A New Proposal of Switched Power Oscillator with Soft-commutation Applied as a HPF Electronic Ballast

L.C. Gomes de Freitas[1]; E.E.A.Coelho[1] ; J.B. Vierira Jr.[1] ; M. G. Simoes[2] and L. C. de Freitas[1]

[1] Universasidade Federal de Uberlândia - Faculdade de Engenharia Elétrica
Campus Santa Mônica - Bloco 3N, Uberlândia, Brazil
URL:www.ufu.br

[2] Colorado School of Mines - Engineering Division
1610 Illinois St. Golden, USA
URL:www.mines.edu

Corresponding Author: L.C. de Freitas - E-mail:freitas@ufu.br

Abstract: A new switched power oscillator with reduced conduction losses, zero voltage and zero current turning on, and zero voltage turning off, is presented in this paper. The proposed topology consists on a Buck plus Boost converter operating in continuous conduction mode (CCM) associated to a self-oscillating LC series resonant circuit. This new power oscillator can be applied as an electronic Ballast for fluorescent lamps as well as self-oscillating auxiliary medium open loop power supply. Circuit description and experimental results of the proposed HPF electronic ballast with low THD_I (7.3%), high PF (99.73%), and Crest Factor equal to 1.4 are presented. A high power factor electronic ballast prototype switching at 40 kHz for a 40 W fluorescent lamp has been built and analyzed experimentally and by simulation.

I. INTRODUCTION

This work can be understood as a result of a study that has firstly began in [1] where a new proposal of switched power oscillator with soft-switching was presented [2].

This converter uses self-oscillating techniques which makes it a low cost converter. That being so, in [1] the operation principles of the new switched power oscillator with soft-commutation were verified. The next step was to study its practical applications.

It is widely well known that many of the larger power converters require a small amount of auxiliary power supply for the supply of the control circuit and drive circuits. Often the auxiliary requirements are derived from 50/60 Hz line transformers increasing the cost, weight and size of the converters. Therefore, on solution is to use low-power, high frequency converter to supply the auxiliary needs. Thus, in [3], [4] the converter proposed in [1] applied as a self-oscillating auxiliary medium open loop power supply was studied [2].

After that, the focus was to study the new self-oscillating switched power oscillator applied as an inverter stage for electronic ballast for fluorescent lamps [2].

The fluorescent lamp performance is improved when electronic ballasts are used in place of magnetic ballasts. When operating in high-frequency, the following characteristics can be obtained [5], [6], [7]: 1) the luminous efficacy increases about 10%, which reduces the energy consumption; 2) weight and size can be reduced as a consequence of the high frequency; 3) flickering as well as stroboscopic effects can be eliminated; and 4) the audible noise falls to unnoticeable levels.

Most of these goals have been achieved with high-frequency electronic ballasts, but their individual cost is still high from the industry point of view. That is why the usage of high-frequency alternating current to power the fluorescent lamp is still widely studied.

Therefore, when lower power cost because of the greater lumens per watt, longer lamp life-time, and improved performance characteristics are added to a low cost converter able to power a fluorescent lamp meeting the international specifications assuring a good quality energy processing is achieved, electronic ballasts become more attractive to the industry.

0-7803-8270-6/04/$17.00 (C) 2004 IEEE

Thus, this paper proposes, a low cost switched power oscillator applied as a HPF electronic ballast. As it has been presented in [3] the inverter stage (Self-oscillating Boost EIE Converter) can be understood as being formed by two stages. The first one stage is a self-oscillating LC series resonant circuit and the second is a soft-commutated Boost EIE converter studied in [10], although in the literature it has been presented as a power factor correction stage called Buck plus Boost converter [11]. The Boost EIE converter, operating in continuous conduction mode, works like a current source providing the necessary energy to keep the oscillation. A brief outline of the origin of the Self-oscillating Boost EIE converter can be seen in [3], [10].

The chief advantage of this converter over existing topologies, once that it also presents soft switching, lies in the structure where the oscillation current is diverted from the switches in order to reduce the conduction losses [1], [2]. More over, there is no need of auxiliary start device and the proposed topology is self-protected against short-circuit at the load, which guarantee low cost. In the other hand, a simplified protection device against load voltage increasing is needed.

