Design and Implementation of Electronic Ballast for Fluorescent Lamps

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Abstract— **This paper presents the design, simulation and practical implementation of an electronic ballast for a fluorescent lamp with active PFC. A comparison between simulations and experimental results is done. The experimental results are closed with simulation ones and verifying the functionality of the proposed electronic ballast. The electronic ballast is developed around IR21592 and PFC preregulator is developed around UC3854.**

Keywords- electronic ballast; fluorescent lamp; PFC; EMI

I. Introduction

The fluorescent lamps were commercial introduced in 1938. Between lighting sources, the fluorescent lamps are becoming popular and widespread in many applications, because of longer lifetime, better lumen efficacy. A fluorescent lamp is a gas discharge lamp. They have no filament through its. Typical fluorescent tube is filled with inert gas and a small amount of mercury that creates vapor. Cathodes (a tungsten filament), which are at each end, send a current through mercury vapors, sealed in the lamp. The fluorescent lamps use electricity to excite mercury vapors. Ultraviolet radiation is produced as electrons from the cathodes knock mercury electrons out of their orbits. The inside of the fluorescent lamp has a phosphor coating. This coating converts ultraviolet radiation into visible light. The conversion of electric power into light is more efficiently in a fluorescent lamp than an incandescent lamp. The cost of fluorescent lamp is higher than the cost of incandescent lamp, but the energy is saved using fluorescent lamps. A disadvantage of fluorescent lamps, it is that they require a ballast to control the current through the lamp [1].

The lamp ballast has two main functions:

- to provide a starting kick and
- to limit the current to the proper value for the lamp.

There are two types of ballasts: inductive ballasts and electronic ballasts. The electronic ballasts are more efficiently as inductive ballasts. Inductive ballasts have to be operated in conjunction with starters for lamp ignition. Electronic ballast operates at high frequencies from 20kHz to 50kHz and uses electronics circuitry to optimize the operation of the lamp. Electronic ballasts for fluorescent lamps becoming more common due to its superior performances. The lamp does not have flicker to the human eyes. Operating the electronic ballast at higher frequency leads to a smaller and compact circuit.

The use of ballasts in fluorescent lamps usually introduces harmonics into the utility that lead to a poor input power factor. Reduction of the line current harmonics is needed in order to comply with standards. International standard IEC61000-3-2 [2] and its European version EN61000-3-2, impose limits for the harmonic contents of the line current, which can be demanded from AC mains by electronic equipments. There are active or passive power factor correction circuits. Many power factor correction circuits have been proposed in the last years. The block diagram of electronic ballast with active power factor correction is presented in figure 1 [3].

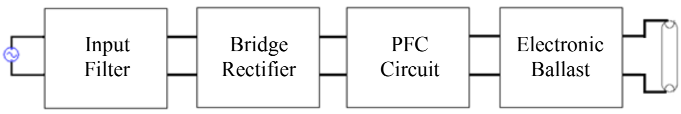

Figure 1. Electronic ballast with active power factor correction – block diagram.

It is seen from the figure that the proposed topology contain an input filter, a bridge rectifier, a PFC circuit and the electronic ballast. Using a PFC preregulator the input current shape is roughly input voltage shape.

II. Design Considerations

A. Design of the PFC Preregulator

The power factor correction preregulator is developed around of the boost converter. For this power supply we choose average current mode control. The boost converter is supplied from the rectified line voltage. The principle schematic of PFC preregulator with average current mode control is presented in figure 2 [4].

This technique of current control is most popular technique for its good performances. The most important advantages are constant switching frequency, no need compensation ramp, operation in continuous conduction mode, etc.

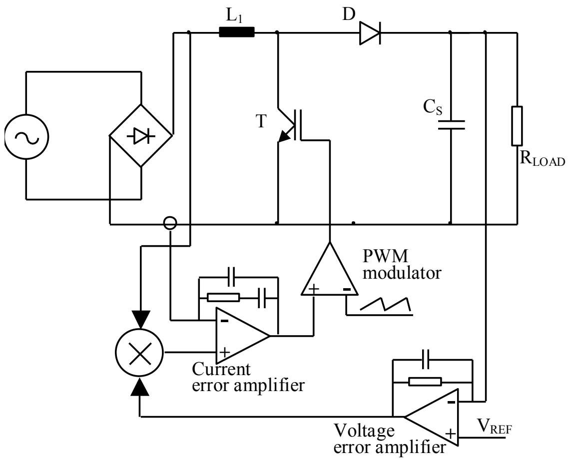

Figure 2. Boost converter with average current mode control

As one can see in figure 3, average inductor current shape is roughly sinusoidal reference (input voltage).

