A New Single Soft Switched Resonant LED Driver Circuit

Mahsa Shirinzad

B.S. Student

Department of Electrical and Computer Engineering

Isfahan University of Technology

Isfahan, IRAN

Email: shirinzad\_9@yahoo.com

Saeed Soleimani

B.S. Student

Department of Electrical and Computer Engineering

Isfahan University of Technology

Isfahan, IRAN

Email: s.soleimani1993@gmail.com

Ehsan Adib

Associate Professor

Department of Electrical and Computer Engineering

Isfahan University of Technology

Isfahan, IRAN

Email: e.adib@cc.iut.ac.ir

Abstract— This paper presents a single switch soft switched buck-boost resonant converter for LED drive applications. Zero current switching condition results in high efficiency. The proposed circuit provides a constant average output current independent of output voltage which makes it suitable for LED driving applications. The average output current is independent of output voltage and is a function of switching frequency, resonance capacitor and input voltage. Thus in a specific output current the circuit works with a constant frequency and duty cycle, which makes the control circuit very simple. The circuit is suitable for cost sensitive applications due to minimized number of components. Boosting capability makes this converter proper to be connected to photovoltaic cells as the input power source. Simulation results for a 12V/60V converter are presented.

Keywords-LED Driver; resonant converter; zero current switching

#  Introduction

The total demand for energy is growing with nonstop pace. Lighting applications are responsible for almost 20% of electricity consumption [1]. One of the critical issues in lighting design is the luminance efficiency in order to provide more lumens while consuming less energy [2]. Light Emitting Diodes (LEDs) have brilliant characteristics to fulfill this desire and these diodes have become very popular during the past decade. LEDs are now widely used in many indoor and outdoor lighting applications [3]-[7]. In recent years LEDs have replaced fluorescent and incandescent traditional lamps due to higher efficiency, higher brightness, longer life span, faster response, higher compactness and wide color range. Environmental friendliness is the other advantage due to lack of mercury or other toxic chemicals in their structure [6]-[10].

LED lighting density depends on the current running through it. Thus current regulation is necessary to feed the LED string. Furthermore, a constant current omits the flicker in LEDs. A 50Hz flicker can cause eye fatigue or other harms to the eye in long time exposure. To achieve current regulation, an appropriate LED driver should provide a constant regulated current. Switching power supplies are a great choice to drive LED strings due to providing higher efficiency, higher power density and higher control accuracy in comparison with linear regulators.

In recent years, numerous LED drivers have been presented and different topologies have been used. The main approach is designing a converter with a constant output current or a converter with independent output current from output voltage. In [11] a LED driver based on buck converter is presented. In this converter, a high power factor, high efficiency and low harmonic current can be achieved with one switch. However, this converter is hard switched, which means that switching losses are high. A hard switched buck converter in [12] and a boost converter in [13] are presented for high efficiency and low cost LED driving applications. In [14] a high efficiency resonant buck converter is proposed. PFC and dimming is achieved due to discontinuous conduction mode. However, this converter suffers from high number of elements. In [15] buck-boost family converters (Ćuk, SEPIC and buck-boost) are compared for Driving LED Lamps. A single stage flyback converter working in discontinuous conduction mode with power factor correction is presented in [16]. Since a flyback converter transfers a fixed amount of power to the output, the output current remains almost constant when the output voltage is constant. However, voltage of the LEDs change with temperature, which leads to current variation. A forward converter for low cost, high efficiency and high power factor applications is proposed in [17]. A single-stage single-switch flyback-forward LED driver with power factor correction is presented in [18]. This converter in cost efficient since it applies only one switch. A half bridge topology is proposed as a LED driver in [19]. In this converter high efficiency is achieved over the entire output voltage range.

In this paper a flicker free single soft switch resonant LED Driver with a simple control circuit is presented. In the series resonance branch switching is performed when the inductor current reaches zero so the switching loss would be omitted which results in improved circuit efficiency. Moreover working in a boosting mode has made the driver completely suitable to be powered by renewable photovoltaic sources. The proposed circuit works with a constant duty cycle and constant frequency. Simulation results and theoretical analysis are presented.

In the second section of this paper, the proposed converter and its operation modes are illustrated. In the third section, operating principle with theoretical analysis of the proposed converter is discussed and it is established that this converter can be used as a constant current source. To verify the theoretical analysis simulation result are presented in the final section of the paper.

# Proposed Topology

The proposed converter illustrated in “Fig. 1” can operate as step down or step up converter. However, the main focus in this paper is on step up application of this converter. As mentioned before the advantage of this converter is maintaining a constant output current, which makes it suitable for LED driving applications.



1. Proposed Converter

As illustrated in “Fig. 1”, the proposed converter consists of a unidirectional switch (s), an output capacitor ($C\_{o}$), a series resonant circuit ($L\_{1}$ and $C\_{1}$), an inductor which transfers the energy to the output ($L\_{3}$) and finally an inductor ($L\_{2}$) with high inductance which is used for discharging resonant capacitor ($C\_{1}$). Note that the input voltage is a constant DC voltage and the capacitance of the output capacitor, $C\_{o}$, is large enough to consider the output voltage constant. “Fig. 2” illustrates the equivalent circuit of each operation mode. Since $L\_{2}$ has a large inductance, the current through it will be almost constant in a switching period. Thus this inductor is modeled as a small current source in the equivalent circuit.