II. THE SELF-OSCILLATING BOOST EIE CONVERTER WITH SOFT-COMMUTATION

The circuit of the proposed power oscillator portrayed in Fig. 1 is composed of two switches M_1 and M_2 which are responsible for charging the boost inductor L_b. Two ultra fast diodes D_1 and D_2 provide the energy transference to the load and to the capacitor C_{os}.

In the other hand, including a suitable capacitors C_{R1}, C_{R2} in parallel to the switches M_1 and M_2 respectively, one oscillation among capacitors C_{R1} and C_{R2} and the Boost inductor L_b begins at the end of the last stage of operation when the Boost current i_{Lb} decreases to zero. Due this oscillation, a zero voltage and zero current turning on of the switches M_1 and M_2 can be achieved in the beginning of the new switching cycle.

Hence, the oscillation charge of the capacitors C_{R1} and C_{R2} provides a zero voltage turning off of the switches M_1 and M_2 at the end of the first stage of operation.

The gate-to-source voltage of the switches M_1 and M_2 are obtained by using two isolated windings (L_{s1} and L_{s2}) magnetic coupled to the inductor L_{os}. The L_{s1} and L_{s2} inductance values are selected in order to source or deliver enough current to turn on a Mosfet gate on relatively rapidly. The capacitor C_f is a single DC filter allowing just the high-frequency AC signal to the load R.

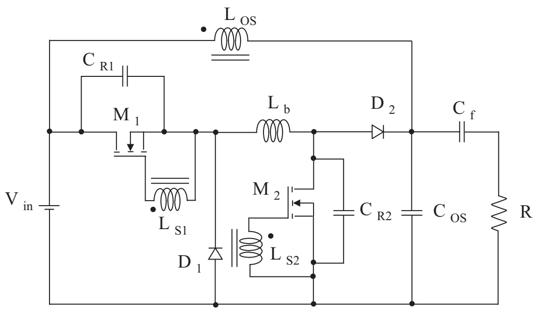


Figure 1: Self-oscillating Boost EIE Converter

III. PRINCIPLE OF OPERATION

To establish the principle of operation, the following assumptions must be taken into account:

1)The switches M_1 e M_2 operates with a fixed switching frequency and with duty cycle equal to 0,5;

2)The source V_{in} is considered a single DC source and ripple free.

Based on the above assumptions and considering a single switching period, the proposed circuit can be illustrated by six topological stages in on switching cycle as shown in Fig.2. On the first one, the oscillation begins with frequency f_0, which can be selected by L_{os} and C_{os} values. At the same time the energy transference occurs from source to the Boost inductor L_b when the switches M_1 and M_2 are turned on.

- *First stage - energy storage by the inductor L_b:*

At initial instant, the inductor current i_{Lb} and the drain-to-source voltage of the switches M_1 and M_2 are equal to zero. When the $L_{os}C_{os}$ oscillation begins, a gate-to-source voltage for M_1 and M_2 is applied simultaneously. That being so, the switches M_1 and M_2 are zero voltage and zero current turned on and the Boost current i_{Lb} linearly increases by the voltage V_{in}. Figure 2(a) depicts the equivalent circuit.

- *Second stage - zero voltage turning off of switches M_1 and M_2*:

There is a negative derivative of the oscillation current i_{Los}. Therefore, switches M_1 and M_2 are turned off because there is no gate-to-source voltage applied. Hence, the Boost current i_{Lb} is diverted from switches M_1 and M_2 to capacitors C_{R1} and C_{R2}, which are charged up with V_{in} and V_{Cos} respectively. Figure 2(b) depicts the equivalent circuit.

The third stage begins while the switches M_1 and M_2 are still opened and the diodes D_1 and D_2 are forward biased. Therefore, the power which has been stored by the Boost inductor L_b in the first stage is delivered, through diodes D_1 and D_2, to the load R and to the capacitor C_{os}.

