

Design And Simulation of Single stage High PF Electronic ballast with boost topology for multiple Fluorescent lamps

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Abstract— Performance analysis and Simulation of single-stage high-power-factor (HPF) electronic ballast with boost topology for multiple (four) fluorescent lamps are presented in this paper. The simulation is done for four 36W fluorescent lamps in MATLAB/Simulink environment. The input is 220V single phase AC supply at 50 Hz. The circuit presents an input LC configuration, to shape the input line current and also to reduce the unwanted disturbances injected from the high frequency electronic ballast into the mains. The circuit also comprises of boost converter which acts as an inherent power factor corrector (PFC). Single stage topology has been taken into consideration which reduces the requirement of extra power switches. By integrating the power switches used in boost converter and half bridge inverter, new single stage HPF electronic ballast is implemented which is used to both correct the input power factor and drive the fluorescent lamp. The switching frequency of the half bridge inverter has been chosen at 50 kHz. Performance analysis and simulation results prove that improved power factor can be obtained along with improved ballast efficiency.

Index Terms— Electronic ballast, LC configuration, single stage boost topology, switching frequency, power factor corrector (PFC), high-power-factor (HPF).

I. INTRODUCTION

Lighting ballast is a piece of equipment required to control the starting and operating voltages of electrical gas discharge lights. The term lighting ballast can refer to any component of the circuit intended to limit the flow of current through the light, from a single resistor to more complex devices. Ballast is used to perform the following two functions:

- Provide the starting kick.
- Limit the current to the proper value for the tube you are using.

In the old days fluorescent fixtures had a starter or a power switch with a 'start' position which is in essence a manual starter. Some cheap ones still do use this technology. The starter is a time delay switch which when first powered, allows the filaments at each end of the tube to warm up and then interrupts this part of the circuit. The inductive kick as a result of interrupting the current through the inductive ballast provides enough voltage to ionize the gas mixture in the tube and then the current through the tube keeps the filaments hot usually. A few iterations are sometimes needed to get the tube to

light. The starter may keep cycling indefinitely if either it or one of the tubes is faulty. While the lamp is on, a preheat ballast is just an inductor which at 50 Hz has the appropriate impedance to limit the current to the tube(s) to the proper value. Ballasts must generally be fairly closely matched to the lamp in terms tube wattage, length, and diameter.

Recent trend presents high-frequency electronic ballast with high power factor, greater efficiency, low harmonic distortion, low cost and less maintenance [1]-[4]. Single electronic ballast may be used for multiple fluorescent lamps [4, 5, 9]. These electronic ballasts use resonant inverter for high-frequency generation [5]-[9]. The high-frequency operation also makes the lamp start easily and reliably, and eliminates audible noise and flickering effect. This paper present performance analysis and simulation of single stage high-power-factor (HPF) electronic ballast with boost topology for multiple (four) fluorescent lamps which require reduced number of power switches.

Paper is arranged in following sections. Section II presents the conventional electronic ballast. Section III presents dual stage topology based electronic ballast. Section IV presents proposed single stage topology based electronic ballast. Section V presents simulations and discussion and Section VI presents conclusions.

II. CONVENTIONAL ELECTRONIC BALLAST

The high-frequency electronic ballast is an AC/AC power converter, converting line-frequency power from the utility line to a high-frequency AC power in order to drive the discharge lamp. Figure 1. shows the circuit

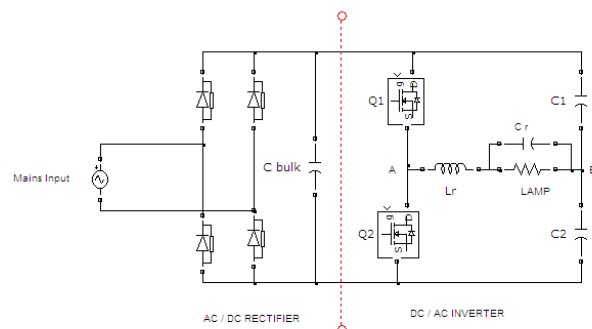


Figure 1. Half bridge series resonant parallel loaded ballast.

diagram of typical high frequency electronic ballasts. The AC/DC rectifier contains four diodes and one bulk capacitor. This simple rectification scheme is still widely used because of its lower cost.

