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A Bridgeless Resonant Pseudo Boost PFC Rectifier based Electronic Ballast for Compact Fluorscent Lamp

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ABSTRACT: Artificial lighting is being used more and more in the world. In developing countries, we can still find a widespread use of fuel based lighting but nowadays the situation is changing and the demand for electric based lighting is growing. Electric lighting consumes about 19% of the world total electricity use.Here a Pseudo Boost rectifier based electronic ballast with a natural power factor correction (PFC) is proposed. Compared with existing single-phase bridgeless topologies, the proposed topology has the merits of less component counts. The absence of an input diode bridge and the presence of only one diode in the current path during each stage of the switching cycle result in higher power density and less conduction losses; hence, improved thermal management compared to existing PFC rectifiers is obtained. The proposed topology is designed to work in resonant mode to achieve an automatic PFC close to unity in a simple and effective manner.

KEYWORDS: Compact Fluorscent Lamp, Electronic Ballast, Pseudo Boost rectifier, Zero Current Switching.

I.INTRODUCTION

Artificial lighting is being used more and more in the world. The usage is quite non homogeneous. In developing countries, we can still find a widespread use of fuel based lighting but nowadays the situation is changing and the demand for electric based lighting is growing. Electric lighting consumes about 19% of the world total electricity use. So, we should remember and consider that the improvement in energy efficient lighting will also be helpful for the progress in developing countries. A Compact Fluorescent Lamp (CFL) is a fluorescent light bulb made to be used in the same manner that incandescent light bulbs have been used traditionally. A CFL provides the same light output as an incandescent bulb, but typically uses only a quarter of the energy that an incandescent would. With the quantity of light (that is lumen output) CFL provides good quality (color rendering index) for different applications .CFLs also put out only a fraction of the heat that incandescent bulbs put out. This saves even more on electric bills in buildings with air conditioning and makes buildings without air conditioning more comfortable in the summer. Besides saving so much energy, a CFL lasts about 5 to 15 times longer than an incandescent bulb. Therefore, by using CFLs a building or home owner can save money in heating and cooling costs and on the amount spent on lamp replacement. To control lamp current and provide the required start-up voltage CFL requires ballast which may be either magnetic or electronic. Most early CFLs used magnetic ballasts, which operate at line frequency-50 Hz. Magnetic ballasts consists of a wire-wound coil connected in series with the lamp is available for use with conventional and compact fluorescent lamps. Due to their inductive nature, electromagnetic ballasts consume approximately 15 to 25 percent of the rated lamp power which is dissipated as heat. In addition, many of these types of ballasts suffer from a low displacement power factor (approximately 0.5 lagging power factor).Electronic ballasts consist of solid state devices used to create a high frequency ac voltage supplied to the lamp. Electronic units are lighter and more efficient and give better life. Typical operating frequencies are 20 to 60 kilohertz.The compact fluorescent lamp consists of a soda-lime glass tube filled with a few torr of gas basically argon and a drop of mercury. Metal electrodes are sealed at the tube ends and conduct electric current from the external circuit to the gas present internally. There are two main parts in a CFL namely a gas-filled tube(bolb or burner) and an electronic ballast. An electrical current from the ballast flows through the mercury vapor, emitting ultraviolet light .This ultraviolet light further excites a phosphor coating present inside the tube. This

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

coating is responsible for emitting visible light. Electronic ballasts usually contains a small circuit board along with rectifiers, a filter capacitor and two switching transistors. These transistors are usually connected as a high-frequency resonant series DC to AC inverter. This high frequency, around 40 kHz is then applied to the lamp tube.

II.LITERATURE SURVEY

Most of the PFC rectifiers utilize a boost/buck–boost topology converter at their front end due to its high power factor (PF) capability [1]–[4]. However, a conventional PFC scheme has lower efficiency due to significant losses in the diode bridge. During each switching cycle interval, the current flows through three power semiconductor devices. The forward voltage-drop across the bridge diodes degrades the converter efficiency, especially at low-line input voltage. In response to these concerns, considerable research efforts have been directed toward the development of efficient bridgeless PFC circuit topologies [5]–[24]. A bridgeless PFC circuit allows the current to flow through a minimum number of switching devices compared to the conventional PFC circuit. Accordingly, the converter's conduction losses can be significantly reduced, and higher efficiency and lower cost can be obtained. However,most of the previous proposed bridgeless PFC converters have at least one of the following drawbacks: high components count, components are not fully utilized over whole ac-line cycle, complex control, dc output voltage is always higher than the peak input voltage, lack of galvanic isolation, and due to the floating ground, some topologies require additional diodes and/or capacitors to minimize EMI. In order to overcome most of these problems, an interesting reduced component count topology has been introduced in [25]. However, the proposed topology in [25] still suffers from having at least two semiconductors in the current conduction path during each switching cycle. In [26], a zero current switch topology is presented. This topology has reduced-component count; however, the load is floating with respect to the input. A novel low-count topology has been introduced in [27]. The proposed topology has low-component count with an input stage similar to a boost converter.The main Objective of this paper is to develop a high energy efficient bridgeless resonant pseudo Boost power factor correction rectifier based electronic ballast for a Compact Fluorscent lamp and thereby improving the power factor.

