# AUTOMATIC LUMINOUS CONTROL EMPLOYING SELF-OSCILLATING ELECTRONIC BALLAST

Álysson R. Seidel, Marco A. Dalla Costa, Fábio E. Bisogno, Douglas Pappis, and Ricardo N. do Prado
Federal University of Santa Maria
UFSM – GEDRE - PPGEE
97105-900 - Santa Maria - RS - Brazil - Fax +55.55.220.8030
e-mail: rnprado@ieee.org

***Abstract* — This paper presents a simple alternative of automatic luminous control for electronic ballasts operating in self-sustained oscillating mode feeding fluorescent lamps to energy saving. The luminous flux level control is based on a signal from a lighting dependent resistor, which measures the luminous flux level. The dimming feature is obtained using switching frequency variation. Thus, the circuit interprets the measurement from the sensor to control the switching frequency in the self-oscillating gate-driver circuit automatically. Experimental results from one 40 W fluorescent lamp are presented to demonstrate the feasibility of the proposed system.**

KEYWORDS

Self-oscillating; electronic ballast; fluorescent lamps; dimming.

## I. INTRODUCTION

A considerable amount of the energy used worldwide is consumed as artificial lighting. Efforts have been made to increase the efficiency of illuminating systems. Electronic ballast has higher efficiency over its electromagnetic ballast counterpart. Among them, self-oscillating electronic ballasts involve low cost, simplicity and reliability. In order to reduce electrical energy consumption, automatic systems can be used replacing dedicated ballasts. Their drawback is their higher cost compared over the dedicated ballasts. Therefore, an interesting alternative of low cost, and energy saving is a self-oscillating electronic ballast with automatic dimming capability.

This paper proposes an automatic control circuit for self-oscillating electronic ballast feeding fluorescent lamps, in order to provide automatic dimming capability, accomplished just using analogical components. Dimmable systems using the self-oscillating gate-driver circuit have been reported with manual control in [1] and [3] to set the desired lighting level. Besides, automatic systems can be achieved using appropriated sensors and microcontroller [4], [5], [6], and [7].

The goal of this work is to determine a feasible circuit to become the self-oscillating electronic ballast an automatic system without additional integrated circuits or microcontroller. Therefore, the contribution of this work that it is a low cost alternative to be used in several electronic ballast applications. Thus, this kind of system helps to overcome the main dimming drawback that is its circuit complexity. In this way, we intend to make dimming systems simple structures in order turn them feasible for ordinary applications.

Fig. 1 shows the block diagram of the proposed system integrated with self-oscillating electronic ballast. It can be seen that the rectifier, inverter, resonant filter, lamp, and self-oscillating electronic gate-driver circuit form the self-oscillating electronic ballast. The proposed system adds a dimming circuit to the block diagram to control the environment lighting level automatically. The desired lighting level is controlled as it is shown in the highlighted block diagram, in Fig. 1.

The remainder of this paper is organized as follows. Section II presents the proposed system. Section III shows a guideline of design procedure for this work. Section IV experimental results are presented. In Section V a discussion of the proposed work is presented. Finally, some conclusions are drawn based on the results obtained.

## II. PROPOSED SYSTEM

In this section, the operational principle of the proposed circuit is described. Firstly, Fig. 2 shows the traditional self-oscillating electronic ballast, which is comprised for the half-bridge converter and the self-oscillating gate-driver circuit. The self-oscillating electronic ballast operational principle is based on the feedback of *LCC* resonant filter current by means of a current transformer, CT ($L_{s1}/L_{s2}/L_p$), and it is not described in detail because it is well known [1].

Dimmable capability is obtained through frequency variation that reduces the fluorescent lamp power when operational frequency increases. Reference [1] shows the way to control the switching frequency just using low power passive components, which is used in this system.

