Ignitors of Electronic Ballasts For HID Lamps

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Abstract¾ This paper presents a study on four different ignitor topologies that can be used in electronic ballasts based on half bridge inverters, developed to operate high pressure sodium lamps and metal halide lamps. This study can be extended to full bridge inverters. As it will be demonstrated, each topology presents advantages and disadvantages that can be used as a parameter to define which of them can be considered the best choice. Besides, a high frequency ballast to operate a halide lamp is also presented.

I. INTRODUCTION

A common characteristic to all kinds of discharge lamps is the need to ignite and stabilize the discharge. Ignition involves conversion of the starting gas from a non-conductive into a conductive state.

In mercury lamps, the ignition is made using a piece of molybdenum or tungsten wire positioned close to one of the main electrodes [1]. The main voltage is enough to initiate the discharge through the small gap between this auxiliary and the main electrode, so it is necessary to use just an inductance to limit the lamp current.

Since it is impractical to include an auxiliary starting probe within the arc tube in lamps like high-pressure sodium and metal halide, the lamp must be ignited by a high-voltage pulse [1], that needs sufficient amplitude and appropriate width and rise time [2]. In low frequency ballasts, this is usually obtained through a separate electronic device, which is part of the control gear circuit.

This way, this paper presents a study about some different topologies used as ignition circuits for high-pressure lamp electronic ballasts that will provide this high-voltage in order to strike these lamps.

II. INVERTER

The inverter topology chosen as the base during almost all of this study is the half bridge inverter using a LC filter, as can be seen on Fig. 1.

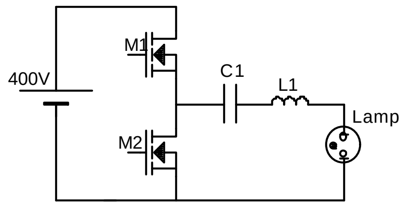

Fig. 1 – Half Bridge Inverter.

The MOSFET's control signals are generated by an UC3524 and, in the case of the high-pressure sodium lamp, the used switch frequency is 50kHz. An IR2110 drives the MOSFET's using the signals generated by the UC3524.

The LC values were chosen to allow the lamp operation at full power (400W). During these tests two different models of 400 W high-pressure sodium lamps were used to prove that the circuits could be used with lamps from any manufacturer:

- VIALOX NAVT E40 – Osram.
- SON-T 400W – Philips.

III. IGNITOR CIRCUITS

The voltage level necessary to guarantee high-pressure sodium lamp ignition according to IEC is 2,775V +/-25V and according to NEMA is 2,225V +/-25V [3]. To confirm these values, a high quality low frequency commercial set of ballast and ignitor was used. As shown on Fig. 2, the ignition voltage level in this case is 2.2kV (Ax2). This figure also presents the lamp current (Ch2).

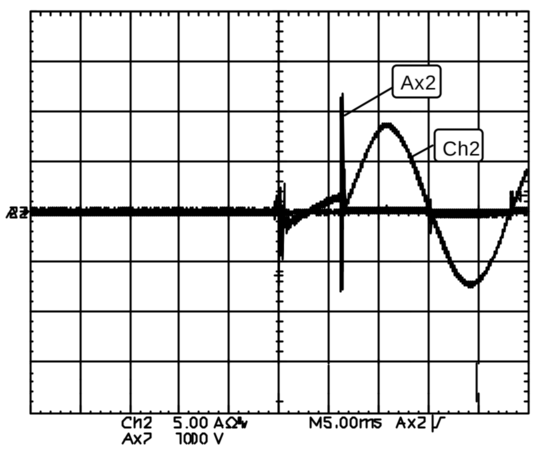

Fig. 2 – Ignition Voltage From a Commercial Ballast.

Based on this information, the minimum voltage value that should be obtained from the ignitor circuits was defined at 2.5kV.

