METAL HALIDE ELECTRONIC BALLAST WITH POWER FACTOR CORRECTION AND CONSTANT POWER AT THE LAMP

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Abstract **– This paper introduces an electronic ballast for 250W metal halide lamp designed to present as mainly features: high power factor, lamp power control, dimming, self turn-on and turn-off, output short-circuit protection and acoustic resonance avoidance.**

This work is part of a study that is developing electronic ballasts for different kinds and power of High Intensity Discharge lamps, like high pressure sodium lamps, metal halide lamps and mercury lamps.

The biggest challenge found was acoustic resonance phenomenon, whose behavior is still more problematic than that one registered in sodium lamps because of discharge tube shape. This fact leads to the need to develop new strategies to overcome acoustic resonance consequences.

Keywords – metal halide, electronic, ballast, acoustic resonance.

I. INTRODUCTION

An electronic ballast for 250W metal halide lamp is introduced. It presents important features that ensure high quality circuit performance. Among then it is interesting to cite:

- High power factor, obtained through a boost converter operating in CRM – Critical Conduction Mode.
- Lamp power control and dimming obtained varying lamp current frequency using a microcontroller.
- Self turn on and turn off using a simple photo-diode sensor connected to the microcontroller.
- Output short-circuit protection warranted by LC output filter project.
- Acoustic resonance avoidance based in special modulation, even under high frequency lamp current.

All of features mentioned above can be considered important; however acoustic resonance avoidance technique is undoubtedly the most important one. This can be easily observed in works like that ones showed in [1] and [2], where mainly preoccupation is to avoid it.

A. Acoustic Resonance

As known, if a HID lamp is driven by an AC power source, the discharge electric properties depend on ballast frequency. After lamp ignition and arc stabilization, the lamp impedance changes continuously during an AC cycle, if the lamp is operated on mains frequency (50/60Hz). Notwithstanding, its operation with high frequency electronic ballasts can cause the arc instability appearance, kwon as acoustic resonance.

The frequency range operation susceptible to acoustic resonance is usually between 1kHz and 300kHz and its origin is usually related to the periodic power supply that results in gas pressure fluctuation at the same frequency. If this frequency coincides to arc discharge tube frequency resonance, stationary waves are generated and arc is bowed [5].

These gas density oscillations can cause several problems to the lamp, like arc instability, light output fluctuation, color temperature, color point variations, arc extinction and, in the worst case that happens with high pressure sodium lamps, crack the arc tube.

Based on all of these facts it is easy to conclude that many circuits already have been proposed to avoid resonance, but most of then provides low frequency current lamp to avoid it, as can be seen in [1] and [3].

II. PROTOTYPE

A complete prototype circuit has been developed and its presentation is divided in three stages.

A. Input Stage

As known, usually electronic ballasts input stage is composed by traditional full-bridge rectifier circuits followed by a great capacitor, that leads to high harmonic current distortion and low power factor. Several techniques already have been proposed to improve electronic ballasts power factor, as bus capacitor reduction [4], passive filters [6], valley-fill and boost converter operating at discontinuous conduction mode (DCM), critical conduction mode (CRM) [7] and continuous conduction mode (CCM) [1] and [8]. Each one of them presents qualities and limitations that would have been practical e theoretically analyzed and, through obtained results, a CRM boost converter controlled by a L6560 has been chosen because it presents:

- Low cost implementation.
- Simple design procedure.
- Good power factor at 250W, without large switch current and losses.
- No special auxiliary source need.

Besides, the mainly reason to choose boost converter (see Fig. 1) as the adopted solution was the need to work with input voltages between 180V and 250V.

