Presentation of a new design current supply based on inductive ballast; ripple comparison with SMPS

Radu Bogdan Dragomir*, Brandusa Pantelimon†, Radu Dragomir°, Dorina Dragomir□

* Univ. of Politehnica Bucharest/Dept. of El. Engineering, Bucharest, Romania, dragomirbogdan1986@yahoo.com

† University of Politehnica Bucharest/Dept. of El. Engineering, Bucharest, Romania, bpante@electro.masurari.pub

° National Communication Research Institute INSCC, Bucharest, Romania, radu.dragomir@inscc.ro

□ "Traian Vuia" Metrology High School, Bucharest, Romania, ddor1955@gmail.com

Abstract - **This paper presents a new design approach of a very low cost LED power supply. The innovation comes from the re-usage of the inductive ballast already functioning in street lighting solutions based on fluorescent lamps. No active component, except a rectifying bridge was used. Instead, for circuit compensation, passive circuit elements like resistor, coil and capacitance were used. This power supply solution was created as an alternative of more complex and more expensive SMPS (switching mode power supply), having a lower efficacy also. Design principle and architecture of the driver are explained. Output voltage and current ripples were studied using simulation tools. The influence of the value associated to inductive ballast and to the electrolytic capacitor was studied in order to obtain the best compromise between electrical solution and cost. Technical specifications of the LED cluster were taken into account for current supply design. Output ripples of a SMPS were compared with the best chosen inductive ballast current supply. Advantages and disadvantages of each solution are explained.**

Keywords - *current ripples, voltage ripples, LED cluster, SMPS*

I. INTRODUCTION

In the last decade, a global movement that encourages reduction of CO2 was implemented by the majority of European governments. Therefore incandescent bulbs and fluorescent lamps which are high demanders of energy are step by step getting out of the lighting scene and make place for more energy efficient ways of lighting. Even if the fluorescent lamps have a better efficiency than the incandescent, the technology of production is not so eco-friendly. Recently, several countries have prohibited the sales of fluorescent lamps to foster local LED industries and concentrate on expanding the LED markets [1].

Solid State Lighting is one of the top lighting solutions. Each year the LED manufacturers announce higher lm/W which is traduced in better luminance for a lower energy bill. By using the LED technology, savings of up to 70% comparing to incandescence bulbs, can be made at the same illuminance value.

[1]Lifetime of a LED cluster is another attractive part of this technology. Having a proper thermal management, a cluster can reach a lifetime of more than 50.000 hours, more than 5 times the lifetime of a fluorescent lamp. This advantage is decreased due to a shorter lifetime of SMPS (20.000 hours) that are commonly used as drivers. The main problem for this driver is the fast aging of electrolytic capacitors or the sensibility of different active components [2].

The total cost of a LED lighting device with SMPS is very high comparing other solutions. This value is obtained because, comparing to the traditional ways of lighting where no driver is needed, two main parts are used: the cluster of LEDs and the power supply. The cost of the cluster remains the same, but a SMPS driver doubles the price of the lighting device.

For solving these two issues and design a robust solution, at a lower price a new solution is proposed. The solution is based on inductive ballast. Main drawback is a lower protection on high voltage and voltage fluctuation and also the lower efficiency due to high breakdown voltage on ballast. From another point of view, a driver that is using ballast has a higher ratio of recycling than a SMPS so is using more eco-friendly materials.

This paper approaches the study of a LED driver based on passive circuit elements. An optimization of the driver is study. Subject of interest is the function between the inductive value of the ballast and the ripples that overlaps the waveforms of the current and voltage. A comparative research with a SMPS was done.

II. DRIVER'S PRINCIPLE DESIGN AND ARCHITECTURE

The LED cluster is commanded in current. The purpose of the inductive ballast based driver is to make the conversion from an alternative voltage power supply (national electric grid) to a current DC power supply using a rectifier bridge. Also the power supply must respect the technical specifications of the LED cluster. A model description is made in Fig. 1.

The input of the driver is connected to the national grid, AC input: 230V, 50Hz. It is composed from a resistor designed for protection, a capacitor used for filtering and inductive ballast. In case of a short circuit the resistor R acts as a fuse and disconnects the load saving it from destruction. Due to its property of storing electrical charge, the capacitor is used to "damp" changes in voltage for short period of time that can perturb the input of the driver. Another role of the capacitor C1 is for power factor correction.

