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Analysis of a High-Power-Factor Electronics Ballast for Electrodeless Fluorescent Lamp using SEPIC Topology

Mr. Regulagadda Rajavardhan and Dr. Prawin Angel Michael

PG Student, EEE Dept., Karunya University, Coimbatore
Associate Professor, EEE Dept., Karunya University, Coimbatore

Abstract

The Lighting systems based on fluorescent lamps (FLs) became popular due to their well-known features. The proposed topology of Electronic Ballast is composed of a single-ended primary-inductance converter, used as power-factor (PF) correction stage, integrated with a resonant half-bridge inverter, used as lamp-power control stage. To eliminate the harmonic components generated by the high frequency switching of the PF correction (PFC) stage, because otherwise, high-frequency harmonics can decrease the system PF and cause interference problems with other equipment. An integrated converter that incorporates both the PFC and the PC stages is proposed. A method for achieving luminous flux control in this type of integrated converters is also investigated. The power factor achieved is 0.962 and efficiency is 88.7% and the total harmonic distortion in input current is 8.29%.

Keywords-Power Factor correction (PFC), SEPIC, integration technique, high-frequency.

I INTRODUCTION

20th century was the time of inventions and societies adaptation to new energy, electrical power. Developments in industry and growth of populations raised the need for energy sources. However, world has limited capacity to regenerate the sources and pollution affects badly the sustainability of sources. Recently, awareness of the sustainability problems of world, force the governments and committees to develop ways to promote sustainability. In these ways; a key point is energy saving [1]. Energy saving can be succeeded by using electrical power efficiently and properly. In this manner, many technologies are developing in order reduce the consumption.

One way to reduce the use of electrical energy consumption is the use of high-frequency electronic ballasts feeding discharge lamps. The traditional FLs have low lifetime of 10 000 h whereas, in electrodeless FLs 100 000 h [2].

Fig 1: Fluorescent Lamp

The presence of electrodes in FLs cause lamp to fail its filaments soon. The absence of electrodes is main advantage of EFLs which makes possible for long lifetime [3].

The EFL contains the following stages as shown in Fig 2.

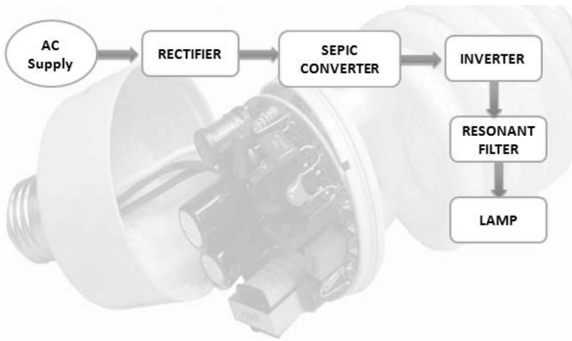


Fig 2: EFL operating stages

The Electromagnetic Interference (EMI) filter is designed to eliminate the harmonic components generated by the high-switching frequency of Power Factor Correction (PFC) stage, because high-frequency harmonics can decrease the system Power Factor (PF).

In this paper the PFC stage i.e, SEPIC converter and PC stage i.e, Half-Bridge Inverter stages are integrated to cooperate with low cost usage of components. The switches are operated with a high-switching frequency of 250KHz [4].

This paper is organized as follows. In section II Electronic Ballast construction. Section III deals with the operation of EFLs. Section IV deals with dimming methodology in EFLs. Section V shows the results obtained, VI deals with the applications of EFLs and the section VII describes the conclusion of this paper.

II ELECTRONIC BALLAST CONSTRUCTION

The Electronic Ballast is a combination of rectifier, DC-DC converter (SEPIC) used as PFC, DC-AC Inverter (Half-Bridge inverter) as PC, resonant filter and lamp. The simulink MATLAB diagram of proposed method is presented in fig 3 and the integrated model is shown in fig 4.