Various stages in the circuit are:

Rectifier: A rectifier is a circuit which converts Alternating Current (AC) into a Direct Current (DC) form. The full wave rectifier is a means of converting alternating current (ac) into direct current (dc) using both half cycles of the input ac voltage. As its name implies, it converts both the positive going and the negative going parts of the sine wave into useable dc, and therefore is more efficient than a half wave rectifier, which only converts half of the complete sine wave into useable dc.

Boost Converter: In order to improve the consumption of electrical energy and to provide agreement with power quality standards, electronic ballasts have incorporated PF correction (PFC) techniques. Usually, PFC circuits present better results related to PF and THD in the input current. A Boost Converter is a circuit that uses a power switch, an inductor, and a diode to transfer energy from input to output. It is known that the boost converter operating in the DCM comes close to emulating a resistor, so the input ac line current will automatically follow the sinusoidal line voltage waveform. Therefore, input current shaper can be implemented with a boost converter operating in the DCM. The PFC stage is composed of an active power switch Q, an energy transfer diode D, an inductor L, and a bulk dc-link capacitor C. The inductor L draws current from the ac line voltage source during the switching-on of the active power switch Q in every high frequency switching cycle. When the active power switch Q is switched off, the energy stored in the inductor is transferred to the dc-link capacitor C through the energy transfer diode D. The component C is a bulk electrolytic capacitor to provide a smooth dc-link voltage to the load circuit. Since the power switch Q is switched on and switched off at a high frequency, the input current becomes a pulsating waveform at the same frequency. By properly controlling the amplitude and duration of the pulsating current, the average of the input current can be made to be sinusoidal and in phase with the ac input voltage source. Consequently, a nearly unity PF and very low THD can

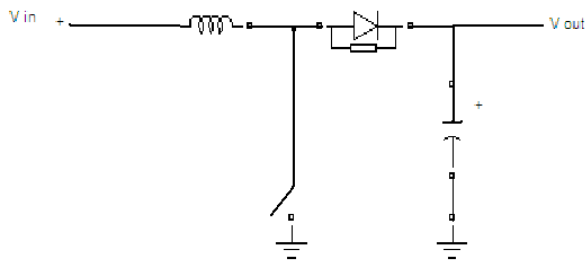


Figure 2. Simple Boost Converter.

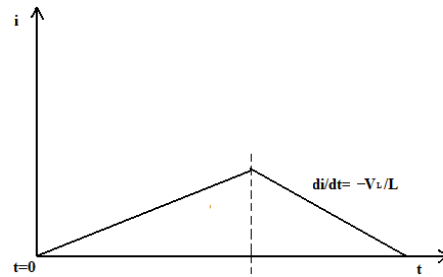


Figure 3. Charging and Discharging Phase.

be achieved. Figure 2. shows simple boost converter topology and Figure 3. shows charging and discharging phase of capacitor.

High Frequency Inverter: A half-bridge high-frequency inverter with zero-voltage switching and constant duty-ratio forms the second stage of the ballast circuit. Each fluorescent lamp is connected to a small high-frequency resonant filter. The series capacitor (Cs) of the resonant filter blocks the DC component of the output voltage.

Series Resonant Filter: A series Resonant Inverter is proposed for applications in high frequency distributed AC power systems. The advantages of the LCC topology are low total harmonic distortion (THD) high efficiency and the ability to handle varying loads.

III. DUAL STAGE TOPOLOGY BASED ELECTRONIC BALLAST

The traditional dual-stage HPF electronic ballast topology (for one fluorescent lamp) consists of two stages. The first stage is an active PFC stage supplied by a full-bridge diode rectifier with a boost converter. This stage is used to correct the input PF, i.e., the ballast is seen as a resistive load by the ac line voltage source, in addition to generating a regulated dc output voltage to feed the electronic ballast. The second stage is the high-frequency resonant inverter used to ignite the lamp and to stabilize the lamp current during steady-state operation. Normally, a half-bridge series-resonant parallel-loaded inverter is used to implement the resonant inverter. Figure 4. shows two stage HPF electronic ballast for fluorescent lamps.

