LED LAMP DRIVE USING MICROCONTROLLER-BASED QUADRATIC BUCK CONVERTER

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***Abstract* – This paper presents a new proposal of LED lamp driver using the microcontrolled Quadratic Buck DC/DC converter. The main focus is to improve the LED drive characteristcs using the microcontroller PIC16F873A. Therefore, greater durability and efficiency can be achieved. Mathematical analyses and experimental results are presented in this paper.**

***Keywords* - LED lamp, microcontrollers, PIC, quadratic Buck converter.**

I. INTRODUCTION

Nowadays, an abrupt change has been observerved in the area of illumination. Solid-State lamps manufactured with semiconductors materials, which are commonly used in toys and luminous panel of sound receiver. It has already begun to substitute incandescent lamps in many applications, particularly those requiring durability, compactness, cool operation, and/or directionality (e.g., traffic, automotive display, and architectural/directed-area lighting) [1]. The reasons for these changes are:

- the high efficiency in the conversion of the electric energy in luminous energy [1];
- higher durability (a LED has a useful life of 100.000 hours) [1];
- the heat produced by Joule effect is extremely reduced.

According to [2-8], the white LED's can achieve a luminous efficiency around of 150-200 lm/W, this value is two times bigger than that of fluorescent lamps and ten times bigger than that of incandescent lamps. A typical LED indicator traditionally was produced at power a rate that varies from 30mW to 60mW. At the end of the 1990's, it was possible to find a new type of diode which was capable to operate with power rates of 1 W for continuous use.

Today, LEDs are available for various colors and they are also suitable for white illumination. New single power LEDs are designed for an input power of 1W, 3W or 5W and their energy efficiency has already surpassed that of incandescent and halogen bulbs. Recent industrial research results claim already LED energy efficiencies above 100lm/W [4].

In a previous work a very dissipative driver has been built a tested and limitation of this solution has been obtained [9]. Other works have been developed with the objective to get one better performance of the drive LED lamps according to in [10].

This work presents an alternative driver based in a quadratic buck circuit with a control using a microcontroller PIC16F873A. The proposed circuit presents as advantage, wide range of DC conversion, thus allowing, the drive of LED Lamps from a universal input voltage. One of the advantages of the proposed converter with regard to the reference [10] it is not the use of electrolytic capacitors due to small useful life of the same ones with regard to excessively, turning around ten times lower [11]. The use of a quadratic buck topology implies the series connection of all the LED´s without any dissipative elements.

II. LED LAMP DRIVER PROPOSED: BASIC OPERATION

Initially the Buck converter was used and the regulation was not possible provoking still the sprouting of flicker. Due to needed of achieve a better regulation of the output current and also for low output power, was used the single-switch quadratic Buck converter drawn in Fig. 1.

According to [12], the circuit contains two LC filters, one active switch and three passive switches. The main advantage of this converter is the use of one MOSFET control circuit, in comparison with cascade converter, which requires two control circuits. In quadratic buck operating continuous conduction, the voltage transformation is obtained as a function of the duty ratio U = (ton/Ts)2, where ton is the on-time of the switch and Ts is the corresponding switching period.

In the following discussion, for simplicity, we assume that ac ripples in the capacitor voltages and inductor currents are negligible. In Fig. 1, when the MOSFET (S) is turned on, diode D1 is turned on simultaneously, conducting the current ID1= IL2 – IL1. The average MOSFET current is equal to UL2. Since the average MOSFET current must also be equal to IL1, we have which confirms that diode D1 is indeed on.

$$i_{D1} = (1-U)I_{L1} > 0 \tag{1}$$

During the MOSFET on-time, diodes D2 and D3 are off. When the MOSFET is turned off, diode D1 is off and diode D2 provides a path for current IL1, while diode D3 provides a path for current IL2. The resulting dc gain for this converter is given by U2. The dynamic behavior of many classes of power circuits can be analyzed using the notion of averaged circuit models, which have been derived mainly for high frequency switching dc-to-dc converters operating in the continuous conduction mode (CCM). This model is also called a low-frequency model. A technique widely used for modeling dc-dc converters is the PWM-switch (pulsewidth modulation) model. Once its invariant property is determined, the averaged equivalent circuit model of the converter can be analyzed using straight circuit analysis techniques.

