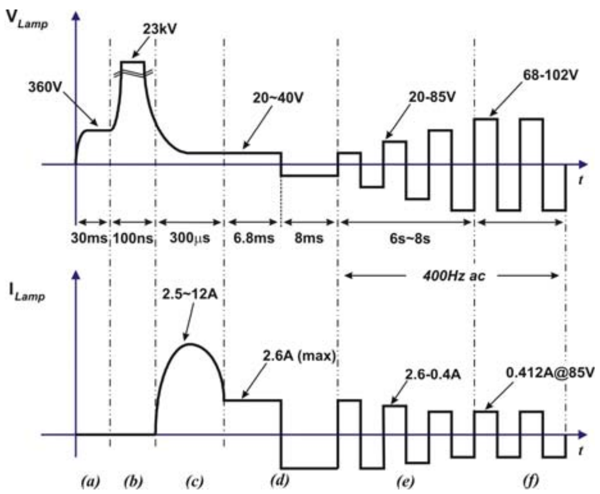

***Fig. 2** – Operating stages of the D2S-35W lamp [6].*

Ignition – at ignition, the resistance of the lamp is very high, and the current and power are both zero. It is necessary to apply a high voltage pulse to start the ionization process of the discharge path. The ignition voltage for cold ignition, when the lamp is at room temperature, has a minimum amplitude of 7 kV. When ignition must be started right after the arc is extinguished, the applied voltage must be higher, between 18 kV and 23 kV due to an increase in the internal pressure of the discharge tube.

Take over – right after ignition, the impedance of the lamp drops drastically. Due to its inertia, the ballast takes a certain amount of time to start delivering power to the lamp. Therefore, it is necessary to provide a current to sustain the arc, which is done by means of a capacitor capable of storing the necessary energy for this operating stage placed in parallel with the lamp.

Heating – when the gases inside the discharge tube of the lamp are cold, it is necessary to warm them up so that the lamp is capable to provide the electrons used in the discharge process. This time interval must be short, in order to reach nominal luminosity as fast as possible. This stage is characterized by a high current and a polarity inversion frequency much lower than 400 Hz. It is also known as the direct current stage.

Transition – the automotive lamp should operate according to SAE (Society of Automotive Engineers) specifications. Since voltage and current during the heating stage are quite different from the rated specifications, it is during this stage that the electrical parameters reach their rated values.

Steady-State – in steady-state the rated current of the lamp is approximately 412 mA, with a voltage of 85V and power equal to 35 W.

***Table II** – Dynamic parameters of the D2S-35W lamp [6].*

Stage	Parameter	Value
Pre-Ignition	Open circuit voltage	360 V(minimum)
	Time	30 ms
Ignition	Ignition voltage	23 kV (maximum)
	Pulse width	1 s (maximum)
	Frequency of the applied pulse	20 Hz (minimum)
Take over	Take over current	2.5 A (minimum) to 12 A (maximum)
	Take over time	300 μs (maximum)
Heating	Current	2.6 A (maximum)
	Integral current	12 ~ 30 mAs
	Time	10 ms each half-cycle
Transition	Current	2.6 A (maximum)
	Power	75 W (maximum) @ 50 V
	Time	6 ~ 12 s
Steady-State	Power	35 W
	Voltage	68 ~ 102 V
	Frequency	250 ~ 10 kHz
	Waveform asymmetry	< 1%
	Current transition rate	100 mA/μs (minimum)

III. FLYBACK AND VOLTAGE SOURCE INVERTER TOPOLOGY

One of the most popular configurations for electronic ballasts supplying metallic vapor lamps uses a Flyback converter as the input stage and the Voltage Source Inverter as the second conversion stage. The converter of the second stage operates in an open loop and produces a square wave low frequency AC voltage. The input converter is the responsible for controlling the power provided to the lamp and for increasing the voltage supplied by the battery, whose nominal value is 12V [7]. Fig. 3 depicts the schematic for this configuration.