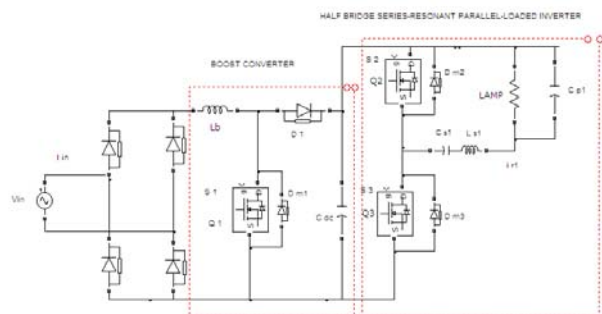


Figure 4. Two stage HPF electronic ballast for fluorescent lamps.

IV. PROPOSED SINGLE STAGE TOPOLOGY BASED ELECTRONIC BALLAST

As can be seen from Figure 4, the active power switches Q1 and Q3 have a common terminal, and they can be operated synchronously. Thus, the number of components used in the above electronic ballast can be reduced by integrating the two-stage into a single-stage, thus obtaining new single-stage HPF electronic ballast as shown in Figure 5.

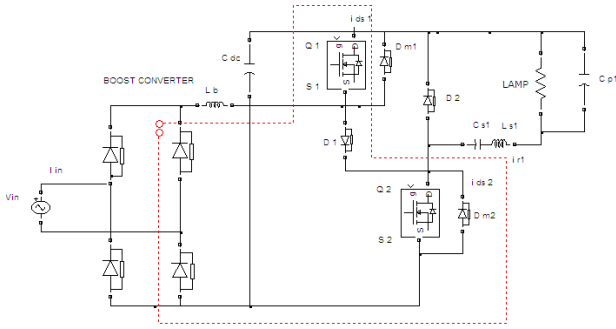


Figure 5. Single stage HPF electronic ballast for fluorescent lamps.

This single-stage topology is used to both correct the input PF and drive the fluorescent lamp. There exists a clear reduction in cost not only for avoiding the use of one more controlled switch but also because only one control circuit can be used.

The working of the proposed circuit is shown for one switching cycle for one fluorescent lamp. There are six modes of operation. They are as follows:

MODE I ($t_0 < t < t_1$)

Active power switch Q₂ is turned off before time 't₀'. At this time freewheeling diode D_{m2} conducts because the load current I_r is negative. The load resonant current I_r flows through the freewheeling diode D_{m2} and dc-link capacitor C_{dc}. At the beginning of this mode, a turn-on signal is applied to the gate of the active power switch Q₂.

The line voltage is imposed on inductor L_b as soon as active power switch Q₂ is turned on. At DCM operation, the inductor current i_L of the boost converter increases linearly from zero. Hence, the turn-on of the switch Q₂ occurs at zero-current switching condition. The slope of i_L is proportional to the input line voltage. In the interval of this mode, the input current i_{in} is equal to i_b. The current of i_{ds2} is the difference between the inductor current i_L and the load resonant current i_r. When the difference between i_L and i_r becomes positive, the diode D_{m2} is turned off and it marks the end of MODE I. Figure 6. shows equivalent circuit of Mode I.

MODE II ($t_1 < t < t_2$)

The power switch Q₂ is in the on state. L_b is continuously under the effect of line voltage and i_L increases. In this mode, the currents i_L and I_r naturally shifts itself from diode D_{m2} to the active power switch Q₂. The load

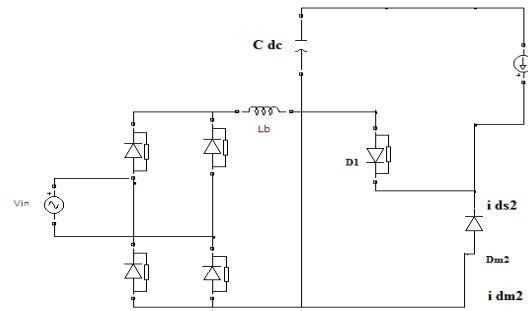


Figure 6. Equivalent circuit of Mode I ($t_0 < t < t_1$).

resonant current i_r goes through the active power switch Q₂ and dc-link capacitor C_{dc} where as both the currents I_r and i_L pass through the active power switch Q₂. Thus two paths are followed. One, from the line source through the inductor L_b and power switch Q₂ and back to the rectifier stage constitute the boost converter circuit. Second, the resonant load current flowing through the power switch Q₂ and the discharge capacitor C_{dc}. When the active power switch Q₂ is turned off, Mode II ends and the operation enters Mode III. Figure 7. shows equivalent circuit of Mode II.