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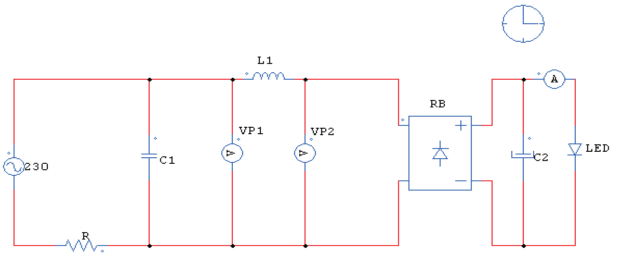

Fig. 1. Driver design.

The inductive ballast L1 is the core component within the circuit. L1 value is designed to provide the LED assembly with the constant current required by the lighting pattern. The ballast current is limited to the saturation current in the hysteresis figure of the magnetic core in order to prevent its overheating.

The rectifier bridge provides the LED assembly with DC voltage. The C2 electrolytic capacitor and the LED assembly are the last part. C2 is filtering the rectifier voltage to the DC value with an affordable voltage ripple.

III. LED Current Cipples as Function of Chosen Ballast

Two different values of ballast inductance (L=30mH and 381mH) were chose having the same DC capacitor (C= 100 μF). The inductance current, I_L, the inductance voltage, U_L, the filtering capacitor voltage, UC, and the LED current, I_{LED}, have been plotted, as seen in Fig. 2. The initial current is charging the filtering capacitor up to a maximum voltage, which is energizing the LED load into conduction. Once the steady state regime is set, the filtering capacitor voltage is periodically tripping around a DC level to renew the capacitor energy during a small conduction angle of the rectifier bridge [3].

Taking into consideration the two functioning working regimes for the power supply (transitory and steady state), 2 simulation were performed for each value of L and C. Transitory regime was performed by using MATLAB simulation while the steady state is designed by PSIM. Critical situation is given by the transient regime where the current absorbed is high and this can lead to optical flux fluctuation.

In Fig. 2 (upper part) shows the current that pass through the inductance. Maximum value of it must be under the value provided by supplier in technical specifi-

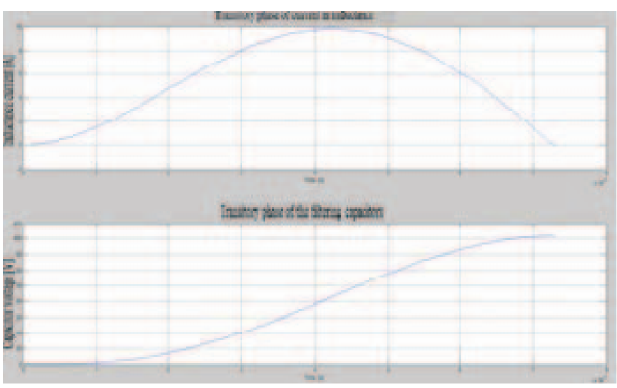

Fig. 2. Transitory phases of the inductance current and filtering capacitor voltage L = 30 mH, C = 100 μF, r = 10 Ω.

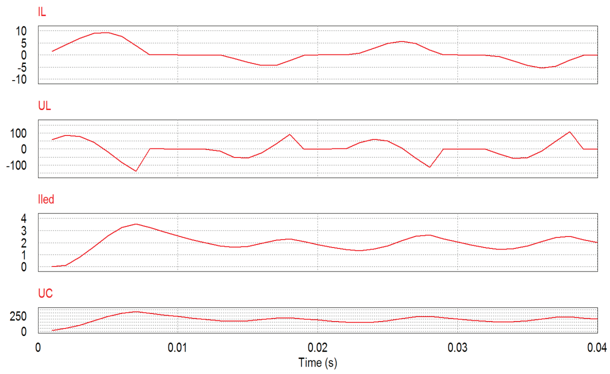

Fig. 3. I_L, U_L, I_{LED}, U_C, Curves in steady state regime L = 30 mH, C = 100 μF.

cation data sheet. Second graphic of the plot shows that the capacitor is charging from 0 V up to nominal voltage.

Time needed by capacitor to charge in this configuration Once the capacitor is fully charged, the current absorbed through the ballast decrease to zero. In that point the capacitor starts to provide current to LED matrix. is of 7.3 ms. This solution is not acceptable due to the high ballast current.

In steady state more parameters were taken in consideration: inductive current noted I_L, inductive voltage U_L, current through LED array I_{LED} and filtering capacitor U_C. Fig. 3 shows the continuous operation mode after the filtering capacitor was energized. After the steady state is established (the same amount of time as in the simulation of transient regime), the filtering capacitor voltage is periodically oscillating around a DC value to renew the capacitor energy during a small conduction angle of rectifier bridge [3]. Obtained date detected a current I_{LED} ripple around 0.5A with a voltage ripple on capacitor U_C of almost 40V.