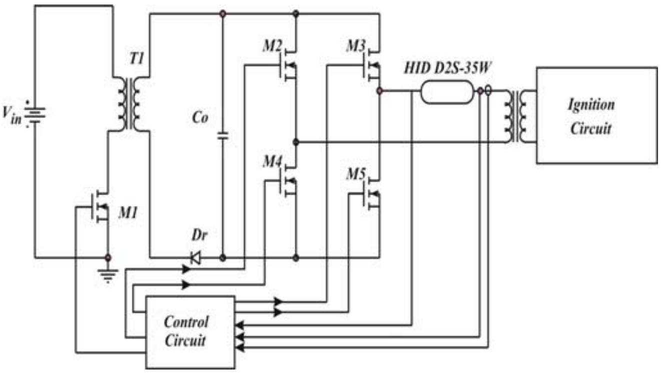

Fig 3 *– Configuration for supplying the D2S-35W lamp.*

The Flyback converter is used as the input stage due to a series of characteristics, among which one can point out its low cost due to the small number of components, it can handle large load variations, and it does not require a filtering inductor, among others. It is the power control stage. Fig. 4 presents the implemented prototype.

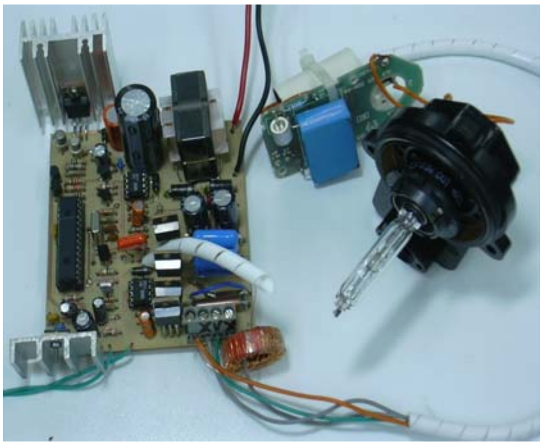

Fig. 4 *– Picture of the implemented prototype.*

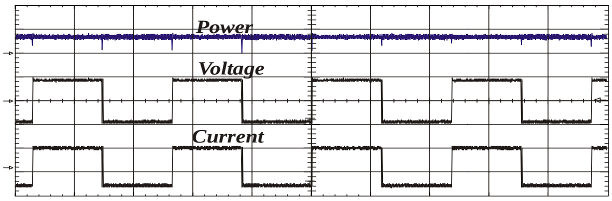

Fig. 5 *– Experimental results.*

Fig. 5 shows the power, voltage and current when driving a D2S-35W lamp using the implemented Flyback and Voltage Source Inverter topology.

IV. CURRENT-FED INVERTER TOPOLOGY

Fig. 6 shows the Current-Fed Inverter topology. It was studied and during simulation process some barriers were detected [8]. The current polarity transition obtained was around 4mA/µs rate. However, the specified dynamic parameter, showed is table II, must be upper than 100 mA/µs. To obtain this rate, the switching frequency must be very high to reduce the output capacitor and to reduce the necessary time to remove its storage energy. Fig. 7 presents a simulation result.

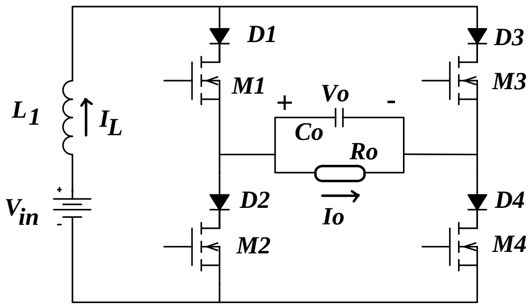

Fig. 6 *– Current-Fed Inverter Topology.*

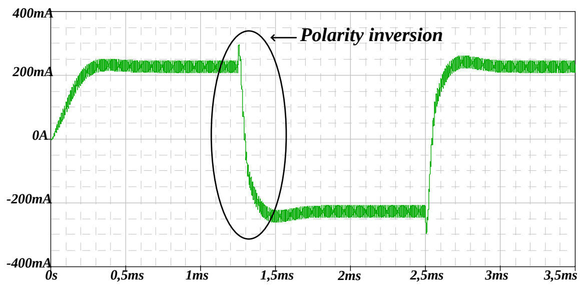

Fig. 7 *– Current polarity transition: simulation result.*

V. BOOST INVERTER TOPOLOGY

This topology [9], as the Current Fed Inverter topology, presents the same current rate problem. Fig. 8 presents this topology and Fig. 9 shows the experimental result when, during the current polarity transition, the lamp arc extinguishes.

