PRACTICAL IMPLEMENTATION OF A LC RESONANT COVERTER FOR LED LIGHTING APPLICATIONS

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REZUMAT. Această lucrare de cercetare prezintă o abordare teoretică şi practică cu privire la o tehnologie comună pentru dispozitivele de iluminat CFL şi LED. Balastul CFL atunci când este reconfigurat în mod corespunzător poate acţiona ca un convertor LC rezonant cu caracter de sursă de curent constant. Astfel, prezenta lucrare propune două lămpi cu LED de 4W, respectiv 8W, bazate pe topologia de balast electronic cel mai des întâlnită iar performanţele sunt subliniate prin intermediul măsurătorilor practice.

Cuvinte cheie: CFL, LED, convertor LC rezonant, sursă de curent constant, tehnologie comună.

ABSTRACT. This research paper presents a theoretical and practical approach in terms of common technology ground for energy saving lighting bulbs like CFLs and LED based devices. The CFL ballast when properly reconfigured can act like a LC resonant converter with constant current behavior. Thus, the paper is introducing two, 4W and 8W LED lamps based on the most common electronic ballast and the performances are highlighted by means of practical measurements.

Keywords: CFL, LED, LC resonant convertor, constant current source, common technology.

1. INTRODUCTION

For decades the incandescent bulb has been the first option in artificial lighting. The global energy demand has exponentially increased, and, as a result, the necessity of founding new, more efficient lighting devices has occurred. For the last 10 years, this option was the CFL, not so well recognized by the consumers like a good overall incandescent lamp replacement most because of the cost and poor light quality for the cheap models [1],[2]. Nowadays, the incandescent bulb is rejected from the markets by government's decisions, so for now the CFL represent the only economical option for Edison type, artificial lighting lamps. In the last years a new trend has energized the artificial lighting industry and that is the light emitting diode, LED. According to [3],[4],[5] these diodes could represent a breakthrough in terms of low energy consumption, long expected lifetime, good light spectrum, small size, a.s.o.

2. STATE OF THE ART IN CFL AND LED LIGHTING DEVICES

The most common CFL technology is composed by an electronic ballast and a fluorescent tube mounted in an Edison type enclosure. In this paper we will be focused on the electronic ballast, where we try to analyze the great potential of this part. Most common ballast topology found in CFL is the self-oscillating, half-bridge inverter.

In the last few years one of most dynamic industries is the light emitting diode, LED, market. This is because of the great potential of this type of lighting device. Two of the most important advantages for the LED lighting systems are the luminance efficiency associated with a long expected working lifetime. With a view to transform the light emitting diode into an incandescent lamp replacement device we need to take into account its working principle and the right control system, [6]. In the Fig. 1 we can see that the forward voltage of a regular LED is decreasing with the junction temperature. This means that the intensity of the output light could change with temperature. Unfortunately, the operation of the LEDs in the lighting devices is normally associated with high temperature variations. This negative effect could be prevented if the drive circuit is not controlling the forward voltage of the LED but the current passing trough. This aspect is worldwide accepted. As a result, the control system of a LED must be a constant current drive.

The electric representation of a LED [7],[8] could be done like in Fig.2, where it could be presented as a voltage source mounted in series with a resistor and a diode, but also like a Zener diode.

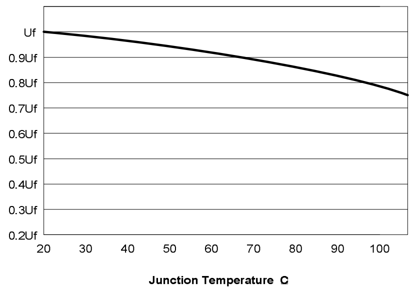

Fig.1. LED forward voltage drop with the junction temperature

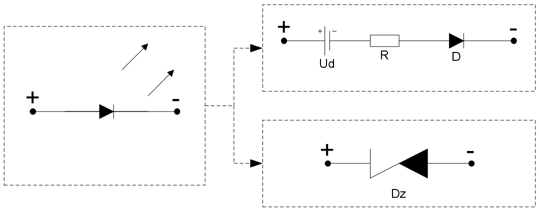

Fig.2 Possible equivalent LED model

In the LED drive industry there are a few of constant current drive technologies, based on controlling the LED current with the help of a current sense resistor. To obtain a constant current drive, the circuit, which most of the time is a PWM controlled device, is sensing the voltage drop on the current sense resistor. If this voltage is kept to a constant value, this means that we have a constant current through the LED.