III.PROPOSED SYSTEM

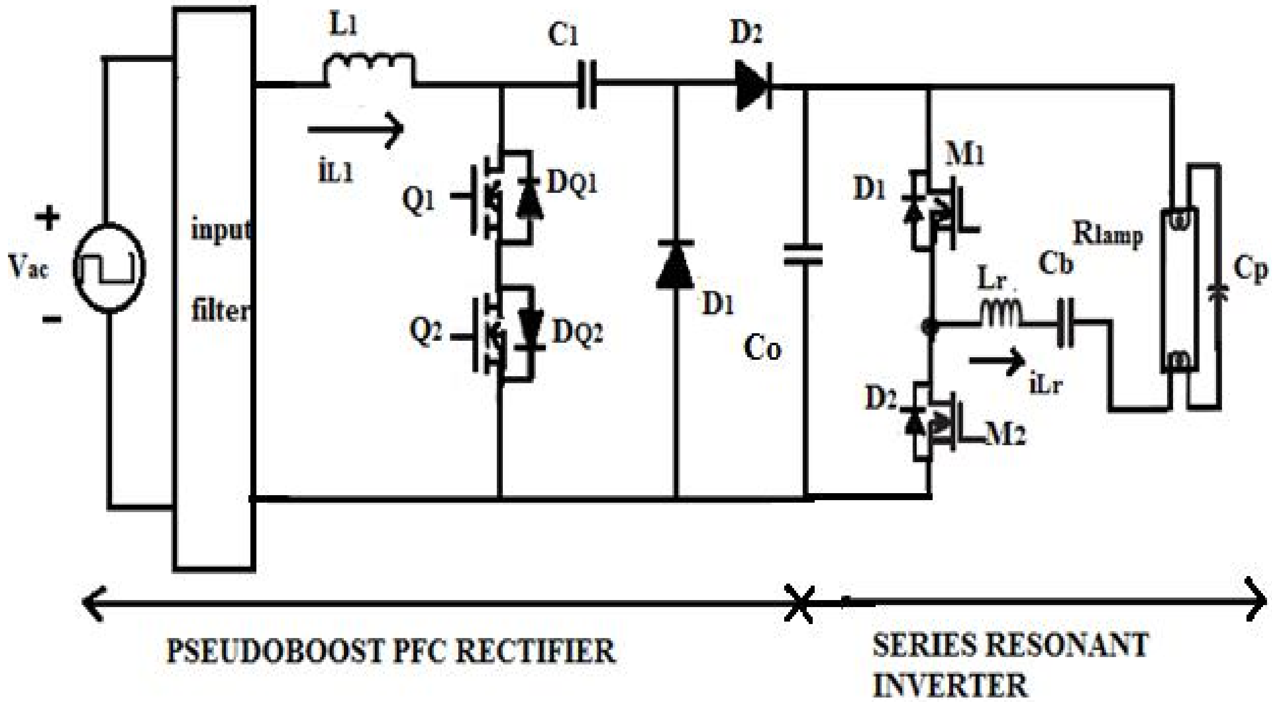

Fig. 1 Proposed System

ISSN (Print) : 2320 – 3765
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Vol. 4, Issue 9, September 2015

The proposed electronic ballast shown in figure 1,consists of a bridgeless PFC resonant pseudoBoost converter and a high frequency series resonant inverter. The PFC converter improves the input power factor and series resonant inverter provides sufficient ignition voltage and supplies constant lamp current at high frequency to drive the fluorescent lamp. 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. Since the harmonics in the square wave are attenuated by the LC network, an analysis is carried out only using the fundamental component of the square wave voltage. The switchesM_1 and M_2 are alternatively switched on and off at a switching frequency of 20KhZ.The switching frequency of the resonant inverter is kept more than the resonant frequency of the inverter to confirm Zero voltage switchingwhich reduces switching losses at high frequency.