The average current mode control technique consists in existence of two loops. Inner loop is a current loop and the outer loop is a voltage loop. The inductor current is sensed and compared to a sinusoidal reference by a current error amplifier. Current error amplifier output is compared with a ramp. In this way, it is generate a PWM signal to drive the switch. The voltage loop is necessary to maintain the output voltage to value imposed by reference signal V_{REF} [5].

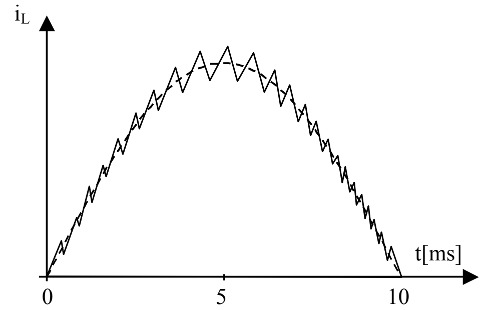

Figure 3. Inductor current for average current mode control.

We need a 250W PFC preregulator for the electronic ballast. We used a boost converter with UC3854 as control circuit. The circuit specifications are:

- Maximum output power: 250W
- Output voltage: 400V
- Input line voltage: 230V (+10%, -15%)
- Line frequency: 50Hz
- Switching frequency: 50kHz

The electrical diagram of boost power factor correction preregulator is shown in figure 4. The 20V auxiliary power supply can be obtained from an auxiliary winding of inductor [6].

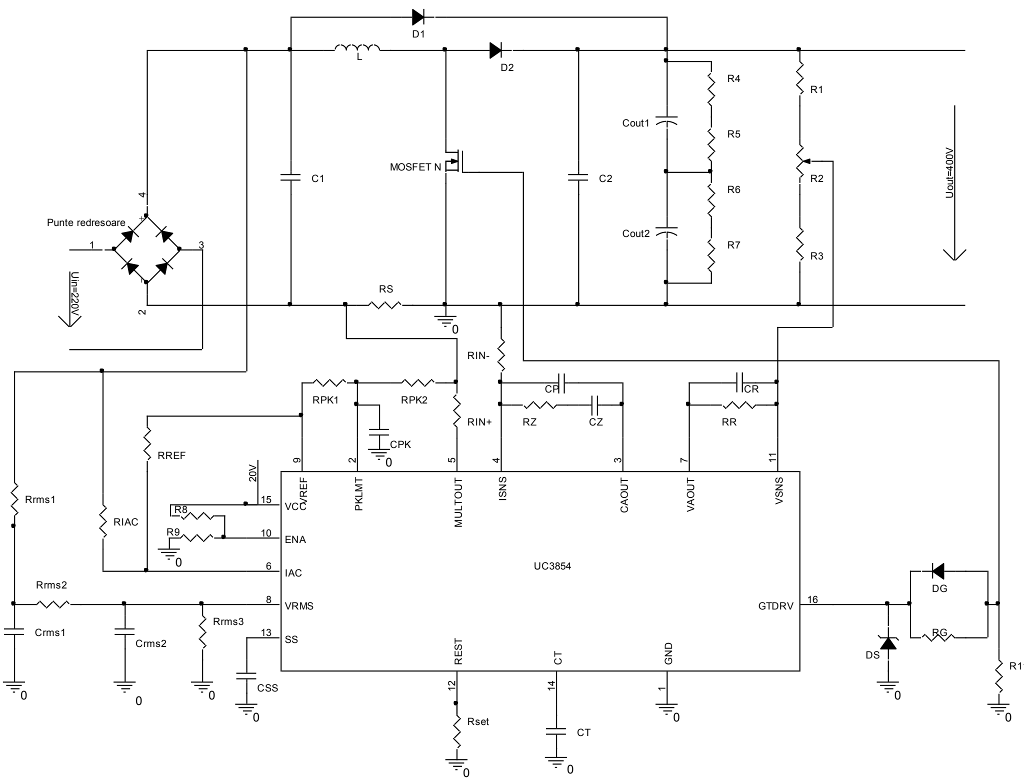

Figure 4. Schematic of boost power factor correction preregulator.

