# Self-Oscillating Electronic Ballast with Dimming Feature


R. K. Pavão, A. R. Seidel, F. E. Bisogno, H. Pinheiro and R. N. do Prado

Researching Group of Electronic Ballasts – GEDRE
PPGEE – NUPEDEE – CT
Federal University of Santa Maria
97105-900 – Santa Maria - RS - Brazil
rnprado@ieee.org



***Abstract*** **– This paper presents two simple alternatives of electronic ballast operating in self sustained oscillating mode with dimming capability for fluorescent lamps. A simple modification in the drive circuit allows dim the lamp. The describing function method and the extended Nyquist criterion are used in the analysis and the design. Experimental results from two 40 W electronic ballast are presented to demonstrate the performance and to validate the analysis carried out.**


## I. INTRODUCTION

Nowadays, about 20% of electric energy used in the world is consumed in the form of artificial lighting. One solution to reduce this consumption is to use electronic ballasts in high frequency feeding fluorescent lamps. Besides the energy consumption reduction, the electronic ballast has the following advantages if compared with electromagnetic ballast counterpart: higher efficiency, lighter weight, lower volume, and absence of flicker and audible noise.

Furthermore, reduction in the electric energy consumption can be obtained through dimming capability of electronic ballast [1], [2]. The electronic ballasts which operate in self sustained oscillating mode have the above mentioned features in addition to the lowest cost, simplicity and reliability.

Until recently, self-oscillating electronic ballasts with dimming capability have not been reported. An alternative solution to achieve dimming in self-oscillating electronic ballast has been introduced in [8]. However, the resulted circuit is complex which shadowed the main advantages of the self-oscillating electronic ballast (SOEB) that is its simplicity.

This paper proposes two simple self-oscillating electronic ballast circuits. The proposed solutions just require two additional low power passive components, within the branch $B_D$ of Fig. 1, to add dimming capability to the SOEB of Fig. 1.

Despite of the simplicity of the proposed solution, the circuit analysis can become intricate. In order to overcome this drawback this paper resort to the use of the describing function method and the extended Nyquist stability criterion to carryout the analyses and to development design procedures for the circuit parameters selection.

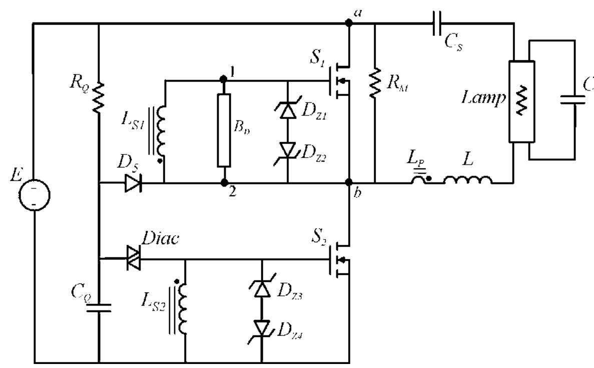


Fig. 1. Self-oscillating dimmable electronic ballast (SODEB)

The remainder of this paper is organized as follows. Section II presents a qualitative analysis of electronic ballast in self-oscillating sustained mode, also proposes two SOEB with dimming feature for fluorescent lamps. In Section III, a design procedure is developed for both proposed SOEB with dimming feature (SODEB). In section IV experimental results are presented. Finally, in Section V some conclusions are drawn based on the results obtained.

## II. ANALYSIS OF THE SELF-OSCILLATING ELECTRONIC BALLAST WITH DIMMING FEATURE

This section presents a review of the traditional SOEB and from this review it is proposed two new SODEB.

### *A. Traditional Self-Oscillating Electronic Ballast (SOEB)*

Traditional SOEB can be seen in Fig. 1, if the branch named $B_D$ is removed. The behavior of this electronic ballast is based on the feedback of LCC resonant inductor current by means of the current transformer (CT). The secondary side of the CT is connected in complementary polarity to the gate-source terminals of Mosfets $S_1$, $S_2$ as shown in Fig. 1. In order to facilitate the understanding of the circuit operation the current transformer will be represented by a sinusoidal current source, $i_S$, in parallel with a magnetizing inductance, $L_m$, and the zener diode voltage will be assumed to be constant. As a result of these approximations it is possible to consider the magnetizing current to be linear, and the inductor current reflected to the secondary side of the transformer to be sinusoidal. Therefore, the zener current $i_Z$ is the sum of magnetizing current, $i_M$ and resonant current $i_S$ as shown in the Fig. 2.