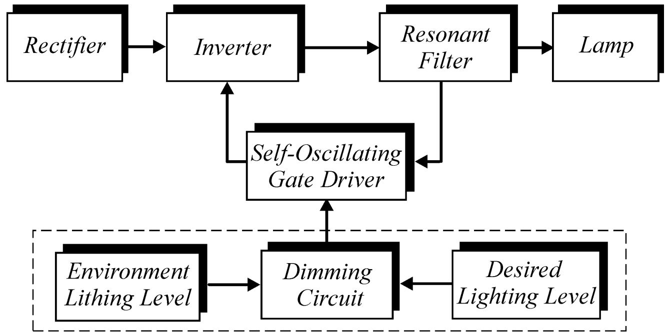



Fig. 1. Illuminating system block diagram

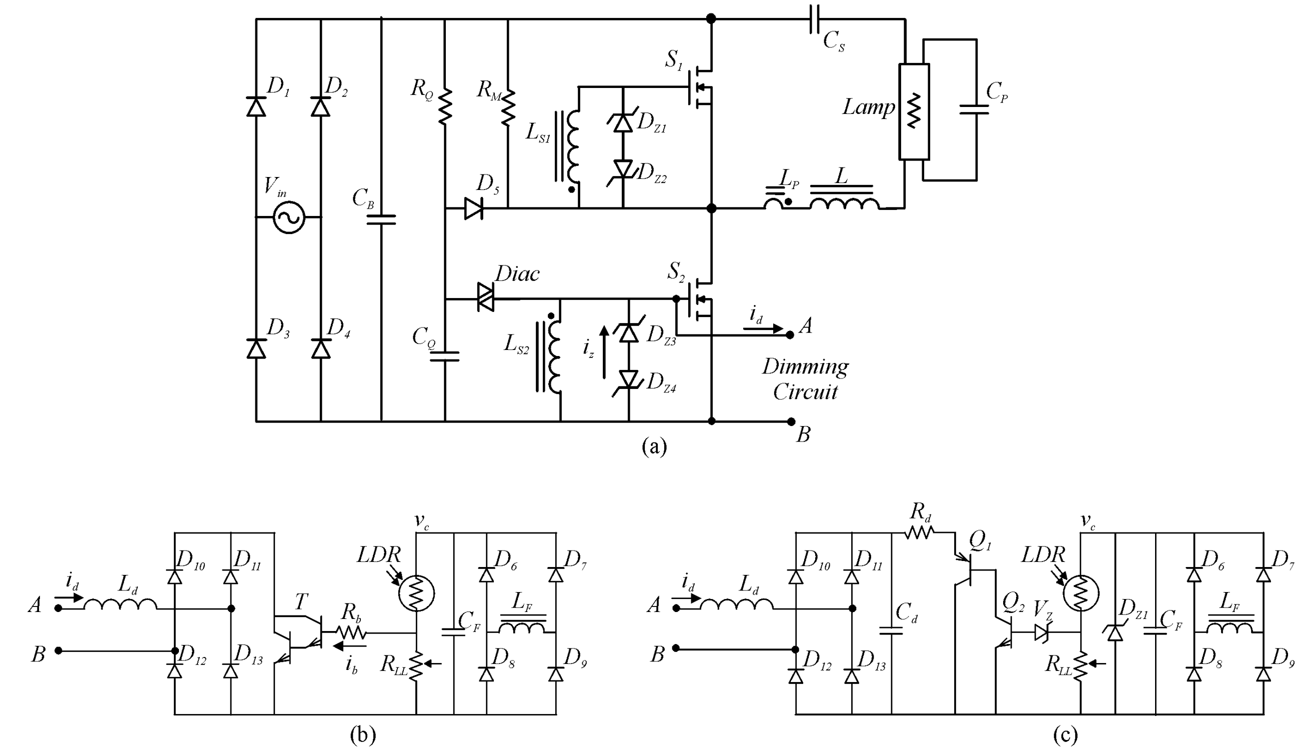



Fig. 2. Complete circuit of the proposed system: (a) Self-oscillating circuit electronic ballast (b) Dimming circuit 1 (c) Dimming circuit 2

Thus, the switching frequency variation is controlled through the current control in the dimming inductor, $L_d$, shown in Fig. 2(b) and (c). In addition, the proposed system employs components to control the current automatically according to the lighting level [4]. In this way, the system must measure the luminous flux, to set the luminous flux through the lamp power. The luminous level is measured through a lighting dependent resistor (*LDR*).

Therefore, the system must read the lighting level through a signal from the *LDR* sensor and to control the $i_L$ current keeping the power in the lamp in appropriated level.

This paper shows two ways to achieve automatic dimming capability:

*1)Dimming Circuit 1*

This circuit is shown in Fig. 2(b). The inductor $L_d$ is connected in series with emitter-collector of a bipolar transistor, *T*, through a bi-directional rectifier bridge $D_{10}$-$D_{13}$, as is reported in [4]. Thus, the transistor *T* operates as a variable resistor that is dependent of the base current $i_b$ to control the current $i_d$. Therefore, the base current controls the lighting level in the lamp changing the switching frequency.