Minimum value of the inductor is given by the equation:

$$L_{min} = \frac{\left(U_S - U_{IN\,min}\right) \cdot U_{IN\,min}}{f_S \cdot U_S \cdot \Delta I_{L\,max}} \tag{1}$$

where ΔI_{Lmax} is maximum ripple of inductor current. We impose ΔI_{Lmax} to be maximum 30% of I_{Lmax}.

The minimum value of the output capacitor is:

$$C_{OUT\,min} = \frac{\left(U_S - U_{IN\,min}\right) \cdot U_{IN\,min}}{2\pi f_l \cdot \eta \cdot U_S \cdot \Delta U_{Spp\,max}} \tag{2}$$

where f_l is line frequency and

$\Delta U_{Spp\,max}$ is peak to peak output voltage ripple.

The switching frequency can be selected by R_{SET} and C_T components:

$$f_S = \frac{1{,}25}{R_{SET} \cdot C_T} \tag{3}$$

B. Design of the Electronic Ballast

Electronic ballast is designed around a dimming ballast controller from International Rectifier (IR21592) [7]. The IR21592 is a complete dimming ballast and 600V half-bridge drivers. The IC contains an oscillator, a high voltage half-bridge gate driver, a phase-control for transformer-less fluorescent lamps. The programmable features of IR21592 IC are ignition to dim time and preheat time and current. The IC provides protection of a lamp to strike, thermal overload, filament failures and lamp failure during normal operation.

Schematic of electronic ballast developed around IR21592 IC is presented in figure 5. The state diagram of dimming ballast is presented in figure 6.

When the power is applied to the ballast, the voltage on the pin 1 (VDC) begins to rise (C_{VDC} capacitor is charging from the DC bus through R_{VAC} startup resistor). When the voltage on pin 1 reaching the under-voltage lockout threshold, the oscillator is enabled and drives the output drivers.

When the ballast reaches the end of UVLO mode, the preheat mode is entered. The IC enters in preheat mode when VCC exceeds the UVLO threshold and VDC exceeds 5.1V. In this moment, the IC start to operate and driving the resonant load circuit (lamp, L_{RES} inductance and C_1 capacitor). The preheat mode frequency of oscillation is selected to obtain a voltage across the lamp (below the minimum lamp ignition voltage), but enough to supply a current to preheat the lamp filaments. The preheating of the lamp filaments is necessary in order to obtain the emission temperature.

The IR21592 IC enters in ignition mode when the voltage on pin 3 (CPH) exceeds 5.0V.

We must to set R_{VAC} and R_{VDC} such that the voltage on pin 1 (VDC) to exceed 5.1V at the DC bus voltage (input voltage U_{DC}). The startup resistor (R_{VAC}) can be calculated with:

$$R_{VAC} = \frac{U_{DC}}{I_{QCCUV}} \tag{4}$$

where I_{QCCUV} is UVLO mode quiescent current (typically 200µA).

