COMPARISON BETWEEN LOW FREQUENCY SQUARE WAVE ELECTRONIC BALLASTS FOR HID LAMPS

Márcio Almeida Có*, Márcio Brumatti*, Domingos S. L. Simonetti** and José Luiz F. Vieira**
* CEFETES - Federal Technologic Education Center of Espírito Santo
** Electrical Engineering Department - Federal University of Espírito Santo
Vitória – Brazil
marcio.co@uol.com.br, marcio_brumatti@bol.com.br, d.simonetti@ele.ufes.br, j.vieira@ele.ufes.br

Abstract – **Electronic ballasts for high intensity discharge (HID) lamps that impose low frequency square waveform current seem to be a good solution to avoid the acoustic resonance phenomenon. This paper presents a comparison between four low frequency square wave electronic ballast topology. The first topology uses three converters stages: the power factor pre-regulator, the DC-DC and the low frequency inverter. The other topologies are obtained integrating theses stages. Experimental results of a three stage and a single power processing stage electronic ballast are shown for a 70W high-pressure sodium lamp.**

KEYWORDS

HID lamps; microcontroller; ballast.

I. INTRODUCTION

The high intensity discharge (HID) lamps present features as high lighting efficiency, longer lifetime and good color rendering, which become them relevant in industrial light system. Due to the lamp negative dynamic impedance characteristic of the lamp, a device to limit its current should be used. Typically electromagnetic ballast is applied. However, it has high size and weight, low efficiency, poor power regulation, and presents high sensibility to voltage changes [1, 2, 3, 4]. 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, due to the high frequency resistive behavior of lamps. Therefore, the pressure waves effect into the tube, called acoustic resonance, can happen. 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 [1, 5, 6].

The acoustic resonance depends on the lamp tube geometry and dimensions, gas composition and thermodynamic conditions of the gas (temperature, pressure and density) [1, 7, 8]. Considering 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 hard to predict the frequencies of resonance occurrence.

Some solutions have been presented in the literature [1, 2, 3, 5-13], using electronic ballast to drive the HID lamps without acoustic resonance, including high frequency operation strategies. However, the low frequency operation driven the lamp with a square waveform seems to be a good solution due to its great simplicity, reliability and mainly due to the severe conditions of acoustic resonance that the low wattage HID lamps are submitted [4, 5, 13, 14].

Four topologies of low frequency square wave electronic ballast for HID lamps is discussed in the next section and are compared in this paper.

II. THE LOW FREQUENCY SQUARE WAVE ELECTRONIC BALLASTS

Topology A – Three Stage Solution: A low frequency square wave electronic ballast can be implemented by using three power-processing stages, as is illustrated in Fig. 1.a. The input one, called power factor pre-regulator (PFP) stage, is based on a boost converter operating in discontinuous conduction mode in order to obtain high power factor, maintaining the DC bus voltage constant. The intermediate stage is a DC-DC buck converter, operating at high frequency to control the lamp current and power. The output stage is a low frequency square wave inverter that drives the lamp [12,13,14,15].

The buck converter must be designed to operate with a ripple current less then 5% to prevent the acoustic resonance.

Topology B – BIBRED: As the first alternative to reduce power stages, are mixed the PFP and DC-DC buck converter, forming the BIBRED (Boost Integrated with Buck Rectifier / Energy storage / Dc-dc converter) converter, that associated to the low frequency inverter completes the ballast circuit, as shown in Fig.1.b.

The output power is controlled changing the duty cycle of S_1 switch. If the voltage on the capacitor C_0 operates in open loop, it can reaches high values during the lamp lifetime and utility line variations. Therefore, this voltage must be controlled acting on the switching frequency.

The input current of the BIBRED converter must operate in discontinuous conduction mode and the output current in continuous conduction mode, as the previous topology.

Topology C – DC-AC step-down converter: By combining the DC-DC buck converter with the inverter stage, and maintaining the PFP stage, another topology can be obtained [12, 15], as shown in Fig. 1.c. To drive the lamp with low frequency square wave current, and still control its value, the switches S_1 and S_3 should operate at low frequency in a complementary mode and the switches S_2 and S_4 should operate at high and fixed frequency, as shown in Fig. 2. The output power is controlled changing the duty cycle of S_2 and S_4 switches.

