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A New Closed Loop AC-DC Pseudo boost Based Converter System for CFL

Nithin Shaji[1], Sreekala . K[2]
[1]*Dept. of EEE, Sree Narayana Gurukulam College Of Engineering, Kerala , India*
[2]*Dept. of EEE, Sree Narayana Gurukulam College Of Engineering, Kerala , India*

Abstract :*This paper proposes a new closed loop bridgeless single phase AC-DC pseudoboost converter based electronic ballast is introduced for compact fluorescent lamps (CFL). Compared to existing topologies of single phase bridgeless system the proposed topology has benefits of closed loop error checking, lesser components, higher power density and lesser conduction losses due to the absence of an input diode in the current path during each stage of switching cycle which in turn results in an improved thermal management property[1]-[8]. Proposed topology is designed to work in resonant mode to achieve automatic power factor correction close to that of unity in a simpler and effective manner. The resonant mode of operation also helps us in achieving zero current turn on in the active power switches, zero current turn off in the output diode and reduces complexity of control circuitry [9] [10]. Closed loop system was able to provide an accurate output and was able to remove disturbances in presence of nonlinearities since they clear out the errors between input and output signals. Experimental results were able to verify the feasibility of the proposed circuitry with satisfactory performance.*
Keywords -*Compact fluorescent lamp (CFL); power factor correction (PFC); pseudoboost; electronic ballast; resonant mode; closed loop*

I. INTRODUCTION

With the increase in need and usage of electricity we have an issue of availability of electric power sources. Indian Central Electricity Authority is anticipating base load energy deficit and peaking shortage to be 2.1% and 2.6% respectively for the 2015-16 fiscal year. One way to mitigate the difference in availability and need of power is through reduction losses in the system.

In India, lighting accounts for almost 20% of the total electricity demand, and is a major component of the load. The majority of lighting needs in the country are met by incandescent bulbs, particularly in the household sector. Extremely energy inefficient as over 90% of electricity is converted into heat, and only 10% is used for lighting. The first step in reducing losses would be through awareness among people to stop all wastage of electricity through replacement of incandescent lamps with CFL lamps. CFL uses only one-fifth to one-third the electric power and last eight to fifteen times longer. Conventional CFL has power factor equals to or above 0.85pf. Fig 2 shows block diagram of conventional CFL.

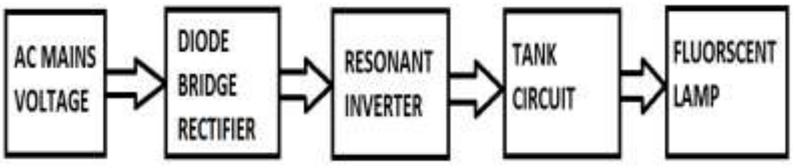


Fig. 1. Block diagram of conventional compact fluorescent lamp

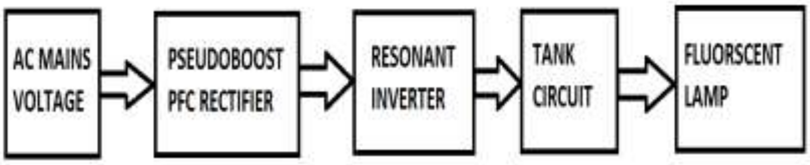


Fig. 2. Block diagram of Pseudoboost compact fluorescent lamp

Fig 2 shows block diagram of proposed new efficient power factor corrected compact fluorescent lamp. For the purpose of improving circuit efficiency and providing better power factor correction properties to ac to dc converter we are using bridgeless resonant pseudoboost rectifier [11]. Absence of an input diode bridge and the presence of only one diode in the current path during each stage of the switching cycle results in higher power density and less conduction losses hence improved thermal management compared to existing PFC rectifier is obtained. Pseudoboost PFC has the merit of less component count. The resonant mode operation gives additional advantages such as zero-current turn-on in active power switches, zero current turn-offs in output diode and reduces the complexity of the control circuitry.

II. CIRCUIT CONFIGURATION

2.1 Peudoboost PFC Converter For CFL

Fig 3 shows the proposed electronic ballast consisting of a bridgeless PFC resonant pseudoboost converter. The PFC converter improves the input power factor. The proposed converter is designed to operate in discontinuous conduction mode (DCM) during the switch turn-on interval and in resonant mode during the switch turn-off intervals. The resonant mode operation gives additional advantages such as zero-current turn-on in the active power switches, zero-current turn-off in the output diode and reduces the complexity of the control circuitry.

