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 6, June 2015

Bridgeless AC-DC PFC Converter based Electronic Ballast for Fluorescent Lighting

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ABSTRACT: Compact Fluorescent Lamps (CFL) are becoming very popular as a source of artificial light because of its better luminous efficiency, size, weight, lower starting voltage and longer life as compared to the incandescent lamp. Here a new bridgeless single phase ac dc converter based electronic ballast is introduced for CFL. Compared with existing single phase bridgeless topologies, the proposed topology has the merits of less component counts, absence of an input 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. 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. Principle of operation and the feasibility of the proposed converter are provided.

KEYWORDS: Compact Fluorescent Lamp, Power Quality Indices, Zero Voltage Switching, Electronic Ballast, Series Resonant inverter, Pseudo boost Converter.

I. INTRODUCTION

Industries, underground railways, underground parking spaces and multistoried buildings etc, use wide range of lighting systems with different power ratings. Nearly 25% to 35% of total power generated across the world is consumed for the lighting purpose. Compact Fluorescent Lamps (CFL) are becoming very popular as a source artificial light because of its better luminous efficiency, size, weight, lower starting voltage and longer life as compared to the incandescent lamp. However, all discharge lamps require adequate striking voltage at the time of starting and current limiting control after the ignition process, because inherently they have negative impedance characteristics. This can be achieved by using magnetic ballasts or electronic ballasts. The magnetic ballasts are large in size and weight, produces audible noise and flickering. The magnetic ballasts have also high losses due to the iron and copper losses in the magnetic core. The fluorescent lamp consists of a glass tube which is completely filled with argon gas and mercury vapours along with two filament electrodes at each end. All discharge lamp inherently have negative resistance characteristics in its operating region. Because of this the fluorescent lamp cannot be connected directly to a voltage source, otherwise it will damage the lamp. Thus, electronic ballast is required to solve two purposes, one is to provide a sufficient ignition voltage for necessary discharge inside the lamp and other is to maintain constant current after the ignition. Electronic ballast is a device which controls the starting voltage and the operating currents of lighting devices built on the principle of electrical gas discharge. It refers to that part of the circuit which limits the flow of current through the lighting device and may vary from being a single resistor to a bigger, complex device. In some fluorescent lighting system like dimmers, it is also responsible for the controlled flow of electrical energy to heat the lamp electrodes. Most of the PFC rectifiers utilize boost/buck boost topology converter at their front end due to its high power factor capability. 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. 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, input THD reduced and power factor improved. Power quality improvement at the input AC mains can be done using two power processing stages. One is a high Power Factor Regulator (PFR) stage, which converts the ac mains voltage to a regulated dc voltage and second stage converts this regulated dc voltage to a high frequency ac voltage, which is essential to drive the fluorescent lamp. In this paper electronic ballast is designed and implemented in Simulink/Matlab software. Basically the proposed circuit consists of the ac input, bridgeless PFC pseudo boost converter and a high

DOI: 10.15662/ijareeie.2015.0406075

frequency series resonant parallel loaded inverter. Section III explains the proposed circuit of electronic ballast and its principle of operation, Section IV explains the design and analysis of the various components that are present in the total circuit, Section V explains the simulation diagram of the total circuit.

II. LITERATURE SURVEY

The fluorescent lamps need a ballast to prevent their destruction by excessive current because of their negative impedance. The electromagnetic ballasts have been replaced by electronic ballast because of their widely known advantages [1]-[3]. Most of the PFC rectifiers utilize a boost/buck–boost topology converter at their front end due to its high power factor (PF) capability [2]. However, a conventional PFC scheme [2] has lower efficiency due to significant losses in the diode bridge. During each switching cycle interval, the current flows through three power semiconductor devices. An efficient bridgeless PFC circuit topology has been introduced [5]-[7]. 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. An interesting reduced component count topology has been introduced in [8]. However, the proposed topology still suffers from having at least two semiconductors in the current conduction path during each switching cycle. In [9], 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 [12]. The proposed topology has low-component count with an input stage similar to a boost converter.
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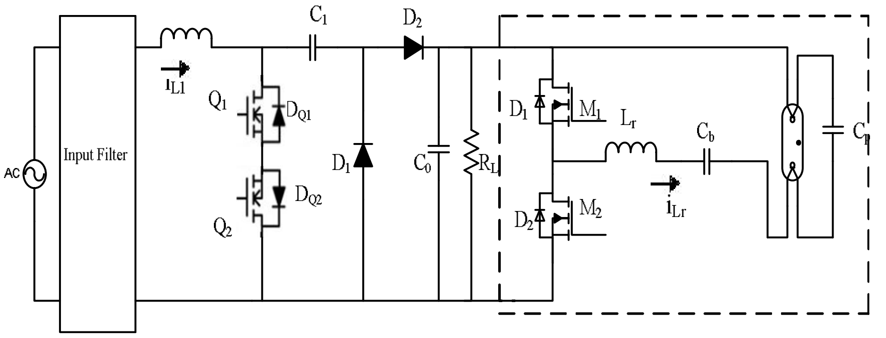
III. THE PROPOSED CIRCUIT OF ELECTRONIC BALLAST