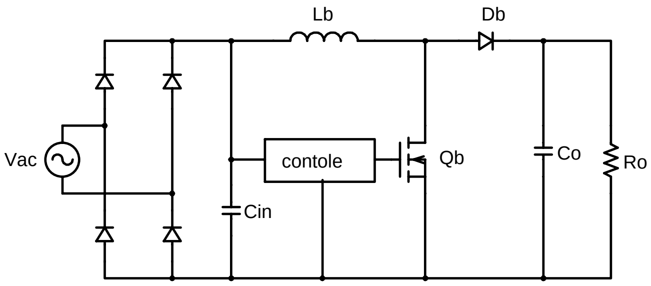

Fig. 1. Generic Boost Converter.

Prototype design still used nominal power equal to 260W and minimal frequency commutation equal to 25kHz as design parameters.

B. Output Stage

It is possible to find several different electronic ballast output stages at the literature, whose mainly differences are number of switches, output filter and control strategies. As this prototype is intended to be used as a commercial circuit, a half bridge inverter, with a traditional LC series filter has been chosen [9]. This circuit is presented in Fig. 2.

Adopted LC filter design procedure protects ballast against short-circuit problems, because used parameters allow a maximum current circuit level under the maximum admissible switches current.

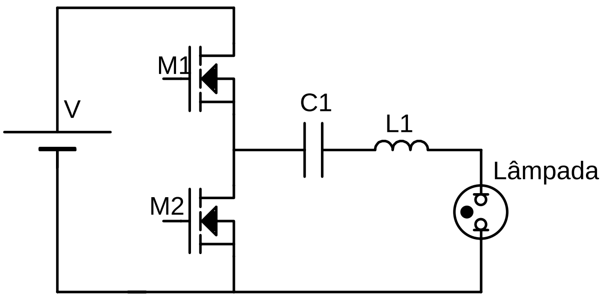

Fig. 2. Inverter – Output Stage.

Inverter switches control is done by a PIC 16F716 microcontroller, whose software presents the following mainly features:

- Generation of complementary switch signals with 0.5 duty cycle.
- Self turn-on lamp after 10 seconds if light sensor detects that daylight decreases.
- Self turn-off lamp after 10 seconds if light sensor detects that daylight increases.
- Ignition test routine, that maintains power circuit enabled during 60 seconds to try to ignite the lamp. After this time, if lamp doesn't strike, power system is disabled during 60 seconds. This process is repeated 5 times because lamp ignition trouble can be related to lamp temperature. So, circuit is definitively disabled if lamp doesn't strike after fifth tentative.
- Lamp power maintenance through CPL - control lamp power routine, that vary switches frequency commutation with purpose to warranty stable lamp power level. The power value is based on signals provided for simple transducers incorporated to the electronic ballast circuit.
- Special modulation loop generates current lamp inversion, spreading power spectrum. At this situation, lamp is operated under minimized power density of individual harmonics, what reduces chances to excite acoustic resonance phenomenon. It is important to say that special modulation is not applied during the begin of process because it borrows lamp strike.

C. Ignitor Circuit

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

Like happens with high-pressure sodium lamps, metal halide lamps must be ignited with a high-voltage pulse that needs sufficient amplitude and appropriate width and rise time [10]. In low frequency ballasts, this ignition voltage is usually obtained through a separate electronic device, which is part of the control gear circuit.

Results presented in [11] demonstrated that the technique using the voltage pulse is the best option to the developed half-bridge inverter prototype, since it presents smaller sensitivity to the parasitic parameters. Simplified circuit is presented at Fig. 3.

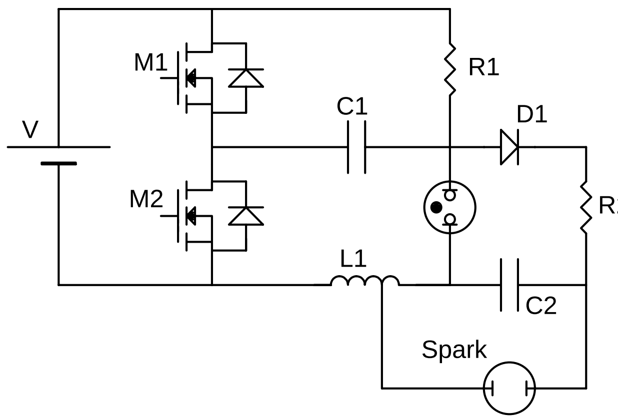

Fig. 3. High-frequency inverter with integrated igniter circuit.