In the second simulation, the value of the inductance increased to 381mH. This value had been chosen after searching in the market ballast with characteristics that can be applicable to the LED array.

Initial time needed by the current to rise until I_{max} =3.5A and fall back to 0A in the new configuration is of 13ms. This means half of period of the input voltage. Transient regime is showed in Fig. 4. Comparing to Fig. 2, the I_{Lmax} obtained for the new design had massive decreased.

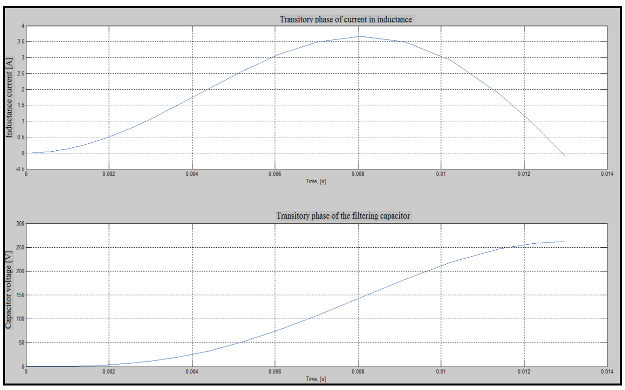

Fig. 4. Transitory phases of the inductance current and filtering capacitor voltage L= 381 mH, C = 100 μF.

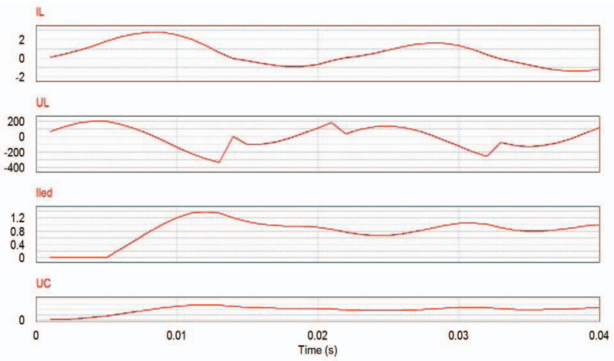

Fig. 5. I_L, U_L, I_{LED}, U_C Curves in steady state regime L = 381 mH, C = 100 μF.

Going back in the steady state regime, the values obtained are indicating that this design is a better solution. The capacitor ripple decreased to 7 V, while the current LED ripples are less than 0.125 A, see Fig. 5. The obtained functioning regime is smoother. This characteristic brings robustness to the power supply and increase the lifetime of the LED array.

IV. LED Current Ripple as Function of Chosen Electrolytic Capacitor

Even if the solution from above is considered to be operable, a current ripple of 0.125 A is leading to perceptible fluctuation of luminous flux at the output of the LED. This intrinsic characteristic of the LED is based on the fact that a diode is current commanded. For solving the problem, the second choice was investigated, the shift of capacitance.

Two different values of DC capacitor (C= 220 μF and 1000 μF) were chose having the same ballast inductance (L=30mH). The electrolytic capacitor improves the ripple output characteristics. It acts as a filter which smooth's the slope of the ripple. Using this technical solution the inductance of the ballast can be reduced so the cost value of the supply can be reduced.

First simulation was made using a L=30mH and a C = 220 μF. Comparing with the design in Fig. 2, Fig. 6 shows out a longer current length of 8.9 ms and a lower current peak of I_L = 6.7 A.

Curves obtained in Fig. 7 showed an important decrease of voltage ripple, if we compare with Fig. 3.

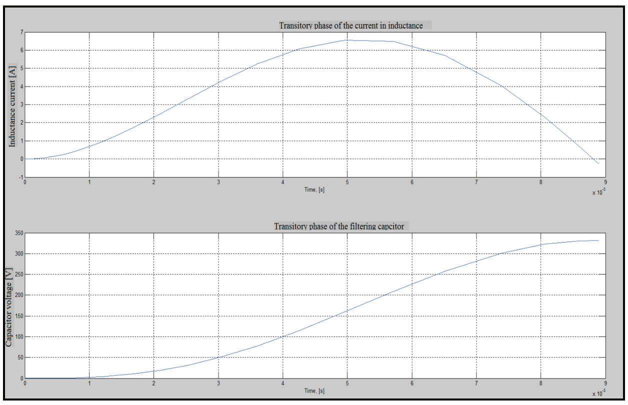

Fig. 6. Transitory phases of the inductance current and filtering capacitor voltage L = 30 mH, C = 220 μF.