Here the power conversion takes place at two levels by using power electronic converters, whenever power electronic devices come into the picture then harmonic contents in the circuit will increase and source current waveform gets distorted. The power factor corrected pseudo boost converter is used to boost up the voltage, which is essential to ignite the electrodes during the starting time of the lamp. The power factor corrected electronic ballast is shown in Fig. 1, which consists of a PFC pseudo boost converter and a high frequency 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 wave voltage which is fed to the load (fluorescent lamp) through an LC network which filters the higher harmonic present in the square wave. Pseudo boost 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.



Pseudo boost converter Series Resonant inverter

Fig.1. PFC Pseudo Boost Converter based Electronic Ballast.

Here the switch current stress is similar to the conventional DCM PFC converter, while the switch voltage stress is higher. Moreover, the two power switches Q_1 and Q_2 can be driven by the same control signal, which significantly simplifies the control circuitry. However, an isolated gate drive is required for the power switch Q_1. The solid state power switches M_1 and M_2 are alternately turned on and off at a switching frequency of 60 kHz.

IV. DESIGN OF SERIES RESONANT INVERTER

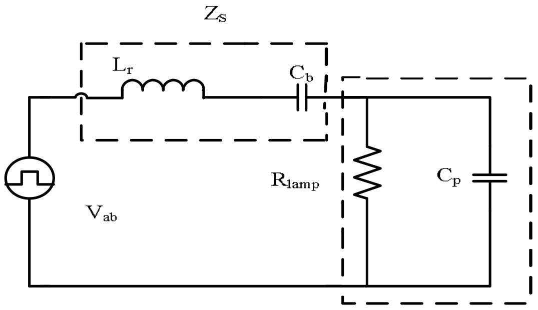


Fig.2. Series Resonant Inverter Equivalent Circuit

Fig. 2 shows equivalent circuit of series resonant inverter. In the equivalent circuit $L_{r,}$ $C_{b,}$ C_p are the resonant parameters and R_{lamp} is the resistance of the fluorescent lamp. The capacitor C_b is used to block the dc component present in the output of the inverter. At the time of starting, the self oscillating technique provides a resonance frequency ($\omega_{starting}$) which is equal to the switching frequency ($\omega_{switching}$).

The relationship between the resonant circuit parameters and the starting resonance frequency is given as,

$$\omega_{starting} = \omega_{switching} = \frac{1}{\sqrt{\frac{L_r C_b C_p}{C_b + C_p}}} \tag{1}$$

In steady state operation the resonance frequency is as $\omega_{running}$,

$$\omega_{running} = \frac{1}{\sqrt{L_r C_s}} \tag{2}$$

If the switching frequency is kept more than steady state resonance frequency then the zero voltage switching is achieved. Consider that

$$\omega_{switching} = 4\omega_{running} \tag{3}$$

The relationship between the lamp voltage and the fundamental component of square voltage source is given in frequency domain as,

$$\frac{V_{lamp}(j\omega)}{V_{ab}(j\omega)} = \frac{Z_p(j\omega)}{Z_s(j\omega) + Z_p} \tag{4}$$