Working description circuit details already have been presented in [11] and will not be repeated.

D. Acoustic Resonance Avoidance Strategies

Experimental results demonstrate that acoustic resonance in metal halide lamps appears easily and strongly than in high-pressure sodium lamps.

During the startup, when gas temperature, pressure and composition change, the lamp arc behavior crosses through several conditions were phenomenon manifestation is registered, ratifying the need to use acoustic resonance avoidance techniques.

Even been a consecrated solution to avoid acoustic resonance, low-frequency square-wave electronic ballast [12] has been discarded because it usually demand bigger, heavier and more expensive circuits.

A second possible approach is based on the fact that is possible to find some power frequency bands were no resonances are detected but it can not be used in this prototype because frequency commutation is changed to control lamp power. Besides, some experimental results demonstrated that free bands changes strongly among different manufacturers.

To spread power spectrum is purposeful used to avoid acoustic resonance too, and can be obtained through lamp frequency current variation [10] or through current phase variation or inversion [13].

Even been easily to be implemented than current phase inversion, frequency variation technique can not be applied because of CPL routine, that limits possible frequency range, reducing the power spectrum spreading.

Based on this set of evidences, spread power spectrum through lamp current inversion has been chosen as the solution to be adopted at the developed prototype.

III. SOFTWARE ROUTINES

At this section, three main routine used at the PIC microcontroller's software are detailed discussed.

A. CPL - Control Lamp Power Routine

This software routine is executed at each 60 seconds to maintain lamp power constant and equal to 100% of nominal lamp power when dimming routine is not applied; or equal to 60% of full lamp power if dimming routine is running.

Lamp voltage is obtained through a simple resistor divider placed in parallel to the lamp and lamp current sample comes from a current transformer implemented using a toroidal ferrite core. These signals are interpreted by the microcontroller through A/D converter.

Once measured voltage and current, lamp power is mathematically calculated and slowly correct through frequency change. For this reason, lamp current frequency is slightly changed always that CPL routine is executed, what can help to avoid acoustic resonance.

The range frequency variation is limited between 50kHz and 75kHz.

Control lamp power routine showed excellent performance with new or old lamps. Lamps from three different manufactures have been tested. Moreover, experimental results demonstrated that, in reason of the CPL routine, very old lamps whose arc where extinguished when operated by traditional magnetic ballasts, could be used without problems, increasing lamps life time and reducing maintenance expenses.

B. Dimming

At the actual days there is an increasing demand to maximize energy savings of lighting sources, so many users would like to further increase the energy savings of HID lamps through dimming. For this reason, manufactures are already paying attention about this possibility [14].

Dimming method applied at this circuit is called bi-level dimming, in which HID lamps is run in a low mode of reduced lamp power when less light is required. Lamps are then switched to 100% lamp power when full illumination is needed. It procedure application uses the following operational guidelines proposed by [14]:

- Lamp must be started in full-power mode and must be operated in that mode for a minimum of fifteen minutes prior to reduced-power operation. Because of this, developed system maintains lamp operating with 100% lamp power during twenty minutes after starting.
- Minimum open circuit voltage of dimming system must meet ANSI requirements in both high or low modes of operation.
- Minimum lamp operating wattage indicated in this case is 138W. If operated below these wattages, the bimetal switch that normally shorts the main and starting electrodes in standard type lamps may not function properly, and this could result in rupture of the arc tube. At the developed prototype minimum lamp power adopted is 150W.
- HID lamps should not be held in the dimmed mode for extended periods of time. For this reason, periodic cycling to full power is recommended. At the dimming routine at each sixty minutes, lamp power is changed to full power condition during five minutes.
- Rated life of HID lamps is the total burning time in dimmed and full-power modes.
- Dimming technique should not bee applied during period of time considered important. To attend this recommendation, the times presented at the table I are observed:

TABLE I
Dimming Periods of time

Power Variation According to the Need	
Time	**Power**
Startup	Lamp is operated with nominal power during twenty minutes, when is turned to dimming power (60%) in function of the peak period.
08:00 pm	Full-power (100%) in function of the high number of pedestrian usually registered.
00:30am	Dimming condition (60%) in function of the small number of pedestrian usually registered.
05:30 am	Full-power (100%) because many people start working at this time.

These intervals of time can be easily changed in function of region seasonality or local standards or necessities.

C. Special Modulation

As stated before, a previous theoretical study demonstrated that special modulation by current phase inversion is the best option to the developed circuit. This technique has been previously proposed by [13] as a solution to avoid acoustic resonance in metal halide lamps operated in high-frequency.

Angle of inversion should vary among 90º and 180º. Several of them were tested, but better results were obtained exactly with these bound angles. For this reason their results will be presented.

Current phase inversion can be obtained through instantaneous changes in the gate voltages duty-cycle, as can be seen at Fig. 4.

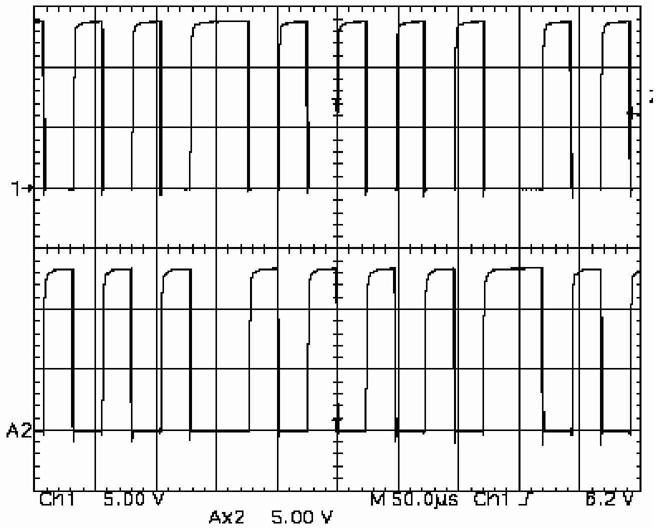

Fig. 4. Gate Voltage Signals.

Fig. 5 shows theoretical lamp current using 90º angle inversion.

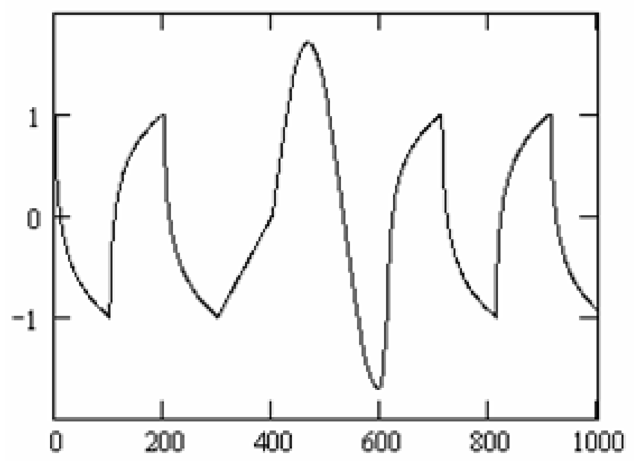

Fig. 5. Theoretical Lamp Current - 90º Phase Inversion.

This wave form analysis leads to the theoretical harmonic spectrum showed at Fig. 6.