At this point it is important to state that it's possible to find in the current literature several different circuits that can be used as ignitor. From now on we will show the practical results obtained in the laboratory using four chosen topologies and the 400W high-pressure sodium lamps.

A. Pulse Voltage

The first technique used to provide high ignition voltage to the lamp was the one known as pulse voltage. In the laboratory, two circuits were implemented to test the method.

The first, was based on a circuit proposed by [4], and is presented on Fig. 3 and uses a spark gap as the key component.

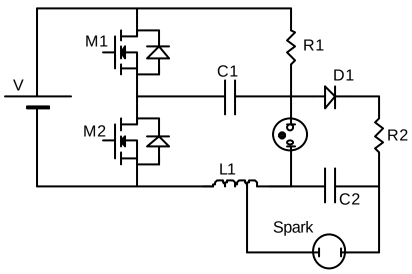

Fig. 3 – Ignitor Using Spark Gap.

Spark gap or gas discharge tube consists of two or more metal electrodes held close to each other by a highly insulating material. The space between the electrodes is hermetically sealed with a suitable mixture of gases at low pressures. The space between and the shape of the electrodes, the nature of the surface treatment of the electrodes and the gas pressure determine the breakdown voltage of the gas tubes. By controlling one or more variables, gas tubes can be made with breakdown voltages as low as 75 volts to as high as many thousand volts.

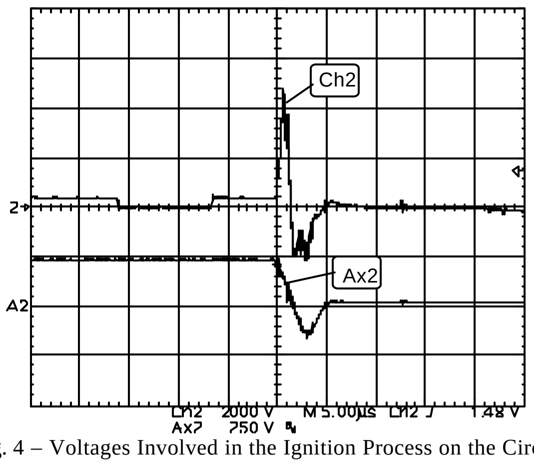

Fig. 4 – Voltages Involved in the Ignition Process on the Circuit Using Spark Gap.

The explanation on circuit behavior is given through the waveforms on Fig. 4. When the circuit is turned on, the lamp is off and its impedance is very high. This way, all voltage supplied by the inverter is applied on it. This voltage is rectified by D1 and charges C2 through R2. When the voltage over C2 (Ax2) reaches the spark gap breakdown voltage, the energy stored in C2 is applied in a small number of coil turns, generating a high voltage through L1 (Ch2).

When the lamp ignites, the voltage on it is much smaller than before and this prevents that the voltage on C2 reaches the spark gap breakdown voltage again.

If the lamp doesn't ignite for any reason, the capacitor C2 is recharged and the process is repeated until the converter has been turned off or when the lamp ignites successfully.

A second option using this same technique is based on a circuit using a SIDAC, that is a bi-directional device designed for direct interface with the AC power line. Upon reaching the break over voltage in each direction, the device switches from a blocking state to a low voltage ON state. Conduction will continue like a TRIAC until the main terminal current drops below the holding current [5].

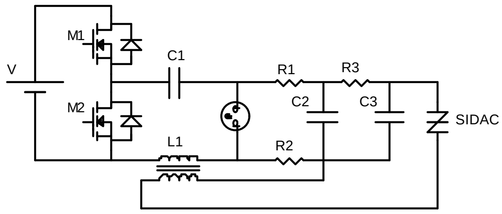

Fig. 5 – Ignitor Using SIDAC.

This circuit behavior is very similar to the previous circuit and can be summarized in the following way: when the voltage over C3 reaches the SIDAC's breakdown voltage, it discharges C3 into an auxiliary winding of L1. The high step-up ratio of L1 supplies the starting pulse to the lamp. Once more, after the lamp strikes, there is insufficient charge voltage on the capacitor C3 to avalanche the SIDAC and no further start pulses are supplied.