In order to integrate the buck converter with the full bridge, the L_{buck} should be placed in series with the lamp. So, its value has to be as small as possible to ensure fast polarity changes of the lamp current. A capacitor filter (C_p) is still needed to reduce the lamp ripple current, preventing the acoustic resonance.

Topology D – Dual-fed full bridge BIBRED - The electronic ballast can be obtained combining the three stages, forming a single power processing stage, as shown in Fig. 1.d [4]. The dual fed full bridge BIBRED converter can obtain high power factor, controlling a square wave low frequency lamp current. The bridge's switches are commanded as the same way of the DC-AC step-down topology.

The input inductance (L_{boost}) is designed to provide discontinuous conduction mode, ensuring high power factor. The output inductance (L_{buck}) is placed in series to the lamp. The C_p filter reduces the lamp ripple current.

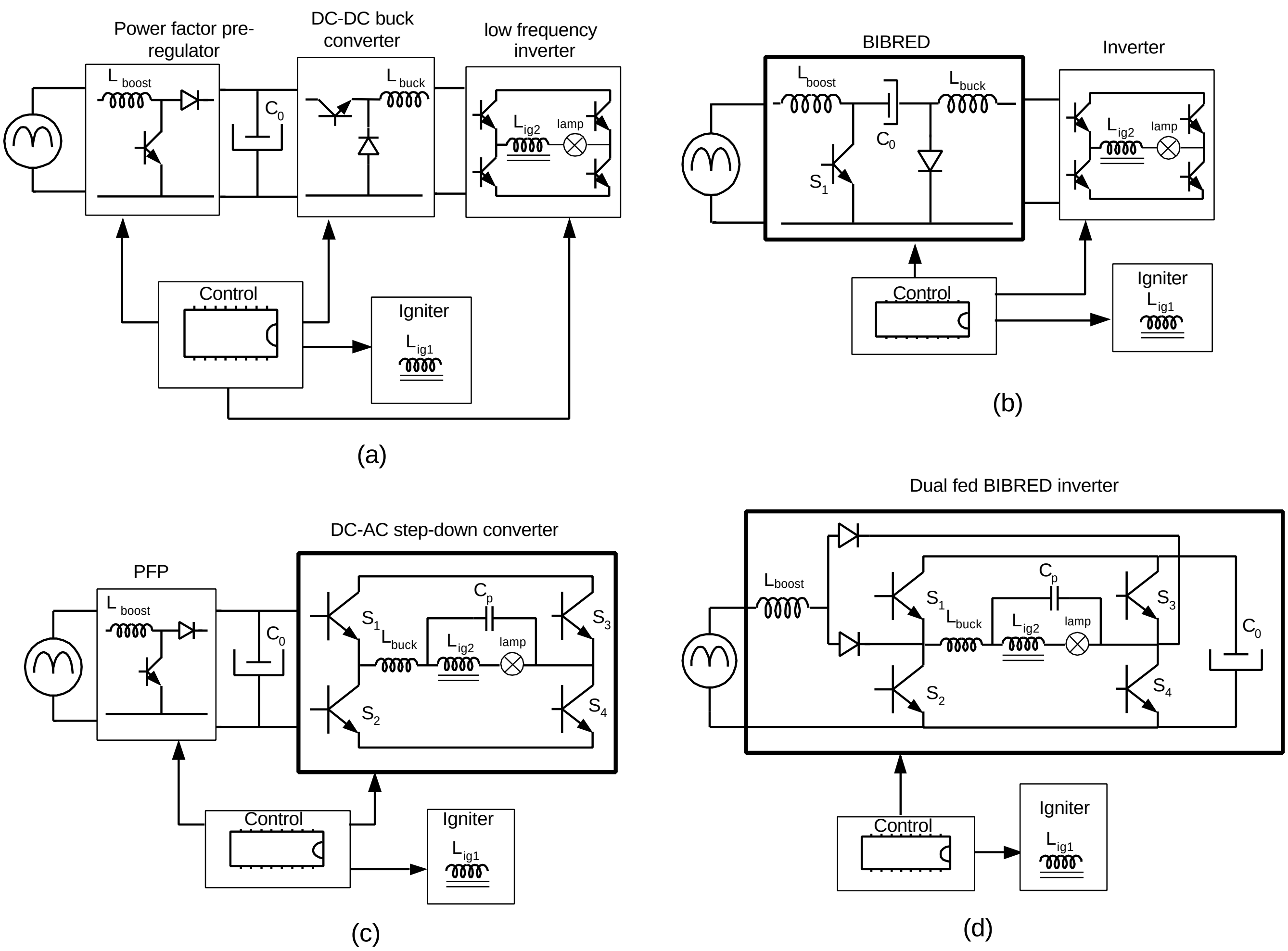


Fig. 1 - The square wave low frequency lamp current electronic ballasts: a) with three power-processing stages, b) using a BIBRED converter, c) using a DC-AC step-down converter, d) using a dual-fed full bridge BIBRED converter.

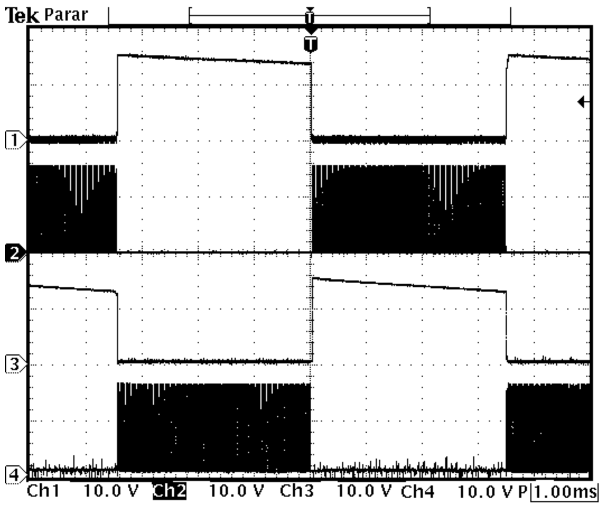


Fig. 2 – S_1-S_4 Gate commands.

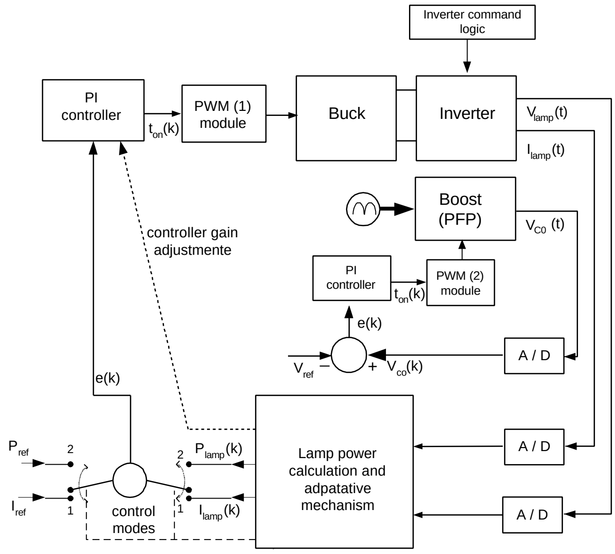


Fig. 3 – Block diagram of three stage topology control.

III. CONTROL STRATEGY

The three stages and the single stage topologies were selected to be implemented. The analysis and some results can be extended to the other two topologies. Both prototypes use a dedicated device that performs the control signals of each structure (using high performance RISC CPU microcontroller PIC16F873, from Microchip).

Three stage topology:

Lamp current and power control: After the start-up and during the warm-up phase the lamp current is kept constant at a pre-established value until the lamp reaches the nominal power. At this time, the control assures fixed lamp power, compensating the lamp voltage rising and the utility line variation, through a digital PI control acting over the duty cycle of buck converter. To avoid over current and unstable function during the two operations mode (current and power control) the PI controller gain is changed in a schedule way. The Fig. 3 shows a block diagram of this control.

DC bus voltage control: the boost converter should provide high power factor independent of line or load variations, so through a digital PI control, acting over the duty cycle of this converter, the DC bus voltage is maintained constant.

Inverter commands: the signals that drive the full-bridge inverter are generated by a timer interruption of the microcontroller.