The PWM-switch model is a powerful and convenient tool in the analysis of converters, transient response studies, and controller design [12].

This model usually requires that the active and passive switches are to be appearing in pairs and to form a three-terminal network. However, this methodology can be extended for the analysis of the single-switch quadratic buck converter that has one active switch and three passive switches. This approach is called separated PWM, which results that the pair transistor S and diode D3 can be replaced by the corresponding current and voltage source, the diode D2 by a voltage source and D1 by a current source. The above methodology is only useful in the CCM operation [12].

III. CONTROL STRATEGY EMPLOYED IN THE QUADRATIC BUCK CONVERTER

In Fig. 2 the basic circuit diagram for the switch control for quadratic buck converter can be seen. A microcontroller PIC was used due to flexibility and because can be programmed if it is needed to change something on the operation program.

The method of control used was the average-current mode, where the current value is collected with the voltage value on a resistor, known by A/D converter and analised by the PIC that verifies, according with the program built in, if the current value is up or down the middle current parameter, and, so, change de PWM increasing the duty cicle in the first case or decreasing in the other.

For the connection of the PIC with the switch control has been used an optocoupler and associated with a current buffer to turn on the switch.

The PIC choosed for the project was the PIC16F873A that have 28 terminals used both by input ports or by output ports, it´s a microcontroler that have high perfomance and relatively low costs, and, for this project, it is better than others because of the 2 PWM´s modules (which was used just one), and the A/D converter.

To sum up, in basis with the values read the current by A/D converter, and with some programmed routines, the PIC determines the PWM with the correct width pulse to change the current to reach the middle current.

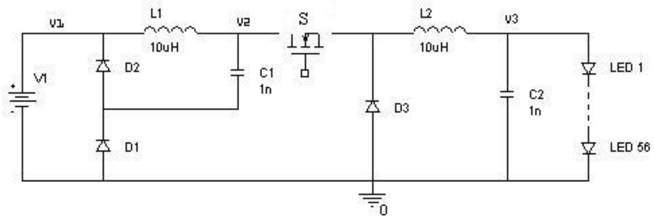

Fig. 1- Schematic of the quadratic buck converter.

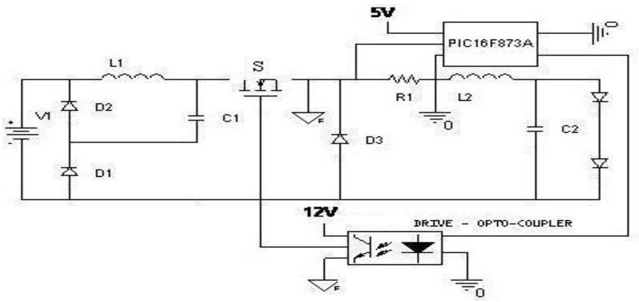

Fig. 2-Circuit diagram of the quadratic buck converter.

IV. EXPERIMENTAL RESULTS

Experimental tests were performed for the proposed LED lamp drive as the following parameter set was employed.

TABLE I
Parameter set employed in the experimental tests

LED lamp	
Parameter	**Value**
Nominal voltage	168V
Nominal current	20mA
Quadratic Buck Converter	
Parameter	**Value**
Input voltage	V_{IN}=311 V
Switching frequency	F_S= 100 KHz
Inductors (L1 and L2)	$L = 180$ mH
Switch *S*	IRFBC40
Diodes (D1, D2, and D3)	HFA04TB60
Capacitor C1	C = 10μF
Capacitor C2	C = 1nF

The voltage waveforms in the input, drain of the switch, and output observed during the experiment are shown in figs. 3 and 4. In fig. 5, can be observed the voltage and output corrent, fig. 6 presents the used LED's (a) off and (b) on.