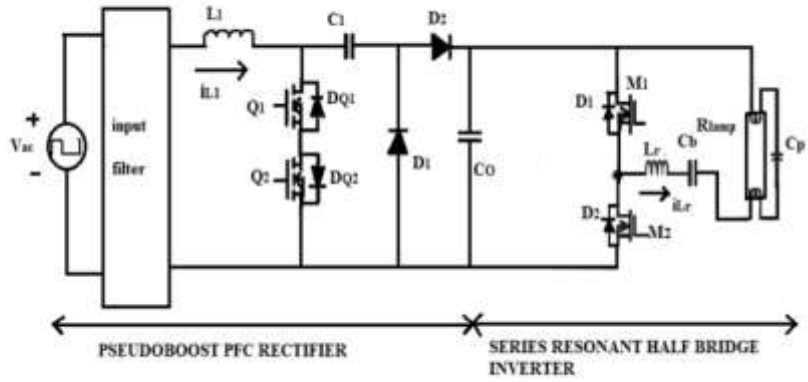


Fig 3 Pseudoboost electronic ballast for CFL

2.2Series Resonant Half Bridge Inverter

Series resonant inverter provides sufficient ignition voltage and supplies constant lamp current at high frequency to drive the fluorescent lamp [4][9]. The quasi half bridge inverter produces a square voltage which is fed to the load through the LC network which filters the odd harmonics present in the square wave. The switching frequency of the resonant inverter is kept more than the resonant frequency of the inverter to confirm Zero voltage switching which reduces switching losses at high frequency. The switches M1 and M2 are alternatively switched on and off at a switching frequency of 20 KHz.

At the time of starting, the fluorescent lamp behaves as an open circuit and during steady state operation it is considered as a pure resistor. As compared to the lamp resistance the filament resistance is neglected and switching devices are considered ideal switches. The dc blocking capacitor Cb is much larger than the resonant capacitor Cp so that its voltage ripple is negligible.

III. CIRCUIT OPERATION AND ANALYSIS

For simplifying circuit analyses following assumptions are made:

1) Input voltage is pure sinusoidal
2) Ideal lossless components
3) Switching frequency (fs) is much higher than the ac line frequency (f_L)
4) Output capacitor Co is large enough such that the output voltage can be considered constant over the whole line period.

3.1 Peudoboost PFC Converter For CFL
(1)Stage I ($t_0 < t < t_1$)

This stage starts when the switch Q_1 is turned-on. The body diode of Q_2 is forward biased by the inductor current I_{L1}.Diode D_1 is reverse biased by the voltage across C_1while D_2 is reverse biased by the voltages $V_{C1} + V_0$. In this stage the current through inductor L_1 increases linearly with the input voltage, while the voltage across capacitor C_1 remains constant at V_X.

(2)Stage II ($t_1 < t < t_2$)

This stage starts when the switch Q_1 is turned-off and Diode D_2 is turned-on simultaneously providing a path for the inductor current i_{L1} . As a result diode D_1remains reverse biased during this interval. The series tank consisting of L_1 and C_1 are excited by the input voltage V_{ac} through diode D_2. The stage ends when the resonant current i_{L1} reaches zero and diode D_2 turns-off with zero current. During this stage, capacitor C_1 is charged until it reaches a peak value.

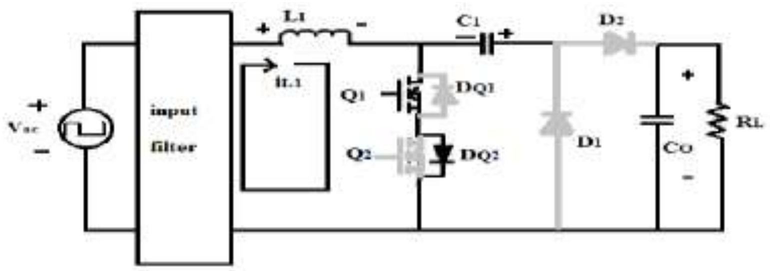
(3)Stage III ($t_2 < t < t_3$)

During this stage diode D_1 is forward biased to provide a path during the negative cycle of the resonating inductor current i_{L1}. This stage ends when the inductor current reaches zero. Thus, during this stage $D_1$is switched ON and OFF under zero current conditions. Assuming the constant input voltage over a switching period, the capacitor is charged.