IV. PSEUDOBOOST CONVERTER

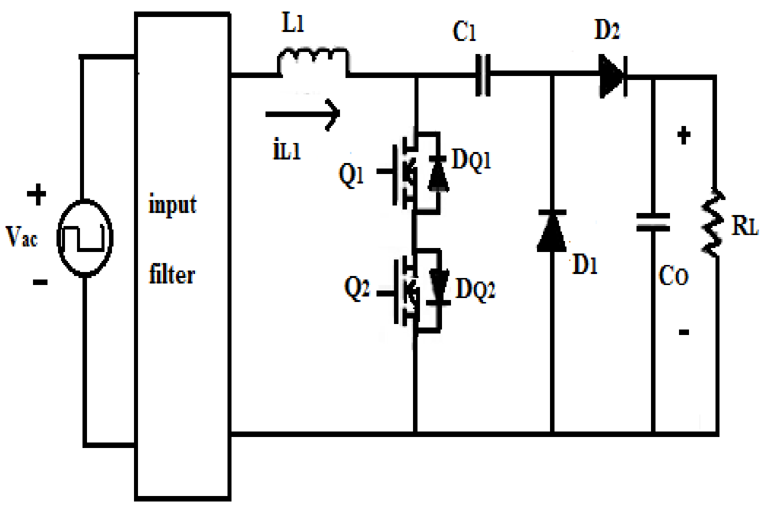

Fig.2 Pseudo boost Converter

The term Bridgeless Resonant PseudoBoost PFC rectifier refers to a type of bridgeless ac to dc converter with natural power factor correction. Pseudoboost PFC has the merits of less component counts. The absence of an input diode bridge and the presence of only one diode in the current path during each stage of the switching cycle result in higher power density and less conduction losses; hence, improved thermal management compared to existing PFC rectifiers is obtained. The converteris designed to operate in discontinuous-conduction mode (DCM) during the switch turn-on interval and in resonant mode during the switch turnoff intervals. As a result, the switch current stress is similar to the conventional DCM PFC converter, while the switch voltage stress is higher. 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. Moreover, the two power switches $Q_1$and Q_2can be driven by the same control signal, which significantly simplifies the control circuitry.Thus, during each switching period T_s the current path goes through only two or one semiconductor devices instead of three. As a result, the total conduction losses of the semiconductor devices will be considerably lower compared to the conventional bridgeless PFC converters. Following assumptions are made: input voltage is pure sinusoidal, ideal lossless components, the switching frequency(f_s) is much higher than the ac line frequency (f_L), and theoutput capacitor $C_o$is large enough such that the output voltage can be considered constant over the whole line period. Based on these assumptions, the circuit operations in one switching period $T_s$in a positive ac-line cycle can be divided into four distinct topological stages.

A. Circuit Operations

Stage (t_o,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_o.In this

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

stage, the current through inductor L_1increases linearlywith the input voltage, while the voltage across capacitor C_1 remains constant at voltage V_x.

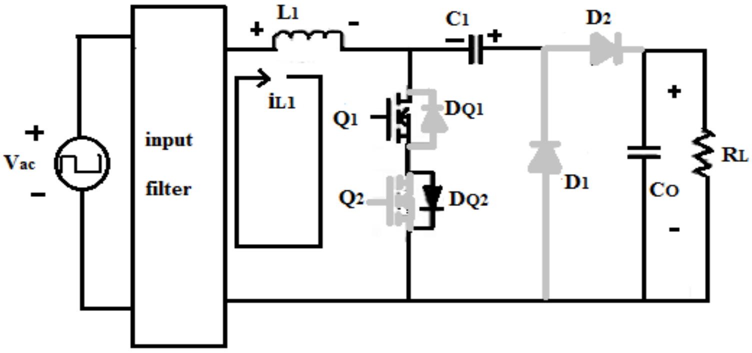

Fig.3 Stage 1

Stage 2(t_1,t_2) -This stage starts when switch $Q_1$is turned OFF and diode $D_2$is turned ON simultaneously providing a path for the inductor currents 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_2turns OFF with zero current.