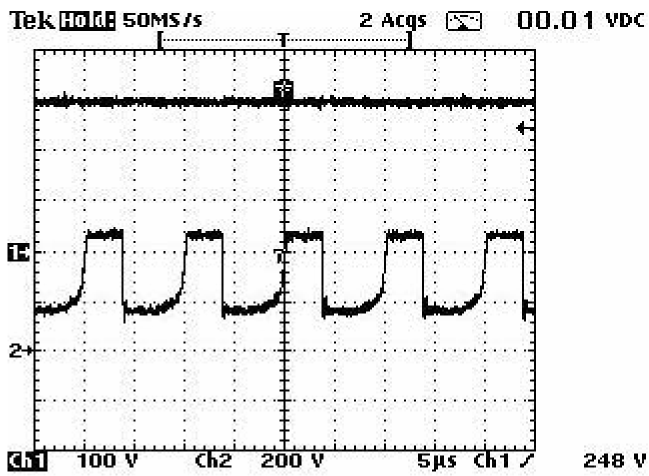

Fig. 3 - Waveforms of voltages V1 and V2.

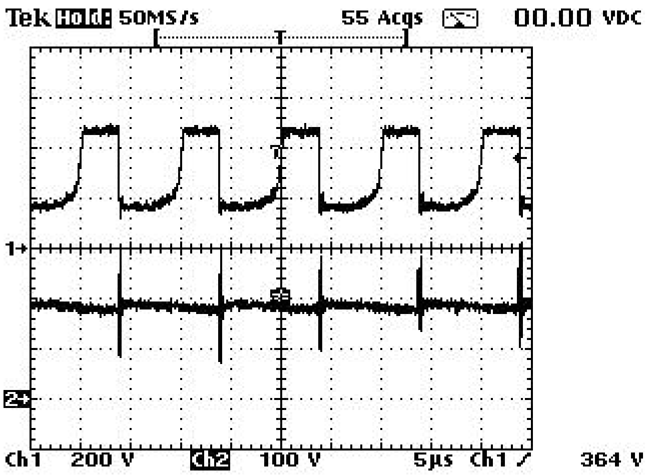

Fig. 4 - Waveforms of voltages V2 and V3.

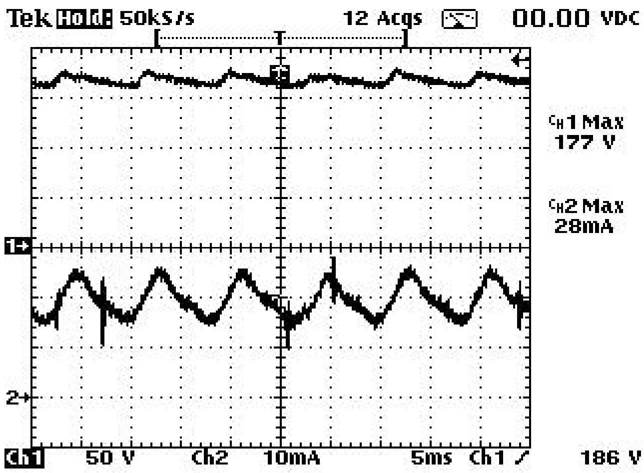

Fig. 5-Waveforms of outuput voltage and current

a) off LED .

b) on LED.

Fig. 6- Photos prototype.

V. CONCLUSION

Through the analyses of the experimental results with the prototype, it is possible to prove that the microcontrolled drive of quadratic buck presents a good regulation of the output current, thus guaranteeing, the useful life and the high luminous efficiency of the LED.

Uniting these characteristics with the low energy consumption and not the emission of infra-red and ultraviolet rays, it has a trend of that in the future the actual lamps will be substituted by LED lamp.

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REFERENCES

[1] Jeff Y. Tsao, “Solid-state lighting: lamps, chips, and materials for tomorrow”, IEEE Circuits & Devices, May-June 2004, pp. 28-37.

