AUTO DIMMABLE SELF-OSCILLATING ELECTRONIC BALLAST FOR HPS LAMP

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***Abstract* – This paper shows a self-oscillating auto-dimmable electronic ballast used to feed an HPS lamp. Ballast topology comprises a rectifier associated with a half-bridge inverter and a resonant filter connected to lamp. It still has an igniter to start the lamp and a auto-dimmable circuit, which controls output power and light intensity.**

KEYWORDS

HPS Lamp, Self-Oscillating, Dimming, Ballast.

I. INTRODUCTION

Nowadays, when talking about energy saving, we ever report to artificial lighting systems, which consume a great amount of the electrical energy produced in the world. So any improvement related to efficiency and light quality from these systems is desirable. And the discharge lamps, particularly the high intensity discharge lamps (HID) are very attractive due to its luminous efficacy and light quality. However, unlike the incandescent lamps, they require extra circuitry to operate the lamps, mainly regarding to control the current through them.

Recent studies have used electronic ballast to operate HID lamps, due to its low weight, reduced size, dimming facility, extended lamp life and absence of flickering. The most uses high frequency switching and LC series resonant filter to operate the lamp. Some uses self-exited switch command with full-bridge inverter topology.

This paper intents to design a self-oscillating electronic ballast, based on a half-bridge inverter with high frequency switching and LC series resonant filter to feed a high pressure sodium lamp from standard 220V 50/60Hz AC source.

II. HIGH-PRESSURE SODIUM LAMP

The high-pressure sodium (HPS) lamp is based on the principle of an electric discharge in sodium vapor at high pressure. The electrons excite sodium atoms, which emit luminous radiation at sodium characteristic wavelengths [1]. Its constructive aspect presents an inner arc tube light transmitting, sodium resistant and high melt point compounded where discharge occurs. There is also an outer envelope bulb that protects the discharge tube metal parts from chemical attack and external temperature variations. The discharge tube contains a mixture of basically sodium and xenon gas, where xenon is used to improve luminous efficacy and facilitate ignition. Despite the low color rendering index (CRI) presented by sodium lamps (about 25), its luminous efficacy is high, standing between 100 – 130 lumens per watt, making it the better choice where efficiency is desirable instead of color quality. Figure 1 shows a typical HPS lamp. This lamp needs a high-voltage, high frequency pulse to start, since it does not have starting electrodes. Also, it requires a considerable warm-up time, up to steady state vapor pressure and full light output. So a special device with igniter and current controller is needed to properly operate the lamp.

III. ACOUSTIC RESONANCE

The high frequency operation of HPS lamps can cause the appearing of standing pressure waves called acoustic resonance. As a consequence from this phenomenon the discharge arc can become unstable, changing its position inside the discharge tube, changing color light and flickering, leading arc to extinguish. In some cases the acoustic resonance can be hard enough to cause the arc to touch and break the discharge tube, due to local overheating [1]. To avoid the occurrence of acoustic resonance, the proposed ballast will operate at 30 kHz switching frequency, which leads to 60 kHz power frequency at the lamp and also avoid audible noise.

IV. POWER STAGE

The power stage comprises a half-bridge inverter and a LC series resonant filter to provide a high-frequency AC waveform to the lamp.