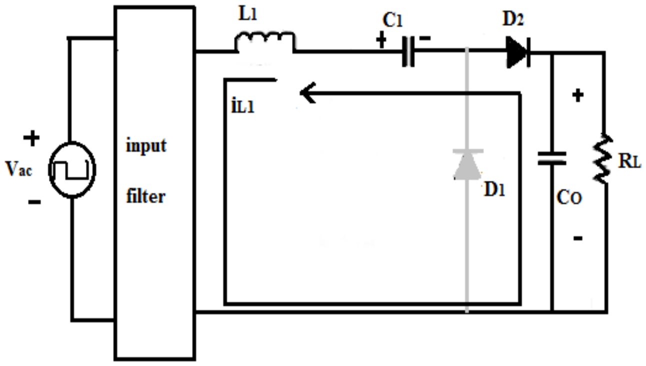

Fig.4 Stage 2

Stage 3(t_2,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, duringthis stage diode D_1 is switched ON and OFF under zero current conditions. Assuming the constant input voltage over a switching period, the capacitor is discharged.

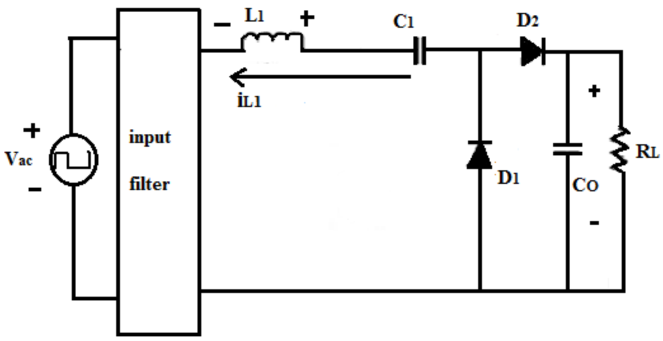

Fig.5 Stage 3

ISSN (Print) : 2320 – 3765
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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Stage 4(t_3,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.

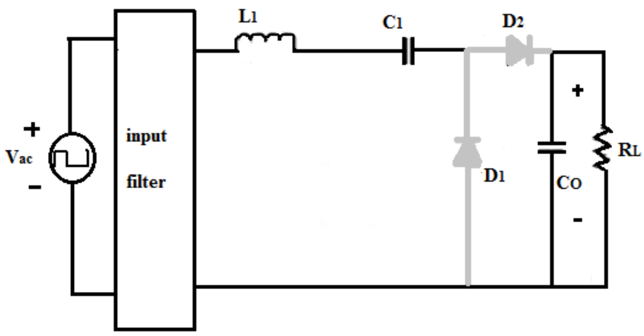

Fig.6 Stage 4

B. Design Equations

The PseudoBoost Converter is designed for an input voltage V_{in}= 108V, V_o=300V and P_{in}=10 W with a switching frequency of 20 KhZ.
The Voltage Conversion ratio M is:
M =1.96
Inductor equation is given by :
$L_1 = \frac{R_L T_S}{4}$ square$(\frac{F}{\pi})$……………………………. (1)
L_1 = 3.5 mH.
Resonating Capacitor is given by:
$f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{L_1 C_1}}$……………………................... (2)
C_1 = 11 nF.
The dimensionless conduction parameter K is defined by:
$K = \frac{2L_1}{R_L T_S}$……………………………………….. (3)
K = 0.01.Duty cycle d_1 is :
$d_1 = M\sqrt{2K}$……………………………………... (4)
d_1 = 27.
P = Square(V)/R………………………………… (5)
R = 9000 Ohms.

V.SERIES RESONANT HALF BRIDGE INVERTER

Series resonant inverter provides sufficient ignition voltage and supplies constant lamp current at high frequency to drive the fluorescent lamp. 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. Since the harmonics in the square wave are attenuated by the LC network, an analysis is carried out only using the fundamental component of the square wave voltage. The switches M_1 and M_2 are alternatively switched on and off at a switching frequency of 20KhZ.

A. Circuit Operations

Mode 1 (t_o<t<t_1) - At t_o, 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_o(-)-D_2-L_r-C_b-(R_{lamp}|| C_p)-C_o(+)

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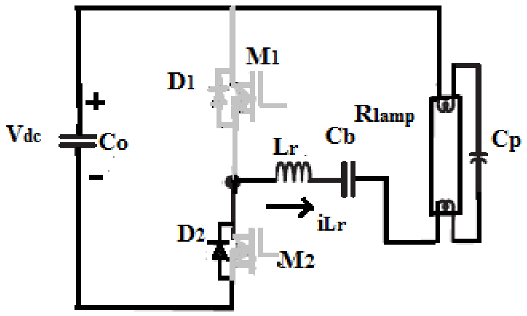