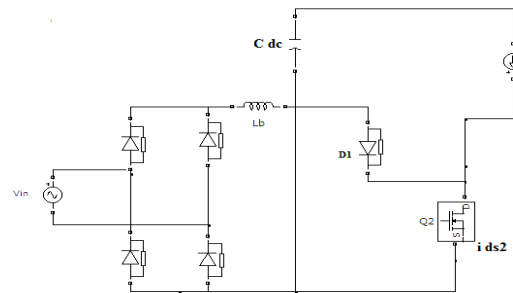


Figure 7. Equivalent circuit of Mode II ($t_1 < t < t_2$).

MODE III ($t_2 < t < t_3$)

When the gate signal V_{g1} is applied the power switch Q₁ comes into action. This marks the beginning of mode III. At this point of time, the inductor i_L reaches its peak value and the active power switch Q₂ is turned off. The inductor current i_L freewheels through D_{m1} to charge the

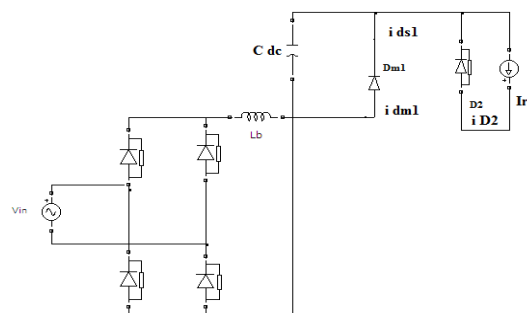


Figure 8. Equivalent circuit of Mode III ($t_2 < t < t_3$).

dc-link capacitor C_{dc} . The load resonant current I_r flows through the freewheeling diode D_2 . Thus two current paths can be seen. One, the load resonant current freewheeling through diode D_2 . Second, the inductor current charging the dc link capacitor C_{dc} through the diode D_{m1} . The voltage across L_b is equal to $V_{rec} - V_{dc}$. Therefore, the inductor current i_L decreases linearly. Since the peak of the inductor current i_L is proportional to the output load, the next operation mode is determined by the relationships between inductor current i_L and load current I_r . Thus two modes are possible after mode III, depending on which of the inductor current i_L and load current I_r reaches zero first. Figure 8. shows equivalent circuit of Mode III.

MODE IV A ($t_3 < t < t_4$)

In this mode the output load is heavy, and thus the inductor current $|i_L|$ is greater than the load current $|I_r|$. The inductor current i_L flows through D_{m1} and charges the dc-link capacitor C_{dc} . The inductor current i_L decreases continuously. During this mode, the load current i_r goes to negative and flows through diodes D_1 and D_{m1} . Mode IV-A finishes at the time when the inductor current $|i_L|$ equals load current $|i_r|$, and then, the operating mode enters MODE V-A. At this instant, the current $|i_r| - |i_L|$ naturally shifts from the diode D_{m1} to the active power switch Q_1 . That is to say, the active power switch Q_1 turns on softly at the zero-current-switching condition to reduce the switching losses. Figure 9. shows equivalent circuit of Mode IV A.

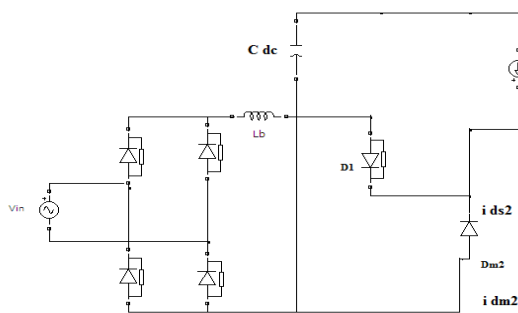


Figure 9. Equivalent circuit of Mode IV A ($t_3 < t < t_4$).

