MICROCONTROLLED ELECTRONIC GEAR FOR HID LOW POWER METAL HALIDE LAMPS

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***Abstract* – This paper presents an electronic control gear for metal halide lamps that operates with a low frequency current inverter to drive the lamp, and a DC-DC buck converter to control the lamp current and the power. All signals of the power stages are provided by a dedicated microcontroller. An overview of the lamp operation phases and the strategies to avoid acoustic resonance are mentioned. A 70W prototype without acoustic resonance and stroboscope effect was implemented. The approach can be easily extended for other rated power and other high intensity discharge lamps.**

I. INTRODUCTION

The high intensity discharge (HID) lamps present features of high lighting efficiency, longer lifetime and good color rendering, which become them relevant in industrial light system. They are now starting to get a new market, the commercial establishments, with low wattage metal halide (MH) versions (35 up to 150W), which are replacing the fluorescent and halogen lamps used at this time. Due to the negative impedance characteristic of the lamps, a device to limit the current should be used. Normally an electromagnetic ballast is applied. However, they have a high size and weight, low efficiency, poor power regulation and sensibility to voltage changes [1, 2, 3]. Electronic ballast can overcome all these drawbacks.

At a glance, high frequency operation (dozens up to hundreds of kHz) is the best choice for the electronic ballast inverter stage, because the resistive behavior of lamps at high frequencies. Therefore, the pressure waves effect into the tube, called acoustic resonance, can happened. This phenomenon perturbs the discharge path, causing: arc bowing and snaking, flicker, changing in the color temperature, and in the worst case the arc can be extinguished. The acoustic resonance depends on the lamp tube geometry and dimensions, gas composition and thermodynamic conditions of the gas (temperature, pressure and density)[1, 4, 5].

In low wattage MH lamp, the frequencies of resonance occurrence are scatter over the entire practical frequency range and the free windows are very narrow. These facts restrict the operation of this lamp at high frequency. Considering yet the presence of many manufactures in the lamp market, the tolerance in the production process and the changes in thermodynamic conditions of the lamp during lifetime, it is impossible to predict the acoustic resonance in this type of lamps. Some solutions were presented in the literature in order to employ electronic ballast driving high pressure discharge lamps without acoustic resonance :

- high frequency operation (around 20 to 200kHz), into the narrow windows free of resonance [2, 6, 7, 8]. This solution is usually used with sodium vapor lamps because their free windows are larger;
- extra-high frequency operation, where the resonance does not appear [1, 3]. In these cases the switching losses and the parasitic inductance and capacitance should be account in the design. The pre-determination of the lowest frequency above which acoustic resonance does not occur is still required for each lamp type, for 70W MH lamps this frequency is above 500kHz;
- the use of a modulation strategy circuit that modify the inverter frequency before the undesired phenomenon grows up. This is possible because the time constant of instability is greater than the switching period [4, 5, 9, 10, 11];
- low frequency operation (around 50 to 250 Hz), driven the lamp with a rectangular waveform, avoiding yet the re-ignition and improving the power factor of the lamp [11, 12].

Because its great simplicity, reliability, and mainly from the severe conditions of acoustic resonance that the low wattage metal halide lamps are submitted, the best choice in this case is the rectangular waveform low frequency inverter. Before discuss the proposed electronic gear, the operation phases will be described in the next section.

II. OPERATION PHASES OF THE LAMP AND CIRCUIT CHARACTERISTICS

The operation of HID lamp can be described in three distinct phases: starting, warm-up and nominal power operation. On the other hand, the starting of these lamps consist of the following phases: breakdown, glow discharge, glow to arc transition.

An adequate high ignition voltage is needed to the electrical breakdown of the starting gases within the arc tube. The lamp can be ignited by high voltage pulses from an ignitor circuit or by a high frequency resonant circuit. The first solution is more interesting for operation with low frequency inverters, because do not need to change its operation frequency during the start up. The amplitude of ignition voltage depends on many factors, such as: arc tube geometry, gas composition, electrode material, and vapor pressure and temperature. Under normal thermodynamics conditions the MH lamps need around 4kV pulse ignition voltage, which increases a lot after few minutes of operation. For this reason a re-ignition wait time is required [13, 14, 15]

Normally, the initial breakdown causes a glow discharge to take place. During this phase few light is emitted, and the lamp has a positive impedance characteristic. The source has to supply enough energy to warm-up the electrodes and still sustain the arc. The end of starting process is the glow-to-arc transition, which is considered the critical phase. This fact occurs because the high voltages and low currents from the glow discharge change to low voltages and high currents of thermionic arc, due to the continuous ionization [16].