Fig.7 Mode 1

Mode 2 (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_o(+)-(R_{lamp}||C_p)-C_b-L_r-M_2-C_o(-)

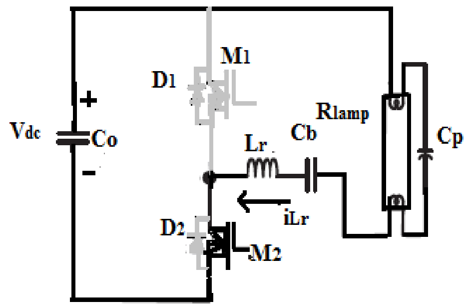

Fig.8 Mode 2

Mode 3 (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

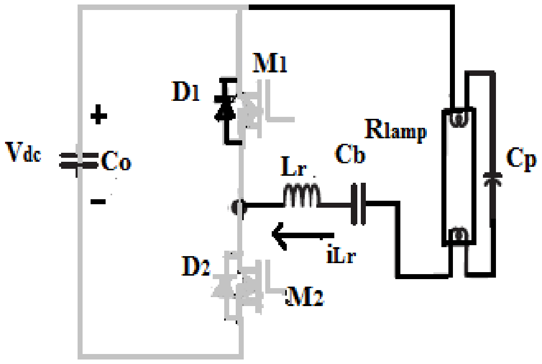

Fig.9 Mode 3

ISSN (Print) : 2320 – 3765
ISSN (Online) : 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Mode 4 (t_3<t<t_4) - At t_3, M_1 starts 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 t4 and then mode 1 to Mode 4 repeat for the next switching cycle. The path of current is given as :
M_1-L_r-C_b-(R_{lamp}||C_p)-M_1

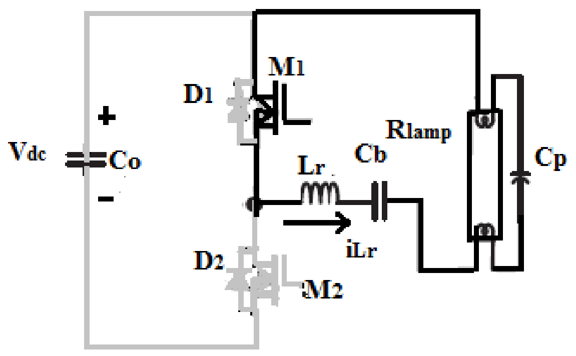

Fig.10 Mode 4

B. Design Equations

At the time of starting, the selfoscillating technique provides a resonant frequency ($\omega_{starting}$) which is made equal to the switching frequency ($\omega_{switching}$). The relationship between the resonant parameters and the starting resonant frequency is given as:

$\omega_{starting}$=$\omega_{switching}$=$\frac{1}{\sqrt{L_r\left(\frac{C_b C_p}{C_b C_p}\right)}}$.................. (6)

The steady-state resonant frequency is given as:

$\omega_{running}$=$\frac{1}{\sqrt{L_r C_b}}$.................................... (7)

If the switching frequency is more than the steady state resonant frequency then the zero voltage switching (ZVS) is ensured. Considering that,

$\omega_{starting}$ = 4 $\omega_{switching}$.................................. (8)

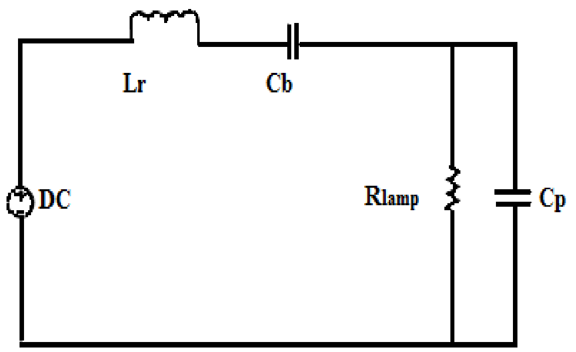

Fig.11 Equivalent circuit of series resonant inverter

Figure 12 shows the equivalent circuit of the series resonant parallel loaded inverter under the steady-state operation of the lamp. In this circuit,L_r,$C_b$and $C_p$are the resonant circuit parameters and R_{lamp} is the resistance of the fluorescent lamp.The relationship between the rated lamp voltage and the fundamental component of the output of voltage source inverter is given as:

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Vol. 4, Issue 9, September 2015

$$\frac{V_{lamp}(jw)}{V_{ab}(jw)} = \frac{Z_P\ (jw)}{Z_s(jw)+Z_P\ (jw)} \quad \text{……………………..} \ (9)$$

Solving (6) to (9) the resonant parameters are given by:

$$C_b = 15\left(\frac{V_{lamp}}{V_{ab}}\right)\left(\frac{1}{R_{lamp}\omega_{switching}}\right) \quad \text{……………} \ (10)$$

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

$$L_r = \frac{16}{C_b\ \omega_{switching}^2} \text{………………………………} \ (11)$$

R_{lamp} = square(V_o)/Power……………………… (12)

R_{lamp} = 1210 Ohms…………………………… (13)

$$C_b = 15\left(\frac{V_{lamp}}{V_{ab}}\right)\left(\frac{1}{R_{lamp}\omega_{switching}}\right) \text{…………..} \quad (14)$$

C_b = 4.7 nF…………………………………… (15)

$$C_p = \frac{C_b}{15} \text{……………………………………….. } (16)$$

C_b = 2.3 nF…………………………………… (17)

$$L_r = \frac{16}{C_b\ \omega_{switching}^2} \text{………………………………} \ (18)$$

Lr = 28.9 mH………………………………… (19)

VI. RESULT AND DISCUSSION

To verify the feasibility and validity of the proposed converter, MATLAB/SIMULINK software is applied for the simulation of the proposed system with an input voltage V_{ac}= 108 V_{rms}, f_s= 20 kHz, Power = 10 W and output voltage of converter is set as V_0= 300V.