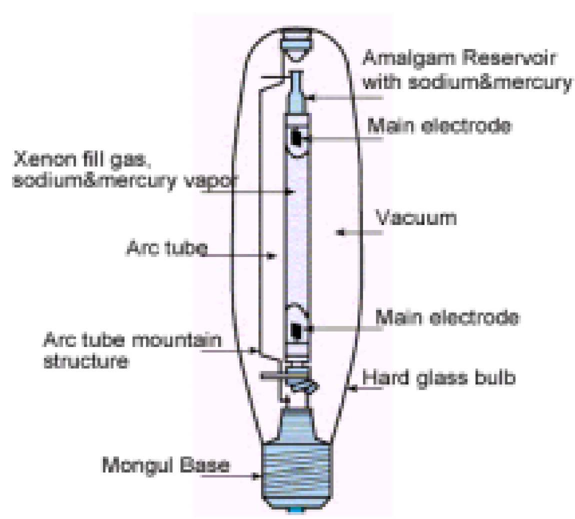

Figure 1 – High Pressure Sodium Lamp

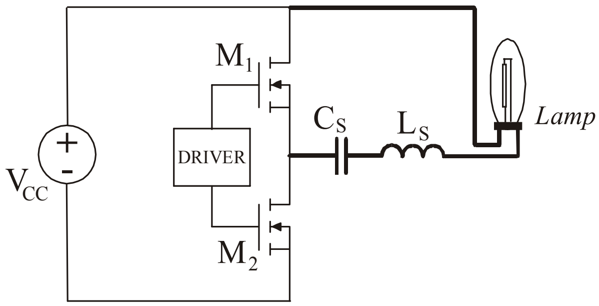

Figure 2 – Typical half-bridge inverter

AC line source sinusoidal voltage at 60 Hz is rectified, filtered and delivered to a bus controlled by two switches, in that case power MOSFets. By applying a control signal at MOSFet's gate, it can be turned on until the control signal is off. So, switching alternately both switches of the inverter, we can generate a square wave high frequency signal to feed the lamp. The resonant filter acts like band-pass filter, filtering the high-level harmonics in the signal, providing only sinusoidal waveform to the lamp.
The power delivered to the lamp can be estimated by considering the circuit in Figure 3, and can be expressed as:

$$P_1 = \frac{2V_B^2 R_1}{\pi\left[\left(\omega_s L_1 - \frac{1}{\omega_s C_1}\right)^2 + R_1^2\right]} \tag{1}$$

where V_B is the inverter bus voltage, $\omega_s = 2\pi f_s$, f_s is the switching frequency and R_1 is the lamp resistance. This calculation assumes that the lamp is a pure resistance (R_1), as stated previously [2], [3]. The current lamp is controlled by the LC series resonant filter, which is calculated through the abacus given by

$$\frac{\omega_s L_1}{R_1} = \sqrt{\left(\frac{2V_B^2}{\pi^2 R_1 P_1} - 1\right)} + \frac{1}{\omega_s C_1 R_1} \tag{2}$$

which is the equation (1) rewritten to a form more like the abacus built by [2] and showed in Figure 3.