Single stage topology:

Lamp current and power control: As the same way of the three stage topology the lamp current is kept constant through a digital PI. In this case the control acts over the duty cycle of S_2 and S_4 switches. When the lamp reaches the nominal power the reference current is constantly calculated taking in account the lamp voltage to ensure the fixed rated power. The PI controller gain is changed in a schedule way. The Fig. 4 shows a block diagram of this control.

DC bus voltage control: A digital PI control, acting over the switching frequency, maintains the DC bus voltage constant independent of lamp voltage or utility line voltage variations. This controlled voltage assures the discontinuous conduction mode in L_{boost}, providing high power factor.

Inverter commands: A time interruption of the microcontroller generates the signals of S_1 and S_3 switches. This interruption still change which PWM module that operate (PWM 1 or PWM2 module).

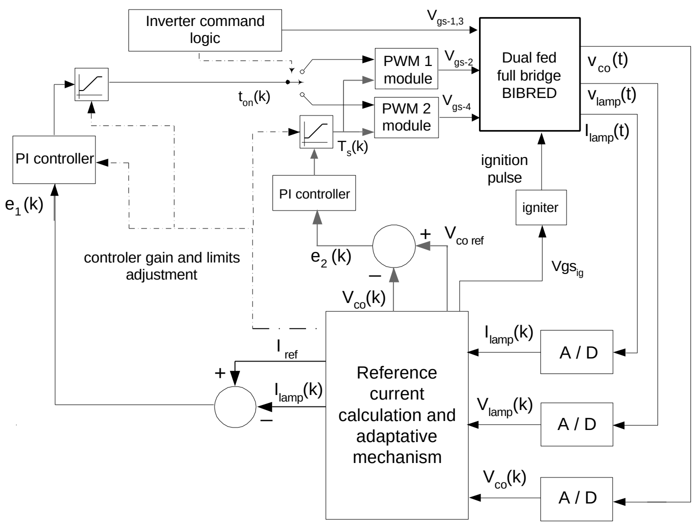


Fig. 4 – Block diagram of single stage topology control.

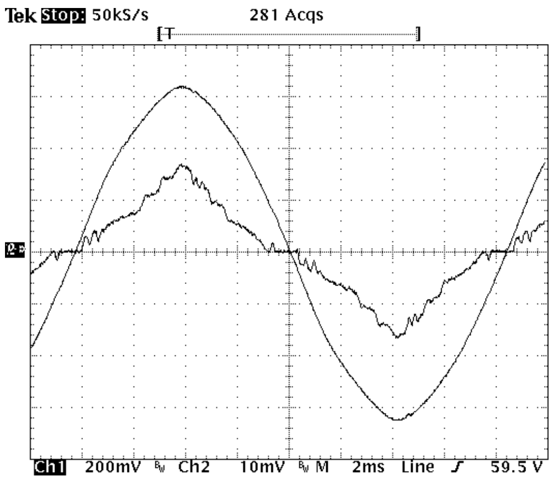
IV. EXPERIMENTAL RESULTS

The electronic ballast specifications are:

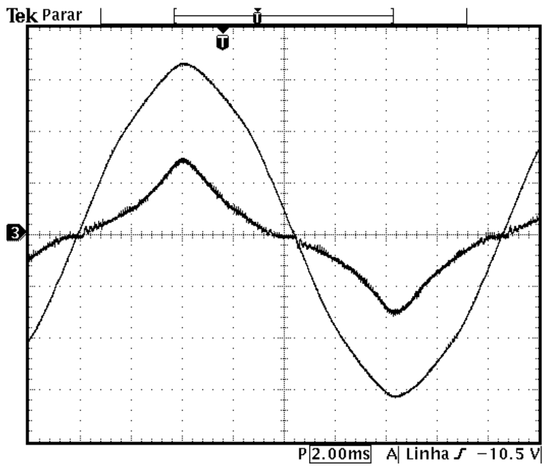
RMS AC mains voltage: 220V, 60Hz;
Output power: 70W (High pressure sodium lamp)
Inverter switching frequency: 150Hz;
PWM rated switching frequency: 50kHz (three stage) and 35kHz to 60kHz (single stage);

The Fig. 5a and b shows the input voltage and current for three stages and single stage topologies. In both cases high power factor and low THD were obtained, since a boost converter in discontinuous conduction mode was used. The results were: THD = 19% and FP = 0,98 (three stage); and THD = 25% and PF = 0,97(single stage).