After glow to arc transition starts the warm-up phase, when the electrons collisions maintains rising the temperature of the arc tube, vaporizing the metal and increasing the pressure. During this phase that may last many seconds, the voltage over the lamp increases and the current must be limited. Finally, when a full high-pressure arc is established, the temperature and brightness have reached their equilibrium.

During the lamp lifetime, the final lamp voltage rises, increasing the lamp power and reduction the lamp lifetime. This problem is particularly excessive in high pressure sodium and metal halide lamps [17, 18, 19].

For an electronic control gear the current should be maintained constant during the warm-up, resulting in a reduction of this phase time. When the power reaches the rated value it starts to be controlled either to compensate the voltage lamp increasing and the utility line voltage variation. The desired lamp current (I) and power (P) versus lamp voltage characteristics for an electronic control gear is illustrated in Fig. 1, where all values should be considered as rms values.

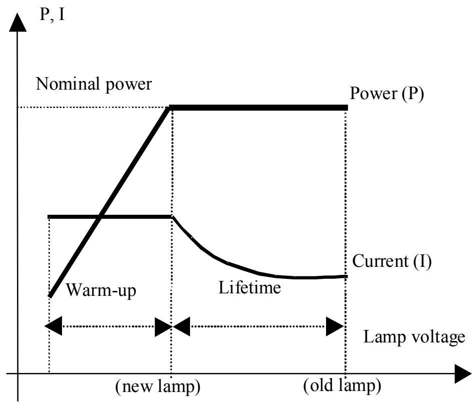

Fig. 1 – Lamp current (I) vs. lamp voltage and the lamp power (P) vs. lamp voltage.

III. THE PROPOSED ELECTRONIC CONTROL GEAR

The Fig.2 shows of the proposed electronic control gear structure. It is formed by: 1. power factor pre-regulator; 2. DC-DC buck converter, operating at high frequency that controls the current and the power of the lamp; 3. the low frequency rectangular wave current inverter to drive the lamp; and 4. the ignitor circuit. A dedicated Microcontroller performs the control signals of all structure.