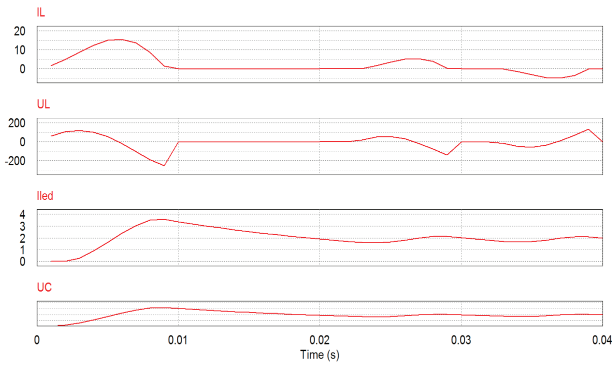

Fig. 7. I_L, U_L, I_{LED}, U_C Curves in steady state regime L=30mH, C= 220 μF.

Level obtained is 20V, which means an improvement with 100%. Also the current ripple has improved and reached a value of only 0.25A

Second solution that was tried is with the same ballast inductance, 30 mH but using a greater capacitor of 1000 μF. From Fig. 8 are deduced the 7.5 V voltage ripple and the very small current ripple of 0.05A.

The steady state characteristics are considered to be ‘flat’, as in Fig. 9.

Taken into consideration all the simulations from above, it was decided to make a prototype of the power supply that is using both solutions (a good value of the inductance with a ‘calibrated electrolytic capacitor with high capacitance). The prototype that was a success and implemented in serial life is using an inductance of the ballast of 381mH and an electrolytic capacitor of 220 μF.

V. SMPS Design Functioning Principle

Switching mode power supply (SMPS) is an electronic power supply used for efficient electrical power conversion. The driver uses a switching regulator for converting voltage and current characteristics. The non-linearity of the supply is given by permanent transition between full-on and full-off stage. The efficiency of the equipment comes from the fact that the period spent on full-on power is very short, so low power dissipation occurs. Low power dissipation is involving a small heat sink and small SMPS dimensions as well. Voltage regulating is accomplished by the on-off ratio.

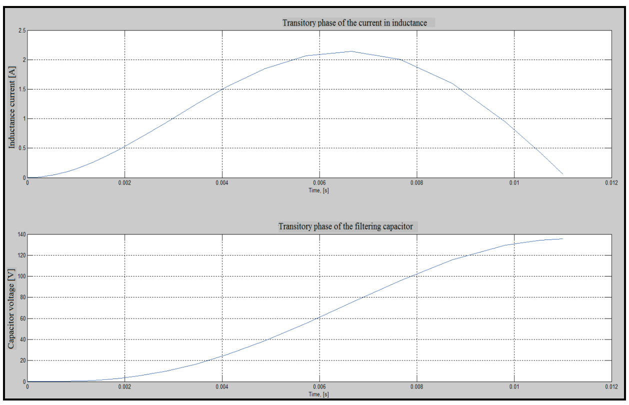

Fig. 8. Transitory phases of the inductance current and filtering capacitor voltage L = 30mH, C= 1000 μF.

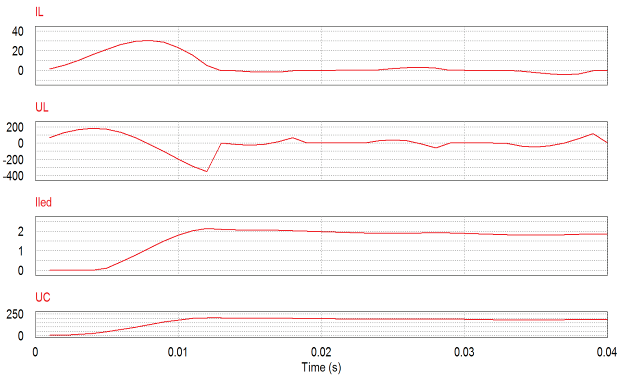

Fig. 9. I_L, U_L, I_{LED}, Curves in steady state regime
L = 30 mH, C = 1000 μF.

The LED power supply design requires an AC–DC converter with high power factor correction (PFC) and low total harmonics distortions (THD) to comply with IEC 61000-3-2 Class C standard [4].

The circuit diagram consists of an input electromagnetic interference filter (EMI), a filtering input capacitor, a power switching stage (transformer, switching transistor and rectifier bridge), pulse width modulation stage (PWM), output filtering capacitor, feedback loop, and protections: overload protection (OLP), overcurrent protection (OCP) and overvoltage protection (OVP) [5], [6].

The SMPS block diagram is presented in Fig. 10.

The SMPS main function is to convert an AC voltage into DC power. The rectified main voltage is filtered by a large filtering capacitor in PFC. A power MOSFET is chopping the DC voltage at high frequency and the desired duty cycle. The higher the switching frequency the higher the switching process efficiency the smaller is the switching transformer. An integrated control circuit is feeding the MOSFET with a PWM signal [7]. EMI filter is dumping the electromagnetic emissions at the standard levels.