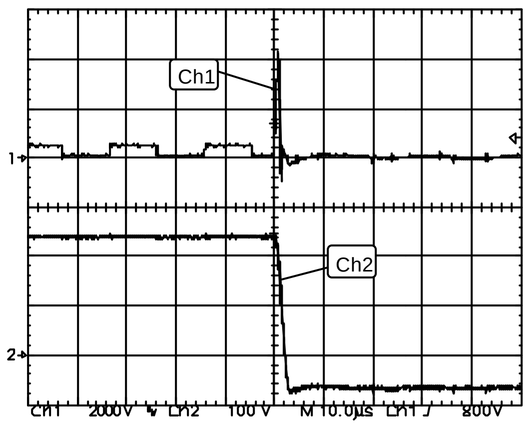

Fig. 6 – Voltages Involved in the Ignition Process on the Circuit Using SIDAC.

The voltage on C3 (Ch2) and the voltage applied on the lamp (Ch1), during the transient time, are shown on Fig. 6. The maximum voltage value measured on the lamp is 4.2kV.

Since this also occurred with the previous circuit, the over voltage generated during the start up process was higher than suggested in [5]. This can be easily changed through the turn ratio in L1.

It is important to note that it is not recommended, in this case, to use the same circuit as used with the spark gap because when this is done, the SIDAC doesn't recover and it continues conducting after the lamp strikes, which causes grade power dissipation over SIDAC that can destroy it. In this case, an intermediate charge state assembled by R1, R2 and C2 was used.

The comparison between these two different circuits that use the same technique can be done as follows:

- The first one is easily operated because it stops the current circulation over the ignition circuit even by using a simple auxiliary circuit.
- The circuit using SIDAC needs more components in the auxiliary circuit, but actually SIDAC is much cheaper than a spark gap.
- The need to use an insulated coil doesn't seem to be a bigger disadvantage on the second circuit.

B. Auxiliary Capacitor

Still using the same LC filter, a new ignitor circuit that uses an auxiliary capacitor was implemented (Fig. 7).

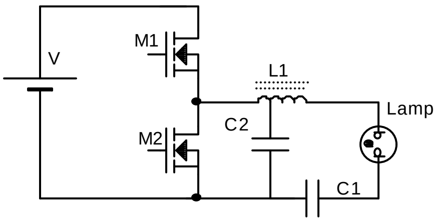

Fig. 7 – Ignitor Using an Auxiliary Capacitor.

This small capacitor is connected to a tap on the main inductor to ignite the lamp. When the lamp is off, the inductor acts as an autotransformer and produces the required ignition voltage [6], which is shown on Fig. 8. It is necessary to use a correction factor on this figure because the voltage probe utilized had a 1.000 attenuation factor.

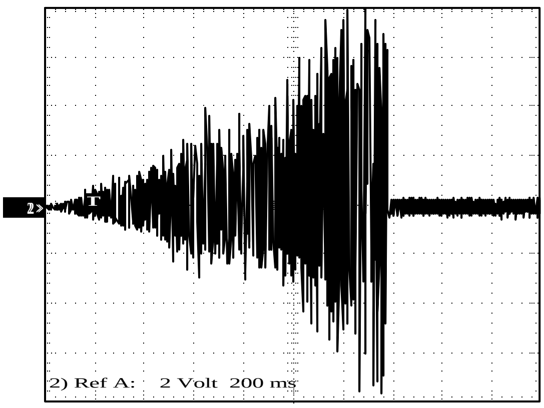

Fig. 8 – Voltages Involved in the Ignition Process on the Circuit Auxiliary Capacitor.

When the lamp strikes, the capacitor effect on the circuit is reduced, but not eliminated, as shown on Fig. 9, where the current in the lamp (Ch1) and the current supplied by the inverter (Ch2) is shown.

