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Analysis and design of igniters for HID lamps fed with square waveforms

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Abstract

In this paper, the analysis and design of three igniters based on a LC series network is presented. The proposed igniters have larger elevation capacity and smaller size than a typical LC series resonant network, because LC series networks include one transformer or one autotransformer, respectively. The proposed igniters are adequate for high intensity discharge (HID) lamp ignition and recommended for electronic ballasts that fed HID lamps with square waves, because they need no extra semiconductor elements. The igniters were evaluated with an electronic ballast that feeds a 70W HID halogen lamp with low frequency square waveforms, after which acoustic resonances were eliminated. Experimental results of the igniters with selected electronic ballast are presented.

1 Introduction

An igniter is required for HID lamps fed with square wave forms used to eliminate acoustic resonances in HID lamps. The igniter must be small and inexpensive.

An LC series resonant network and transformer can be used for lamp ignition [1–8]. Magnetic element saturation troubles limit the voltage elevation capacity only if an LC series resonant network is implemented [1]. Extra igniter elements are needed if a transformer is implemented [2–8], because lamp igniter must be disconnected after the lamp ignition, which increases the cost and complexity of the ballast.

In this paper two igniters based on a LC series network (they work only at 23μs-40μs) are proposed, one of them with a transformer and the other with an autotransformer. The proposed igniters are smaller than typical LC series resonant network and characterized by an elevated capacity, so that extra igniter elements are not needed to disconnect the igniter.

This paper has the following structure. An analysis of power stage of selected ballasts is made in Section 2. In Section 3 a comparative analysis of the proposed igniter and the typical LC serial resonant network configuration is presented. In Section 4 experimental results are shown, and final conclusions are presented in Section 5.

2 Power stage

The block diagram of selected ballast is shown in Fig. 1. A buck converter is shown in this figure; it is operating in continuous conduction mode (CCM). This converter stabilizes the arc discharge and feeds the inverter. To stabilize the lamp current, a close loop control stage is needed. For this purpose a sliding mode control is used. Therefore, a fast response and stability in load and main voltage variations is obtained. A DC bus can be given by DC-DC converter that integrates the power factor correction.

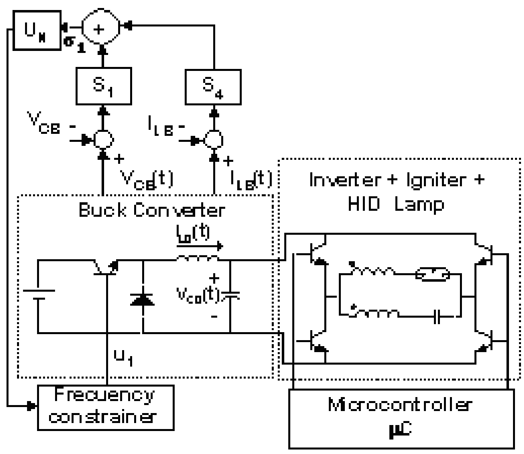

Figure 1: Block diagram of selected topology with a nonlinear control stage.

To avoid the acoustic resonance, the inverter feeds the HID lamp (70W metal Halide) with low frequency square waveforms (400Hz, avoiding the effects of parasitic elements). The group inverter-igniter is driven by a microcontroller. This microcontroller applies two different frequencies to this group, one of which is high (>100 kHz) and applied to ignite the lamp. The other frequency is low (=400 Hz) and is applied during the steady state when the lamp has been stabilized.

3 Comparative analysis of the igniters

In this paper three igniters integrated with the inverter are analyzed. These igniters are shown in Fig. 2.

The three igniters have a resonant tank LC that filters the square waveform provided by the inverter, due before the ignition the lamp behaves as an open circuit, the secondary of the transformer and autotransformer do not influence operation of the circuit during this state and therefore the three circuits can be modeled as the circuits of Fig. 2.

When the lamp ignites and the arc gets stabilized, then the switching frequency of the inverter changes from high (>100 kHz) to low (=400 Hz) frequency. At low frequency the impedance of the inductances is reduced, and the capacitive impedance increased reaching the values that have no effect on the circuit operation.