After solving equations [1], [2], [3] and [4] the blocking capacitor is given as,

$$C_s = \frac{15\, V_{lamp}}{V_{ab}\, R_{lamp}\omega_{switching}} \tag{5}$$

On solving equations [1], [2], [3] the parallel resonant capacitor is as,

$$C_p = \frac{C_s}{15} \tag{6}$$

On solving equations [1] and [6] the resonant inductor is given as,

$$L_r = \frac{16}{C_s \omega_{switching}^2} \tag{7}$$

Where, V_{lamp} is the rated lamp voltage, V_{ab} is the fundamental component of square voltage, R_{lamp} is the lamp resistance under steady state condition, ω_s is the angular switching frequency, C_b is the blocking capacitor, C_p is parallel resonant capacitor and L_r is series resonant inductor.

V. MODES OF OPERATION

The operating modes and resonant inverter key waveforms are explained below. The sinusoidal input voltage is considered as constant in each switching cycle, since the switching frequency is much higher than the line frequency.

Mode 1[t_0, 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_1, while D_2 is reverse biased by the voltage $V_{C1} + V_0$. In this stage, the current through inductor L_1 increases linearly with the input voltage, while the voltage across the capacitor C_1 remains constant V_X. At t_0, body diode D_2 starts conducting and the dc link capacitor is charged and during this interval the gate pulse (S_2) is also applied to active switch M_2. The path of current is given in Fig.3a.

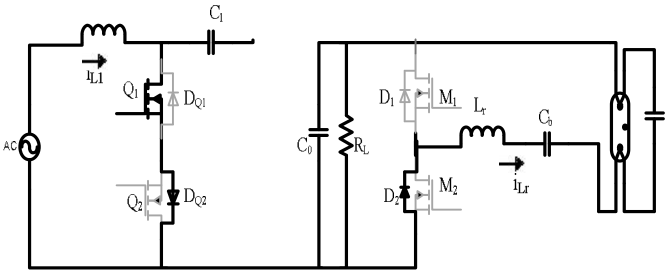


Fig.3a Mode 1

Mode 2 [t_1, t_2]

This stage starts when the switch Q_1 is turned OFF and diode D_2 is turned ON simultaneously. As a result D_1 remains 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 as shown in Fig. 3(b). 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. At t_1, the MOSFET 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 in Fig.3b.

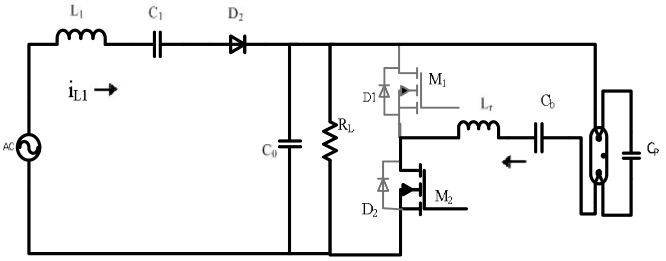


Fig.3b Mode 2

Mode 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, during this 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 until it reaches a voltage V_x. MOSFET M_2 is turned off at t_2 and body diode D_1 starts conducting, thus allowing resonant current to flow in the direction due to resonant nature of the circuit. During this interval the gate pulse is also applied to active switch M_1. The path of the current is given as in Fig. 3c.

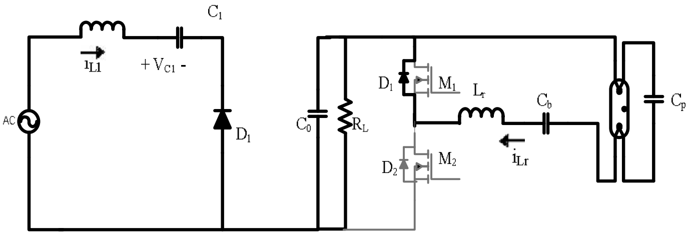


Fig.3c Mode 3

Mode 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. At t_3, the MOSFET 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 path of current is given in Fig.3d. This mode ends up at t_4 and then mode I to mode IV repeat for the next switching cycle.