The control of the current $i_b$ is done through a voltage divider supplied from a high-frequency rectified voltage source $v_c$ through a resistor and a *LDR* sensor. This voltage source comprises an additional winding named $L_F$, which is coupled with the resonant inductor *L*, a rectifier bridge ($D_6$-$D_9$), and a large filter capacitor $C_F$, as shown in Fig. 2(b). Thus, in the dimming circuit, the current $i_b$ is supplied from a rectified voltage, and is controlled automatically through the *LDR* sensor, and the setting lighting level resistor $R_{LL}$ with a voltage divider configuration. The resistor value of $R_{LL}$ sets the desirable lighting level through the series connection with *LDR* sensor and the voltage source. As a result, the current $i_d$ changes when *LDR* changes its equivalent resistance. The large filter capacitor $C_F$ is used in order to avoid uncomfortable changing of the lamp luminous flux, and to guarantee the lamp ignition at full power.

In resume, the lighting output level is controlled automatically from a *LDR* sensor that changes the switching frequency through a dependent circuit. As a result, the collector current transistor increases (or decreases) and becomes the switching frequency higher (or lower), changing the lamp output power.

*2) Dimming Circuit 2*

This circuit is shown in Fig. 2(c). The inductor $L_d$ is connected with a voltage source $v_c$ through a bi-directional rectifier bridge $D_{10}$-$D_{13}$. Thus, the voltage source operates as a limiter of the current $i_d$. Switching frequency $f_s$ increases as the current $i_d$ increases. Therefore, this voltage controls the lighting level in the lamp.

The control of the voltage is done according to the lighting level. In order to supply this control circuit, a voltage source is used, such as described in II.*1*. A voltage divider through $R_{LL}$ and the *LDR* provides a reference voltage level to control the transistor $Q_2$. Thus, $Q_2$ enable transistor $Q_1$, which results in a controlled voltage $v_c$. Therefore, the *LDR* resistance value sets the power in the lamp. Comparing the dimming circuits, both are feasible. However, circuit 2 is more adaptable than 1 due some benefits such as: low cost, and simplicity.

.

## III. DESIGN PROCEDURE

The design of the proposed system involves two main steps. First one is the resonant filter design [8], and the second is the dimming components and self-oscillating gate drivers determination, [1] and [2].

### *A. Resonant Filter Design*

The design of the resonant filter comprises:

*1)Input Data:*

The operating switching frequency and voltage applied in the resonant filter, and equivalent lamp resistances are shown in Table I.

*2)Resonant Filter Parameters:*

To determine the filter parameters, the following approximations are considered:

- Fundamental approximation $V_f$;
- Fluorescent lamp is represented by its equivalent resistance in steady-state (R), and starting (100*R).
- $C_p$, $C_S$ and $L$ are considered linear, and time invariants;

The following steps are used to determine the resonant components:

*a) Phase Angle $\phi$*

The phase angle $\phi$ is determined in order to guarantee the starting of fluorescent lamp, the lamp power in steady state and zero voltage switching (ZVS).

The phase angle is given by

$$\phi=\arctan\left(\left(L\omega-\frac{1}{C_S\omega}-\frac{R^2C_P\omega}{(1+C_P^2R^2\omega^2)}\right)\cdot\frac{1+C_P^2R^2\omega^2}{R}\right),$$

and fluorescent lamp power, using its equivalent resistance of fluorescent lamp, is given by

$$P(\phi)=\frac{E^2\cdot 2}{\pi^2}\cdot\frac{\left(1+C_P^2R^2\omega^2\right)R}{R^2+\left(R\cdot\tan(\phi)\right)^2}, \qquad (1)$$

being: $\omega=2\pi f_s$, being $f_s$: switching frequency, and R: equivalent lamp resistance. Thus the phase angle $\phi$ can be determined graphically according to Fig. 3.