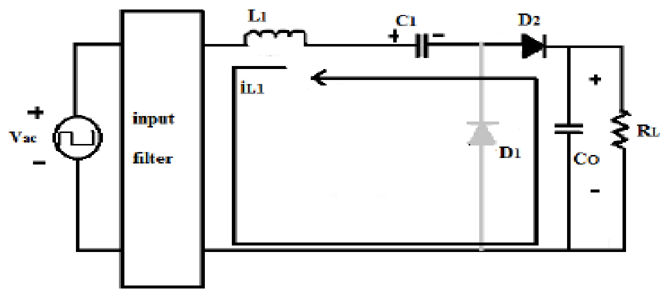
(4)Stage IV ($t_3 < t < t_4$)

During this stage all switches are in their off-state. The inductor current is zero, while the capacitor voltage remains constant($V_{C1} = V_X$). It shall be noted that for this converter to operate as specified, the length of this stage must be greater than or equal to zero.

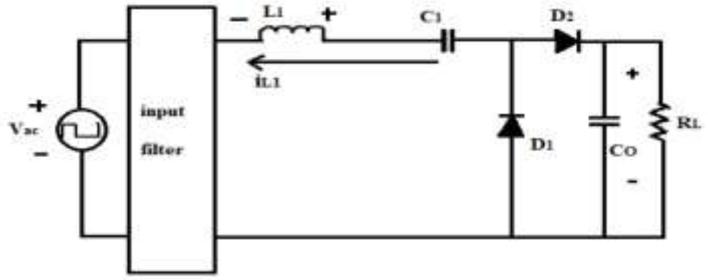
Fig 5 & 6 shows theoretical waveform of the proposed converter in positive and negative half cycle.



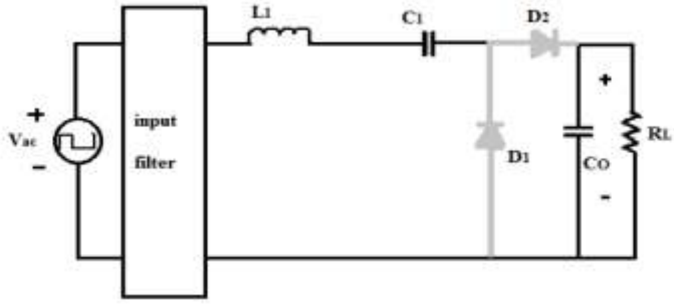
(a) Stage I



(b) Stage II



(c) Stage III



(d) Stage IV

Fig 4 Stages of operation of Pseudoboost converter for CFL

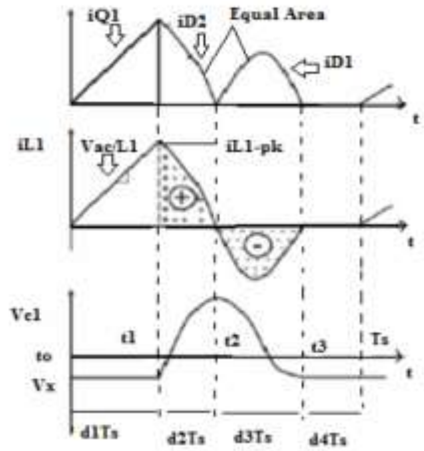


Fig 5 Theoretical waveform of Pseudoboost converter during positive half cycle

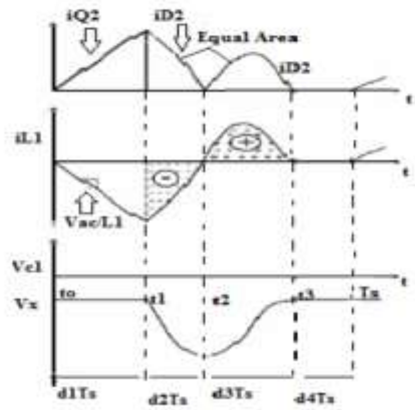


Fig 6 Theoretical waveform of Pseudoboost converter during negative half cycle

3.2 Series Resonant Half Bridge Inverter

(1)Mode I ($t_0 < t < t_1$)

At t_0, body diode D_2 starts conducting and the DC link capacitor is charged and during this interval the gate pulse is also applied to active switch M_2. The path of current is given as: C_0(-)$-D_2-L_r - C_b -(R_{lamp} \,||\, C_p)- C_0$(+)