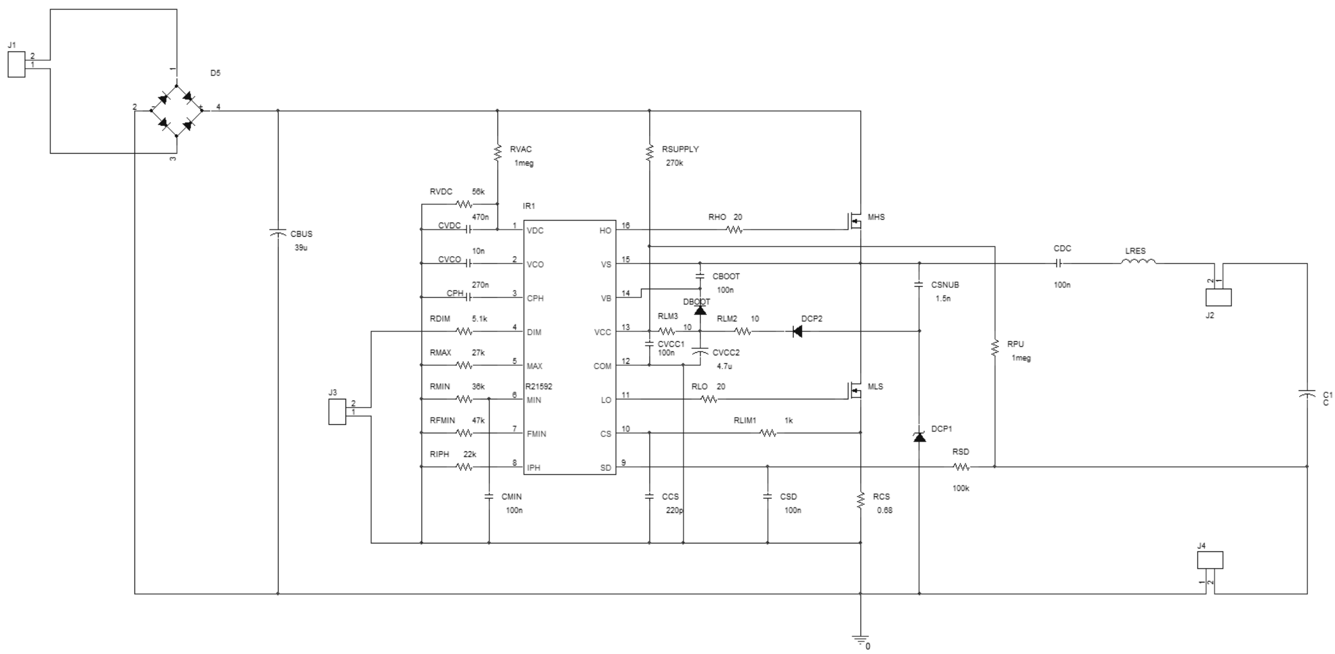

Figure 5. Schematic of electronic ballast.

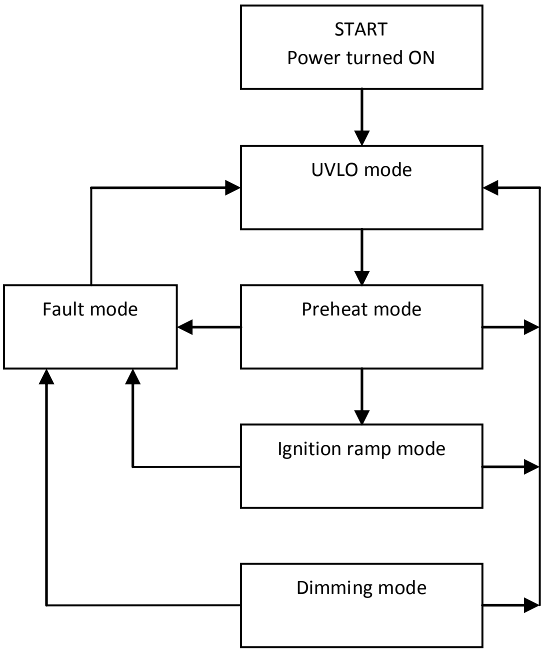

Figure 6. Dimming ballast state diagram.

The R_{VDC} resistor can be calculated with:

$$R_{VDC} = \frac{\frac{5.1V}{U_{DC}} \cdot R_{VAC}}{1 - \frac{5.1V}{U_{DC}}} \tag{5}$$

R_{VDC} increases when U_{AC_ON} decreases.

In order to obtain the values for external components, we used Ballast Designer software from International Rectifier. This software helps us to choose a fluorescent lamp from 38 types, to choose the IC, to calculate the values of external components and simulate the circuit.

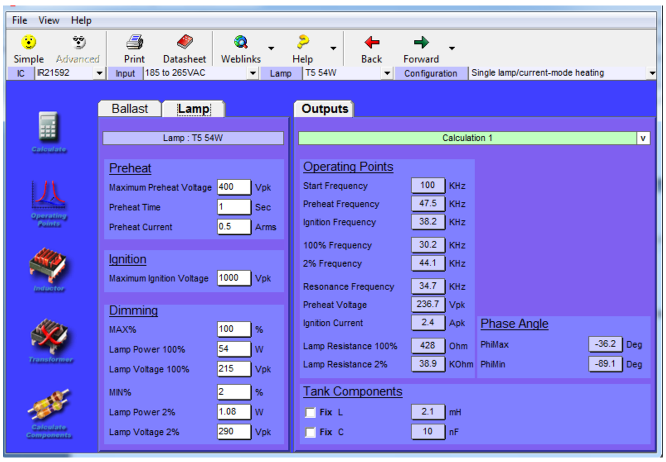

Figure 7. The outputs from Ballast Designer software.