3.1 General analysis

The two proposed igniters (Figs. 2c and 2d) are conformed for L_aC_x network in series configuration. The inductance L_a is coupled to L_b (transformer or autotransformer configuration). High voltages (4.5kV peak) can be reached with these configurations assuring the lamp ignition. The ignition sequence takes 23μs-90μs (3-6 pulses of 100 kHz-130 kHz). The operating frequency of the inverter changes from 100 kHz-130 kHz to 400Hz when a lamp ignition is reached. Therefore, at 400Hz, inductors' impedance are very low (short circuit) and the impedance capacity is very high (open circuit) so that these impedances can be ignored.

For the analysis, only the maximum values of current and voltages are considered, and the values of all variables are valid only for the state previous to the starting of the lamp, during which the impedance of the lamp is considered infinite.

The maximum voltage in the primary inductor L_a is:

$$V_{La} = I_{La}X_{La} = I_{La}\omega_{st}L_a \quad (1)$$

where ω_{st} is the switching frequency at the starting, L_a is the primary inductor, and I_{La} is the maximum current through L_a.

The stored energy in L_a is [9]:

$$\varepsilon = \frac{L_a I_{La}^2}{2}. \quad (2)$$

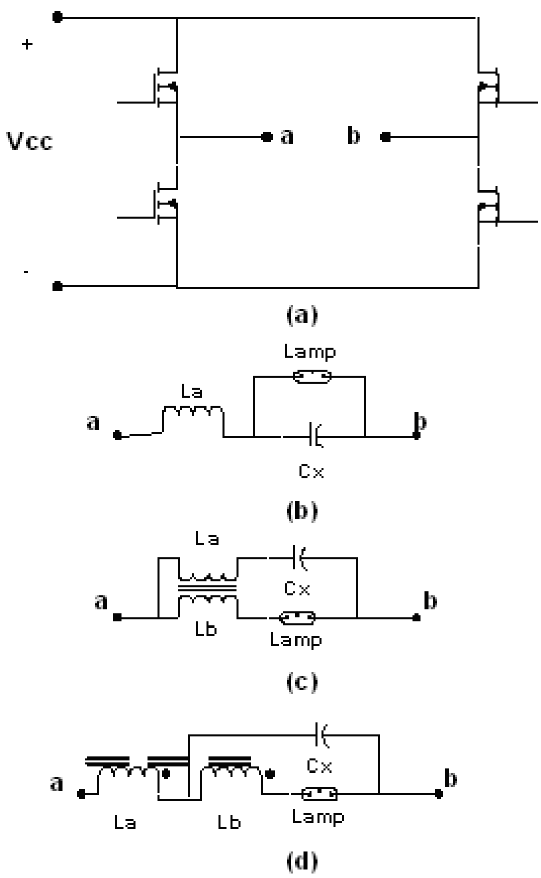

Figure 2: a) inverter; b) typical igniter [1]; c) transformer configuration; d) autotransformer configuration.

3.2 Igniters analysis: lamp ignition stage

3.2.1 Typical configuration [1]

The maximum current I_s in the primary inductor L_a is (Fig. 3a):

$$I_s = \frac{V_{in}}{X_{La} - X_{Cx}}. \tag{3}$$

On the other hand, the capacitive reactance X_{Cx} is (Fig. 3a):

$$X_{Cx} = \frac{V_{lamp}}{Is}. \tag{4}$$

Substituting (4) in (3) results in the following expression:

$$V_{lamp} = I_s L_a \omega_s - V_{in} = V_{La} - V_{in} \tag{5}$$

where: V_{lamp} is the lamp ignition voltage and V_{in} is the maximum value of the first harmonic of the inverter voltage.

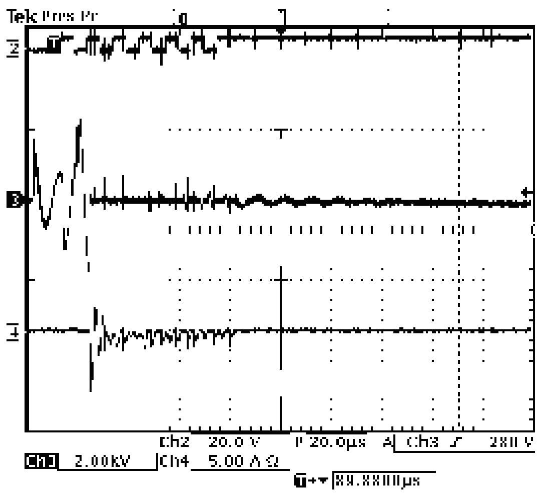

Figure 3: Experimental results of the transformer configuration during the lamp ignition period. Top to down: inverter synchronization pulses, lamp ignition current, and lamp ignition voltage.