- *Third stage - energy transference*:

Boost current i_{Lb} starts linearly decreasing and the capacitor C_{os} and the load R receives the energy that is delivered by Boost inductor L_b through the freewheel diodes D_1 and D_2. This stage is finished when the current i_{Lb} reaches zero and the auxiliary commutation capacitor C_{R1} is charged up with V_{in} and the auxiliary commutation capacitor C_{R2} charged up with V_{Cos}. The equivalent circuit of this stage can be viewed in Fig. 2(c).

- *Fourth stage - Resonance among auxiliary commutation capacitors C_{R1} and C_{R2}, Boost inductor L_b and V_{in}*:

This stage begins when Boost current i_{Lb} reaches zero. During this stage, an oscillation among auxiliary commutation capacitors C_{R1}, C_{R2}, and Boost inductor L_b through V_{in} occurs. So that, the discharge of the auxiliary commutation capacitors C_{R1} and C_{R2} initiates through the body diodes D_{S1} and D_{S2}. The end of this stage is reached when the drain-to-source voltage of switch M_1 ($V_{C_{R1}}$) is zero.

- *Fifth stage - Full discharge of the auxiliary commutation capacitor C_{R2}*:

During this stage, the auxiliary commutation capacitor C_{R2} is completely discharged through the body diodes D_{S1} and D_{S2}. Thus, this stage ends when the oscillation current $i_{L_{os}}$ has its derivative inverted again.

- *Sixth stage - zero voltage and zero current turning on of switches M_1 and M_2*:

At the end of the fifth stage of operation, when the derivative of the oscillation current $i_{L_{os}}$ is positive, a gate-to-source voltage is applied to the switches M_1 and M_2 simultaneously. That being so, the current i_{L_b} starts to flow through then and a new switching cycle begins. It is important to emphasize that since there is resonance period among auxiliary commutation capacitors C_{R1} and C_{R2}, Boost inductor L_b and V_{in}, the body diodes D_{S1} and D_{S2} are forward biased and a soft-switching can be achieved. The Fig. 2(f) depicts the equivalent circuit.