III. Simulation and Experimental Results

In the PFC preregulator we choose:

- $L=500\mu H$
- $C_{OUT}=470\mu F$
- $R_S=0,1\Omega$
- $R_{PK1}=7,5k\Omega$ and $R_{PK1}=1,5k\Omega$
- $R_{RMS1}=1M\Omega$, $R_{RMS2}=100k\Omega$ and $R_{RMS3}=10k\Omega$
- $C_{RMS1}=220nF$ and $C_{RMS2}=2,2\mu F$

The input voltage waveform (from oscilloscope) is shown in figure 8.

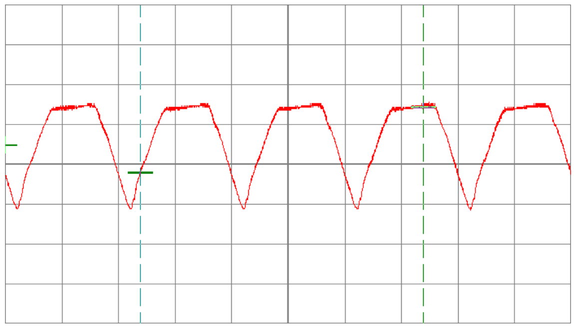

Figure 8. Input voltage (100V/div and 5ms/div).

The inductor current waveform is shown in figure 9 and a detail of the inductor current is shown in figure 10. One can observe that this preregulator present a high power factor and a low THD. The input current is almost sinusoidal. The high frequency components can be eliminated with an input filter.

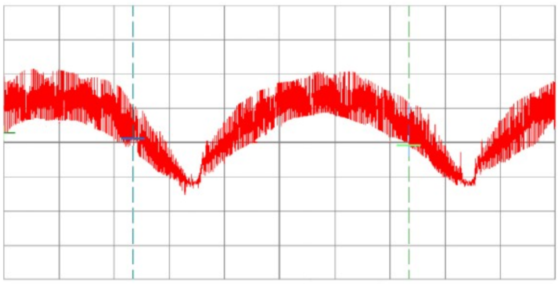

Figure 9. Inductor current (0.5A/div and 2ms/div).

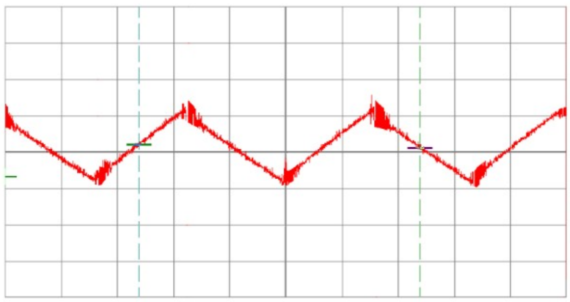

Figure 10. Detail of inductor current.

Drain voltage of power MOSFET is shown in figure 11. The maximum voltage on power transistor has the same value as output voltage.

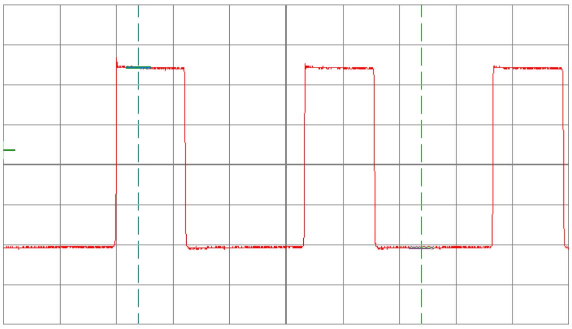

Figure 11. Drain voltage of power transistor (100V/div and 5us/div).

The output voltage ripple is shown in figure 12.

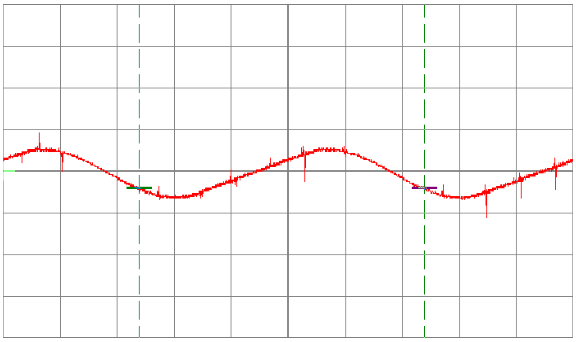

Figure 12. Ripple of output voltage (5V/div and 2ms/div).

The simulation results obtained with Ballast Designer software are presented in next figures. The input voltage to the resonant circuit during the three stages of lamp operation is presented in figure 13.