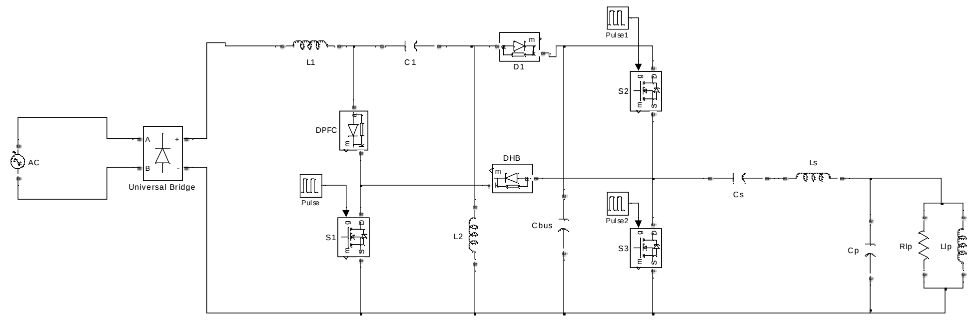


Fig 3: Non-integrated electronic ballast

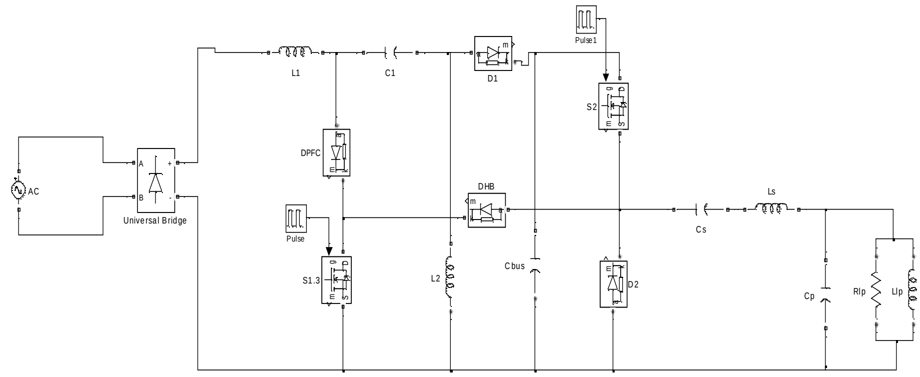


Fig 4: Proposed integrated EFL simulink model

A. SEPIC as PFC stage

The SEPIC is used as PFC stage for EFLs. The SEPIC is used effectively as step-up or step-down and it works same as Buck-Boost converter and has an advantage of non-inverting output. As this converter is employed with an input inductor, the elimination of EMI filter is possible. Hence this reduces number of stages and makes circuit simple.

$$L_1 = \frac{V_g DT}{\Delta I_{L1}} - (1)$$

$$L_2 = \frac{-V_0(1-D)T}{\Delta I_{L_2}} - (2)$$

B. Half-Bridge Resonant Inverter as PC stage

The half-bridge inverter is followed by a resonant filter, to perform lamp starting and stabilization [5].

The resonant filter LCC, operates near the filter resonant frequency during starting process. The resonant filter adapt the square waveform supplied by the inverter and attenuating the higher order harmonics and supplying lamp with sinusoidal waveforms.

C. Integration of PFC and PC stages

The integration of these stages provide less complexity., simple control circuit and less cost.

The switches S1 and S3 are integrated in order to have simple circuitary. This type of integration is known as T-type [6]. The shared switch must handle the currents both the sum of both stages. The diodes DPFC and DHB are used to prevent circulating currents from one stage to the other i.e, PFC and PC.

The diode D2 is used as intrinsic diode of switch S3. The voltage and current over this diode is same as before and after integration technique.

D. Electrical Model of EFL

The EFL under study state presents two external coils (Lcore) connected in parallel [7] [8]. These coils act as primary winding of a transformer and load of secondary winding is plasma inside the discharge lamp. In this way the energy is transfered from primary to secondary by producing luminous radiation. The equivalent electrical model of Lamp is shown in Fig 5.

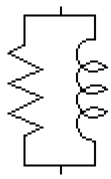


Fig 5 : Electrical Model of EFL

In the above figure the Lamp model is given as by equivalent resistance and equivalent inductance.