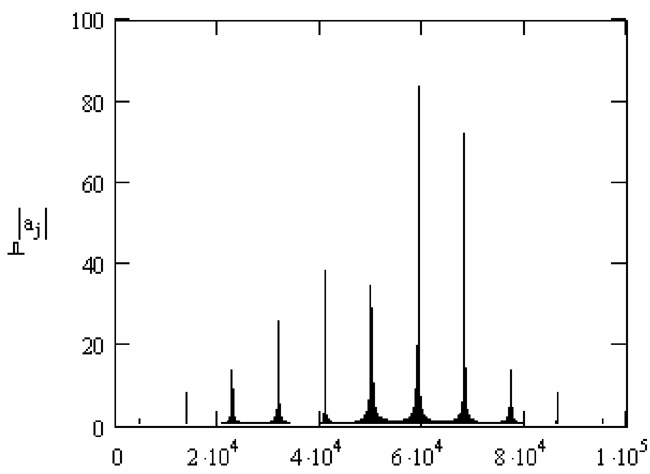

Fig. 6. Theoretical Lamp Current Spectrum- 90º Phase Inversion.

On the other hand, Fig. 7 shows theoretical lamp current obtained when 180° current inversion is used.

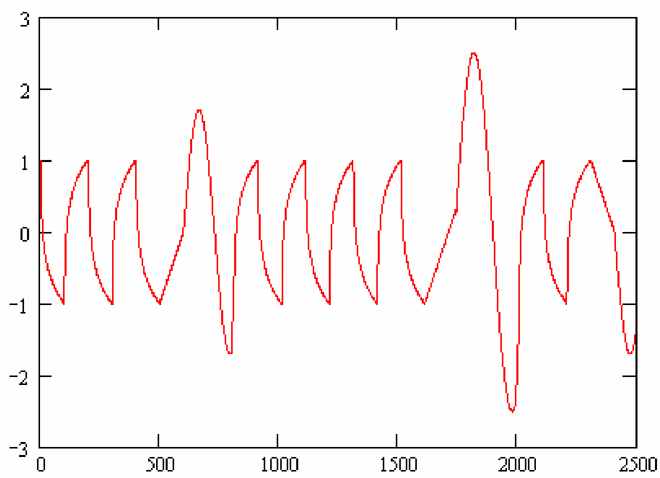

Fig. 7. Theoretical Lamp Current - 180º Phase Inversion.

Fig. 8 demonstrates that, theoretically, spreading power spectrum harmonic obtained with 180º is better than that one obtained with 90º inversion phase.

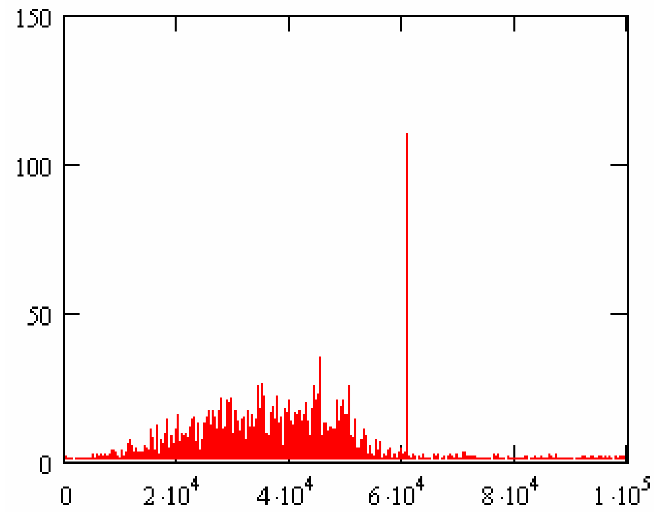

Fig. 8. Theoretical Lamp Current Spectrum - 180º Phase Inversion.

IV. EXPERIMENTAL RESULTS

Ten samples of lamps from three different manufactures and different ages were used to confirm experimental results.