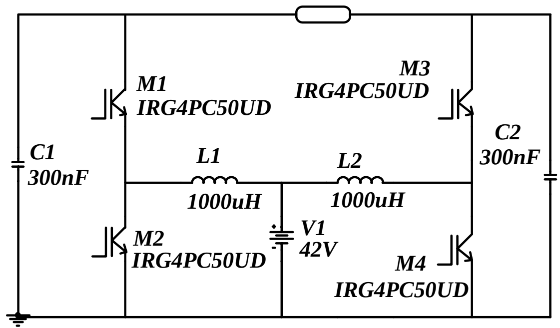

Fig. 8 *– Boost Inverter Topology.*

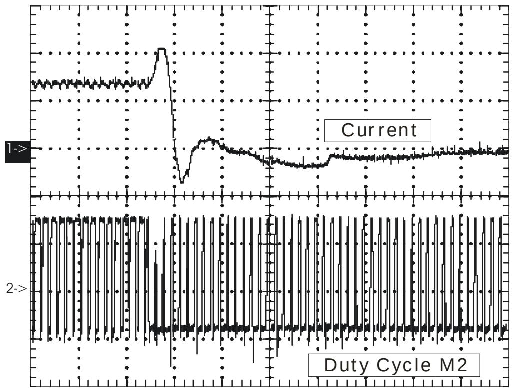

Fig. 9 *– Experimental result.*

VI. CURRENT-FED PUSH PULL INVERTER TOPOLOGY

The topology showed in Fig. 10 supply D2S-35W lamp with a high frequency alternated current. So, to avoid the acoustic resonance, the modulation signal is a random PWM. This modulation technique ensures the power is not concentrated in some specific frequencies [7]. Fig. 11 presents the topology power spectrum. Fig. 12 shows the current rate can be obtained with this topology.

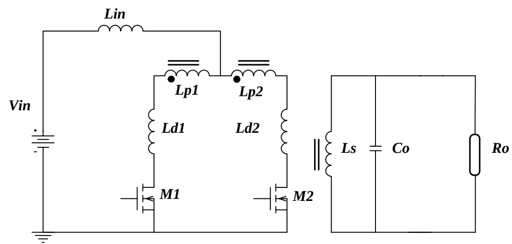

Fig. 10 *– Current-Fed Push Pull Inverter.*

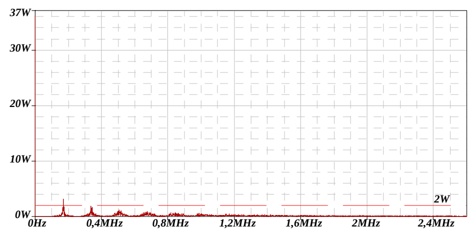

Fig. 11 *– Power spectrum.*

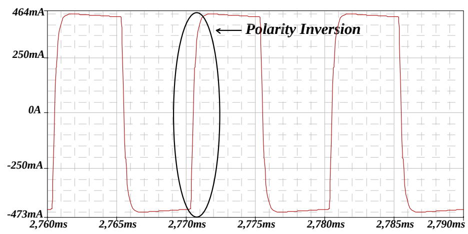

Fig. 12 *–Input current-of the Push Pull Inverter.*

VII. CONCLUSION

The Flyback and Inverter topology makes the design of the ballast relatively simple. The choice of the Flyback converter for the first stage and the Voltage Source Inverter for the second stage is much appropriated. Although, there is a need for two conversion stages and consequently five switches, the configuration promptly complies with all the requirements for supplying the D2S-35W HID lamp. The greatest disadvantage of this structure is its low efficiency, around 80%. In order to improve the efficiency, a single-stage conversion was studied [7].

To drive the lamp using a single stage topology, Current-Fed Inverter, Boost Inverter and Current-Fed Push Pull Inverter topologies were studied. The two first topologies have a current rate obstacle. Besides, the Current-Fed Inverter employs two associated semiconductors because they need to support reverse voltage. When these problems could be transposed, this technology may become more attractive in this and others applications.

The last presented topology can be theoretically used to drive the lamp, but the lamp stages control and modulation may become an implementation challenge.

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