The value of the current sense resistor, could establish the value of the current passing through the LED. The most common drive topologies used by the LED-drive industry are the classical buck, boost, buck-boost or flyback.

In this paper we will be focused on a new, different way of establishing a constant current through the LED, with the help of a quasi-resonant converter.

3. CFL AND LED UNIFIED TECHNOLOGY

According to our proposed system, the CFL ballast will have as a load not the equivalent resistance of a fluorescent tube but the electrical representation of a LED, connected via a simple, high frequency, single-phase, bridge rectifier. As a result, the actual CFL ballast becomes a LED driver without any changes in the electronic schematics. The old self-commutated inverter operates now as a parallel connected, quasi-resonant dc-to-dc converter. This investigation is necessary because the transient behavior of the circuit becomes now more complex as in the case of the CFL and because it is very important to prove that we achieve the necessary constant current operation mode for the LED.

Fig.3 presents the proposed electronic schematics were the resistance of the fluorescent tube is replaced by the high frequency, full bridge rectifier associated with one of the two equivalent representations of a LED.

In order to analyze the constant current behavior of the system we need to simplify the electronic schematics to a level where we can apply the analytical relations. According to Fig.4 the input alternative voltage supply, the low frequency rectifier and the low pass LC filter will be modeled as a simple continuous voltage supply. The self-oscillating inverter will be considered like a half-bridge, fixed frequency controlled inverter, as presented in Fig.5.

In Fig. 6 the high frequency, full bridge rectifier and the Zener diode representing the LED are replaced by two Zener diodes.