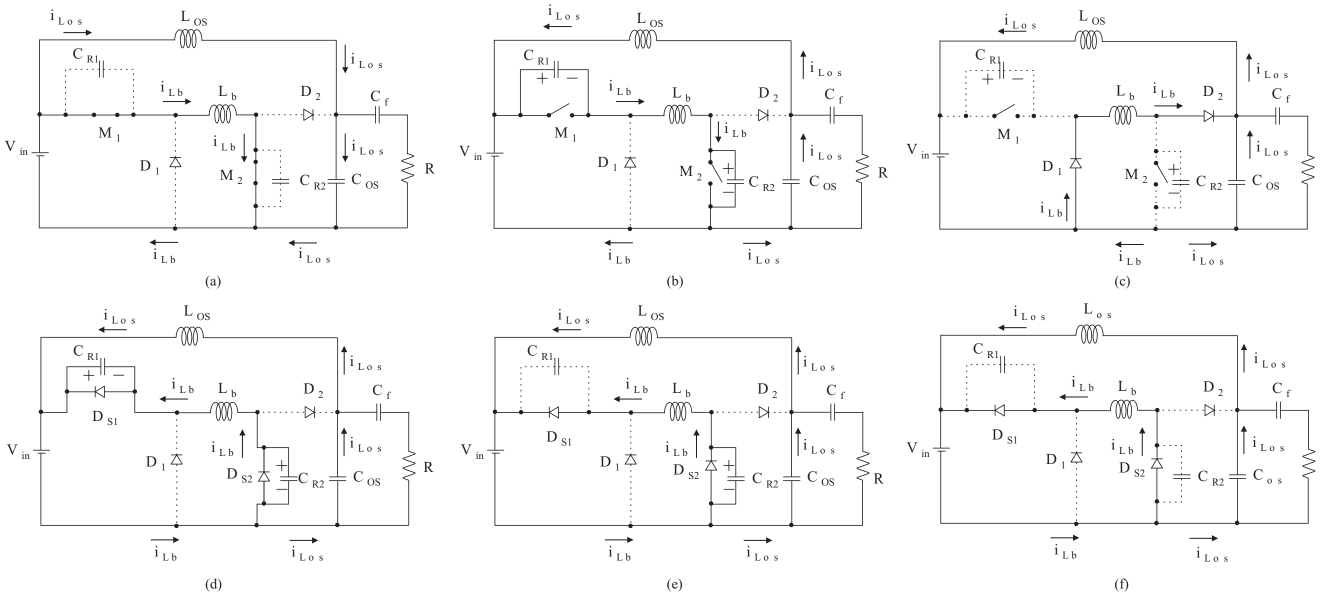


Figure 2: Operation stages of the Self-oscillating Boost EIE Converter

IV. A NEW PROPOSAL OF SELF-OSCILLATING HPF ELECTRONIC BALLAST

In this section, the main goal is to illustrate, using simulation and experimental results, the performance of the Self-Oscillating Boost EIE Converter with Soft-commutation applied as a HPF electronic ballast for a 40 W fluorescent lamp. The serious resonante parallel circuit (LCC filter) has been widely studied in literature [12], [13], [14] and has been applied in order to improve the performance of the fluorescent lamp. The power factor correction stage used to provide low THD_I (total harmonic distortion) of the input current i_{in} and high power factor was a Buck-Boost converter operating in discontinuous conduction mode (DCM).

The Buck-Boost converter operating in DCM, has been presented as a great choice mainly because of the low cost, good DC voltage regulation and the non necessity of control circuit. Adding another winding (L_{S3}) to the oscillation inductor L_{os} the gate-to-source voltage of the switch M_3 could be obtained, so that the power factor correction stage operates switching at the same frequency of the inverter stage.

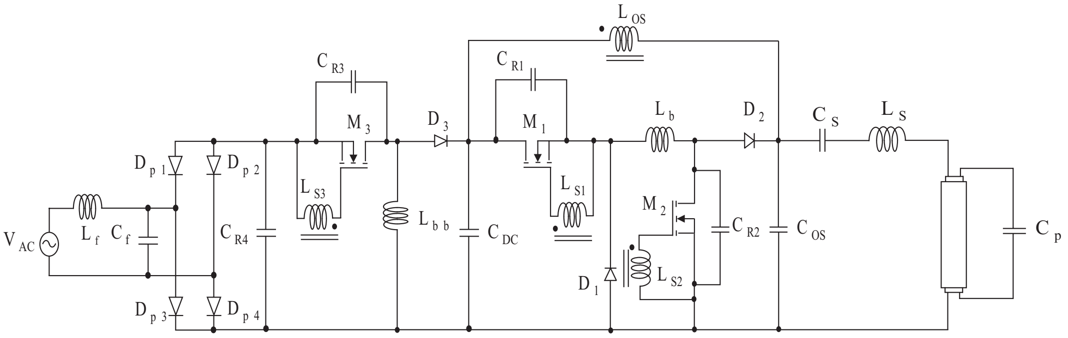


Figure 3: Self-oscillating HPF electronic ballast

The focus is to show that the Self-oscillating Boost EIE Converter with Soft-commutation is a great choice for being applied as a low cost electronic ballast meeting, in this kind of application, all the internacional standards such as IEC61000-3-2 which limits the harmonic line content of the input power line and power factor.

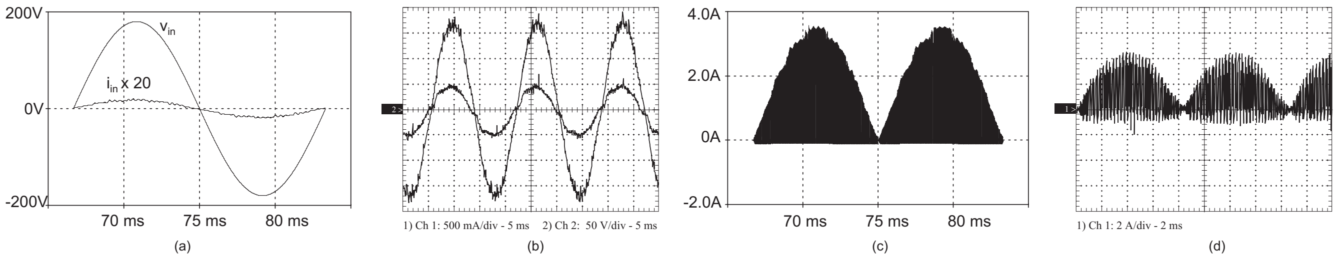
V. SIMULATION AND EXPERIMENTAL RESULTS

A prototype of the proposed switched power oscillator applied as a high power factor electronic ballast for a 40W fluorescent lamp was built at laboratory based on the simulation analysis.