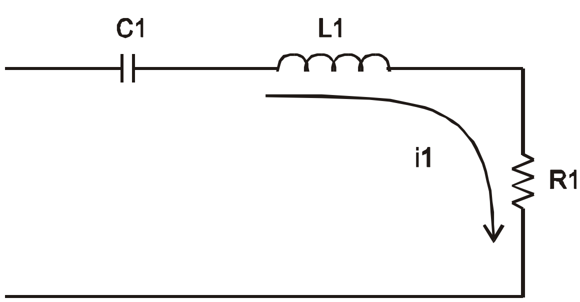

Figure 3 – Resonant Circuit

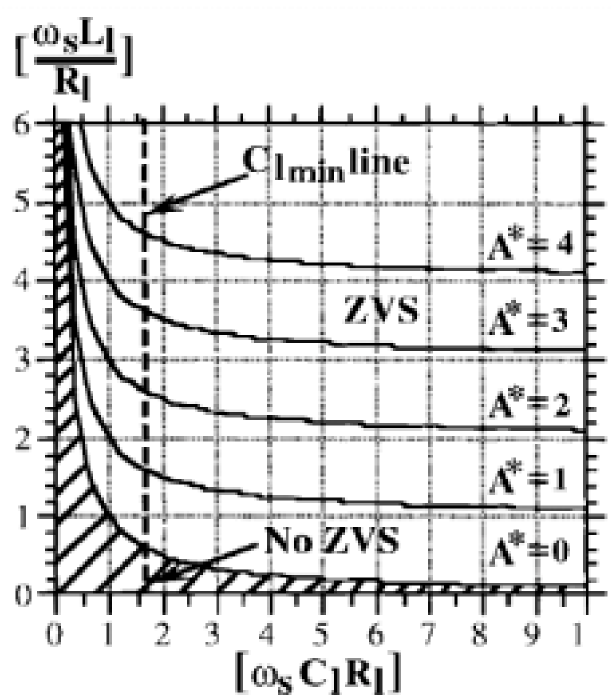

Figure 4 – Abacus to find L and C

V. AUTOMATIC DIMMING

Using a dimming method proposed in [5], where is possible to dim the self-oscillating by the frequency variation with a branch put in one of the switches, we intent to vary the branch resistance with a LDR to control the current through the branch. The method consists in control the current applied at the transistor gate from a secondary winding coupled with the resonant inductor L. The current control occurs through the LDR connect in series with the transistor gate. So, a LDR resistance reduction results in a current increase in the gate, consequently a switching frequency increase and a reduced luminous flux in the lamp is observed. The R resistor controls the luminous intensity and the C2 capacitor has a high capacitance so the ignition goes on the maximum power level and the luminous variation occurs gradually.

VI. IGNITER

To start the HPS lamp, a high-voltage pulse has to be applied at the lamp terminals. An LC series resonant inverter cannot generate such pulse by itself, becoming necessary an external device that do it. This is achieved by inserting a high-voltage pulse generator circuit in series with the lamp. An electronic igniter is mainly driven by a SIDAC, that is like a DIAC with higher breakout voltage levels. When voltage over SIDAC reaches the breakout level, the component fires a voltage pulse over a transformer, which generates the high-voltage required to start the lamp. Once the lamp is on, a protection circuit stop the SIDAC circuit to being charged.

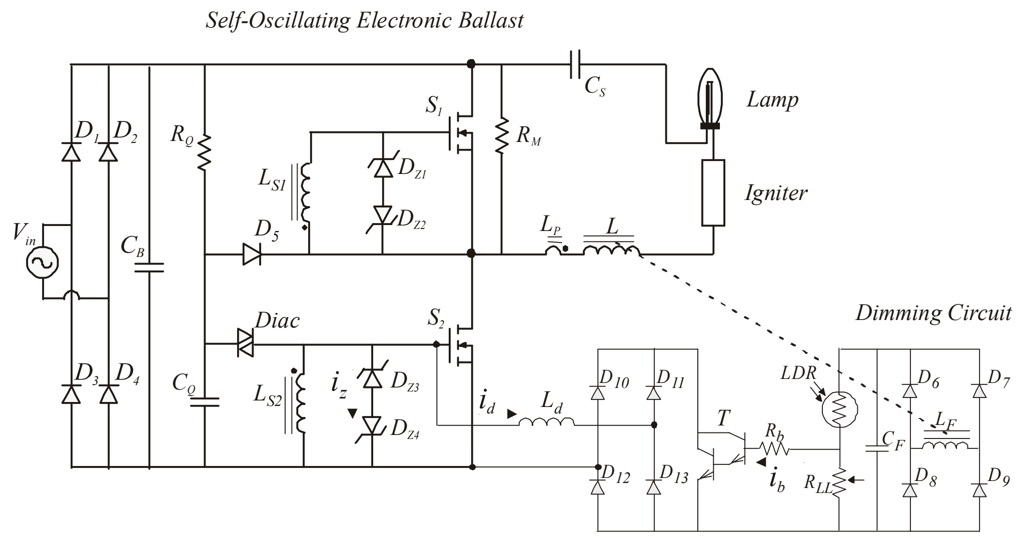

Figure 5 – The Proposed Circuit

VII. SELF-OSCILLATING DRIVER CIRCUIT

A saturable transformer that generates control signals to the switches is the basics of the self-oscillating switch driver. The primary winding of the transformer is connected in series with the resonant tank, generating signal at the secondary windings. The signal is clamped by zener diodes resulting in a square waveform. Once the circuit oscillation has been started, the resonant current drives the inverter switches alternately in a self-sustained form. The transformer used is a high permeability saturable toroidal core, and the death time between the control pulses is achieved by core saturation. The self-oscillating control circuit design was made based on a method described in [4], using control tools and stability analysis.