When the zener current $i_Z$ crosses zero and changes its polarity at time $t_1$, $t_2$ and $t_3$, also does the gate-source voltage of Mosfet ($S_1$, $S_2$). As a result, there will be a change in the conduction state of the switch $S_1$ and $S_2$. From this analysis, it is possible to conclude that magnetizing inductance $L_m$ and diode zener voltage $V_Z$ are the key elements to define the operation frequency of the electronic ballast in self-sustained oscillating mode.

The circuit of Fig. 1 can be represented in terms of a block diagram as shown in Fig. 3. In order to obtain this block diagram some simplifications have been made: the fluorescent lamp has been represented by an equivalent resistance $R_{Lamp}$, the gate-source capacitance of the Mosfet ($S_1$; $S_2$) and its delay times have been neglected. In addition, the input voltage $E$ has been considered to be constant.

With these simplifications, the Half-Bridge converter and dc source can be represented by a hard limit nonlinearly as shown in Fig. 3. In this figure the resonant filter and the fluorescent lamp are represented by the transfer function $G_F(s)$, from the voltage $V_{ab}$ to the resonant current $I_L$. The magnetizing inductance is represented by a transfer function from the gate-source voltage to the magnetizing current $I_M$. In order to understand the behavior of the circuit in Fig. 3, the describing function method and extended Nyquist criterion are used [10].

*1) Analyses for the SOEB:* If the higher order harmonic generated by the nonlinear element (hard limit nonlinearity) of Fig. 3 are attenuated due to the low pass filter characteristic of the resonant circuit LCC the fundamental component will be predominant. Therefore, the stability of self-sustained oscillation can be investigated using the describing function method and the extended Nyquist criterion. As a result the block diagram of Fig. 3 can be represented as shown in Fig. 4.

In Fig. 4 the describing function associated with the hard limit nonlinearity is given by

$$N = \frac{4V_Z}{\pi I_z}\,. \tag{1}$$

If the self sustained oscillating exists, its amplitude and frequency can be determined from the system characteristic equation of the Fig. 4

$$1 + NG(j\omega) = 0\,, \tag{2}$$

by rearranging (2), it becomes

$$G(j\omega) = -\frac{1}{N}\,. \tag{3}$$

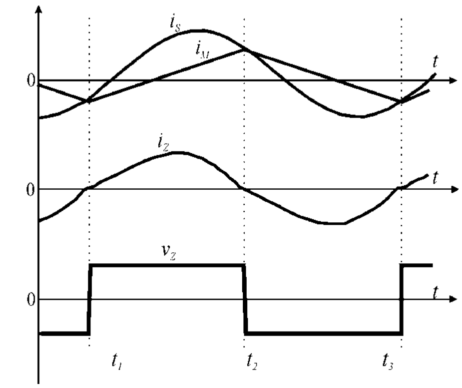

Fig. 2. Waveforms in the drive circuit of SOEB

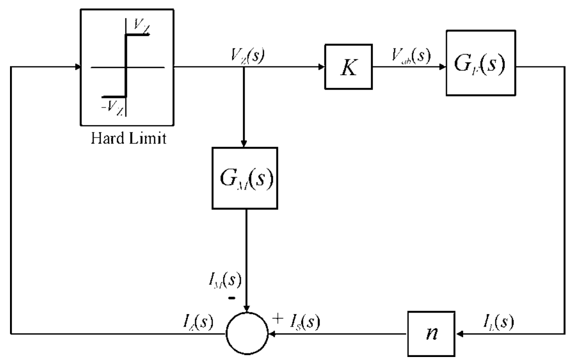

Fig. 3. Interpretation of self-oscillating electronic ballast (SOEB)