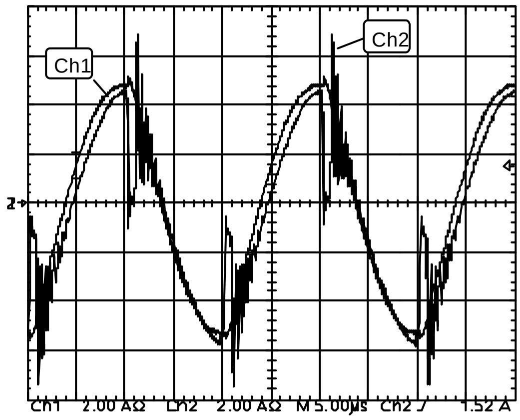

Fig. 9 – Currents on the Lamp and Supplied for the Inverter.

When compared to the first technique, this seems to be the simplest circuit that can be used. But it's necessary be aware of the parasite inductances and capacitances that can absorb the voltage pulses. Depending on the switching frequency adopted it may be necessary to use a pot core or a toroidal core, usually more expensive than E cores used in the first case.

In all of these three first prototypes, the currents and voltages in the lamp and on the switches were very similar and the ignitor circuits didn't seriously affect the inverter behavior after lamp strike. This can be proved through the main waveform acquisitions made with the inverter at full lamp power. Fig. 10 shows current, voltage and power in the lamp in steady state.

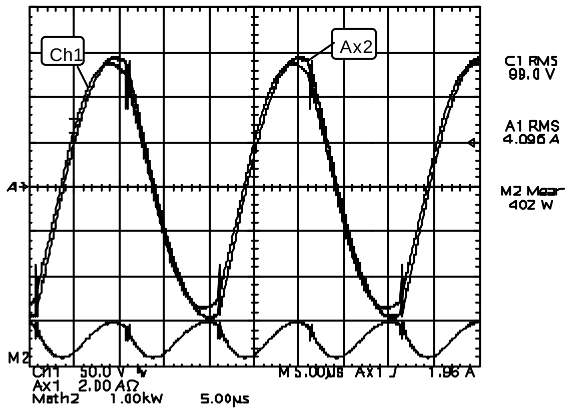

Fig. 10 – Voltage, Current and Power in the Lamp in Steady State.

Fig. 11 shows the current and voltage in one of the main switches also in steady state. These waveforms demonstrate that the switching frequency and LC values are appropriate to secure ZVS commutation, which is vital to simple and suitable converter operation.

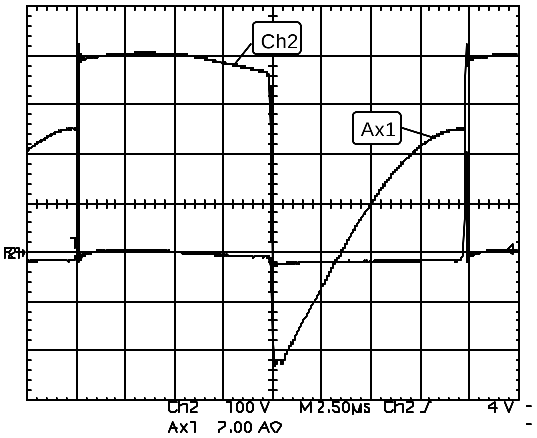

Fig. 11 – Voltage and Current in One of the Main Inverter Switches.

C. LCC Filter

The last technique tested employs a traditional LCC filter, usually found in fluorescent electronic ballasts.

The LCC filter can be used like an ignitor because instead of the LC filter, it can provide a high output voltage. This way, it will fulfill two roles: filter the lamp current and provide the high voltage necessary to strike the lamp.

The complete inverter power circuit is shown on Fig. 12 and the LCC filter transfer function when the lamp is off is shown on Fig. 13.