The Fig. 6 shows a comparison between the efficiency of the both ballast. As expected, a better result for the single stage topology was obtained.



(a)



(b)

Fig. 5 – Input voltage (100V/div.) and input current (0,5A/div.). (a): Three-stage topology. (b): Single stage topology.

Finally, The Fig. 7 shows the square wave lamp voltage and current for three stages and single stage topologies. The lamp operates free from acoustic resonance. As can be seen, a small oscillation occurs in lamp current for the single stage topology. It happens because the buck inductance has a small value and its current inverts each half cycle. To maintain the stable operation, the control loop should operate with a reduced sample period, which is limited by the performance of the microcontroller.

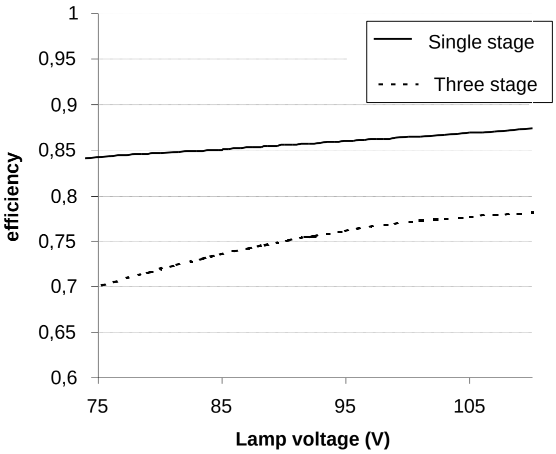
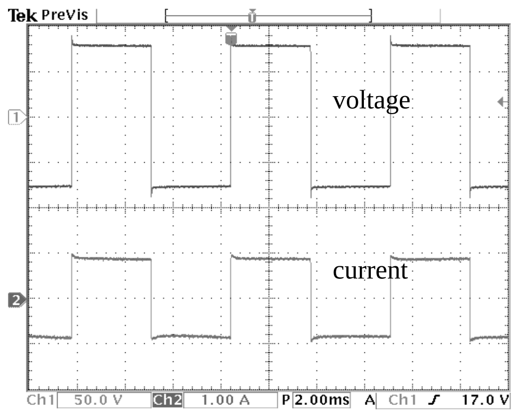
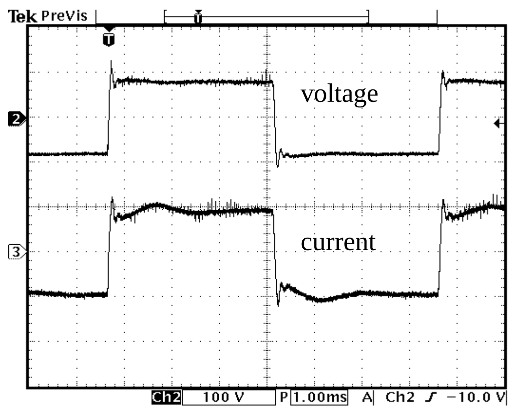


Fig. 6 – Efficiency of three stages and single stage ballasts.



(a) – 50V/div. and 1A/div.



(b) – 100V/div. and 1A/div.

Fig. 7 – Lamp voltage and current. (a): Three stage topology. (b): Single stage topology.

V. CONCLUSIONS

This paper presented four topologies of ballasts to drives HID lamps using a low frequency square wave.

The topologies A and B use an independent DC-DC converter; its buck inductance is designed with a high value to reduce the ripple current. These facts simplify the control and the measurement circuit of the lamp current that can be done with a shunt resistor, since a direct current should be controlled. The disadvantage of this solution is that it increases the size of the ballast.

On the other hand, the topologies C and D uses a DC-DC converter integrated with the inverter. The buck inductance is placed in series with lamp and needs to have a small value. These facts reduce the ballast size, but the alternate current that should be controlled makes more difficult its measurement and control. The disadvantage of these solutions is the Hall effect sensor used.

The topologies A and C use an independent PFP stage that controls the DC bus voltage with fixed frequency. The topologies B and D the PFP stage is integrate to the others stages, so the DC bus voltage control must be done acting on the switching frequency. This fact makes difficult the dimming and the use of the ballast in universal input voltage, because the frequency range required would be very large.