[2] Daniel A. Steigerwald, Jerome C. Bhat, Dave Collins, Robert M. Fletcher, Mari Ochiai Holcomb, Michael J. Ludowise, Paul S. Martin, and Serge L. Rudaz, “Illumination With Solid State Lighting Technology”, IEEE journal of Selected Topics in Quantum electronics, March-April 2002, pp. 310-320.

[3] Michael S. Shur, Arturas Zukauskas, “Solid-State Lighting: Toward Superior Illumination”, Proc. of the IEEE, October 2005, pp. 1691-1703.

[4] H. van der Broeck, G. Sauerlander, M. Wendt, “Power driver topologies and control schemes for LEDs”, Applied Power Electronics Conference, APEC 2007 - Twenty Second Annual IEEE, Feb. 2007 Page(s):1319 - 1325

[5] Steve Johnson, “The Solid State Lighting Initiative: an Industry/DOE collaborative Effort”, Architectural Lighting, November/December 2000.
[6] N.F. Gardner, J. Bhat, D. Collins, L. Cook, M.G. Craford, R.M. Fletcher, P. Grillot, W.K. Gotz, M. Kueper, R. Khare, A. Kim, M.R. Krames, G. Harbers, M. Ludowise, P.S. Martin, M. Misra, G. Mueller, R. Mueller-Mach, S. Rudaz, Y.-C. Shen, D. Steigerwald, S.A. Stockman, S. Subramanya, T. Trottier, J.J. Wierer, “High-flux and high-efficiency nitride-based light-emitting devices”, Lasers and Electro-Optics Society, 2002. LEOS 2002. The 15th Annual Meeting of the IEEE , November 2002, pp. 641-642, vol. 2.
[7] Regina Mueller-Mach, Gerd O. Mueller, Michael R. Krames, and Troy Trottier “High-Power Phosphor-Converted Light-Emitting Diodes Based on III-Nitrides”, IEEE Journal of Selected Topics in Quantum Electronics, March-April 2002, pp. 339-345.
[8] Enciclopedia Libre Universal en Español [Online]. Available: http://enciclopedia.us.es/index.php/Diodo_LED
[9] Manuel Rico-Secades, Member, IEEE, Antonio J. Calleja, Member, IEEE, Javier Ribas, Member, IEEE,Emilio L. Corominas, Member, IEEE, J. Marcos Alonso, Senior Member, IEEE, Jesús Cardesín, Member, IEEE, andJorge García-García, Student Member, IEEE, “Evaluation of a Low-Cost Permanent Emergency Lighting System Based on High-Efficiency LEDs”, IEEE Transaction on Industry Applications, September/October 2005, pp. 1386 – 1390.
[10] M. Rico-Secades, A.J. Calleja, J. Cardesín, J. Ribas, E.L. Corominas, J.M. Alonso, J. García, “Driver for High Efficiency LED Based on Flyback Stage With Current Mode Control for Emergency Lighting System”, Industry Applications Conference, 2004. 39th IAS Annual Meeting, October 2004, pp.1655-1659, vol. 3
[11] Ewaldo L. M. Mehl, “Capacitores Eletrolíticos de Alumínio: Alguns cuidados e considerações práticas”, Internal publication of Federal University of Paraná, [Online].Available: http://www.eletrica.ufpr.br/mehl/downloads.html
[12] J. A. Morales-Saldaña, J. Leyva-Ramos, E. E. Carbajal-Gutiérrez, “Modeling of a Single-Switch Quadratic Buck Converter”, IEEE Transaction on aerospace & Electronic Systems, October 2005, pp.1450-1456
[13] Demian, A.E., Jr.; Gallo, C.A.; Tofoli, F.L.; Vieira, J.B., Jr.; de Freitas, L.C.; Farias, V.J.; Coelho, E.A.A.;“A novel microprocessor-based battery charger circuit with power factor correction”, Applied Power Electronics Conference and Exposition, 2004. APEC '04. Nineteenth Annual IEEE, Volume 3, 2004 Page(s):1407 - 1410 Vol.3.