If equation (3) is satisfied, then the system may exhibit a limit cycle, therefore the interception of $G(j\omega)$ and $-1/N$ as shown in Fig. 5 gives the information of possible self sustained oscillation. Let us assume that the SOEB operates at point $P$, with a fundamental zener diode current $I_Z$, and frequency $\omega$. In addition, suppose that due to a small disturbance, the amplitude $I_Z$ is slightly decreased and the SOEB operation point is moved from $P$ to $A$. Since the new point $A$ is encircled by the curve $G(j\omega)$ according to the extended Nyquist criterion, the amplitude of $I_Z$ will increase. Therefore, the operating point will move along $-1/N$ locus towards operating point $P$. On the other hand, if the amplitude of $I_Z$ is disturbed, so that it is increased, the operating point will move from $P$ to $B$, then the amplitude $I_Z$ is decreased since it is not encircled by the curve $G(j\omega)$, and thus the current $I_Z$ returns to the operating point $P$, as shown in Fig. 5. From the above discussion, it is concluded that SOEB presents a possible self-sustained frequency operation at the point $P$.

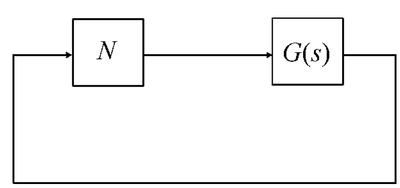

Fig. 4. Simplified block diagram

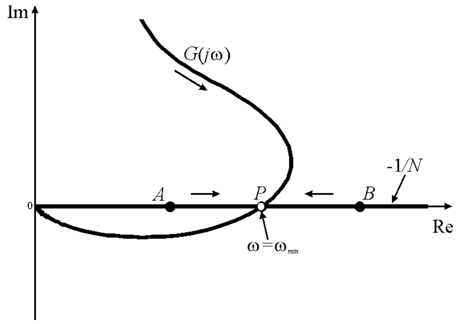


Fig. 5. Nyquist plot of self-oscillating electronic ballast

### B. Self-Oscillating Electronic Ballast with Dimming Feature (SODEB)

In the last section it was demonstrated that current $i_Z$ has an important role in defining the operating frequency of the SOEB. The current $i_Z$ in traditional SOEB depends on both the zener voltage $V_Z$ and magnetizing inductance $L_m$ in order to change the frequency. Since both $V_Z$ and $L_m$ are usually constant one alternative to change the current $i_Z$ is to add an additional network at secondary side of the CT, here it is named $B_D$ and it is shown Fig. 1. Two simple candidate configurations for the implementation of the network $B_D$ are given in Fig. 6.

The next subsection presents qualitative analyses of the SOEB with additional branch $B_D$ (SODEB).

*1) Qualitative Analysis of Self-Oscillating Electronic Ballast with Dimming Capability with the LR Network:* The use of the additional LR network allows increasing the slope of the resulting current $i_D$ which is the sum of the magnetizing current, $i_M$, and the LR network current $i_{BD}$ as shown in Fig. 7. It is possible to see from Fig. 7 that as $i_{BD}$ increases, also the switching frequency. The commutation point changes from the point A to the point $A_L$. As a result, the smaller dimming resistor $R_d$, the larger is the operating frequency, which leads to a smaller power send to the lamp.

*2) Qualitative Analysis of Self-Oscillating Electronic Ballast with Dimming Capability with the CR Network:* The utilization of the CR network reduces the slope of the resulting current $i_D$ which is the sum of the magnetizing current, $i_M$, and the CR network current $i_{BD}$ as shown in Fig. 7. By increasing the current in this CR network result in a reduction of the operating frequency. Therefore, the smaller dimming resistor $R_d$ the smaller is the switching frequency, which leads to an increase on the power in the lamp for operation above resonant frequency. The commutation point changes from the point $A$ to the point $A_C$ as seen in Fig. 7.

The qualitative analysis of the previous subsection allows one to understand the behavior of the proposed SODEB. However, in order to carry out the design it is required to have design equations that allow one to select the main components of the power and control circuits, and to ensure operation in self-sustained oscillation mode. Next section will address these issues.

## III. ELECTRONIC BALLAST DESIGN PROCEDURE WITH DIMMING FEATURE

In this section the SODEB is modeled as a single input single output (SISO) nonlinear system with hard limit nonlinearity. The design procedure is developed in steps for both SOEB with LR and CR network.