Project Specifications

• Input Voltage, V_{in}	127 V.
• DC Bus Voltage, $V_{C_{DC}}$	200 V
• Switching frequency, f_0	42 kHz
• Output Power, P_{out}	40 W
• Lamp Voltage, V_L	95 V

A digital simulation, with the same parameters of the prototype, was performed using PSpice in order to provide a great comparison among simulation and experimental results.



(a) (b) (c) (d)

Figure 4: Input Voltage and input current: Simulation (a), Experimental (b) - Current $I_{L_{bb}}$: Simulation (c), Experimental (d)

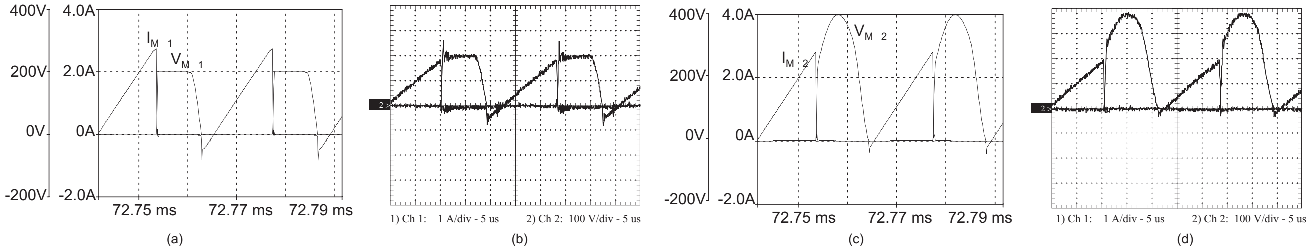


Figure 5: Switch M_1, Drain-to-source voltage and drain current: Simulation (a), Experimental (b) - Switch M_2, Drain-to-source voltage and drain current: Simulation (c), Experimental (d)