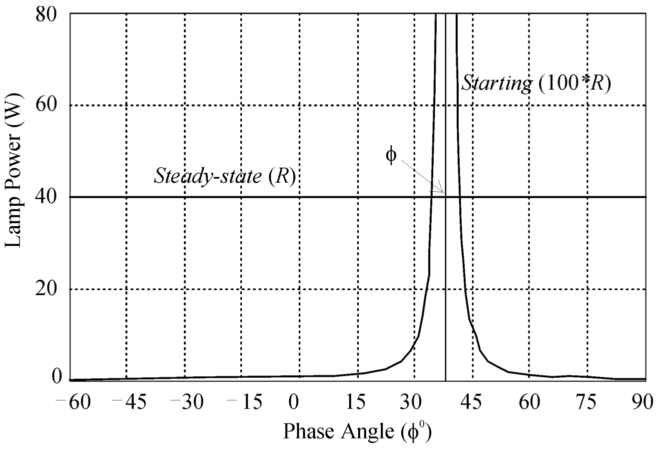



Fig. 3. Power in the fluorescent lamp in Steady state ($R$) and Starting ($R$=100*$R$)) versus phase angle $\phi$

**TABLE I - SUMMARIZED PARAMETERS**

| | |
|---|---|
| **Self-Oscillating Electronic Ballast** | |
| Input voltage | $V_{in}$=127,$V_{rms}$, 60Hz |
| Output Power | P=40 W |
| Equivalent Lamp Resistance | R=204 Ω |
| Range of Switching Frequency | $f_S$=40-50 kHz |
| Zener Diode | $D_{Z1-Z4}$:12V ½ W |
| **Resonant Filter Parameters** | |
| $C_S$ | Polypropylene capacitor, 147nF/250 $V_{ac}$ |
| $C_P$ | Polypropylene capacitor, 22 nF/600 $V_{ac}$ |
| $L$ | Inductor, 700 μH, 150 turns on core EE20 IP6-Thornton |
| **Others** | |
| $D_1$-$D_4$ | Diode 4x1N4004 |
| $R$ | Tubular Fluorescent Lamp 40W |
| $C_F$ | Electrolytic Capacitor / 100 μF 50$V_{dc}$ |
| $S_1$, $S_2$ | Power MOSFET´s IRF740 |
| $D_6$- $D_{13}$ | Diode 8x1N4148 |
| $C_B$ | Electrolytic Capacitor / 47 μF 200$V_{dc}$ |
| $R_{LL}$ | Variable resistor (50 KΩ) |
| $L_d$ | Dimming inductor, 200 μH |
| $LDR$ | Lighting dependent resistor |
| $R_Q$ | Resistor 220 kΩ/1/8W |
| $R_M$ | Resistor 470 kΩ/1/8W |
| $C_Q$ | Ceramic Capacitor 100nF / 63 V |

*b) Paralel Capacitor$C_p$*

Through the phase angle $\phi$ determined in Fig. 3 $C_p$ is

$$C_P(\phi)=\frac{1}{\omega R}\sqrt{\frac{P(\phi)}{R}\left(\frac{\pi^2\left(R^2+\left(R\cdot\tan(\phi)\right)^2\right)}{E^2\cdot 2}\right)-1}. \qquad (2)$$

being: $E$: bus voltage $V_{min}$ and $P$: power in the lamp.

*c) Resonant Inductor L*

The inductance L is determined by

$$L(\phi,C_S)=\frac{R\tan(\phi)\omega^{-1}+C_P(\phi)R^2}{1+\omega^2C_P^2(\phi)R^2}+\frac{1}{C_S\omega^2}, \qquad (3)$$

being $C_s$ a typical value that blocks the dc component to the fluorescent lamp.

From (1), (2) and (3) the filter components are determined and summarized in Table I.

### *B. Dimmable Circuit*

Two main circuit parameters must be determined: 1) Self-oscillating gate-driver circuit and 2) Dimming circuit.

### *C. Self-oscillating Command:*

The parameters of the self-oscillating gate-driver circuit are determined according [1].

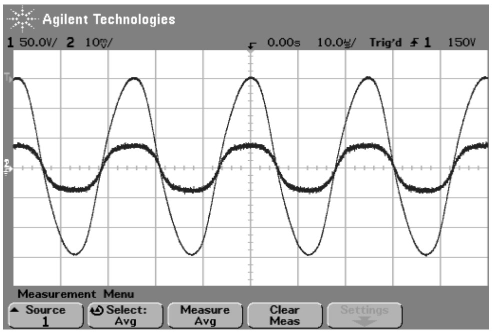
*Dimming Circuit:* The parameters of the dimmable circuit are determined based on the proposition [2].