Combining (1) and (5) and considering that $V_{lamp} >> V_{in}$:

$$L_a = \frac{V_{La}}{I_{La}\omega_{st}} = \frac{V_{in} + V_{lamp}}{I_{La}\omega_{st}} \approx \frac{V_{lamp}}{I_{La}\omega_{st}}. \tag{6}$$

Substituting (6) in (2):

$$\varepsilon_a = \frac{V_{lamp} I_{La}}{2\omega_{st}}. \tag{7}$$

3.2.2 Transformer configuration

Considering that $V_{lamp} >> V_{in}$ and observing Fig. 3b gives:

$$\frac{V_{lamp}}{n} = IsX_{La} = IsL_a\omega_s \tag{8}$$

where n is the transformer turn ratio.

Substituting (8) in (2):

$$\varepsilon_b = \frac{V_{lamp} I_{La}}{2n\omega_{st}}. \tag{9}$$

3.2.3 Autotransformer configuration

Considering that $V_{lamp} >> V_{in}$ and observing Fig. 3c gives:

$$V_{Lamp} = V_{La} + V_{La}n = V_{La}\left(1 + n\right). \tag{10}$$

Combining (1) and (10):

$$L_a = \frac{V_{La}}{I_{La}\omega_{st}} = \frac{V_{lamp}}{\left(1 + n\right) I_{La}\omega_{st}}. \tag{11}$$

Substituting (10) in (2):

$$\varepsilon_c = \frac{V_{lamp} I_{La}}{2\omega_{st}(n + 1)}. \tag{12}$$

These results are normalized to the equations of the typical configuration and summarized at Table 1. As can be observed, a smaller proposed igniter size and a greater elevation capacity than in typical LC resonant network, are obtained. The best results are obtained with the autotransformer configuration since the total voltage applied to the lamp is the sum of the primary and secondary voltages.

Igniter	$\frac{\varepsilon_x}{\varepsilon_a} =$	$\frac{V_{enc}}{V_{La}} =$ $V_{enc} >> V_{in}$
Typical configuration	1	1
Transformer configuration	$\frac{1}{n}$	n
Autotransformer configuration	$\frac{1}{n+1}$	$1+n$

Table 1: Comparison between the typical configuration and the proposed igniters.

Here x can be equal to a, b or c,
a for the typical igniter,
b for the transformer configuration,
c for the autotransformer configuration.

4 Design method

4.1 1-st step: calculation of C$_x$

The operation frequency changes from (100kHz-130kHz) at the ignition to 400Hz after the ignition. Therefore, C_x impedance increases and its current decreases ($I_{Cx} < 10\%\ I_{Lnom}$, I_{Lnom} = nominal lamp current). Simultaneously, L_a and L_b impedances decrease and their effects can be rejected. Then the adequate C_x value is:

$$C_x = \frac{1}{X_{Cx}\omega} \tag{13}$$

where ω is the switching frequency at steady stage (400Hz), X_{Cx} is the capacitor's impedance.

The X_{Cx} value is related to I_{Lnom} and the nominal lamp voltage (V_{Lnom}):

$$X_{Cx} > \frac{V_{Lnom}}{0.1 I_{Lnom}} \tag{14}$$

4.2 2-nd step: calculation of L_a

If the condition of $V_{Lamp} >> V_{in}$ is assumed, then , in accordance with (6), (8), and (12) for three topologies, the inductance L_a can be expressed as:

$$L_a = \frac{V_{La}}{I_{La}\omega_{st}} = \frac{V_{lamp}}{Q I_{La}\omega_{st}} \tag{15}$$

where Q is:

Configuration	**Q**
Typical	1
Transformer	n
Autotransformer	$n+1$

n is the turn relation.

Substituting (3) in (16) gives:

$$L_a = \frac{1}{\omega_s - \frac{V_{in}\omega_s^2 C_x Q}{V_{lamp}}}. \tag{16}$$

The L_b value is calculated for the turn number ratio n, chosen to obtain the lowest value of ε_c or I_s.