Fig. 9 shows input voltage and current obtained with the prototype operating at nominal input voltage and nominal output power. Obtained current shape demonstrates the circuit quality.

Input current analysis using acquired data showed that final power factor is higher than 0.99 and TDH – Total Harmonic Distortion is smaller than 7%.

These values present small changes when input voltage varies between 180V and 250V.

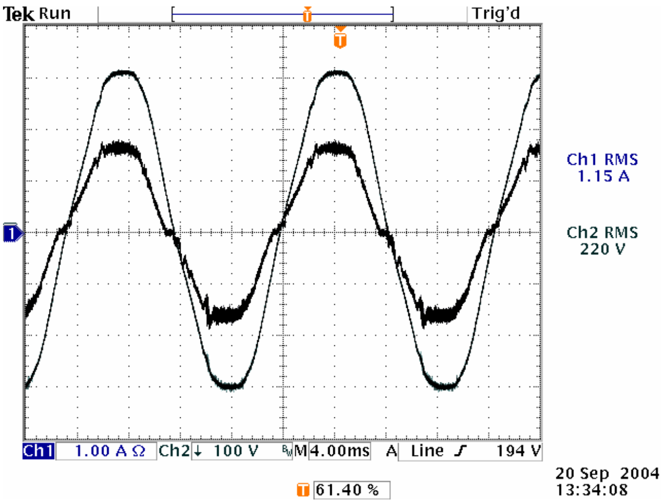

Fig. 9. Input Current and Voltage.

Ignition pulse voltage used to strike the lamp is showed at Fig. 10. It is interesting to register that older sample of lamps needed smaller voltage levels to ignite than newer ones.

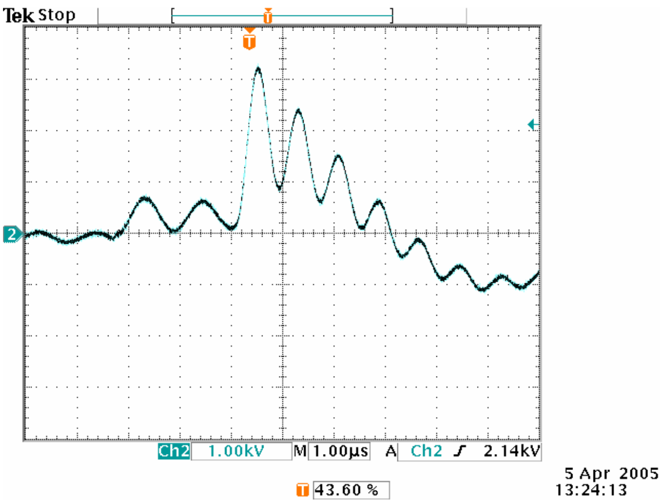

Fig. 10. Ignition Pulse Lamp Voltage.

Fig. 11 shows gate voltage and lamp current when 90° phase inversion is applied.

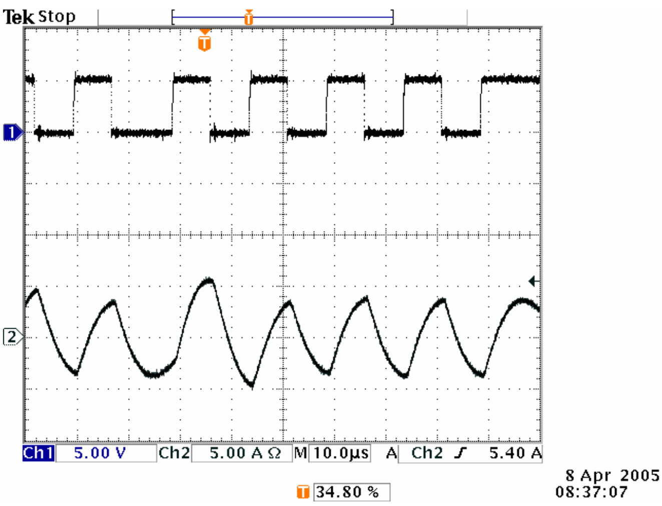

Fig. 11. Gate Voltage in One of the MOSFETS and Current Lamp – 90° Current Inversion.