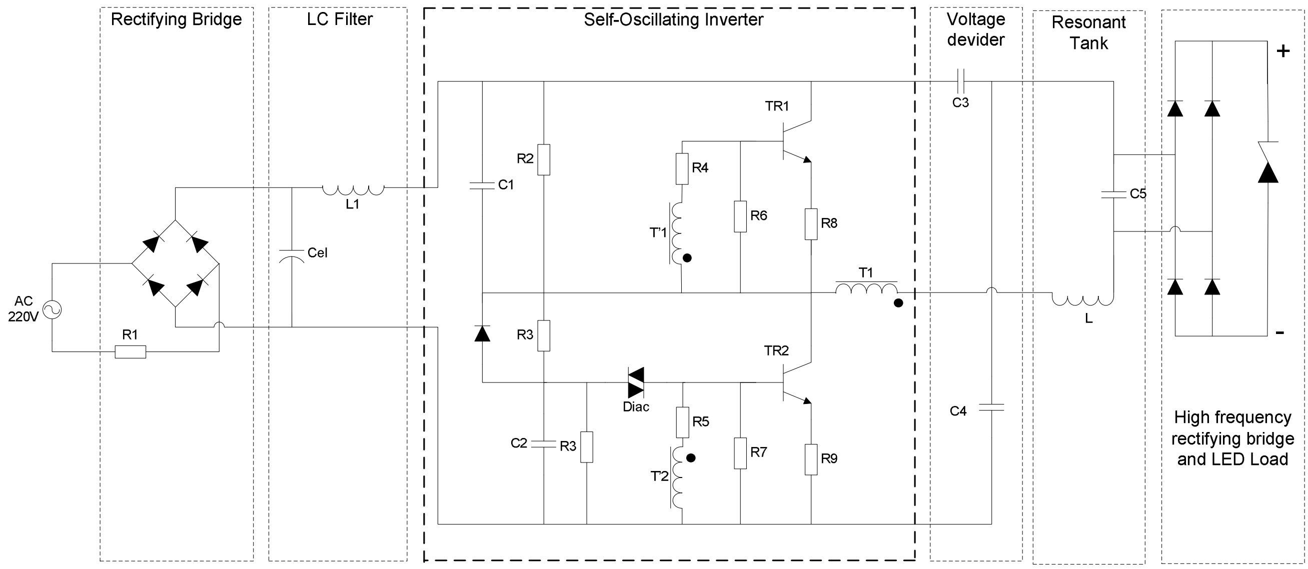

Fig.3 Electronic schematics of a LED controlled by CFL ballast

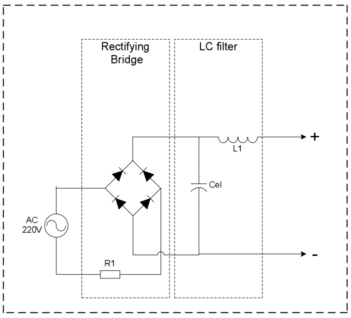

Fig. 4 Model of the CFL input schematics

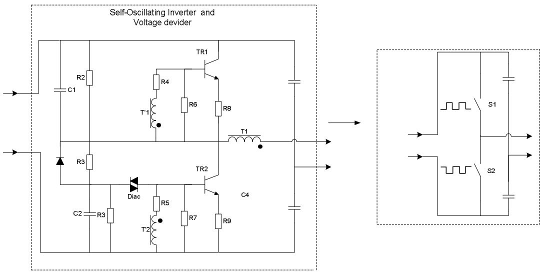

Fig. 5 Modeling of the inverter and DC voltage divider

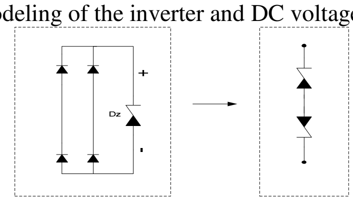

Fig.6 Model of the high frequency rectifier bridge and the LED load

After the above simplification, the resulted circuit is presented in Fig.7. This shows an inverter supplied from a double, bipolar intermediate DC link, a resonant tank (L, C) and the reversed Zener as load.

The inverter generates at his output a rectangular bipolar alternative voltage.

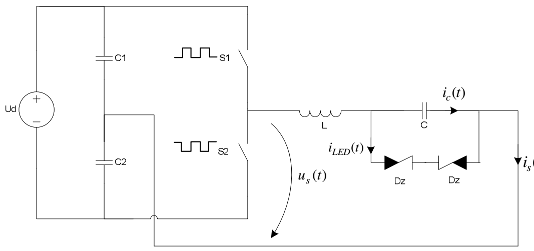

Fig.7 Equivalent schematics of a LED controlled by CFL ballast

We observe that we have $u_C(t) = U_{LED}$ (U_{LED} - Zener diode voltage). The differential equation that describes the operation mode of the circuit from Fig.9 is:

$$\frac{U_d}{2} = L\frac{di_S(t)}{d(t)} + \frac{1}{C}\int i_C(t)d(t) \tag{1}$$

If the Zener diode is not conductive, the circuit is a resonant one. When appears the break-down of the Zener diode, from (1) we can write:

$$\frac{di_S(t)}{d(t)} = \frac{\frac{U_d}{2} + U_{LED} \pm u_{LED}(°C)}{L} \approx \frac{\frac{U_d}{2} + U_{LED}}{L} \tag{2}$$

Where, $u_{LED}(°C)$ is the change of the LED forward voltage with junction temperature (Fig 2). We can admit that: $u_{LED}(temp) << \frac{U_d}{2} + U_{LED}$. Then, supposing that the inductivity of the coil L is high enough, from (2), we obtain the constant average current behavior of the circuit. Due to the high self-oscillating frequency of the circuit, the contribution of the resonant time-intervals is negligible from the point of view of the general operation of the investigated LED.

4. PRACTICAL RESULTS FOR THE PROPOSED CIRCUITS

The present paper presents de experimental results obtained on two types of LC resonant converter with different LED loads. First lamp will be composed by a CFL ballast with a 3 series connected 12V LEDs, while the second lamp is based on the same ballast but the output load is one 12V LED, as presented in Fig.8 and Fig.9. In order to backup the LED-Zenner diode similar electric behavior the results will be presented in parallel for the both types of loads.

In the Fig. 10, Fig. 11 and Fig.12 we present the results for one LED lamp, 3LED lamp and for the circuits with the equivalent Zenner loads.