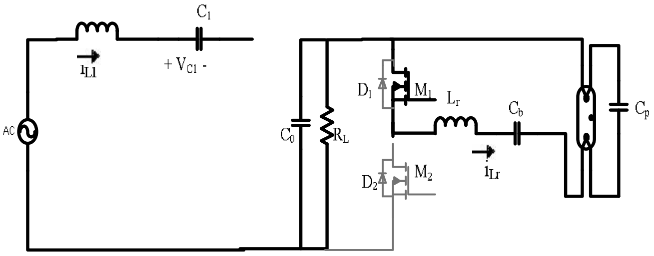


Fig.3d Mode 4

VI. SIMULATION RESULTS

The proposed PFC pseudo boost converter based electronic ballast is modelled in Matlab/Simulink tool, in which compact fluorescent lamp is considered as a resistor at high frequency (60kHz). The design values of the pseudo boost converter components and resonant inverter components have been optimized to get improved power quality at AC mains.

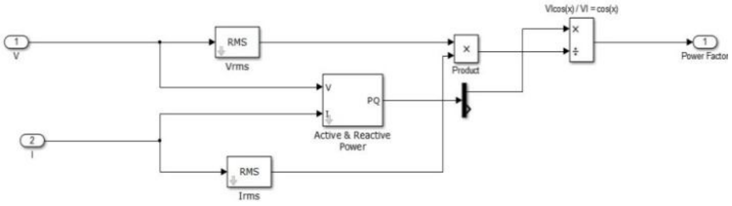


Fig.4. Power Factor Measurement Block

Fig.4. shows the power factor measurement block. In power factor corrected electronic ballast the input power factor can be improved close to unity. It is clearly seen that input voltage and current is taken for PFC.

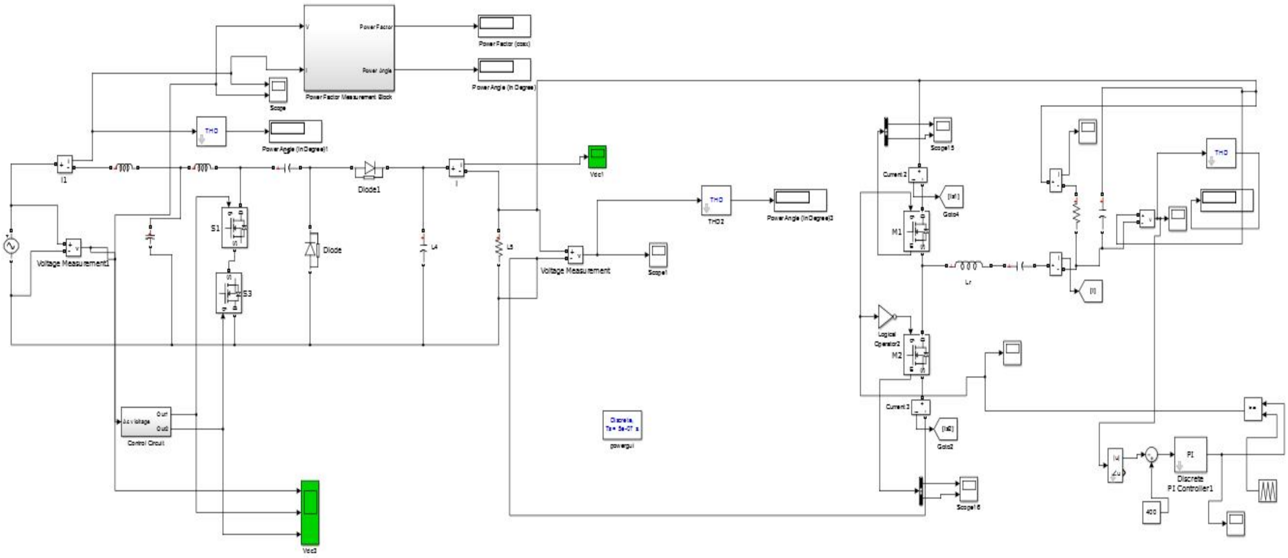


Fig.5. MATLAB Model of Proposed Electronic Ballast

Fig.5 shows the MATLAB model of proposed electronic ballast. The switching frequency is maintained constant at 60 kHz for PWM generation. This converter operates in discontinuous conduction mode during switch turn on interval and resonant mode during switch turn off interval. The designed values of components obtained from equations (1)-(7) are optimized to achieve desired power quality at input ac mains.