### A. SODEB with LR Network

The design steps for the SODEB in this case are:

*1) Step 1: Selection of Resonant Filters Parameters*: Initially it is assumed that the operating frequency and power in the lamp are known [1]. The design of resonant filter is based on the fundamental approximation and the phase angle of the resonant current and shift-phase angle between the resonant current $i_S$ and fundamental voltage of $V_{ab}$. This design step is omitted here since it described in details in [7].

*2) Step 2: Selection of the Switching Frequency Range of the Self-oscillating Electronic Ballast with Dimming Feature*: In this step it is defined the frequency range of the SODEB, in order to ensure the operation with zero voltage switching (ZVS). In Fig. 8 it is possible to see the variation of the lamp power with the frequency where it is indicated the maximal $\omega_{max}$ and minimal $\omega_{min}$ operation frequency. For the design for LR network it is assumed that the parameters given in the Table I are known. Table I given parameters for the design of the SODEB with LR network.

By selecting the minimal switching frequency of the lamp higher than resonant frequency it is possible to ensure ZVS for the entire frequency operation range. Since the contribution of the current in the LR network increases operation frequency.

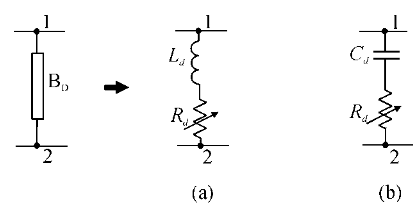


Fig. 6. Branch $B_D$ employing in SODEB for:(a) LR network; (b) CR network

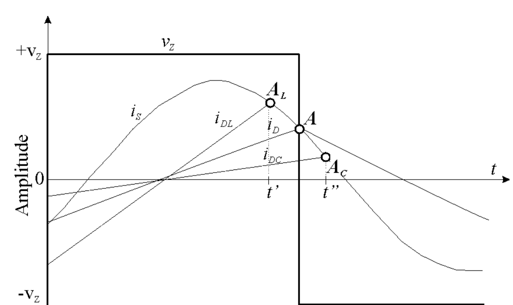


Fig. 7. Theoretical waveforms of self-oscillating dimmable electronic ballast for (a) LR network, (b) CR network

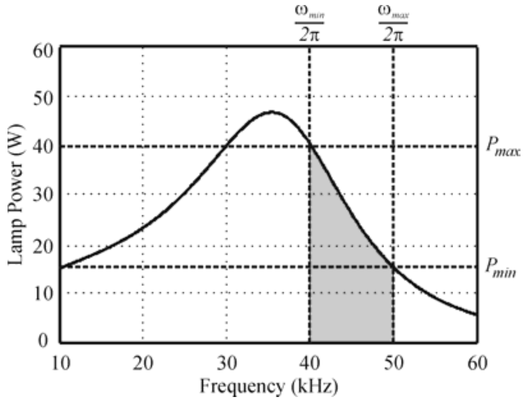


Fig. 8. Power in the lamp versus frequency

TABLE I
DESIGN CONSIDERATION FOR THE CR NETWORK

| | |
|---|---|
| **Impact Maximum** | |
| $\omega$ | $\omega_{min}$ |
| $R_d$ | $\infty$ |
| $P$ | $P_{max}$=Maximal lamp power |
| **Impact Minimum** | |
| $\omega$ | $\omega_{max}$ |
| $R_d$ | 0 |
| $P$ | $P_{min}$=Minimal lamp power |

*3) Step 3: Design of the Magnetizing Inductor $L_m$:* In order to determine $L_m$ it should be considered the operation at the minimal switching frequency where $R_d$ is equal to infinite. From the circuit of Fig. 1 and the block diagram of Fig. 9 it is possible to find out the transfer functions $G_F$(s), $G_S$(s), $G_M$(s) and $G_{BD}$(s) as follows.

$$G_F(s) = \frac{1}{L}\frac{s^2 + as}{s^3 + as^2 + bs + c} \tag{4}$$

$$G(s) = knG_F(s) - \left(G_M(s) + G_{DB}(s)\right) \tag{5}$$

$$G_M(s) = \frac{1}{L_m s} \tag{6}$$

$$G_{BD}(s) = G_{LR}(s) = \frac{1}{L_d s + R_d} \tag{7}$$

where: $s=j\omega$, $a = \frac{1}{RC_p}$, $b = \frac{1}{L(C_s + C_p)}$, $c = \frac{1}{RC_pC_sL}$,