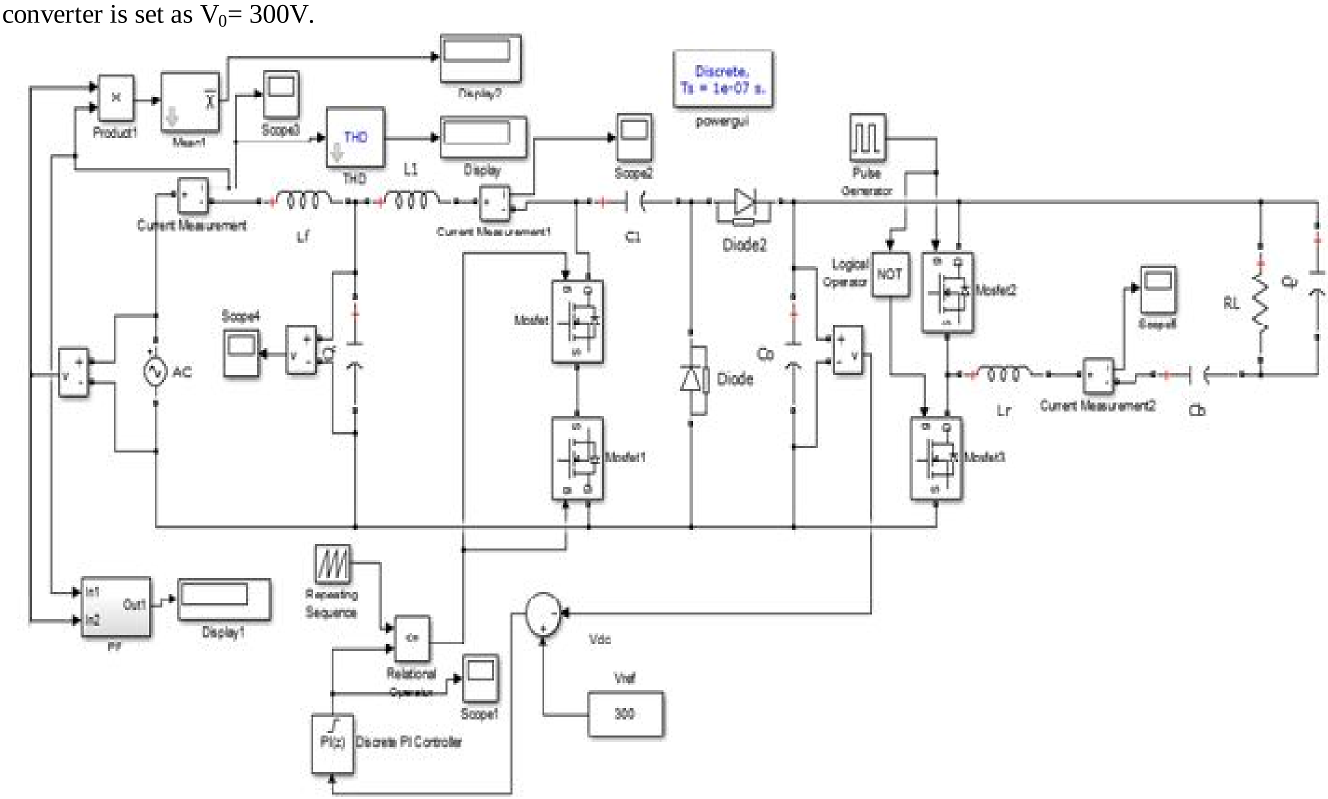

Fig.12Simulation model of proposed system

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

The above figure shows the MATLAB/SIMULINK model of the proposed system. Closed loop simulation of the proposed system using PI Controller is shown in the figure.

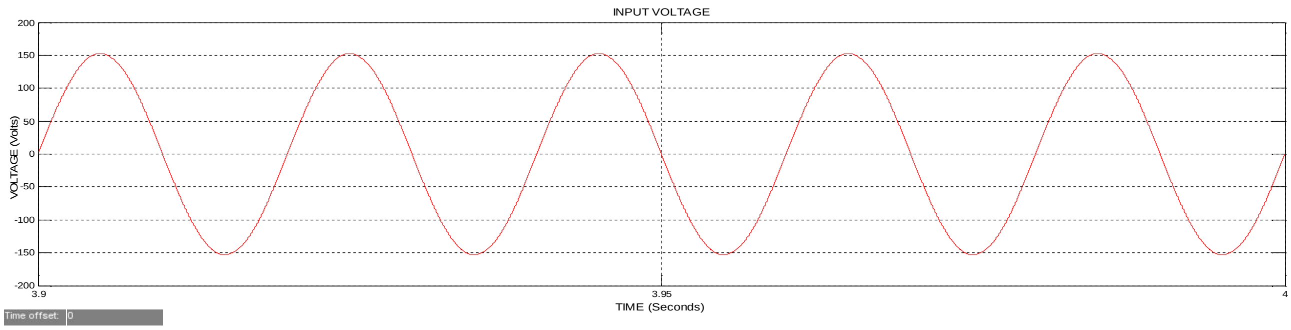

Fig.13 Input Voltage (108 V_{rms})

The input voltage of the pseudoBoost converter based electronic ballast is taken as 108 $V_{rms}$with a switching frequency of 20KhZ and the whole system is designed for a power of 10 W.

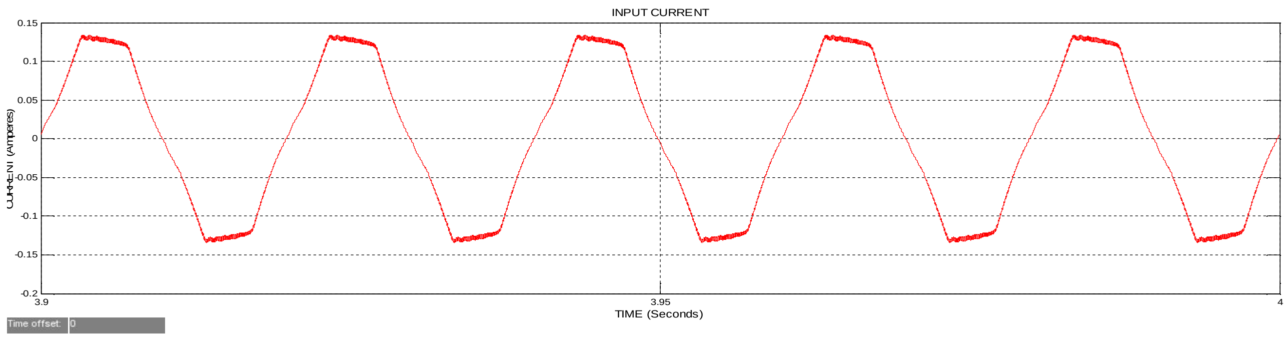

Fig.14 Input Current

The input current is an important feature in power factor correction. Here the input current obtained is almost sinusoidal in nature eventhough having slight distortion in DCM mode. Hence the power factor correction correction rectifier shaped the input current and hence the powerfactor and efficiency is improved.