MODE V A ($t_4 < t < t_5$)

The active power switch Q_1 turns on at the beginning of mode V-A and carries both the inductor current i_L and the load current i_r . The load current i_r goes through the active power switch Q_1 and diode D_1 . The inductor current flows back through the active power switch Q_1 , dc-link capacitor C_{dc} , and rectifier to the ac line source. Mode V-A ends when the inductor current i_L declines to zero. At this instant, the circuit operation enters mode VI. Figure 10. shows equivalent circuit of Mode V A.

MODE IV B ($t_3 < t < t_4$)

In this mode, the output load is light, thus the peak value of the inductor current i_L is small and declines to zero

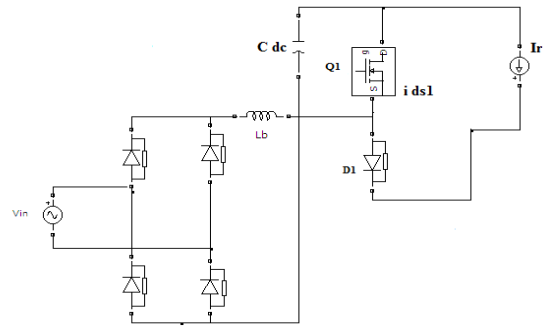


Figure 10. Equivalent circuit of Mode V A ($t_4 < t < t_5$).

faster. When i_L decreases to zero, mode IV-B, instead of mode IV-A, follows mode III. Diode D_1 is turned off. During this mode, the load current i_r flows through the freewheeling diode D_2 . When the load current i_r becomes less than zero, the active power switch Q_1 is turned on through D_1 , and mode V-B is entered. Figure 11. shows equivalent circuit of Mode IV B.

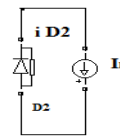


Figure 11. Equivalent circuit of Mode IV B ($t_3 < t < t_4$).

MODE V B ($t_4 < t < t_5$)

The power switch Q_1 is in the active state and carries the load current i_r . Mode V-B ends when the gate signal V_{g2} is applied marking the beginning of mode I of the next cycle. Figure 12. shows equivalent circuit of Mode V B.

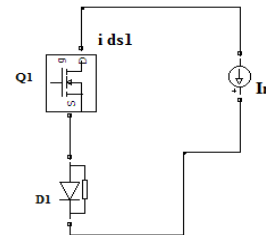


Figure 12. Equivalent circuit of Mode V B ($t_4 < t < t_5$).

MODE VI ($t_5 < t < t_6$)

Mode VI is feasible only when the output load is heavy. During this operating mode, only a negative load current i_r flows through the active power switch Q_1 and the diode D_1 . Mode VI ends when the gate signal V_{g1} is applied marking the beginning of mode I of the next cycle. Figure 13. shows equivalent circuit of Mode VI.

Figure 14. shows current and voltage waveforms for heavy loaded conditions and Figure 15. shows current and voltage waveforms for light loaded conditions respectively.

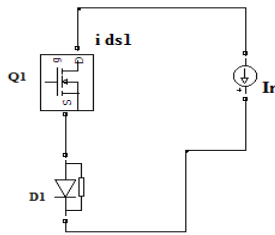


Figure 13. Equivalent circuit of Mode VI ($t_5 < t < t_6$).

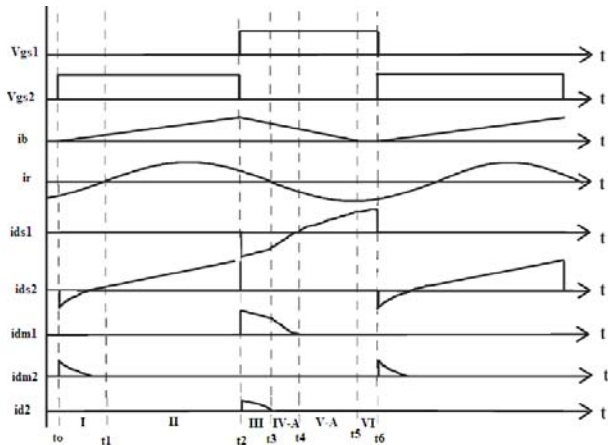


Figure 14. Current and voltage waveforms for heavy loaded conditions.