$K = \frac{E}{2V_z}$ and $R=R_{Lamp}$

By equating the imaginary part of equation (3) to zero, results in the equation $Im(G(j\omega))=Im(KG_F(j\omega)n-(G_M(j\omega)+(G_{DB}(j\omega))=0$, where in this case it has been considering $G_{DB}(j\omega)=0$. As a result, $L_m$ is found as

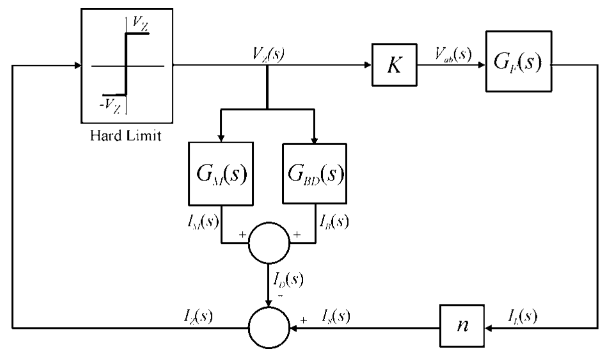


Fig. 9. Block diagram of SODEB

$$L_m = \frac{L\left(\left(c - a\omega^2\right)^2 + \left(b\omega - \omega^3\right)^2\right)}{Kn\left[a\omega^2\left(a\omega^2 - c\right) + \omega^3\left(b\omega - \omega^3\right)\right]}, \tag{8}$$

where: $n = n_P/n_S$ , $n_P$ is the number of turns of the primary side and $n_S$ is the number of turns secondary side of the current transformer CT.

*4) Design of Dimming Inductance $L_d$*: Similarly as carried out for the magnetizing inductance $L_m$ the value of the inductance of the LR network $L_d$ is obtained considering its maximal impact on the circuit operation that is when $R_d$ is equal to zero. As a result, the converter operates at the maximum frequency $\omega_{max}$.

Again, by equating the imaginary part of equation (3) to zero, it is possible to obtain the following equation $Im(G(j\omega))=Im(KG_F(j\omega)n-(G_D(j\omega)+G_{BD}(j\omega)))=0$, which leads to the desired dimming inductance $L_d$

$$L_d = \left[\frac{\omega Kn\left[\omega^2\left(b\omega - \omega^3\right) + a\omega\left(c - a\omega^2\right)\right]}{L\left[\left(b\omega - \omega\right)^2 + \left(c - a\omega^2\right)^2\right]} + \frac{1}{L_m}\right]^{-1} \tag{9}$$

## *B. SODEB with CR Network*

In this case the design steps are:

*1) Step1: Selection of Resonant Filter Parameters:* The selection of the power circuit components is similar as presented in section III.*A.1*.

*2) Step 2: Selection of the Switching Frequency Range of the Self-oscillating Electronic Ballast with Dimming Feature*: One important point to be considered when designing the SODEB using the CR network is to ensure ZVS operation for entire dimming range. In order to ensure ZVS the conditions given in Table II must be satisfied.

Therefore, by selecting the switching frequency $\omega_{min}$ greater than resonant frequency of the LCC filter ZVS is ensured at entire switching frequency range.

TABLE II
DESIGN CONSIDERATION FOR THE LR NETWORK

| | |
|---|---|
| **Impact Maximum** | |
| $\omega$ | $\omega_{max}$ |
| $R_d$ | $\infty$ |
| $P$ | $P_{min}$=Minimal power in the lamp |
| **Impact Minimum** | |
| $\omega$ | $\omega_{min}$ |
| $R_d$ | 0 |
| $P$ | $P_{max}$=Nominal power in the lamp |