(2)Mode II ($t_1 < t < t_2$)

At t_1, the M_2 is turned on at ZVS and the dc link capacitor is discharged. The direction of resonant inductor current changes and it increases up to time t_2. The path of current is given as: C_0(+)$-(R_{lamp} \,||\, C_p)-C_b-L_r - M_2 - C_0$(-)

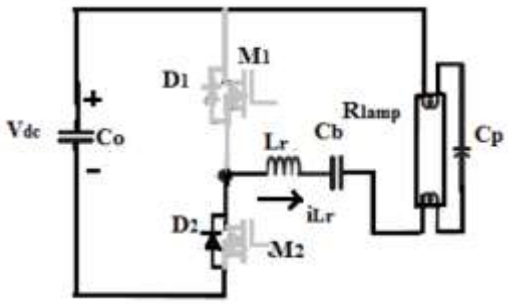
(3)Mode III ($t_2 < t < t_3$)

$M_2$is turned off at t_2 and body diode D_1 starts conducting, thus allows resonant current to flow in the same direction due to resonant nature of the circuit. During this interval the gate pulses is also applied to active switch M_1. The path of the current is given as: $D_1 - (R_{lamp} \,||\, C_p) - C_b - L_r - D_1$

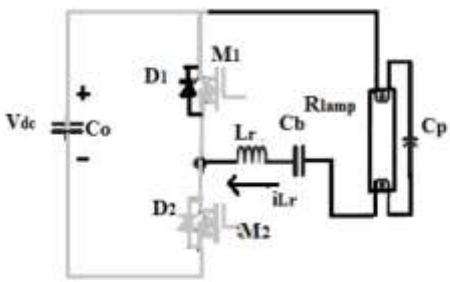
(4)Mode IV ($t_3 < t < t_4$)

At t_3, M_1starts conducting and it is evident that it is turned on at ZVS. This ensures the change in the direction of the resonant current. The mode ends up at t_4 and then Mode I to Mode IV repeats for the next switching cycle. The path of current is given as :$M_1 - L_r - C_b - (R_{lamp} \,||\, C_p) - M_1$

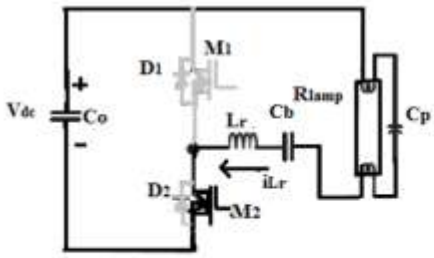
Fig 7shows the circuit diagram and Fig 8 showwaveform of series resonant half bridge inverter with Vab as input voltage.



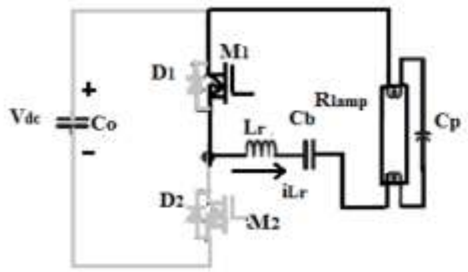
(a)Mode I



(c)Mode III



(b)Mode II



(c) Mode IV

Fig 7 Modes of operation of series resonant half bridge inverter

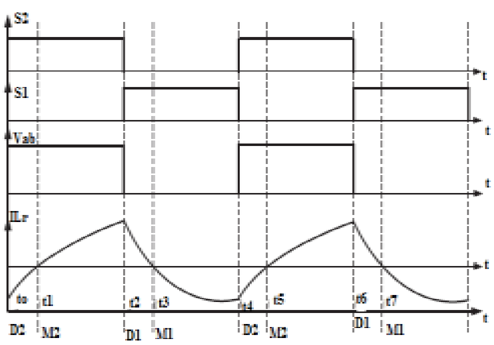


Fig 8 Waveform of series resonant half bridge inverter

3.3 Design OfPseudoboost Power Factor Correction Rectifier

The Pseudoboost Converter is designed based on following parameters Input voltage (Vin), Output voltage (Vo), Power (Pin), Switching frequency (fs).