## IV. EXPERIMENTAL RESULTS

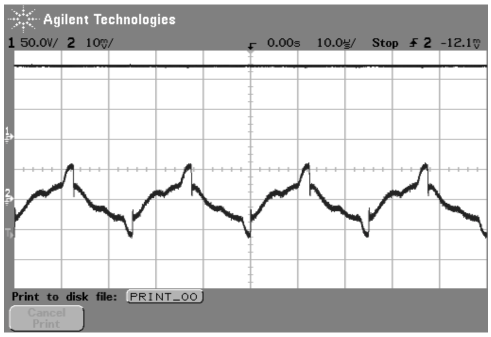
A prototype has been built with the components shown in Fig. 2. Table I shows the main parameters of the proposed system. The resonant filter design parameters, and dimming circuit are accomplished based on [6], and [1].

Fig. 4 shows relevant waveforms of the proposed system. Lamp current and voltage are shown for four power level.

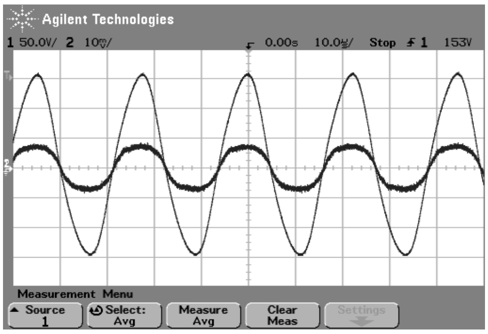
.



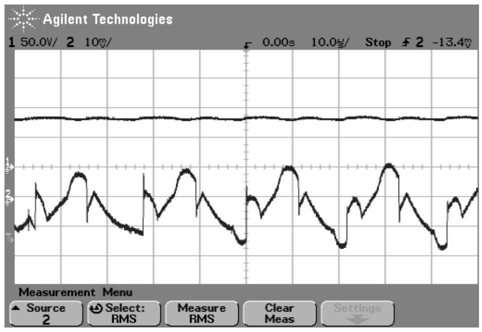

(a) (50V/div; 500 mA/div; 10 μs/div)



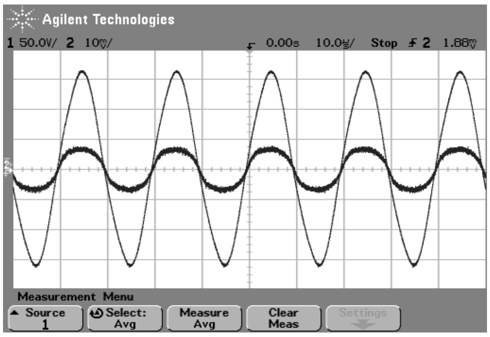

(b) (5V/div; 20 mA/div; 10 μs/div)



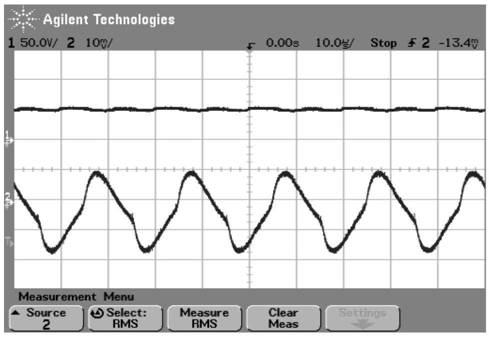

(c) (50V/div; 500 mA/div; 10 μs/div)



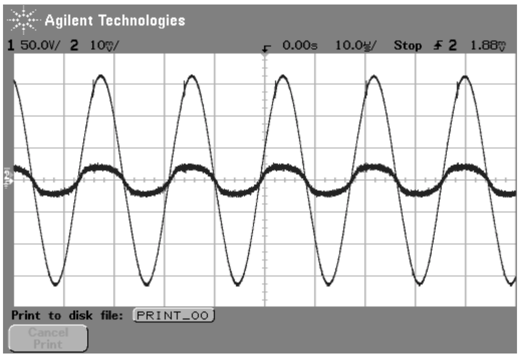

(d) (5V/div; 20 mA/div; 10 μs/div)



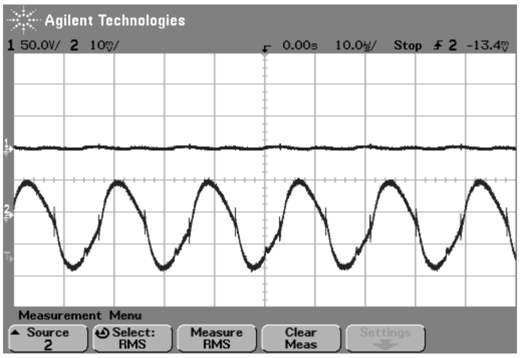

(e) (50 V/div; 500 mA/div; 10 μs/div)