*3) Step 3: Design of the Magnetizing Inductor $L_m$:* In this case, the magnetizing inductance is selected considering the operation with the least influence of the branch $B_D$. Now, by considering that dimming resistance $R_D$ is equal infinite the equation for the magnetizing inductance $L_m$ can be obtained in a similar way as defined in section III.*A.3.* In this way (8) can also be used to design of the magnetizing inductance $L_m$. However, in this case the operating frequency is selected to be the maximum operating frequency $\omega_{max}$ instead of the minimal operating frequency as indicated in Table II, and Fig. 8. In order to quantify the impact of the CR network transfer function $G_{BD}(s)$ has to be derived, in this case it is given by

$$G_{BD}(s) = G_{CR}(s) = \frac{C_d s}{R_d C_d s + 1} . \qquad (10)$$

*4) Step 4: Design of Dimming Capacitance $C_d$:* The selection of capacitor $C_d$ is made in similar way as presented in Section III.*A.3*. The dimming capacitance $C_d$ is selected at the minimal desired switching frequency $\omega_{min}$ to ensure operation with ZVS and its value also can be found as in section III.*A.3.* that is, $Im(G(j\omega))=Im(KG_F(j\omega)n-(G_M(j\omega)+(G_{DB}(j\omega))=0$, which results in

$$C_d = \frac{Kn\left[\omega\left(b\,\omega-\omega^3\right)+a\left(c-a\,\omega^2\right)\right]}{L\left[\left(b\,\omega-\omega\right)^2+\left(c-a\,\omega^2\right)^2\right]}+\frac{1}{L_m\,\omega^2} . \qquad (11)$$

It is important to mention that the lamp equivalent resistance is not constant when the lamp power is changed, therefore its worth to investigate the stability of the self-sustained oscillation under different equivalent lamp resistances.

### *C. Stability of the SODEB*

The stability analysis of the SODEB will be investigated for the LR network. Two typical cases are considered. The first one is related to the operation with the minimal dimming resistance $R_d$ which results in the minimal switching frequency and the maximum lamp power. The second one is related with the maximum dimming resistance $R_d$, which results in the maximum switching frequency and in the minimal lamp power.

Fig. 10 and Fig. 11 show the Nyquist diagrams for different equivalent lamp resistances. It is possible to conclude that points *a*, *b, c* and *d* represent possible stable self-sustained oscillation. Therefore, it is possible to see that even if the equivalent lamp resistance changes significantly, the circuit can exhibits a self-sustained oscillation.

## IV. EXPERIMENTAL RESULTS

Two different SODEB to feed 40 W fluorescent lamp have been implemented. The circuit parameters have been selected using the design procedures given in the previous sections. The given parameters are presented in Table III, and the main components of the implemented SODEB are summarized in Table IV. With theses parameters the SODEB operates with ZVS in the entire dimming range.

The summarized parameters allow the SODEB operates with ZVS commutation in the entire range of switching frequency.

Fig. 12(a) and (b) shows the lamp voltage and current waveforms of the SODEB with LR network in the highest and lowest lamp power level respectively. On the other hand, Fig. 13 (a) e (b) shows the similar waveforms of the SODEB with CR network. It is possible to see that the SODEB with both LR and CR networks operate in a large range of frequency with ZVS.

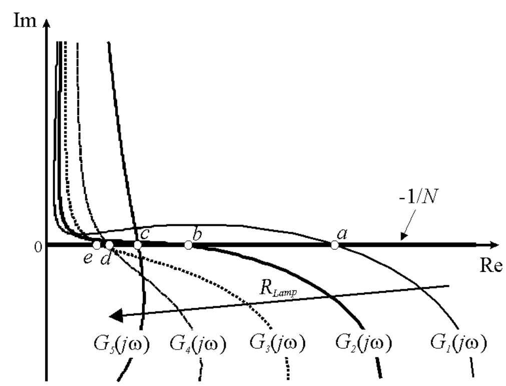


Fig. 10. Nyquist diagrams for different lamp resistances with dimming resistance $R_d$ at minimal value to SODEB with LR network

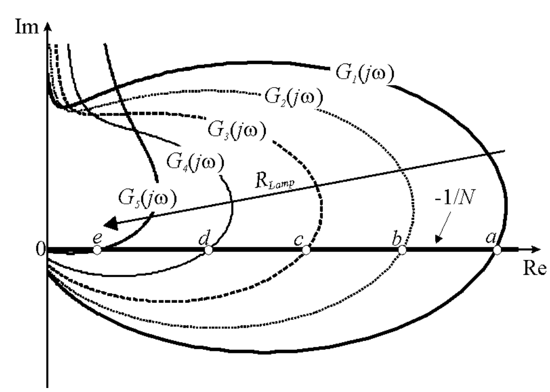


Fig. 11. Nyquist diagrams for different lamp resistances with dimming resistance $R_d$ at maximum value with LR network