Lamp voltage and current are presented at Fig 12, during 90º inversion transitory.

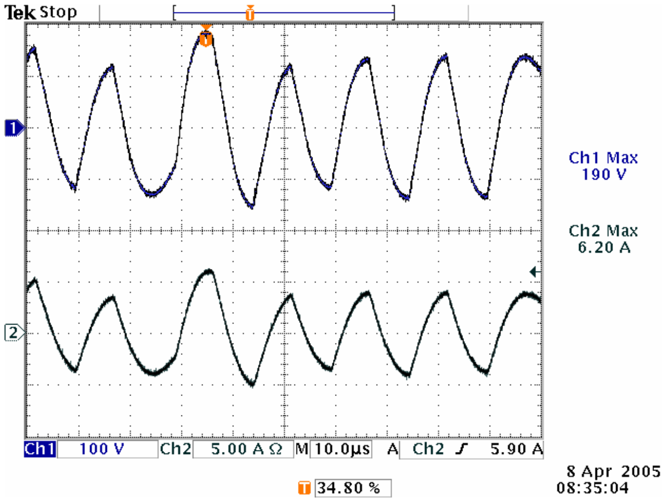

Fig. 12. Lamp Voltage and Lamp Current – 90º Current Inversion.

Fig. 13 confirms theoretical results, showing that power spectrum is not so spread using 90º current inversion. Practical results also demonstrate that three sample from the same manufacture presented strongly acoustic resonance even with 90º modulation applied.

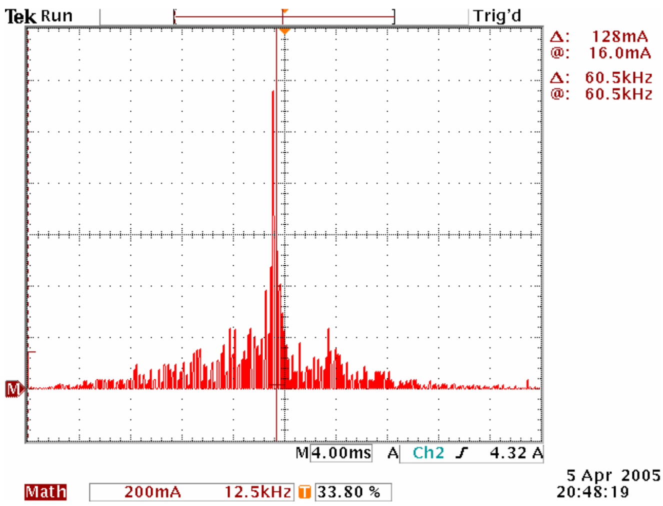

Fig. 13. Current Spectrum – 90º Current Inversion.

On the other hand, acoustic resonance were completely extinguished when this special modulation was used with other 7 lamps.

Intending to avoid acoustic resonance phenomenon in all of tested samples, 180º angle inversion phase also has been implemented and tested through small changes at the microcontroller software, as can be seen at Fig. 14.

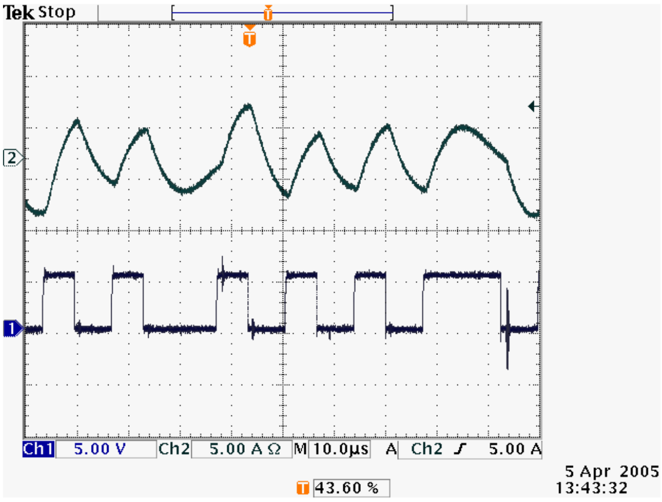

Fig. 14. Gate Voltage in One of the MOSFETS and Current Lamp – 180º Current Inversion.