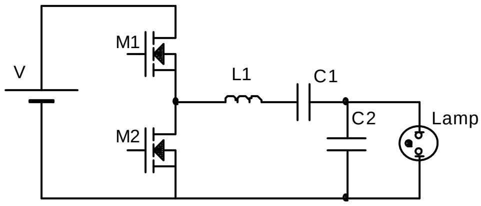

Fig. 12 – Ignitor Using LCC filter.

In this figure, the gain filter variation (G) with quality filter factor and the ratio between switching frequency and resonant frequency is shown [7].

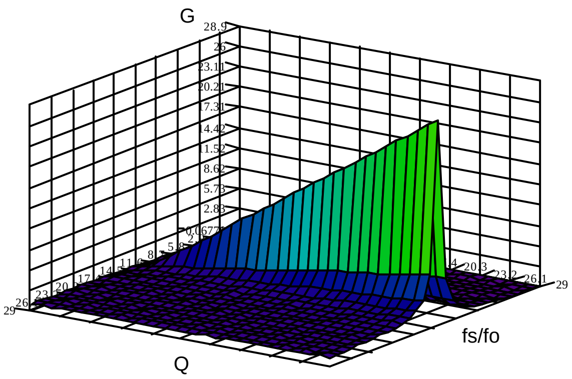

Fig. 13 – LCC Filter Gain.

The filter components choice is made to provide an inductive characteristic to the current during the whole process, from the lamp's startup up to its steady state. This is achieved using a component combination which resonant frequencies are always lower than inverter switching frequency.

The filter resonant frequencies, after and before the startup, are given by:

$$fo = \frac{1}{2.p.\sqrt{L1.Ceq}} \qquad (1)$$

$$fo = \frac{1}{2.p.\sqrt{L1.C1}} \qquad (2)$$

Where:

$$Ceq = \frac{C1.C2}{C1 + C2} \qquad (3)$$

Following these conditions a prototype also using this technique was implemented, although hopped the high current value during the startup.

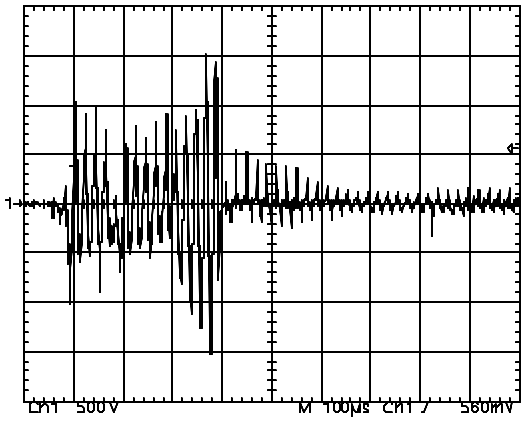

Fig. 14 – Voltages Involved in the Ignition Process on the Circuit Auxiliary Capacitor.

The voltage lamp strike is shown on Fig. 14. As it can be noticed, the voltage level necessary to provide the ignition was smaller than the other three cases. Probably this happened because of the higher voltage pulses frequency and the filter output characteristic.

It is important to remember at this point, that the circuit was designed to provide a higher voltage as shown on Fig. 15, where a simulation result using the same component values used at the prototype is presented.

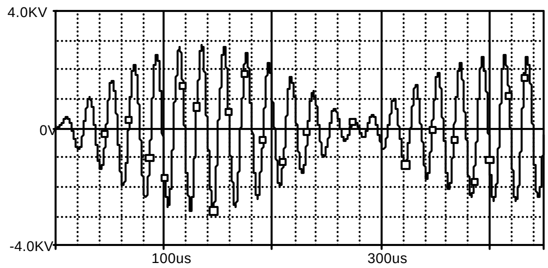

Fig. 15 – Ignition Voltage Simulation.

With this circuit, once more, the nominal voltage and current in the lamp was achieved as observed on Fig. 16.