TABLE III
INPUT DATA

| Specification | |
|---|---|
| Input Voltage | $V_{in}$=110 Vrms, 60Hz |
| Output Power | P=40 W |
| Switching Frequency | f=40 kHz |
| Zener Diode Voltage | $V_Z$:12V |
| Lamp Resistance | $R_{Lamp}$=270Ω |

TABLE IV
SUMMARIZED PARAMETERS

| Resonant Filter Parameters | |
|---|---|
| $C_S$ | Polypropylene capacitor, 147nF/250 Vac |
| $C_P$ | Polypropylene capacitor, 10 nF/600 Vac |
| $L$ | Inductor, 800 μH, 150 turns on core EE20 IP6-Thornton |
| **Self-Oscillating Drive Parameters** | |
| $L_m$ for LR network | $L_m$=688 μH.: n:2/12/12 Turns on core T15 IP6 – Thornton |
| $L_m$ for CR network | $L_m$=570 μH.: n:2/6/6 Turns on core T15 IP6 – Thornton |
| $D_{Z1}$, $D_{Z2}$, $D_{Z1}$, $D_{Z2}$ | Zener Diodes 12 V ¼ W |
| Diac | DB3 |
| $R_Q$ | Resistor 220 kΩ/1/8W |
| $C_Q$ | Ceramic Capacitor 100nF / 63 V |
| $R_M$ | Resistor 470 kΩ/1/8W |
| $D_5$ | High Frequency Diode UF4007 |
| **Others** | |
| $S_1$, $S_2$ | Power MOSFET´s IRF740 |
| $D_1$,$D_2$,$D_3$,$D_4$ | Rectifiers Diodes 4x1N4004 |
| $R_{Lamp}$ | Tubular Fluorescent Lamp 40W |
| $C_B$ | Electrolytic Capacitor 100 μF / 200Vdc |
| **Dimming Components** | |
| $L_d$ | Inductor Dimming, 150uH |
| $C_d$ | Capacitor Dimming, 47 nF / 30 V |
| $R_d$ | Variable Resistor, 1 kΩ |

Fig. 12(c) and (d) are shown the waveforms to the SODEB with LR network inductor current and switch voltage. Fig. 13 (c) and (d) are shown the same waveforms to the SODEB with CR network. Others networks are being considered and will be presented in the next publications. An analysis of the SODEB with bipolar transistor is being made.

As can be seen in the both figures 12 and 13, the SODEB is a reality and from now on will be reported in the literature that by the first time SODEB have been obtained with successfully.

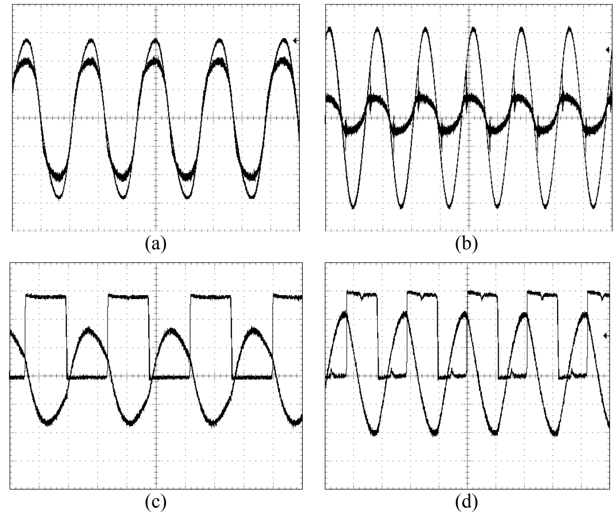


Fig. 12. Self-oscillating dimmable electronic ballast with LR network: (a) Lamp voltage and current for maximal lamp power level (50 V/div 200 mA/div; 12.5μs/div); (32 W); (b) Lamp voltage and current for minimal lamp power level (50 V/div 200 mA/div; 12.5μs/div), (10 W); (c) Switch voltage and resonant inductor current for maximal lamp power level (50 V/div;500 mA/div; 12.5μs/div); (d) Switch voltage and resonant inductor current for minimal lamp power level (50 V/div; 1A/div; 12.5μs/div)