VIII. EXPERIMENTAL RESULTS

The ballast was built based on the principles discussed above. With input and lamp parameters the output voltage was determined. By the analysis explained in [2] the *L* and *C* values were found. Also, by the method described in [4], the saturable current transformer was obtained. The circuit was simulated with a resistance, assuming the high-frequency steady state lamp behavior.

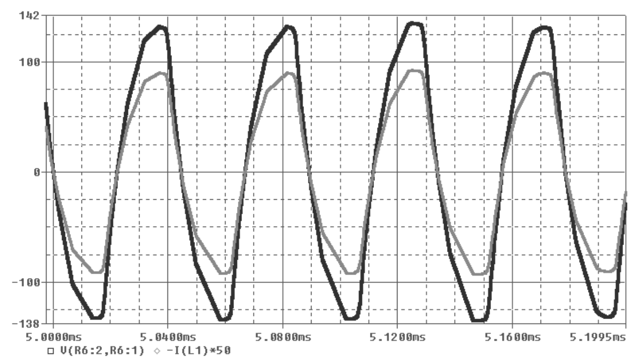

Figure 6 – Simulated Lamp Voltage and Current

The prototype built presented the following waveforms:

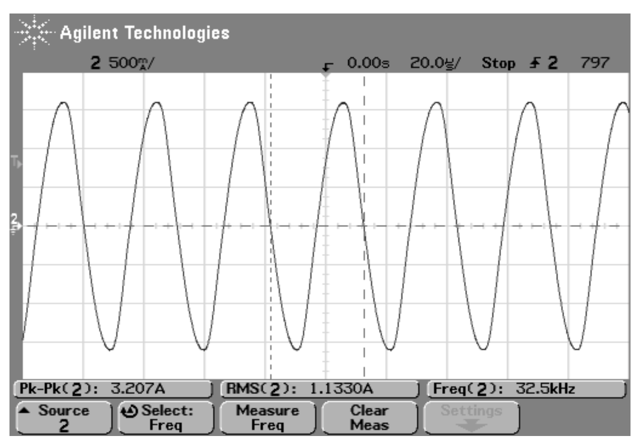

Figure 7 - Lamp Current

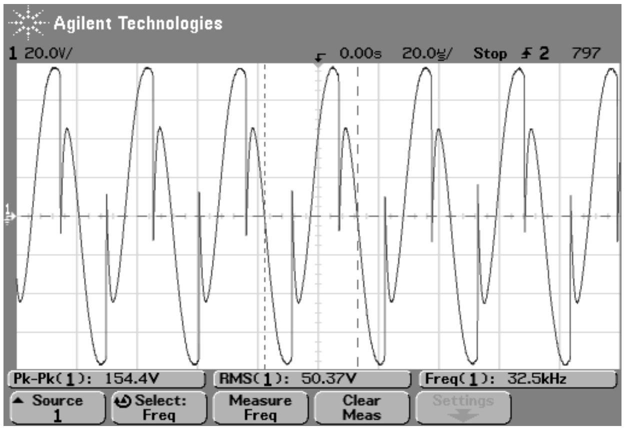

Figure 8 – Lamp Voltage

CONCLUSION

The proposed circuit was built and tested. The theoretical analysis reveals its feasibility, but in practical there are some difficulties to be overcame. The auto dimming has to be designed to operate in a region free of acoustic resonance, as the circuit changes the ballast output frequency. The circuit is a very low cost solution, because don't need electronic driver to control switching and still has dimming capability. The circuit seems to be a good option where a high efficacy low cost application is needed, such as parking, street and public lighting, as well as for indoor applications where the HPS lighting is desirable.

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