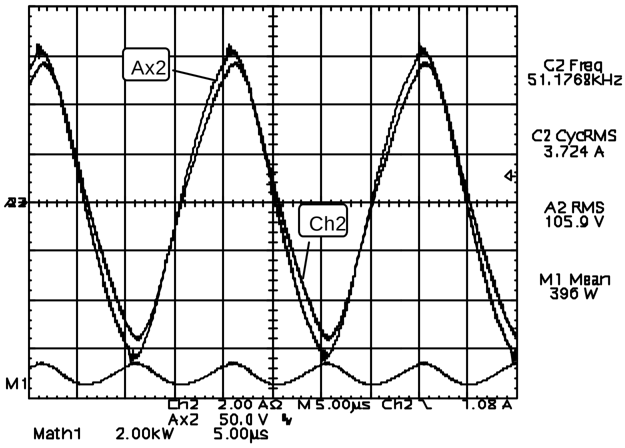

Fig. 16 – Voltage, Current and Power in the Lamp in Steady State.

A small difference between the current and voltage obtained with the practical circuit and that suggested by the lamp manufacturer was registered, but we believe this can be considered normal because this same difference was also registered when this same lamp was operated with a low frequency commercial ballast.

If compared with other previously presented ignitor circuits, this one can be considered the most common of them and because of this, its design methodology can be easily found. Unfortunately, it presents two important disadvantages:

- The capacitance value used in parallel with the lamp and its voltage makes it necessary to use a reasonable quantity of associated capacitors.
- Since a high voltage is obtained through the resonance phenomenon, there is a big value of current circulating through the main switches during the startup.

IV. Ignitor Circuits Utilization in a Practical Electronic Ballast

At this point a prototype developed to suitably operate a 150W metal halide lamp is briefly described. The results obtained with the ignitors circuits studies were used to choose the best one to be used at this conditions.

As it is known, when HID lamps, such as metal halide lamps are operated in high frequency, acoustic resonance can be observed. This phenomenon causes various problems, such as arc instabilities, which sometimes causes the arc to extinguish; light output fluctuation; color temperature variation, and in the worst case, it may crack the arc tube [8]. That is the reason that it is necessary to use some technique to avoid resonance excitation.

Between several different methods found in the literature used to avoid resonance, the simplest of them consists in using a frequency above the boundary where the resonance doesn't happen. Considering the above explanation, a 150kHz inverter frequency commutation was specified. In this case, due to the quasi purely ac discharges in the lamp; the power frequency is twice the applied current frequency.

Metal halide lamps are similar in construction to mercury lamp, which is the most popular HID lamp. The major difference being that the metal halide arc tube contains various metal halides in addition to the mercury and argon and that the arc tubes usually are smaller for equivalent wattages [9-10]. Through this combination it is possible control the lamp spectrum radiation and because of this it is necessary the use of a higher voltage level to ignite the lamp than the high-pressure sodium.

Once more, the topology chosen to supply the lamp was a half-bridge inverter with an output filter (Fig. 7). The inverter was switched at 150kHz, with a fixed 0.5 duty cycle and the pulses are generated by an UC3524. The prototype developed in the laboratory used the mentioned auxiliary capacitor technique to ignite the lamp because it seems to be the best choice in this situation. The gate drive shaping and level shifting for the high side is performed by an IR2110.

As it is normal in this kind of inverter, the LC resonant frequency is lower than the switching frequency to guarantee ZVS commutation. In this first implemented prototype, the inverter is supplied from a 400Vdc source and the LC filter values are 230µH and 8.2nF to supply a 150W lamp.

This 400Vdc voltage level was chosen because it is the most common voltage found when the inverter is supplied by a BOOST converter that can provide high power factor to the structure.

Fig. 17 presents a prototype picture and Fig. 18 shows the ignition voltage obtained. As shown, its peak value is a little higher than 6kV.