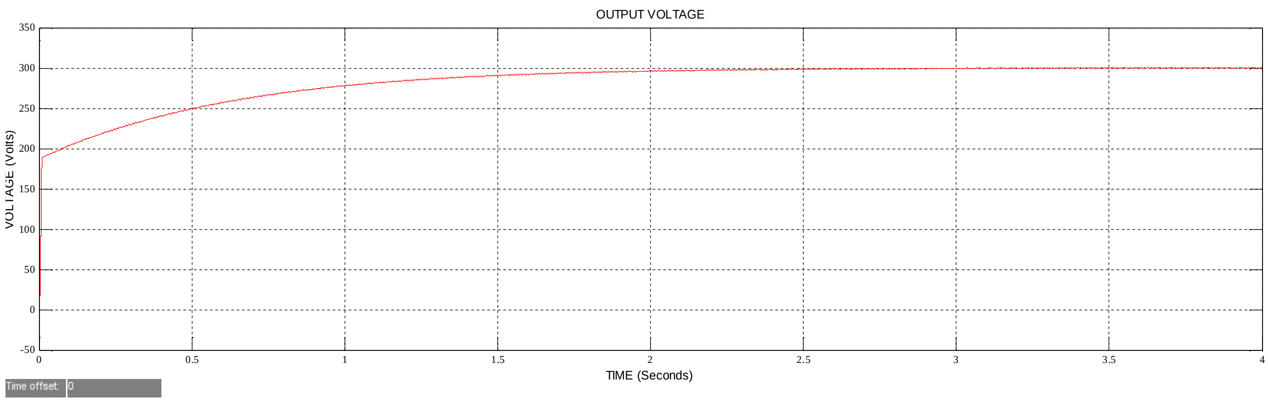

Fig.15 Output Voltage (300V)

Fig.17 shows the Output voltage of the proposed converter. The dc output voltage of the PseudoBoost converter is fixed as 300 V.

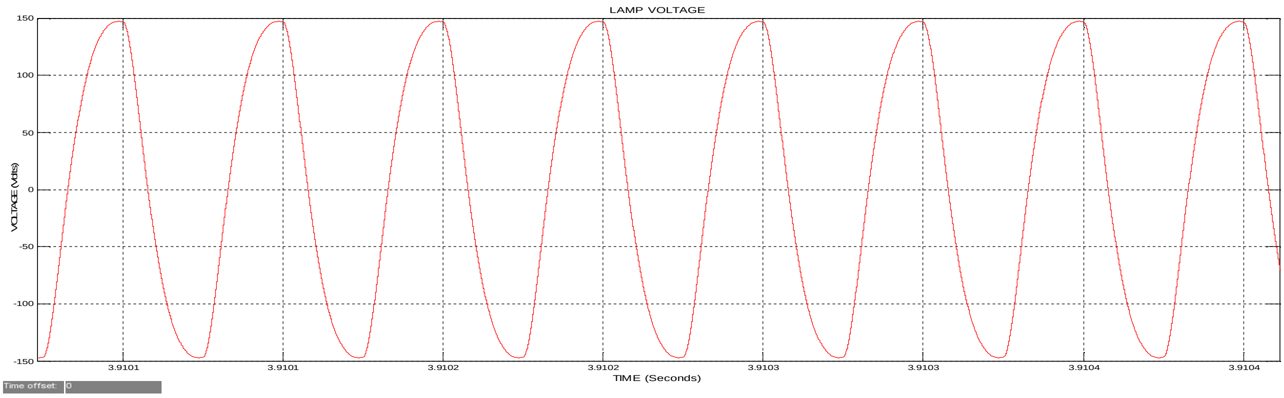

Fig.16 Lamp Voltage

Fig.16 shows the Lamp Voltage waveform. Lamp voltage is maintained within the range of 100 to150.Lamp current is maintained within the range of 0.165 to 0.225.
The Power factor and THD of the proposed system is obtained as 0.99 and 0.085.The efficiency of the proposed system is obtained as 0.92.

VII.CONCLUSION

A pseudo Boost converter based electronic ballast is designed and set up. The proposed electronic ballast has shown improved power quality such as input power factor of 99% and efficiency of 92%. The Current harmonics of the proposed electronic ballast compared with the current harmonic limits of IEC 61000-3-2 class C equipments are within the norms. With a proper design of pseudo Boost PFC converter and series resonant half bridge inverter, the dc link voltage and lamp current have been maintained close to the desired value. The proposed ballast has THD of ac mains current of nearly 8%. The zero voltage switching (ZVS) has been achieved by keeping the switching frequency more than the resonance frequency of resonant inverter to reduce the switching losses.

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Vol. 4, Issue 9, September 2015

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