(f) (5 V/div; 20 mA/div; 20 μs/div)




(g) (50 V/div; 500 mA/div; 20 μs/div)




(h) (5V/div; 20 mA/div; 10 μs/div)

Fig. 4 – Experimental results

It can be seen in Fig. 4 (a), (c), (e), and (g). In order to compare the control voltage level and its effects in the circuit, the voltage in the $R_{LL}$ and the current in the zener diodes $D_{Z1}$-$D_{Z2}$ are shown beside of the lamp current and voltage waveforms. These waveforms are shown in Fig. 4 (b), (d), (f), and (h). Thus, Fig. 4 (a) and (b) show the waveforms for 36.4W. Fig. 4 (c) and (d), for 34.3W. Fig. 4 (e) and (f), 32.4W. And, Fig. 4, waveforms for 21.29W.

In this way, comparing Fig. 4 (a) and Fig. 4 (c) due to Fig. 4 (b) and Fig. 4 (d), it can be seen that the current $i_Z$ decreases when the voltage in the resistor $R_{LL}$ increases.

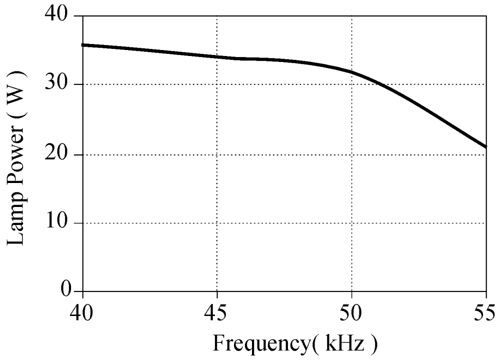



Fig. 5 – Lamp power as the frequency increase

Thus, the current $i_d$, and the switching frequency increase. As a result, the output lamp power level decreases.

## V. DISCUSSION

Based on the results obtained and the way to become feasible the dimming capability through the resonant filter current, a similar technique can be used to control the input voltage, instead of resonant filter current, as can be seen in Fig. 6. Through the sense of bus voltage waveform the switching frequency can be controlled in order to supply electronic ballasts from two different input voltages. Fig. 6 shows a schematic circuit, for two different input voltages. Fig. 7(a) shows the lamp voltages for 220 $V_{RMS}$ and 127 $V_{RMS}$ input voltages. Fig. 7(b) shows the power in the lamp for both voltages respectively. In order to validate this option the fluorescent lamp model was used [9].

Besides, a discussion about dimming circuits feasible is necessary. In this way, it is important to point out two considerations for a final work:

*1)* Pre-heating and heating filaments are not considered. Although, a good alternative has been proposed keeping the filaments temperature [9].

*2)* Power factor correction must be employed to meet IEC 61000-3-2 Class C requirements.