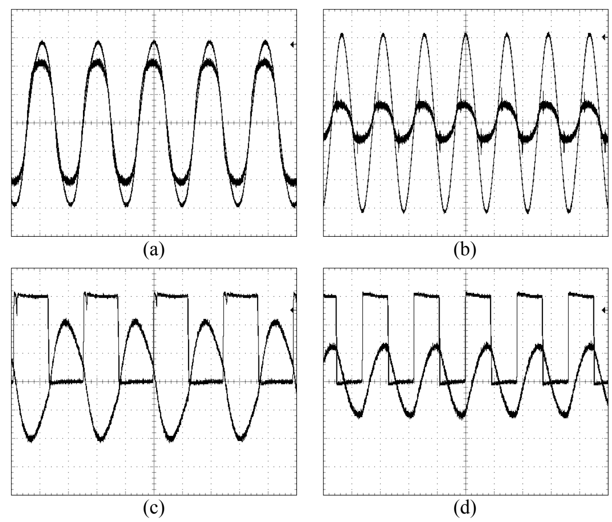


Fig. 13. Self-oscillating dimmable electronic ballast with CR network: (a)Lamp voltage and current for maximal lamp power level (50 V/div 200 mA/div; 12.5us/div), (41 W); (b)Lamp voltage and current for minimal lamp power level (50 V/div 200 mA/div; 12.5 us/div), (16 W); (c) Switch voltage and resonant inductor current for maximal lamp power level (50 V/div;500 mA/div; 10 us/div); (d) Switch voltage and resonant inductor current for minimal lamp power level (50 V/div; 1A/div; 10 us/div)

## V. CONCLUSION

This paper proposes two simple electronic ballasts with dimming feature. A simple modification in the SOEB drive circuit allows controlling the luminous intensity of the fluorescent lamp and to ensure ZVS in all operation conditions. The analysis of the SODEB is carried out using the describing function method and extended Nyquist criterion. In addition, two design procedures have been developed for the power and control circuit parameters selection. Experimental results are presented to validate and to demonstrate the performance and feasibility of the proposed solutions and by first time a SODEB have been developed with successfully.

## VI. REFERENCES


[1] E. E. Hammer, "High Frequency Characteristics of Fluorescent Lamps up to 500 kHz," Journal of the Illum. Engin. Soc., pp.56-61.

[2] E. E. Hammer, and T. K. McGowan, "Characteristics of various F40 fluorescent systems at 60 Hz and high frequency," *IEEE Trans. Ind. Applicat.*, vol. 21, n. 1, pp. 11-16, 1985.

[3] E. E. Hammer and L. Nerone, “Performance Characteristics of an Integrally Ballasted 20-W Fluorescent Quad Lamp,” *Journal of the Illum. Eng. Soc.*, Summer 1993.J.

[4] L. R. Nerone, “A Mathematical Model of the Class D Converter for Compact Fluorescent Ballasts”, *IEEE Tran. On Power Electronics*, vol 10, N o 6, Nov. 1995.

[5] C. Chang, J. Chang and G. W. Bruning. “Analysis of the Self-Oscillating Series Resonant Inverter for Electronic Ballasts.” *IEEE Tran. On Power Electronics*, vol 14, No 3, May 1999.

[6] C. Chang, and G. W. Bruning. “Self-Oscillating Electronic Ballast Analysis via Relay Systems Approach.” APEC’99, record.

[7] A. R Seidel, F. Bisogno, R. K. Pavão and R. N do Prado, “Self-oscillating Electronic Ballast Design based on Point of View of Control System”, IAS *2001*, to be published.

[8] F. Tao, Q. Zhao, F. C. Lee and Naoki Onishi, Self-Oscillating Electronic Ballast with Dimming Control, .” PESC 2001, record

[9] L. R. Nerone, “A Mathematical Model of the Class D Converter for Compact Fluorescent Ballasts”, IEEE Tran. On Power Electronics, vol 10, No 6, Nov. 1997

[10] J.J.E. Slotine and W. Li, *“Applied Nonlinear Control,” Prentice-Hall*, 1991, pp.159-190.

[11] R. N. do Prado, A. R. Seidel, F. E. Bisogno and M. A. D. Costa, “A Design Method for Electronic Ballast for Fluorescent Lamps”, *IECON 2000*, record.