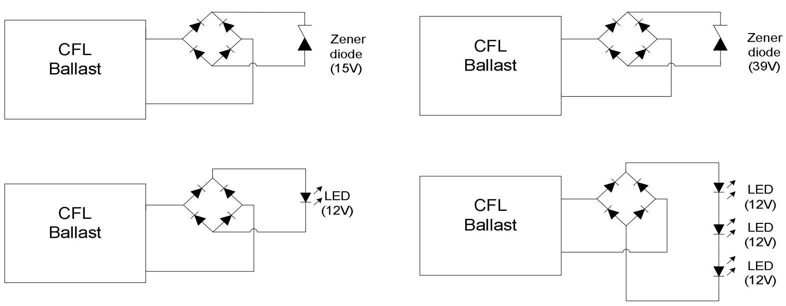

Fig.8 Electronic schematics of a LED controlled by CFL ballast

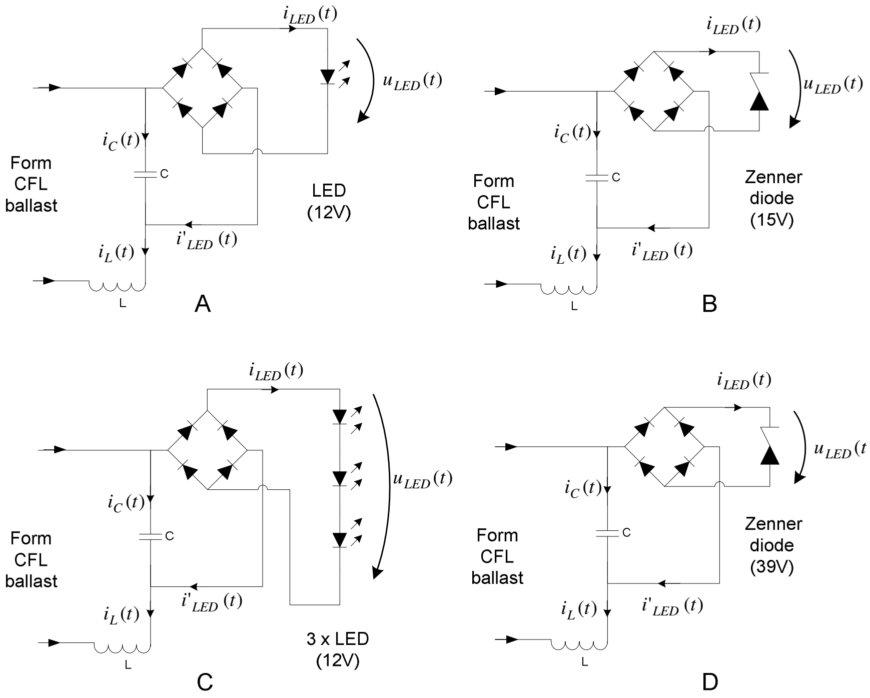

Fig.9 Electronic schematics of a LED controlled by CFL ballast

A- 4W lamp with 12V LED

B- 4W with 15V Zener diode

C- 8W lamp with 36V LED

D- 8W circuit with 39V Zener diode

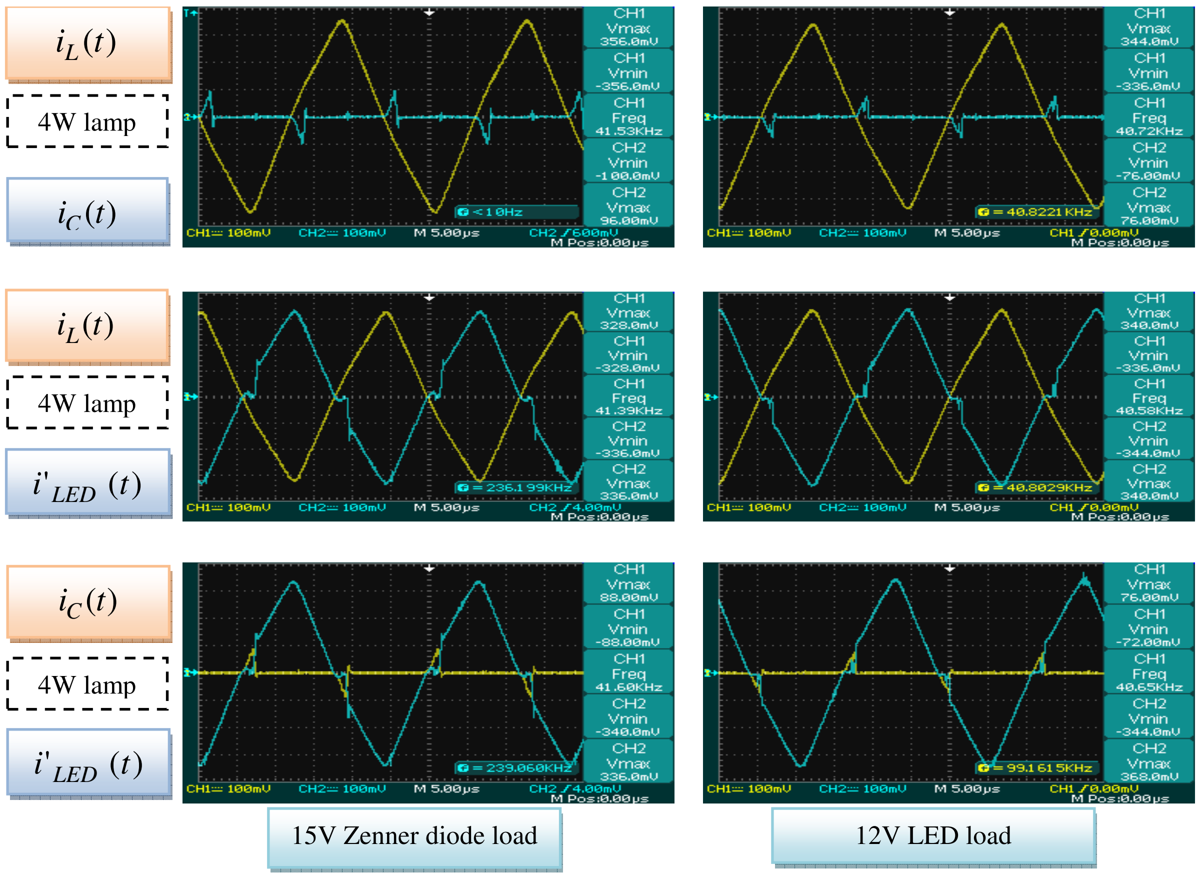

Fig.10 Waveforms of the resonant tank and output currents for the 4 W lamp

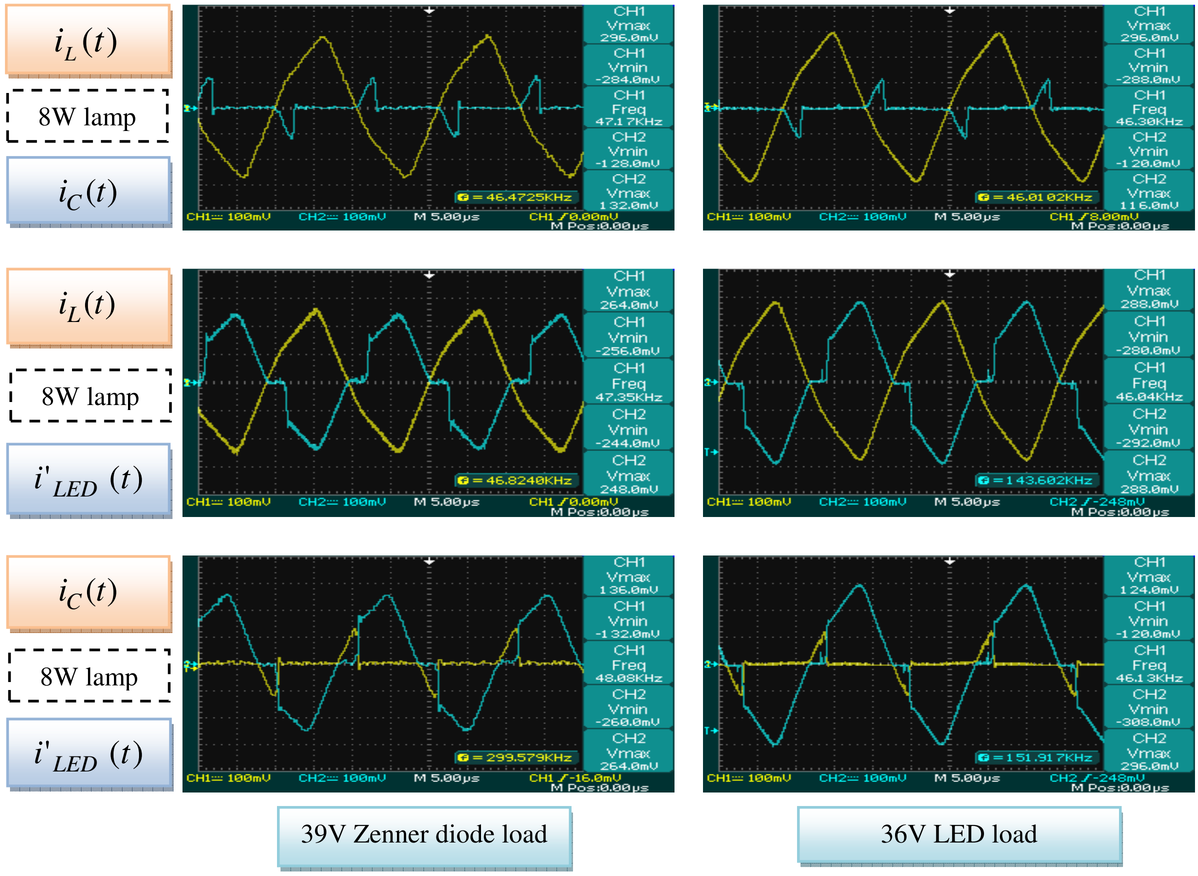

Fig.11 Waveforms of the resonant tank and output currents for the 8 W lamp

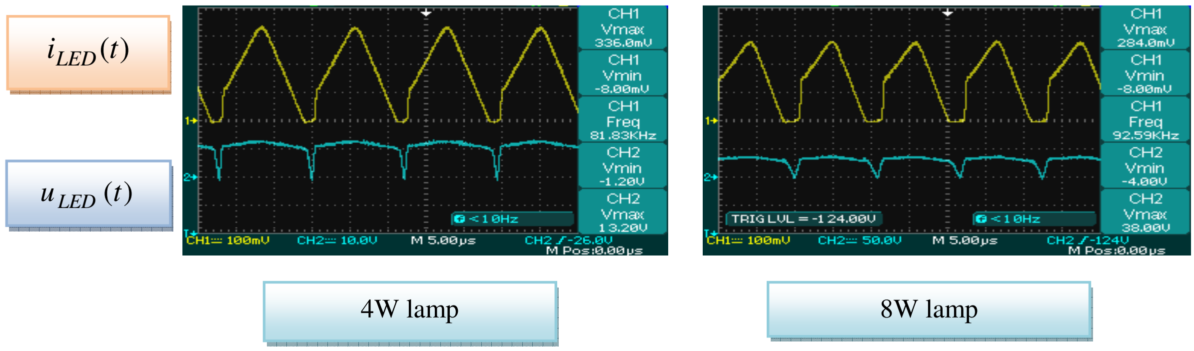

Fig.12 Waveforms of the LED current and voltage

From Fig. 10, Fig. 11 and Fig.12 we can conclude that the functioning cycle could be divided into two periods. First period would be characterized by the fact that the LED current is 0 and because of this, the circuit is working under resonant principle. After that, when the LED current is different form 0, the operation of the circuit is based on the voltage source behavior of the reversed Zener diode (LED). Now, the circuit is not working under resonant characteristics. It is acting like a current source and the LED current is fed by the resonant tank inductor. The resonant behavior will occur again when the LED current will be 0.

5. CONCLUSIONS AND OUTLOOK

✓ In this paper it was presented a new possibility of controlling the LEDs with the help of CFL electronic ballast. All this has been proved by means of analytical investigation of the physical phenomenon and practical measurements.

✓ The possibility of using the exact CFL electronic ballast and adding just a high frequency rectifier in order to control a LED could be the way to the near future artificial light devices. The apart performances of the CFL electronic ballast and the LED's when brought together could lead to a high-performance, low cost, low energy consumption lighting bulb.

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