V. SIMULATIONS AND DISCUSSIONS

A complete simulation model of single stage high-power-factor (HPF) electronic ballast with boost topology for multiple (four) fluorescent lamps is developed as shown in Figure 16. The performance of the proposed electronic ballast is investigated. The parameters of the proposed electronic ballast considered in this study are summarized in Appendix A. Figure 17. shows Input voltage and

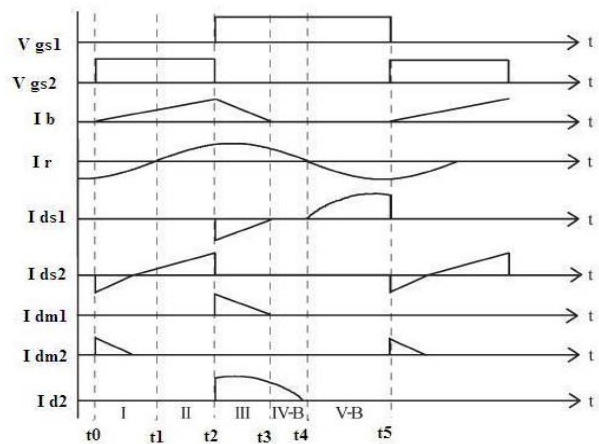


Figure 15. Current and voltage waveforms for light loaded conditions.

current waveform. Figure 18. shows envelope of voltage and current across the lamp. Figure 19. shows Input Current Frequency Spectrums. Table 1 presents simulation results of proposed electronic ballast lighting scheme.

TABLE 1
SIMULATION RESULTS OF PROPOSED ELECTRONIC BALLAST

S.No.	Factor	Proposed electronic ballast (for four lamps)
1.	Power factor	0.975
2.	Total harmonic distortion	25.08%
3.	Switching frequency	50 KHz
4.	Crest factor (Input current)	2.85
5.	Crest factor (Input Voltage)	1.41
6.	V_{rms}	220 V
7.	I_{rms}	0.7 A

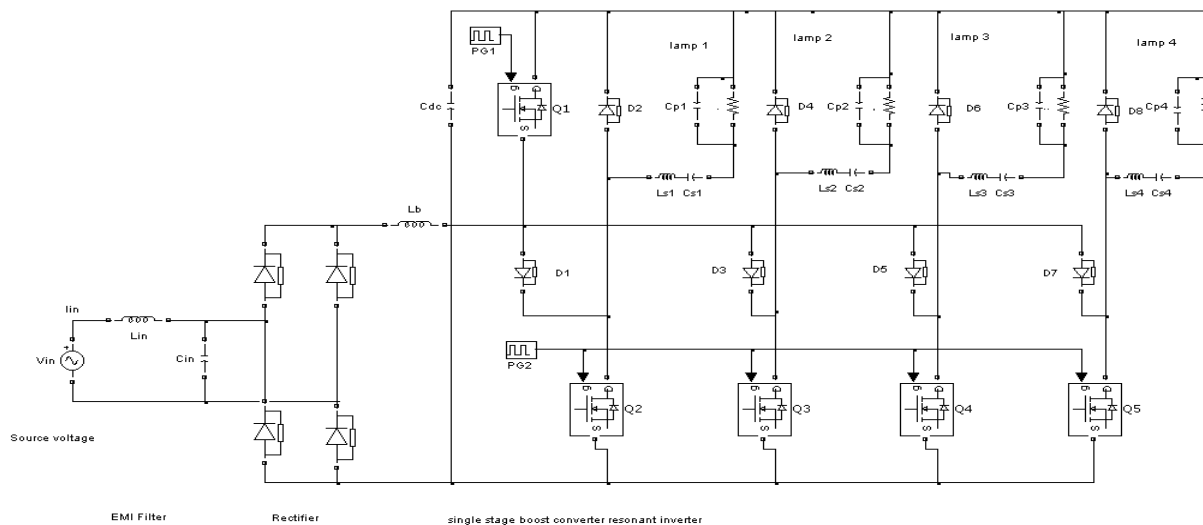


Figure 16. Matlab/Simulink model of proposed four fluorescent lamp lighting system.