The experimental results show that the single stage topology presents a better efficiency and small size than the three stage topology.

REFERENCES

[1] R. Redl and J. D. Paul, "A New High Frequency and High-Efficiency Electronic Ballast for HID Lamps: Topology, Analysis, Design, and Experimental Results", in Applied Power Electronics Conference – APEC, 1999.

[2] B. Lin and Y. Hsieh, "Dimming Control for High Intensity Discharge Lamp with Power Factor Correction", In Proc. EPE 1999.

[3] H. Ohguchi, M. H. Ohsato, T. Shimizu, G. Kimura, H. Takagi, "A High-Frequency Electronic Ballast for HID Lamps Based on a ? / 4 – Long Distributed Constant Line", IEEE Transaction on Power Electronics, Vol. 13, No. 6, November 1998, pp. 1023 - 1029.

[4] M. A. Johnston and R.W.Erickson, "Reduction Of Voltage Stress In The Full Bridge BIBRED By Duty Ratio And Phase Shift Control", in Proc. IEEE, 1994.

[5] H.Peng, S. Ratanapanachote, P. Enjeti, L. Laskai and I. Pitel, "Evaluation of Acoustic Resonance in Metal Halid (MH) Lamp And An Approach to Detect Its Occurrence", in Proc. IEEE Industry Application Society Annual Meeting – IAS, 1997, pp. 2276 – 2283.

[6] S. Wada, A. Okada and S. Morii, "Study of HID Lamp with Reduced Acoustic Resonance's", Journal of the Illuminating Engineering Society, vol.10, No. 1, pp.162-175, Winter 1987

[7] J. M. Alonso, C. Blanco, E. Lopez, A. J. Calleja, M. Rico, "Analysis, Design, and Optimization of the LCC Resonant Inverter as a High-Intensity Discharge Lamp Ballast", IEEE Transaction on Power Electronics, Vol. 13, No. 3, May 1998, pp. 573 - 585.

[8] M. Gulko, D. Medini, S. Ben-Yaakov, "Inductor-Controlled Current-Sourcing Resonant Inverter and its Application as a High Pressure Discharge Lamp Driver", in Proc. Applied Power Electronics Conference – APEC, 1994, pp. 434 – 440

[9] S. Ben-Yaakov and M. Gulko, "Design and Performance of an Electronic Ballast for high-pressure Sodium (HPS) Lamps", in Proc. Applied Power Electronics Conference – APEC, 1995, pp. 665 – 669.

[10] P. Enjeti, L. Laskai and I. Pitel, " A Unity Power Factor Electronic Ballast for Metal Halide Lamps", in Proc. Applied Power Electronics Conference – APEC, 1994, pp. 31 – 37.

[11]P. V. Tichelen, D. Weyen, G. Meynen, "Test Result from High Intensity Discharge Lamps With Current Supplied at 50 Hz, 400 Hz and Modulated between 15 and 35 kHz", in Proc. IEEE Industry Application Society Annual Meeting – IAS, 1996, pp. 2225 – 2230.

[12]H. Nishimura, H. Nagase, K. Uchihashi, T. Shiomi and M. Fukuhara, "A New Electronic Ballast for HID Lamps", Journal of the Illuminating Engineering Society, Summer 1988, pp.70-76,

[13]T. Yamauchi and T. Shiomi, " A Novel Charge Pump Power Factor Correction Electronic Ballast For High Intensity Discharge Lamps" in Proc. IEEE Power Electronics Specialists Conference 1998, pp. 1761-1767.

[14]M.A. Có, C.Z. Resende, D.S.L. Simonetti and J.L.F. Vieira, "Microcontrolled Electronic Gear For Low Wattage Metal Halide (MH) And High-Pressure Sodium (Hps) Lamps" in Proc. IEEE Industry Application Society Annual Meeting – IAS, 2002.

[15]M. Shen, and Z. Quian, and F. Z. Peng, "A Novel Two-Stage Acoustic Resonance Free Electronic Ballast For HID Lamps", in Proc. IEEE Industry Application Society Annual Meeting – IAS, 2002.