Measurements were performed to determine the output voltage ripple of a MEANWELL SMPS. The SMPS testing conditions (ambient temperature, input voltage, operating time before test, load, and output voltage) were similar with the ones of the linear power supply measurements.

A SMPS simulation has not been yet done due to the high complexity of the circuit and shortage of detailed technical information. Fig. 11 shows a ripple over a full-on period of time. Residual periodic trip of the output direct current occures.

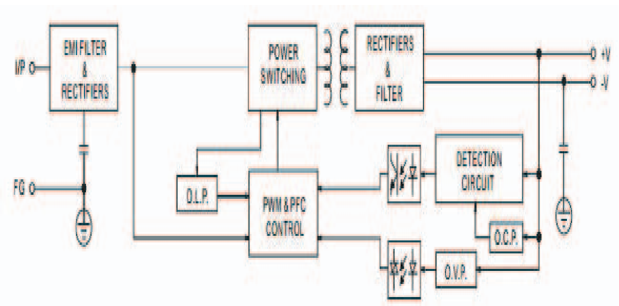

Fig. 10. SMPS Block diagram [5].

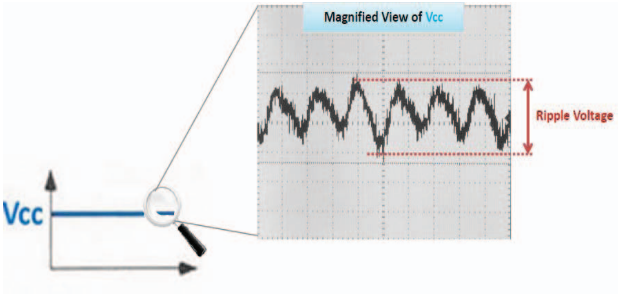

Fig. 11. Voltage ripples for a SMPS driver.

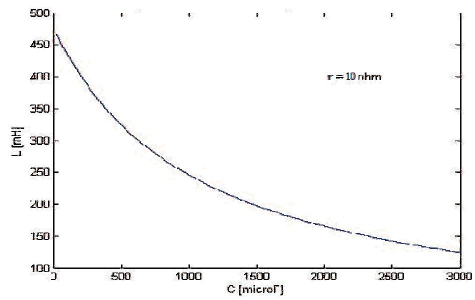

Fig. 12. Inductance versus filtering capacitance, steady-state circuit.

These ripples are endangering neighboring high speed data applications and next door high frequency electronics, leading to data corruption and electronics malfunction. Due to a high robustness of LED applications, higher ripples are tolerated [8]. SMPS is delivering a lower output ripple than a linear power supply. A maximum 150 mV ripple was observed during the measurements (Fig. 11).

Experimental results are proving low output voltage ripples of a SMPS. The efficiency of the SMPS is up to 93%, much higher than the linear power supply [9].

SMPS is providing the forward current control. LED data sheet provides such characteristics as color, efficiency or illuminance rated to the forward current. Accordingly, the user should be able to set the illuminance. This dimming process could be used in theaters, showrooms and office buildings [10].

The main quality of a LED linear power supply is its robustness and the cost effectiveness.

Table 1 summarizes the main characteristics of linear supply and SMPS.

TABLE I.
CHARACTERISTICS OF LINEAR SUPPLY AND SMPS

	Linear Power Supply	SMPS	Comments
Size	x	80% smaller	At the same output power
Weight	x	80% lighter	At the same output power
Input Voltage Range	-10%...+15%	-150%...+150%	
Efficiency	<60%	>80%	
Reliability	$\lambda=10^{-7}$ h^{-1}	$\lambda=10^{-7}$ h^{-1}	
Ripple	~ mV	~ 100 mV	
Noise	Quiet	10000 times worse	LED lighting is not electric noise critical
Transient Response	50 microseconds	3000 microseconds	

VI. Conclusions

Simulations produced inductance and capacitance values to control the output ripples of the LED linear power supply.

The ballast inductance and the filtering capacitance are calculated to provide a constant output current with almost no ripple. Fig. 12 shows out the inductance versus capacitance diagram, providing the lowest LED output current ripple. However, according to theoretical design and simulation, the higher the inductance, the higher the capacitor, the lower the ripple.

A low cost LED linear supply involves a small ballast inductance and a large filtering capacitance. A similar ripple SMPS is a lot more expensive.

LED lighting applications still require linear power supply cost effective solutions, as long as SMPS technologies are leading to high end products.

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