From the measured lamp current and voltage waveforms at each operating point, equivalent resistance and inductances are obtained. The suitable expressions to model the lamp equivalent resistance and inductance as a function of the lamp average power are given by [9].

$$R_{LP}(P_{LP}) = R_1 e^{-\frac{P_{LP}}{P_1}} + R_2 e^{-\frac{P_{LP}}{P_2}} -(3)$$

$$L_{LP}(P_{LP}) = A_3 P_{LP}^3 + A_2 P_{LP}^2 + A_1 P_{LP} + A_0 -(4)$$

Table 1 : Parameters obtained for 100W ICETRON/ENDURA from OSRAM

R1	2.497Ω
R2	43.22 Ω
P1	52.63W
P2	7.41W
A3	0.0020μH/ W^3
A2	0.3288 μH/ W^2
A1	-18.970 μH/W
A0	1330.2 μH

III OPERATION

Stage 1: In the initial condition both the switches S2 and S1, 3 are off. Here the currents in the inductors are iL1=-iL2 and the resonant current iF flows through diode D2.

Stage 2: In this stage, switch S1, 3 is turned on and switch S2 will be still off. Here, the switch S1, 3 is considered only for the SEPIC current. The resonant current circulates through diode D2. When the diode D2 current reaches Zero (iD2=0) this stage ends, due to inversion of the resonant current.

Stage 3: The diode D2 is off and Still S1, 3 is conducting and the resonant current flows through DHB and Switch S1, 3. Here still the inductors L1 and L2 are energizing.

Stage 4: S1, 3 is turned off and in half bridge inverter the resonant current circulates through the body diode of switch S2. Here the inductors L1 and L2 are de-energized by the capacitor Cbus. Both the inductances and resonant circuit supply current to capacitor Cbus. Now, S2 is turned on, with the zero voltage, hence achieving zero voltage switching (ZVS).

Stage 5: Switch S2 is still conducting and resonant current reverses and circulates through switch S2.

Stage 6: Diode D1 current reaches zero, achieving DCM operation. The resonant current circulates through switch S2. Then the switch S2, is turned off at this stage and repeating the process.

IV DIMMING METHODOLOGY

The dimming feature can be achieved by using various methods: frequency modulation [10] [11], pulse width modulation [12], filter parameters variation [13] [14], controlling bus voltage [15] [16].

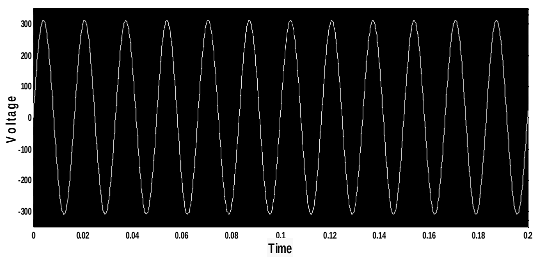
In this paper, the variation of the bus voltage is implemented to achieve dimming of the fluorescent lamp. The duty cycle of the integrated switch S1.3 is varied in order to control the bus voltage i.e, voltage across the diode D2 and, then, the power delivered to the lamp. The advantage of this method is to obtain the PFC stage behavior, a nearly linear characteristic between the bus voltage and lamp power is achieved. The converter input power depends directly on the duty cycle applied to the PFC stage. Hence, if greater duty cycle, the greater input power, and, also, the higher lamp power, the greater *V*bus.

$$D < \frac{V_{\text{bus}}(P_{\text{LP}})}{V_{\text{bus}}(P_{\text{LP}}) + V_{\text{pk}}}.$$

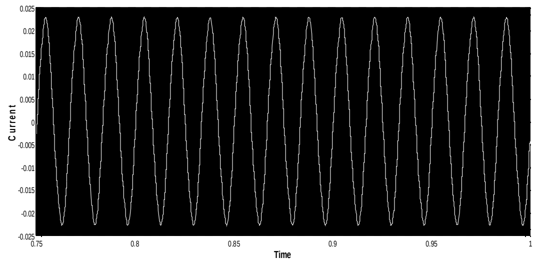
The phase angle change in resonant load is another Dimming method. The lamp luminous output is changed by varying power of the lamp. This lamp-power variation changes the lamp electrical parameters that, will change the phase angle of the total impedance that loads resonant inverter. The analysis of the phase angle of the resonant load results very important in order to verify whether the switch *S*2 will be operating under the Zero Voltage Switching mode.

V RESULTS OBATAINED

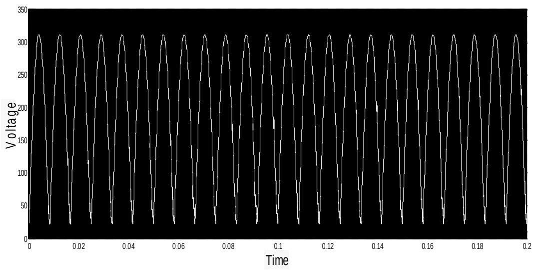
Following are the results obtained for the proposed design and methodology for Electrodeless Fluorescent Lamps (EFLs).