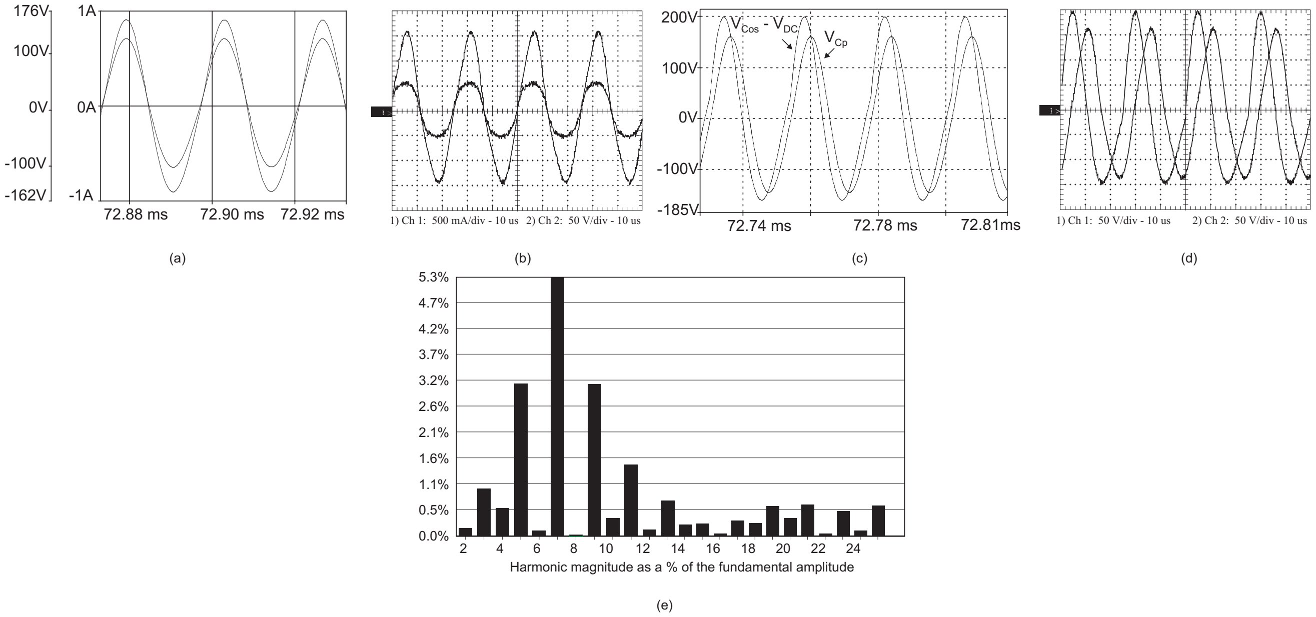


Figure 6: Lamp voltage and lamp current: Simulation (a), Experimental (b) - Voltage across the capacitor C_{os} and capacitor C_p: Simulation (c), Experimental (d) - Frequency spectrum of the input line current (Experimental)(f)

The input current and the input voltage are shown in Fig. 4(a) and (b) where one can see that a high power factor with low THD_I of the line input current were obtained. The harmonic spectrum of the input current is shown in Fig. 6(e).

The drain current and the drain-to-source voltage of switches M_1 and M_2 are shown in Figs. 5(e) and (f) and 5(g) and (h) respectively. A zero voltage and zero current turning on, and a zero voltage turning off providing soft-commutation, can be viewed and a good agreement between simulation and experimental results can be noticed.

The operational characteristic of the lamp can be viewed in Fig. 6(a) and (b) and it is possible to observe that peak value of the lamp current is 500mA and the RMS value is approximately 420mA providing a crest factor equal to 1.19 so that the lamp life can be assured. The RMS value of the lamp voltage is 106 V, hence the output power is equal to 44 W.

Therefore, based on the simulation and experimental analysis presented in this section, it is possible to realize that this equipment is very efficient and attractive to the industry. In conclusion, the proposed power oscillator has been demonstrated itself as a great electronic ballast for fluorescent lamps with high power factor (99.73%), low THD (7.3%) and FC $\leq$ 1.7 and low cost.

VII. CONCLUSION

This paper presented a new soft-switched power oscillator operating in continuous conduction mode associated to a self-oscillating LC series resonant circuit. This converter was named Self-oscillating Boost EIE converter.

From the simplified analysis, it was possible to describe the principle of operation of this power oscillator and it was possible to realize that the switches M_1 and M_2 just conducts the current through the Boost inductor L_b, it means the load current and guarantees low conduction losses. It is a great advantage over existing converters.

A soft-commutation could be achieved using suitable capacitors in parallel to the switches M_1 and M_2 and the oscillation current is diverted from the switches in order to reduce the conduction losses. More over, there is no need of auxiliary start device and the proposed topology is self-protected against short-circuit on the load, which guarantee low cost. In the other hand, a simplified protection device against load voltage increasing is needed.

When applied as an electronic ballast for a 40 W fluorescent lamp, the proposed converter has been shown as a great choice. Meeting all the internacional specifications which limits the harmonic line content of the input power line and power factor. This converter provided a low **THD (7.3%)** and a power factor equal to **99.73%**. Moreover, using a suitable LCC filter, the crest factor has been limited to **1.19** meeting the industry specification.

VI. ACKNOWLEDGEMENTS

The authors would like to thank CAPES, CNPq and FAPEMIG for the financial supports.

References

[1] L.C. Gomes de Freitas, E.A.A. Coelho, V.J. Farias, J.B. Vieira Jr. and L.C. de Freitas, *A New Proposal of Switched Power Oscillator*, CD-ROM, INDUSCON'02, Salvador, BA, Brazil, 2002.

[2] L.C. Gomes de Freitas, *Uma Nova Proposta de Oscilador de Potncia Chaveado com Comutao Suave*, Master thesis, July - 2003, UFU, Uberlandia, MG, Brazil.

[3] L.C. Gomes de Freitas, E.A.A. Coelho, V.J. Farias, J.B. Vieira Jr., L.C. de Freitas, *A New Proposal of Switched Power Oscillator Applied as a Self-oscillating Mediun Open Loop Power Supply*, CD-ROM, IEEE PESC'03, June 15-19, Acapulco, Mexico, 2003.