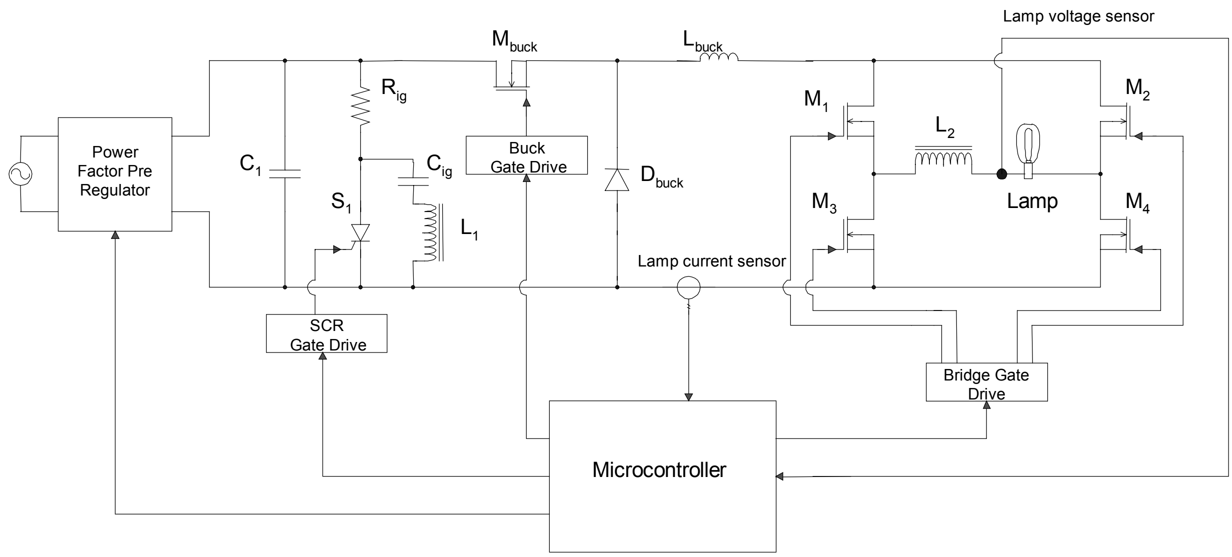

Fig. 2 - The proposed electronic control gear

The inductance of the buck converter, L_{buck}, must be designed to ensure a high frequency current ripple less than 5%, to prevent the acoustic resonance [11].

This circuit supplies a 70 W metal halide lamp, but it can be designed to operate with other rated power and also with high pressure sodium lamps.

A high performance RISC CPU microcontroller (PIC16F873 from Microchip) has been used, operating at 18.432 MHz clock input. This device has some inner peripheral, such timers, 10 bit multi-channel analog-to-digital (A/D) converter and PWM modules.

The microcontroller timer interrupt capability performs the signals for two IR2110 gate drive of the full bridge current inverter and still control the ignition pulse sequence.

The A/D converter measures the lamp voltage and current to be processed by the main software, that contains a digital Proportional – Integrated (PI) control routine. The output of this routine is the value of buck converter duty cycle, which is loaded into PWM module. The flow chart of implemented software routine is shown in Fig. 3.

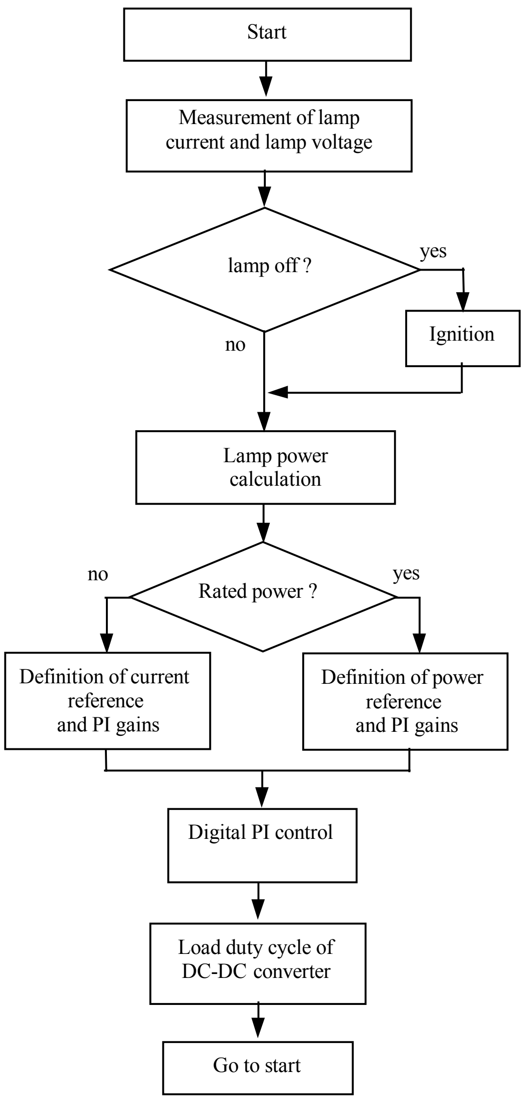

Fig. 3 – Implemented flow chart

The electronic control gear is able to:

- provide an appropriate voltage to start the discharge. The high voltage pulses are obtained when the S_1 thyristor is turned on, through the resonance between C_{ig} and L_1. A 1:10 ratio between the coupled inductances L_1 and L_2 ensure the high voltage ignition pulses;

- command the ignitor circuit properly, so that during a re-ignition sequence the microcontroller provides ignition pulses for a short time interval (5 seconds) followed by a long interrupt time interval (75 seconds). This procedure enable a quicker cooling down of the lamp and as a consequence their earlier re-ignition, reducing the duration of the unsuccessful ignition periods, when compared to the conventional ignitor circuits [20];

- provide the constant current to the lamp during the warm-up time, through a digital current PI control, acting over the duty cycle of the switch M_{buck}. By increasing the input reference current makes possible the reduction of the warm-up time either.