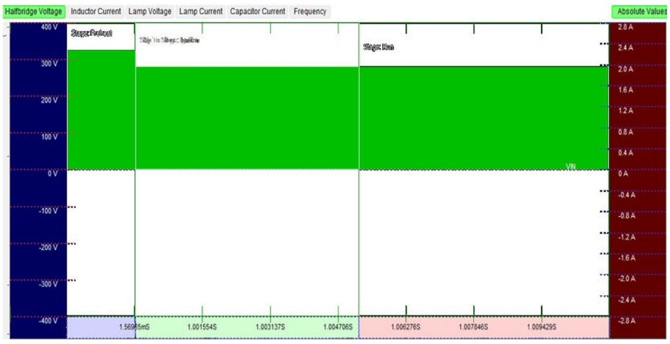

Figure 13. The voltage to the input of resonant circuit.

The input voltage during the run stage is shown in figure 14 (detail).

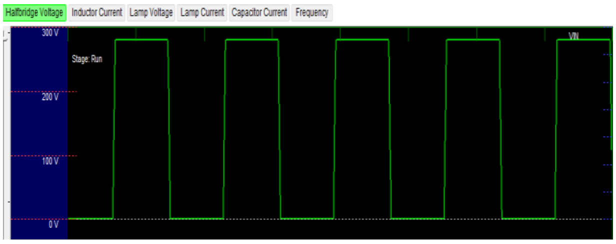

Figure 14. The voltage in the run stage (detail).

Inductor current during the three stages of lamp operation is presented in figure 15 and a detail of this current in run stage is shown in figure 16.

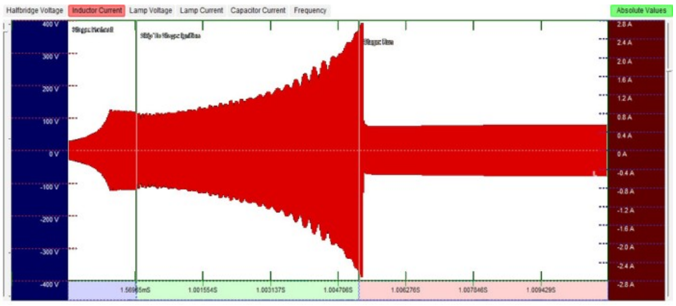

Figure 15. The inductor current.

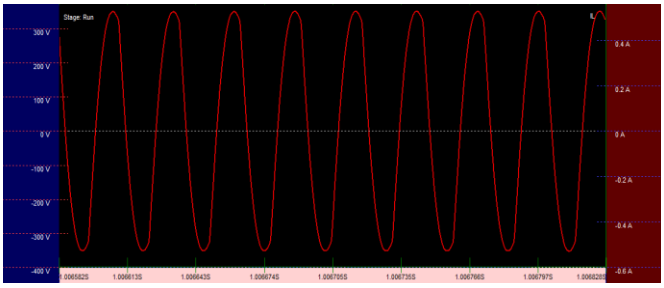

Figure 16. Inductor current in the run stage (detail).

Figure 17 shown the lamp current during the three stages of lamp operation.

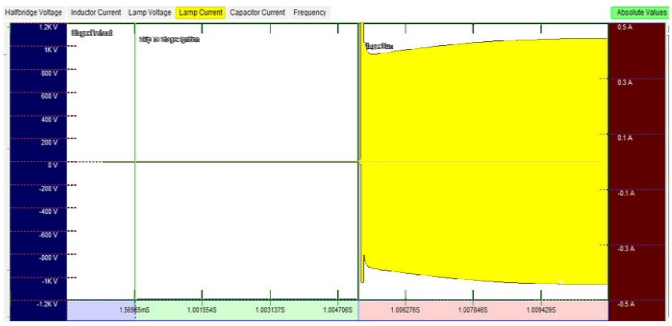

Figure 17. Lamp current.

IV. CONCLUSIONS

The paper presents an electronic ballast with power factor correction. We choose a boost converter with average current mode control for PFC stage. We design and realize the preregulator and electronic ballast with dimming control. It can be observed that this preregulator present a high power factor and a low THD. In order to reduce the high frequency components, it is necessary to use an EMI filter to input.

PFC preregulator was developed around UC3854 IC and electronic ballast around IR21592 IC. Using electronic ballast with PFC preregulator we obtain a greater efficiency, lower EMI, better control, reduced lamp flicker, reduced weight and a longer life for the lamp.

The simulation and experimental results are presented in the paper.

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