Lamp voltage and current are presented at Fig 15, during 180º inversion transitory.

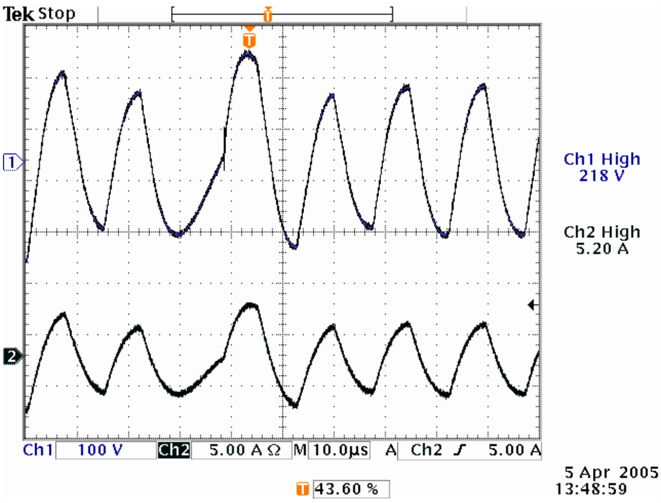

Fig. 15. Lamp Voltage and Lamp Current – 180º Current Inversion.

Fig. 16 confirms theoretical results, showing that power spectrum is better spread using 180º current inversion.

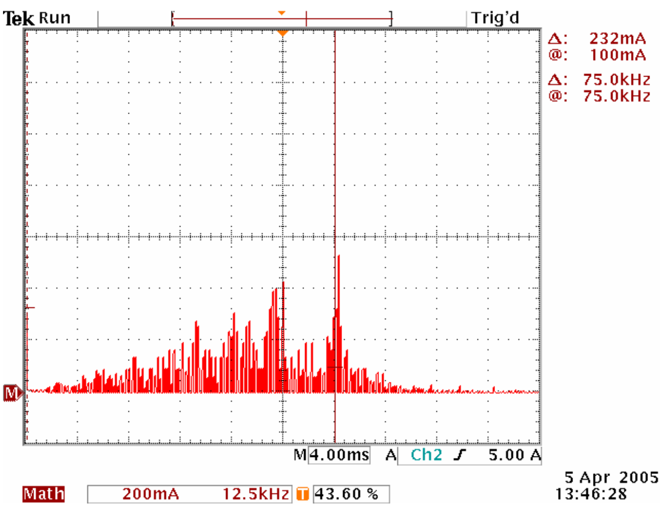

Fig. 16. Current Spectrum – 180º Current Inversion.

Practical results also demonstrate that same three samples presented acoustic resonance, notwithstanding its effect was slighter than that one registered with 90º current inversion.

V. CONCLUSION

A study about electronic ballast able to avoid acoustic resonance in metal halide lamps operated in high frequency was presented. The circuit's heart is a microcontroller that permits to obtain especial commutation techniques and control electrical lamp parameters.

Acoustic electronic avoidance is based on the spread spectrum and presented good results in all tests realized, extinguishing or decreasing acoustic resonance phenomenon. Notwithstanding, through the prototype results is possible to conclude that inversion current phase applied to metal halide lamps didn't present same performance obtained with high-pressure sodium lamps, because acoustic resonance appeared in three samples of lamps tested. New studs will be realized to improve actual results.

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