- after the warn-up, compensate the lamp voltage rising during the lamp lifetime and the utility line variations, through a digital power PI control acting over the duty cycle of M_{buck} ensuring constant power to the lamp.

- control the output luminous flux of the lamp, by changing the input power reference. The output power can be changed from 45W to 70W without arc extinguish. This power reference can be easily changed remotely from serial port available in the microcontroller, which is a great advantage for street and large areas lighting systems.

IV. EXPERIMENTAL RESULTS

An electronic control gear has been built to meet the following specifications:

- rms AC mains voltage: $V_{in} = 220V \pm 15\%$, 60Hz;
- output power: $P_o = 70W$;
- DC-DC switching frequency: $f_s = 50kHz$;
- inverter switching frequency: $f_s = 150Hz$;
- ignition lamp voltage: $V_{ig} = 4kV$.

This section presents experimental results of a 70W ballast prototype for MH lamp. Fig. 4 shows the lamp voltage and lamp current during the starting, immediately after the breakdown, emphasizing the glow discharge, glow-to-arc transition and the thermionic arc.

Fig. 5 shows a detail of the lamp voltage and current at rated power, where the rectangular voltage and current waveforms can be seen.

Fig. 6 shows the current, the voltage and the power of the lamp during the first two minutes. This figure shows the PI control maintaining constant the current during the warm-up. After that, is shown the constant power. Finally, Fig. 7 shows the evaluation of lamp voltage and current after a power reference step down from 70W to 50W.

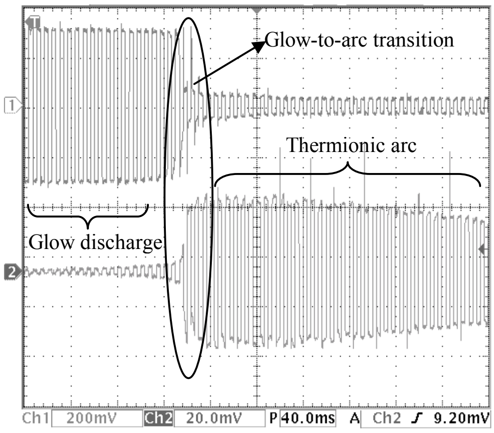

Fig. 4 – Lamp voltage (top trace) and lamp current (bottom trace) during starting phase. (100V/div., 4A/div., 40ms/div.).

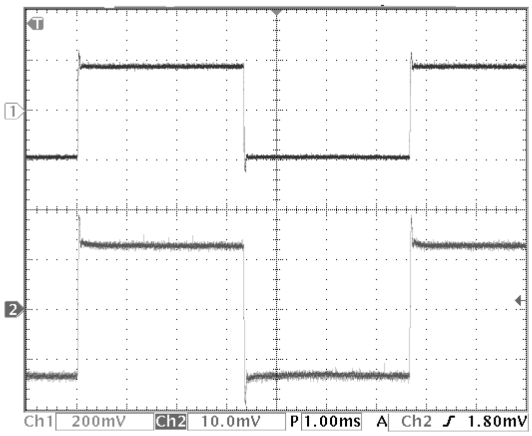

Fig. 5 Lamp voltage (top trace) and lamp current (bottom trace) at rated power operation. (100V/div., 0,5A/div, 1ms/div).