The voltage conversion ratio M is given by equation,$M=\frac{Vo}{Vin}$

Inductor equation is given by, $L_1 = (\frac{R_L T_S}{4})^2 \frac{F}{\pi}$

Resonating capacitor is given by,$f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{L_1 C_1}}$

The dimensionless conduction parameter K is defined by, $K = \frac{2L_1}{R_L T_S}$

Duty cycle d1 is, $d1 = M\sqrt{2K}$

3.4 Design Of Series Resonant Half Bridge Inverter

The Series Resonant Half Bridge Inverter is designed based on parameters Rated Lamp Voltage (V_{lamp}), Power (Pin).

Switching frequency (Ws) $=2\boldsymbol{\pi}$fs

Resistance of lamp, $R_{lamp} = V_{\text{lamp}}{}^2$/Power

Capacitor$C_b = 15(\frac{V_{\text{lamp}}}{V_{\text{ab}}})(\frac{1}{R_{lamp}\ \text{Ws}})$

Capacitor$C_p = \frac{C_b}{15}$

Inductor$L_r = \frac{16}{C_b \text{Ws}^2}$

IV. SIMULATION RESULT

For verifying the feasibility and validity of the proposed converter, MATLAB/SIMULINK software is applied for the simulation of the proposed system with an input voltage of V_{ac} = 108V_{rms} at 50 kHz and output voltage of Pseudoboost converter is set as V_o = 300V. V_{lamp} Which is the rated lamp voltage is taken as 110V. The duty cycle of the pseudoboost converter is set as 48%.simulation parameters used is shown in Table 1.

TABLE I. SIMULATION PARAMETERS

Component	Value	Remarks
L_f	10 mH	Filter Inductor of Converter
L_1	7.3 mH	Main Inductor of Converter
C_1	5.5 nF	Main Capacitor of Converter
C_f	1 µF	Filter Capacitor of Converter
C_o	100 µF	Output Capacitor of Converter
L_r	3.5 mH	Series Resonant Inductor of lamp
C_b	4.7 nF	Blocking Capacitor of lamp
C_p	2.3 nF	Parallel resonant Capacitor of lamp
R_{Lamp}	1210 ohms	Lamp Resistance

Fig 9 shows the simulation model of Pseudoboost PFC converter based electronic ballast for compact fluorescent lamp. A PWM controller was used for the closed loop simulation of the above discussed Pseudoboost converter. The Output Voltage is compared with the reference Output voltage. The compared Output is fed to discrete PI controller Block. The Output of the PI controller is compared with the repeating sequence block which displays the time-output value. This compared Output is fed to the gate of the MOSFET for generating the pulses. The output of PI Controller displays the duty cycle of the converter.

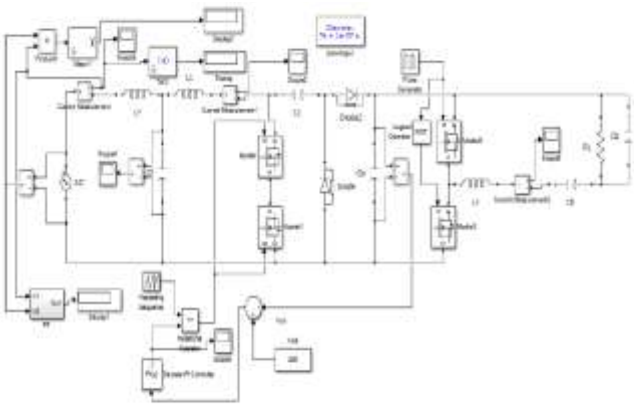


Fig 9 Simulink model of Pseudoboost Converter based Ballast

The input voltage of the pseudoboost converter based electronic ballast is taken as 108V with a switching of 20 kHz. The input current is an important feature in power factor correction. Here in the Fig 11 input current obtained is almost sinusoidal in nature even though having slight distortion and in phase with the input voltage waveform. Therefor the power factor correction rectifier shaped the input current and hence the power factor and efficiency is improved.

Fig 10 shows the resonating nature of the inductor current of pseudoboost converter. From the nature of the inductor current we can conclude that the converter operates in DCM of operation.