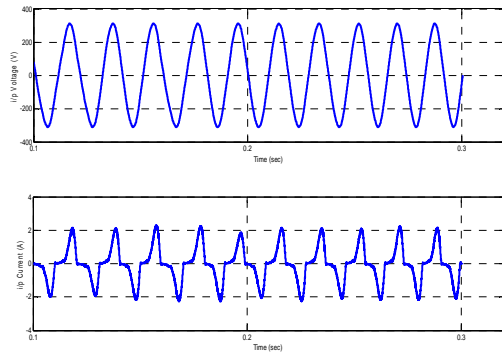


Figure 17. Input Voltage and Current Waveform.

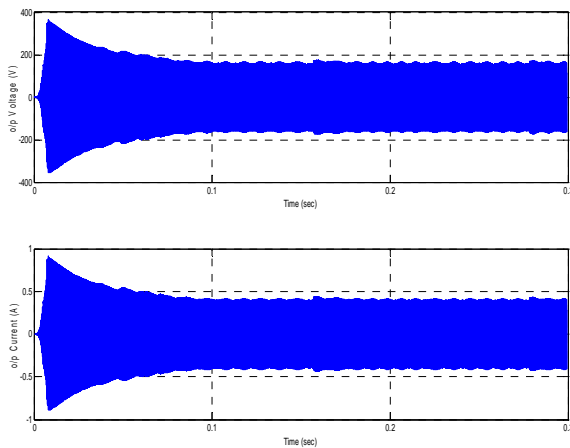


Figure 18. Envelope of lamp voltage and current.

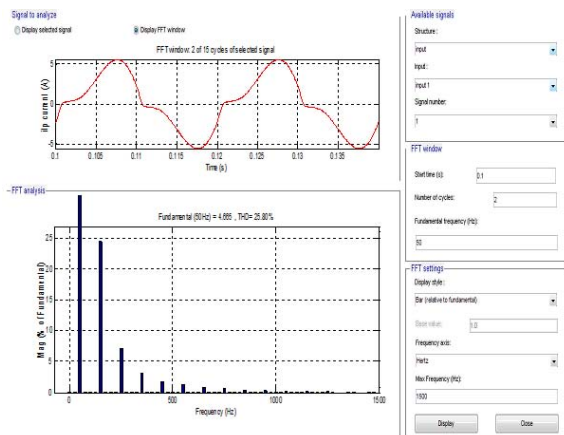


Figure 19. Input Current Frequency Spectrums.

VI. CONCLUSIONS

The paper introduced single stage electronic ballast with high power factor and low harmonic distortion for driving four 36W fluorescent lamps. The proposed electronic ballast is the cascade operation of EMI filter, boost dc-dc converter and series-resonant parallel loaded inverter. The EMI filter used at the mains reduces the harmonic distortion and the RFI injected from the electronic ballast into the mains. The boost dc-dc converter acts as a power factor correction device. The four series-resonant parallel loaded inverters power the four 36W fluorescent lamps. Simulated results have been obtained for the proposed electronic ballast. Considerable numbers of components are reduced resulting in significant reduction in cost in the proposed electronic ballast for multiple fluorescent lamps. A high power factor and reduced THD have been achieved with this electronic ballast.

APPENDIX A DESIGN PARAMETER

S. No	PARAMETER	VALUE
1.	Input Voltage V_{in}	220 V_{rms} , 50 Hz
2.	Switching Frequency f_s	50 KHz
3.	DC link capacitor C_{dc}	155 μF
4.	Boost inductor L_b	0.4 mH
5.	Inductor L_s	1.81 mH
6.	Capacitor C_s	0.15 μF
7.	Capacitor C_p	15 nF
8.	Inductor L_2	60 mH
9.	Capacitor C_6	4.4 nF

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