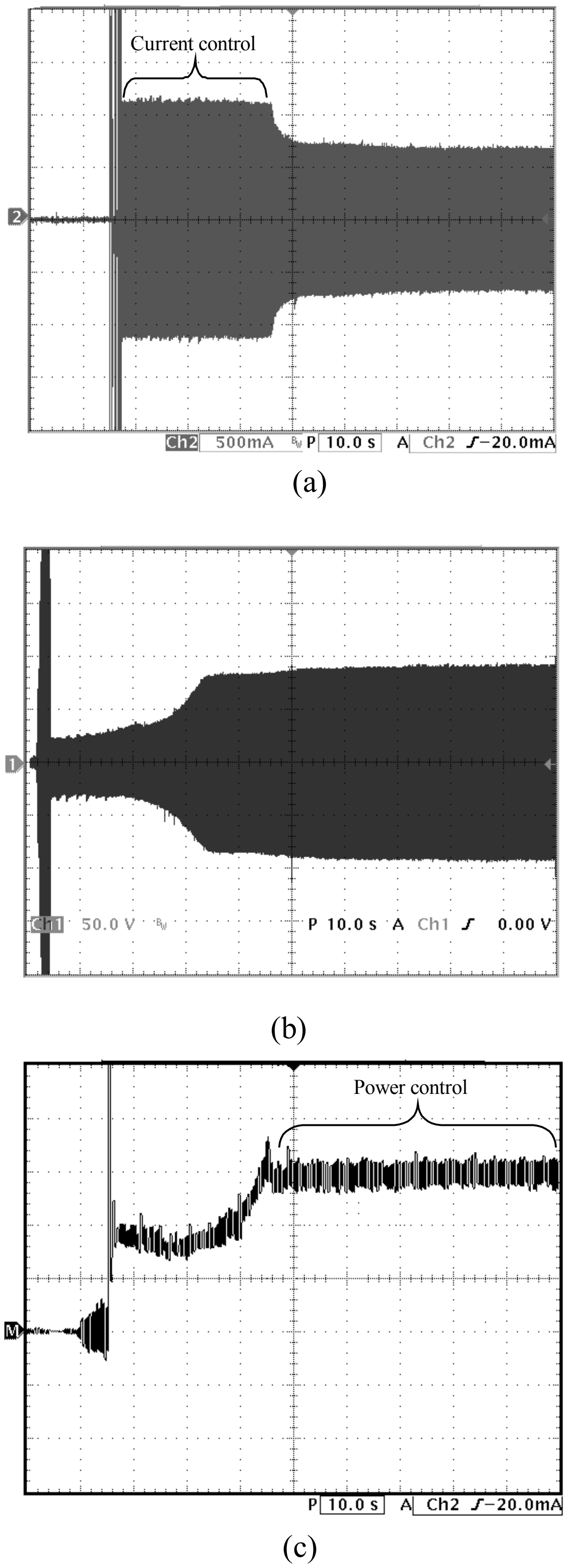

Fig. 6 – Control action during the operation phases of the lamp. (a) lamp current (0,5 A/div, 10s/div), (b) lamp voltage (50 V/div, 10s/div) (c) Lamp power (25 W/div, 10s/div)

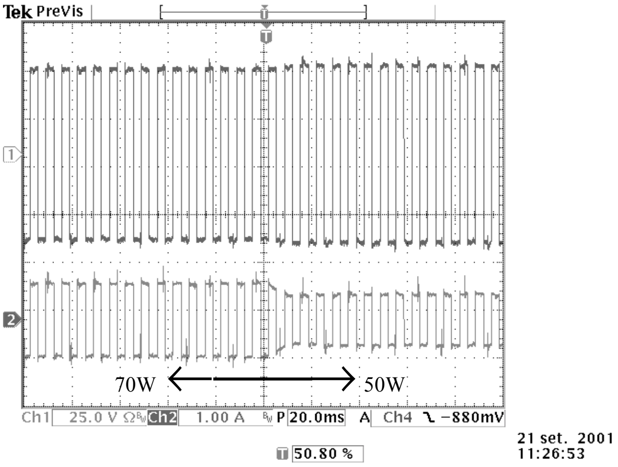

Fig. 7 - Lamp voltage (top trace) and lamp current (bottom trace), during a power reference step down. (100V/div., 0.5 A/div., 1ms/div).

V. CONCLUSIONS

An electronic control gear for metal halide lamp has been presented. It is based on low frequency (150Hz) current inverter, and is fully controlled by a dedicate microcontroller. A DC-DC high frequency (50kHz) converter is used as an intermediate stage. A 70W prototype 70W was built, showing the appropriated operation during all lamps' phases.

The use of a microcontroller becomes simple the circuitry and the control task, allowing:

- to compensate the increase of the voltage lamp during lamp lifetime and the utility line variation;
- luminous flux control;
- warm-up time reduction;
- re-ignition time reduction;

The low frequency rectangular current waveform assures the operation free of acoustic resonance and no re-ignition of the lamp in each cycle. Therefore, no stroboscope effect takes place. Besides that, the design for other rated power and lamp type can be approach in a simple way.

VI. ACKNOWLEDGEMENT

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