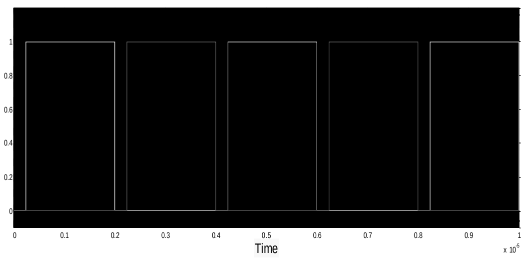
a. Input Voltage (Vpk=311V)



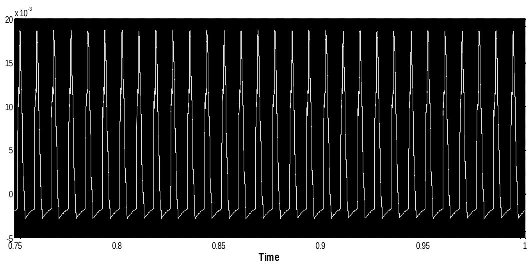
b. Input current



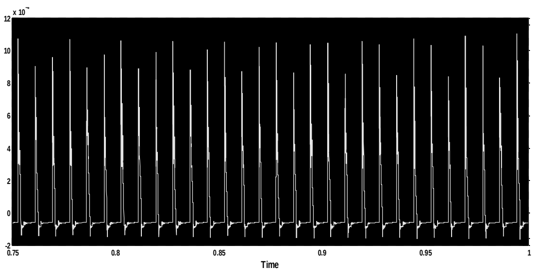
c. Rectified output



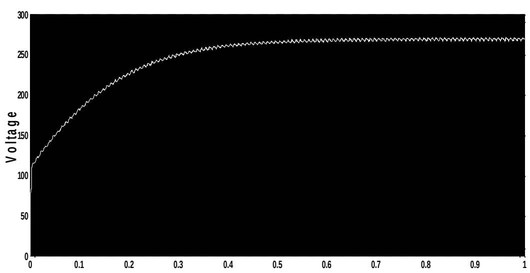
d. Switching pulse



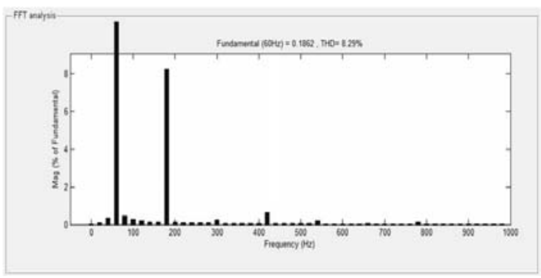
e. Inductor current iL1



f. Inductor current iL2



g. SEPIC/PFC Output Voltage (270V)



h. Input current, THD=8.29%

Design Specifications:

Input rms voltage	:	220V, 60Hz
Switching Frequency	:	250KHz
Duty cycle	:	0.44-0.30
Output Power	:	100W-44W
Efficiency	:	88.7%
PFC stage output voltage	:	270V

VI APPLICATIONS

- The compact fluorescent lamp is now available in the same popular sizes as incandescents and is used as an energy-saving alternative in homes.
- Residential use of fluorescent lighting varies depending on the price of energy, financial and environmental concerns of the local population, and acceptability of the light output.
- Driving and control circuit application.

VII CONCLUSION

Hence the SEPIC operating in Discontinuous Conduction Mode and Half-bridge integrated topology is used to feed an Electrodeless Fluorescent Lamp with reduced component count. Hence obtained the high power Factor of 0.962, high efficiency of 88.7%, total Harmonic Distortion at input current of 8.29% are achieved.

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About Authors:-

Mr. Regulagadda Rajavardhan, persuing Masters degree in a specialization of Power Electronics and Drives from Karunya University, Coimbatore.

Dr. Prawin Angel Michael, Associate Professor, Department of Electrical & Electronics Engineering, Karunya University, Coimbatore. She gained her doctorate degree in Electrical Engineering from Anna University in Space Vector Modulation.