[4] L.C. Gomes de Freitas, E.A.A. Coelho, V.J. Farias, J.B. Vieira Jr. and L.C. de Freitas, *Uma Nova Proposta de Oscilador de Potncia Chaveado*, CD-ROM, CBA'02, Natal, RN, Brazil, 2002.

[5] E.E. Hammer and T.K. Mcgowan, *Characteristics of various F40* fluorescent *systems at 60 Hz and high frequency*, IEEE Trans. Ind. Applicat. Vol. 1A-21, no.1, pp 11-16, 1985.

[6] M.K. Kazimierezuk and W. Szaraniek, *Electronic ballast for* fluorescent *lamps*, IEEE Trans. Power Electron., vol.8, no. 4, pp. 386-395, 1993.

[7] L. Laskai and I.J. Prtel, *Discharge lamp ballasting*, IEEE PESC'95, Atlanta, GA, United States of America, 1995.

[8] F.T. Wakabayashi, C.A. Canesin, *A High Efficiency HPF-ZCS-PWM Sepic Rectifier applied to an Electronic Ballast operating Multiple Tubular Lin Dr4* , CD-ROM, INDUSCON'02, Salvador, BA, Brazil, 2002.

[9] A.L. Michel, D. Pappis, A. Campos, R.N. Prado, *Electronic Ballast With Luminous Automatic Variation and Presence Detection Using Microcontroller and Self-Oscillating Command* , CD-ROM, INDUSCON'02, Salvador, BA, Brazil, 2002.

[10] C.A. Bissochi Jr.,F.R.S. Vicenzi, V.J. Farias,J.B. Vieira Jr.,L.C. de Freitas,, *A New Family of EIE Converters*, CD-ROM, COBEP'02, Florianpolis, SC, Brazil, 2002.

[11] J. Sebastian, P.J. Villegas, and M.M. Hernando, *Power factor correction in single-phase switching power supplies*, COBEP'97, Belo Horizonte, MG, Brazil, pp. 14-27, 1997.

[12] A.V.Jr. Joao, E.A.A. Coelho, V.J. Farias, L.C. de Freitas, J.C. Oliveira, A.S. Morais, J.B. Vieira Jr.,*High power factor electronic ballast employing a boost half bridge topology*, IEEE IECON'2003 (XIX Annual Conference of the IEEE Industrial Electronics Society), Nov/03, CD-ROM, pp. 520-524, ISBN 0-7803-7907-1, Roanoke - Virgnia, E.U.A.

[13] A.V.Jr. Joao, E.A.A. Coelho, V.J. Farias, L.C. de Freitas, A.R. Vaz, J.B. Vieira Jr.,*A high power factor electronic ballast with a single swith and single power stage*, IEEE APEC'2003 (XVIII Applied Power Electronics Conference and Exposition), Fev/03, CD-ROM, ISBN 0-7803-7769-9, Miami - Florida, E.U.A.

[14] F.E. Bisogno, A.R. Seidel, R. Hoslbach, R.N. Prado, *An Overview of Resonant Filter used in Electronic Ballast*, CD-ROM, INDUSCON'02, Salvador, BA, Brazil, 2002.

[15] M.A. Co', D.S.L. Simonetti and J. L. F. Vieira, *High power factor electronic ballast operating in critical conduction mode*, IEEE Trans. Power Electron., vol.13, no.1, pp. 93-101-jan/98.

[16] W. Kaiser, *Conversor eletronico de elevada eficiencia para alimentacao de lampadas* fluorescentes *tubulares - uma metodologia de projeto*, PhD thesis, 1998, USP, Sao Paulo, SP, Brazil.

[17] Brazilian Patent Pending, *Uma Nova Proposta de Oscilador de Potencia com Chaveamento Suave*, Number - MU48102165-8.

[18] L.C. Gomes de Freitas, E.A.A. Coelho, J.B. Vieira Jr., M.G. Simoes L.C. de Freitas, *A Single-Stage PFC Converter Applied as an Electronic Ballast for Fluorescent Lamps*, CD-ROM, IEEE APEC'04, February 22-26, California, USA, 2004.