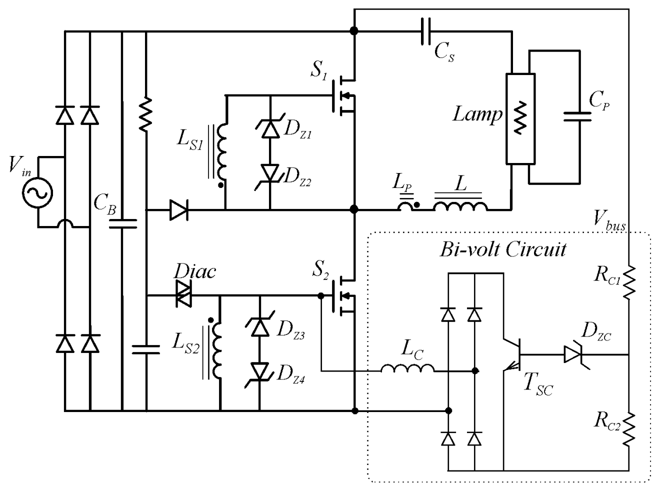



Fig. 6. Bi-volt configuration system

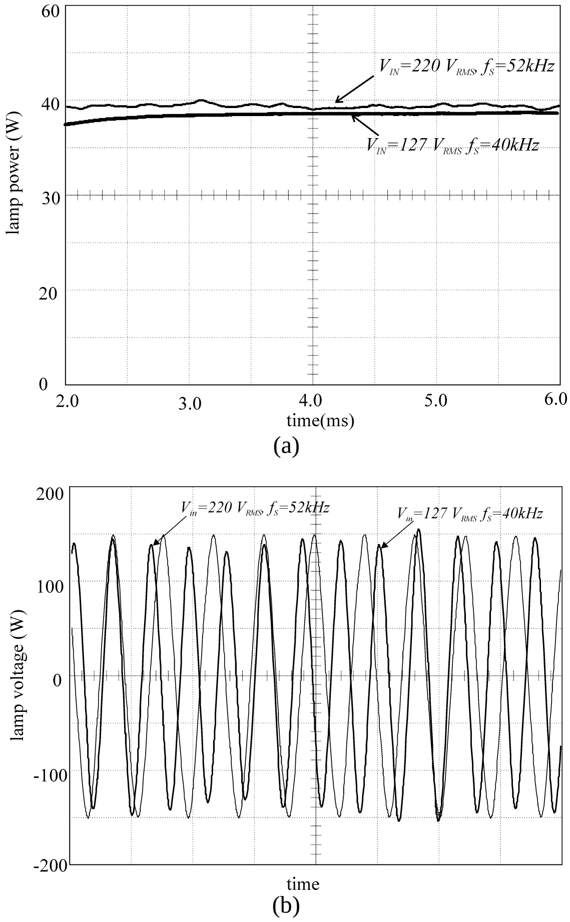



Fig. 7. Simulation Results

## VI. CONCLUSION

An automatic dimmable circuit for self-oscillating electronic ballasts has been proposed as a potential energy saving proposition for several environments. It makes the electronic ballasts versatile without increasing significant cost. Self-oscillating electronic ballast has been used ensuring its characteristic avoiding complexity, maintaining its well-known reliability and simplicity. In addition, the electronic ballast is reduced in size and components numbers comparing traditional automatic systems. Besides, a potential alternative of bi-volt input configuration is presented through simulation results, using a similar idea. Therefore, self-oscillating gate-driver circuit employed in electronic ballasts applications allows implementing energy saving systems with simplicity and low cost.


## ACKNOWLEDGMENT

The authors gratefully acknowledge the support of this work provided by CNPq, and Thornton - INPEC Eletrônica Ltda.


## REFERENCES


[1] R. N. do Prado, A. R. Seidel, F. E. Bisogno, and R. K. Pavão. "Self-Oscillating Electronic Ballast Design Based


.

on the Point of View of Control System," IAS2001, records.
[2] R. N. do Prado, A. R. Seidel, F. E. Bisogno, R. K. Pavão, and H. Pinheiro, Self-oscillating dimmable electronic ballast, IECON 2001, records.
[3] F. Tao, Q. Zhao, F. C. Lee and N. Onishi, Self-Oscillating Electronic Ballast with Dimming Control, PESC 2001, record.
[4] A. L. Michel, D. Pappis, A. Campos, and R. N. do Prado, "Electronic Ballast with Automatic Luminous Variation and Presence Detection Using Microcontroller and Self-Oscillating Command," IAS 2002, record.
[5] T-F. Wu, T-H. Yu, and Y-J. Wu. "A microprocessor-based toggle-control lighting system," *IEEE transaction on industrial electronic*s, vol. 45, no. 3, June, 1998, pp.525-528.
[6] J. M. Alonso, P. J. Villegas, J. Díaz, C. Blanco, and M. Rico. "A microcontroller-based emergency ballast for fluorescent lamps," IEEE Transaction on Industrial Electronics, vol. 44, no. 2, April, 1997, pp.207-215.
[7] R. Hausmann, A. J. Perin, and R. L. Alves, "Microcontrolled electronic ballast for fluorescent lamps with high power factor, controlled Luminescence and Presence Detection," COBEP 2002, records.
[8] Á. R. Seidel; R. Holsbach, R. N. do Prado; and F. E. Bisogno, "Resonant Filter Applications in Electronic Ballast, " IAS 2002, records.
[9] Hsieh, G. -C., and Ling, C. –H, "Harmonized Strategy for Breaking the Striations in the Fluorescent Lamp," IEEE Transactions on Ind. Electronics, vol. 48, no. 2, April 2001.
[10] M. Cervi, Á. R. Seidel, F. E. Bisogno and R. N. do Prado, "Fluorescent Lamp Model Based on the Equivalent Resistance Variation", IAS 2002, record.