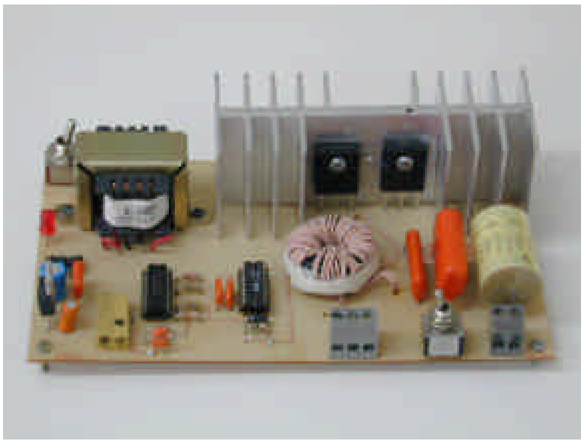

Fig. 17 – Prototype Picture.

Such a high voltage can be useful to restart the lamp without a long cool down time. This value can be easily changed through auxiliary capacitor value or with the turn ratio in resonant inductor.

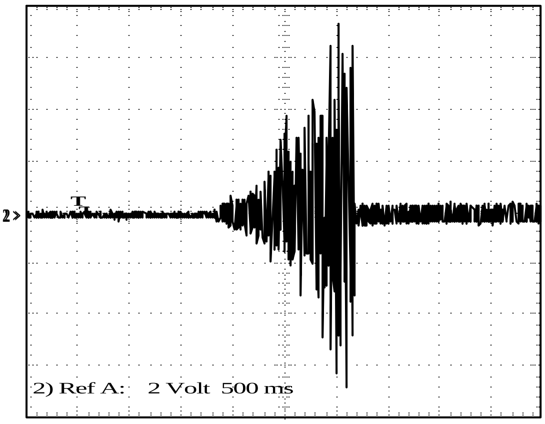

Fig. 18 – Ignition Voltage (2,000V/div).

Fig. 19 presents voltage (Ax1) and current (Ax2) in the lamp after startup. One of the channels was inverted to make it easier to distinguish each waveform.

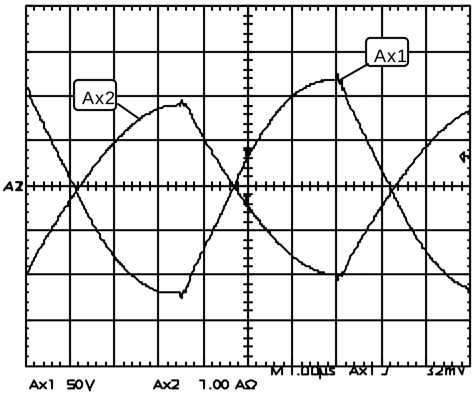

Fig. 19 – Voltage and Current Lamp.

In this situation the power supplied to the lamp was 140W, therefore a little less than its nominal value.

V. Conclusion

A study on four simple ignitor circuits usable in high-pressure lamp electronic ballasts was presented in this paper.

Four simple prototypes were designed and implemented to prove the validity of the studied circuits and show the most important differences between them. The results shown can also be used as a first step to define an ignition technique or circuit usable in practical ballast circuits.

Through the results it was possible to conclude that the technique using an auxiliary capacitor is the best option when the frequency commutation is smaller than 60kHz. Above this limit, parasite parameters harm the ignitor circuit behavior making it necessary to use another kind of core. The circuits using voltage pulse technique presented smaller sensitivity with the parasitic parameters, but in higher frequencies, the need of smaller inductance can lead to some problems with the turn ratio. The circuit using resonant filter presents a suitable behavior, but there is a high current level involved in the startup process. Due to high frequency commutation, to use the auxiliary capacitor technique, it was necessary choose a toroidal core.

Finally, as stated before, the biggest challenge found in operating HID lamps at high frequency, is the phenomenon called acoustic resonance. So, the key to operating HID lamps at high frequencies is to use some technique to avoid exciting the phenomenon. Therefore, in the case of High-pressure sodium lamp the frequency used is included in the boundary that normally no acoustic resonance is detected and a high level of frequency was used in the case of metal halide lamps. At least, during all of the tests, no resonances were detected.

VI. Bibliographical References

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