5 Experimental results

The proposed transformer configuration was designed with the following parameters: $\omega_{st} = 100$ kHz, $L_a = 25\mu$H, $L_b = 900\mu$H, and $C_x = 100$nF. For the autotransformer, the configuration values are: $\omega_{st} = 130$kHz, $L_a = 148$uH, $L_b = 400$uH and $C_x = 10$nF . The electronic ballast was designed with the following parameters: $P_o = 70$W, $V_{in} = 180$Vdc, $V_C = 90$Vdc, $I_L = 0.777$A, $L = 5$mH, $C = 1\mu$F, CDM70W830PH lamp. The C and L values were designed according to current and voltage ripples.

The proposed igniters were tested with the ballast shown in Fig. 1. To test the igniters sequence of six pulses at the designed frequency was applied to each igniter to ignite the lamp. Some experimental results of the electronic ballast are shown in Figs. 3 to 5. In Fig. 3 (transformer configuration) the inverter synchronization pulses, ignition current, and lamp ignition voltage are shown, and, as can be seen in this figure, this sequence of pulses is sufficient to ignite the lamp. In Fig. 4 (autotransformer configuration), the lamp ignition current and lamp ignition voltage are shown, and for this configuration the sequence of pulses also was sufficient to ignite the lamp. In Fig. 5 (transformer configuration), the steady state lamp current and lamp voltage are shown, as can be seen, the waveforms are almost square and the transients of voltage at the commutations are not important. For the autotransformer configuration the waveforms were the same. The efficiency of the inverter stage itself, including the proposed igniters, during the steady state was 99%.

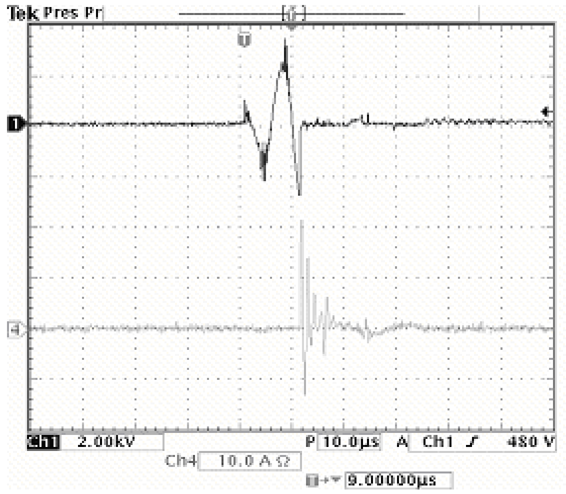

Figure 4: Experimental results of the autotransfomer configuration during the lamp ignition period. Top to down: lamp ignition current and lamp ignition voltage.

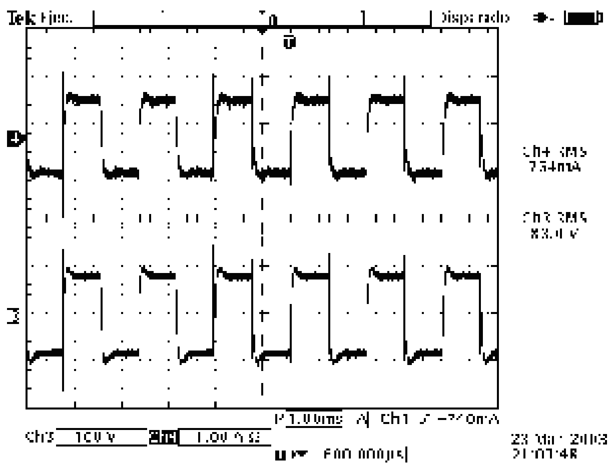

Figure 5: Experimental results during the steady state. Top to down: lamp current and lamp voltage.

6 Conclusions

In this paper, two new configurations of igniters for HID lamps fed with square waveforms, were proposed. The proposed igniters are based on the typical LC series network and are compared with this typical configuration. As a result of this comparison, these igniters demonstrated higher capacity without core saturation troubles and smaller size than a typical LC series resonant network. All the analyzed configurations can be adapted to the inverter that feeds the lamp with no more active components needed. The best of all configuration was the autotransformer configuration.

The experimental results demonstrated a good behavior of the proposed igniters containing the selected electronic ballast with a nonlinear control stage (SMC). Square waves are obtained with this topology and then the acoustic resonance phenomenon is eliminated with no secondary effects due to the igniters. The passive elements of the igniters were designed to minimize the current that flow through them at 10% of the nominal current during the steady state reducing the losses in this components. The efficiency of the inverter stage including the proposed igniters during the steady state was 99%.

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