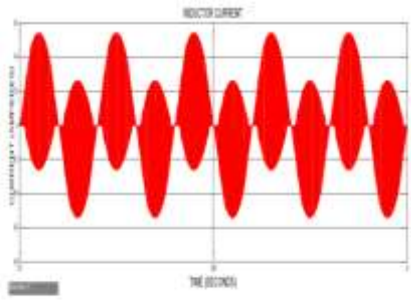


Fig 10 Inductor current of pseudoboost converter

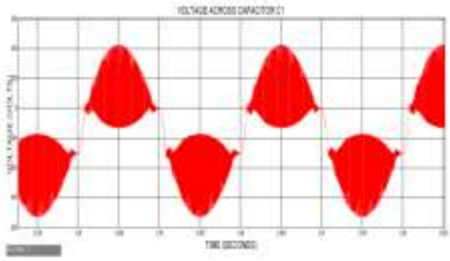


Fig 11 Voltage across Capacitor C1

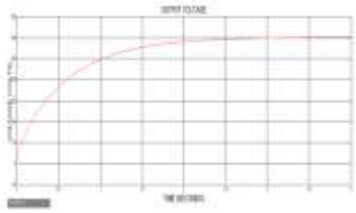


Fig 12 Output Voltage of the Pseudoboost Converter

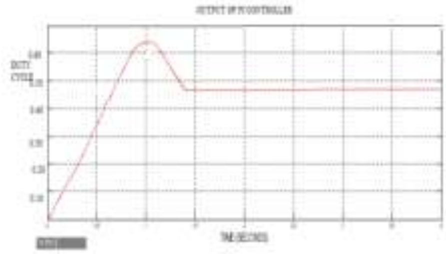


Fig 13 PI Controller Outpute of the Pseudoboost Converter

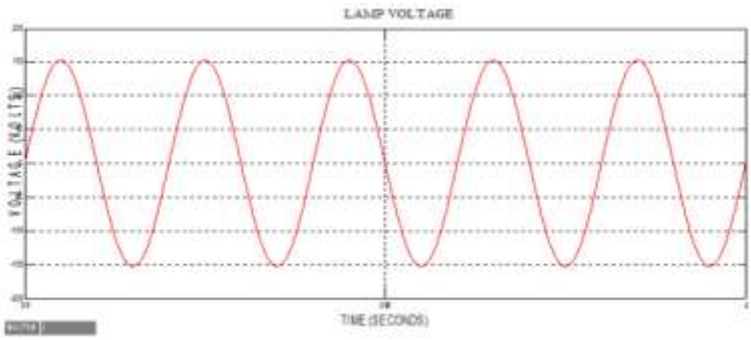


Fig 14 Voltage across the Lamp

As Fig 14 shows the lamp voltage remains constant for wide range of ac mains voltage. Lamp voltage is maintained within the range of 100-150. Lamp current also remains constant for wide range of ac mains voltage. Lamp current is maintained within the range of 0.05-0.165. Output voltages across capacitor C1 and Pseudoboost converter are shown respectively in fig 11 & 12. The fig 13 shows the PI Controller Output.

The results obtained after MATLAB simulation of the Pseudoboost converter based ballast are,

Power factor = 0.9959

Total harmonic Distortion = 0.08905

Efficiency = 97%

The proposed electronic ballast was able to improve power quality such as input power factor of 99% and efficiency of about 97%. The current harmonics of the pseudoboost converter based ballast are within the norms of current harmonic limits of IEC 61000-3-2 class C equipment. Proper design of Pseudoboost PFC converter and series resonant half bridge inverter has resulted in maintaining the DC link voltage and lamp current close to desired values needed. The proposed ballast has THD of nearly 8% for ac mains current. The zero voltage switching (ZVS) has been achieved by keeping the switching frequency more than the resonant inverter to reduce the switching losses.

V. CONCLUSION

Highly efficient bridgeless single phase AC-DC converter based electronic ballast is proposed for compact fluorescent lamps.This electronic ballast is a combination of Pseudoboost AC-DC converter as a power factor regulator in the discontinuous conduction mode and half bridge resonant series resonant inverter. The proposed topology has benefits of closed loop error checking, lesser components, higher power density and lesser conduction losses due to the absence of an input diode in the current path during each stage of switching cycle which in turn results in an improved thermal management property.The proposed electronic ballast was able to improve power quality such as input power factor of 99% and efficiency of about 97%. The current harmonics of the pseudoboost converter based ballast are within the norms of current harmonic limits of IEC 61000-3-2 class C equipment. Proper design of Pseudoboost PFC converter and series resonant half bridge inverter has resulted in maintaining the DC link voltage and lamp current close to desired values needed. The proposed ballast has THD of nearly 8% for ac mains current. The zero voltage switching (ZVS) has been achieved by keeping the switching frequency more than the resonant inverter to reduce the switching losses.

The future research will be focused on applying the converter circuit in LED [12] system and for applications other than the electronic ballast.

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