Parameter	Values
Switching frequency(F_s)	60 kHz
R_{lamp}	672 Ω
L_r, L_1	3.21mH , 100uH
C_b, C_p, C_1	37.56nF , 3nF, 65nF

Table 1: parameter specification

Table 1 shows values of switching frequency, lamp resistance, series resonant inductor, tank inductor, blocking capacitor, parallel resonant capacitor and tank capacitor of pseudoboost converter and resonant inverter. The designed values of components obtained from equations (1)-(7).

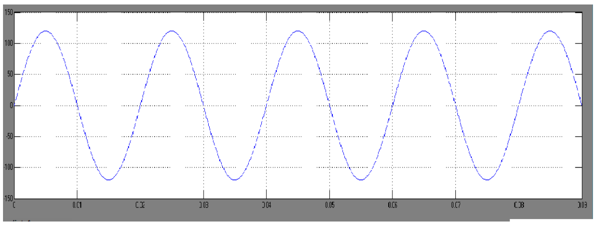


Fig.6. Source Voltage

Fig.6. shows the steady state performance of electronic ballast in terms of source voltage. Input voltage is sinusoidal and in phase with ac line current. The ballast provides sinusoidal starting and operating voltage and current.

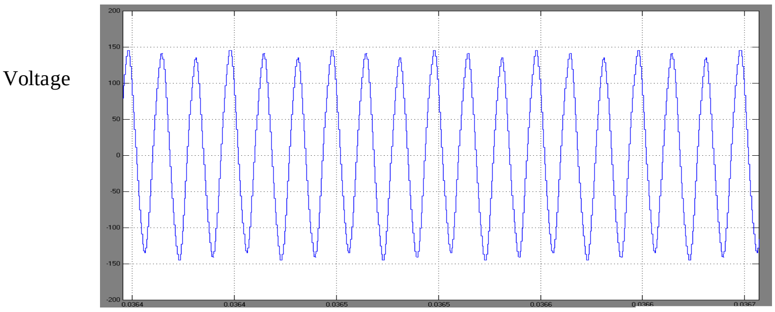


Fig.7. Lamp Voltage

Fig.7 shows the steady state performance of electronic ballast in terms of lamp voltage. Lamp voltage remains constant for wide range of ac mains voltage. Lamp voltage is maintained within the range of 100-150.

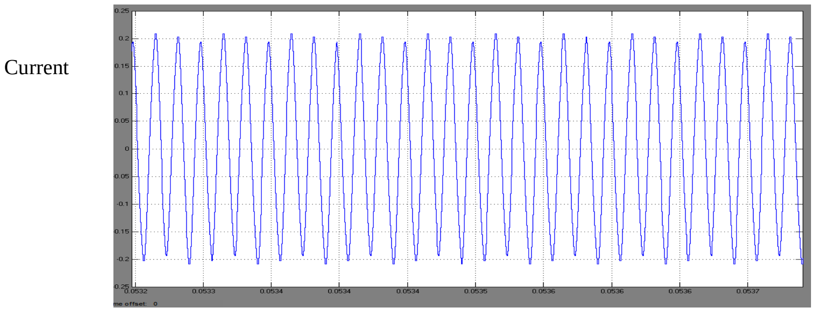


Fig.8. Lamp Current

Fig.8 shows the steady state performance of electronic ballast in terms of lamp current. Lamp current remains constant for wide range of ac mains voltage. Lamp current is maintained within the range of .165-.225.

VII.CONCLUSION

The power factor regulated electronic ballast is designed for compact fluorescent lamps. This electronic ballast is the combination of a pseudo boost AC- DC converter as a power factor regulator in the continuous conduction mode and a half bridge operating series resonant inverter, which is used for converting a constant dc link voltage into high frequency AC voltage to drive the fluorescent lamp. Proper commutation techniques like zero voltage switching and zero current switching are used. In power factor corrected electronic ballast, the input power factor can be improved closed to unity. Power quality improvement at the input AC mains can be done using two power processing stages. One is a high Power Factor Regulator (PFR) stage, which converts the ac mains voltage to a regulated dc voltage and second stage converts this regulated dc voltage to a high frequency ac voltage, which is essential to drive the fluorescent lamp. Here power quality improvement is achieved by pseudo boost converter based electronic ballast operating in Discontinuous Conduction Mode.

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