“Fig. 3” illustrates the steady state waveforms of input current, diode current and $C\_{1}$ voltage. The operation of the proposed converter in a switching period is divided into three operation modes:

Mode I) By assuming that prior to this mode, the currents through inductors $L\_{1}$ and $L\_{3}$ are zero, $V\_{c1}$ voltage is constant and equal to $-V\_{1}$. Thus at $t\_{1}$ the main switch, S, is turned on under ZCS condition. As illustrated in “Fig. 1”, a resonant LC circuit ($C\_{1}$ and $L\_{1}$) is formed which charges capacitor $C\_{1}$. While capacitor is charging, through a half resonance, the current in $L\_{1}$ will increase and then decrease respectively. When the current through $L\_{1}$ reaches zero, the capacitor voltage is maximum. This mode will end at this point.

Mode II) At $t\_{2}$, S is turned off under zero current switching (ZCS) condition and the diode D is turned on under ZCS condition. As illustrated in “Fig. 1”, another resonant LC circuit will form ($C\_{1}$, $L\_{1}$ and $L\_{3}$) that discharges capacitor $C\_{1}$, which results in transferring energy stored in capacitor $C\_{1}$ to the output. Similar to previous mode, the output current will increase and then decrease in a half resonance. Capacitor $C\_{1}$ is discharged until its voltage reaches $-V\_{2}$. This mode ends when the diode current reaches zero.

Mode III) At $t\_{3}$, diode D is turned off under ZCS condition and only the output capacitor will provide load’s energy. The capacitor $C\_{1}$ will continue discharging through inductor $L\_{2}$, until its voltage reaches $-V\_{1}$. At this point this mode ends.

|  |
| --- |
| (a) Mode I |
| (b) Mode II |
|  (c) Mode III |

1. Operation Modes of Proposed Converter



1. Steady State Waveforms of Proposed Converter

# Operating Principle of Proposed Converter

In order to analyze the proposed converter in steady state, several assumptions are made during one switching period.

* All the semiconductor devices are ideal components.
* The current through $L\_{2}$ is assumed constant in a switching period, since $L\_{2}$ has a large inductance.
* The resonance between $C\_{1}$ and $L\_{1}$ must be faster than the resonant between $C\_{1}$, $L\_{1}$ and $L\_{3}$ in order to guarantee ZCS condition. Thus $L\_{3}$ must be chosen Larger than $L\_{1}$.
* Resonance frequency between $C\_{1}$ and $L\_{1}$ is higher than the switching frequency.

As mentioned before, prior to mode I, all currents reached zero and the resonant capacitor voltage is constant and equal to $-V\_{1}$. A frequency domain analysis shows that when the switch is turned on, this capacitor will be charged until its voltage reaches $2V\_{s}+V\_{1}$. At this point, the main switch turns off under ZCS condition and the diode D is turned on under ZCS condition, so the energy stored in capacitor $C\_{1}$, will be transfered to the output through a resonance. Similar frequency domain analysis shows that when the diode is turned on, the capacitor will be discharged until its voltage reaches $2V\_{out}-2V\_{s}-V\_{1}$. Thus:

|  |  |
| --- | --- |
| $$2V\_{out}-2V\_{s}-V\_{1}=-V\_{2}$$ | () |

A half resonance between $C\_{1}$ and $L\_{1}$ occurs in $T\_{1}/2 $, and a half resonance between $C\_{1}$, $L\_{1}$ and $L\_{3}$ occurs in $T\_{2}/2$. The period of the last mode is equal to $T\_{3}$. Thus:

|  |  |
| --- | --- |
| $$\frac{T\_{1}}{2}=t\_{2}-t\_{1}$$$$\frac{T\_{2}}{2}=t\_{3}-t\_{2}$$$$T\_{3}=t\_{4}-t\_{3}$$ | () |

By writing the volt-second balance for inductor $L\_{2}$ and charge balance for capacitor $C\_{1}$, respectively:

|  |  |
| --- | --- |
| $$V\_{s}\frac{T\_{1}}{2}+V\_{out}\frac{T\_{2}}{2}=(V\_{1}+V\_{2})\frac{T\_{3}}{2}$$ | () |
| $$\frac{2}{π}\frac{2V\_{s}+V\_{1}-V\_{out}}{Z\_{2}}\frac{T\_{2}}{2}=I\_{out}.T-I\_{2}\frac{T\_{2}}{2}$$ | () |

Where T is the switching period and $I\_{out}$ is the average output current. $Z\_{2}$ is given from:

|  |  |
| --- | --- |
| $$Z\_{2}=\sqrt{\frac{L\_{3}}{C\_{1}}}$$ | () |

From equation (1) and (3):

|  |  |
| --- | --- |
| $$V\_{1}=\frac{V\_{s}\left(T\_{1}-2T\_{3}\right)+V\_{out}\left(T\_{1}+2T\_{3}\right)}{2T\_{3}}$$ | () |

During mode III:

|  |  |
| --- | --- |
| $$\frac{I\_{2}T\_{3}}{C\_{1}}=V\_{2}-V\_{1}$$ | () |

From equations (3),(4), (6) and (7) , $I\_{out}$ is obtained as:

|  |  |
| --- | --- |
| $$I\_{out}=V\_{s}\frac{C\_{1}}{T}\left(2+\frac{T\_{1}}{T\_{3}}+\frac{T\_{2}}{T\_{3}}\right)$$$$=V\_{s}\frac{C\_{1}}{TT\_{3}}(T+T\_{3})$$ | () |

From this equation it is observed that, the average output current is independent of output voltage, and only depends on switching frequency, capacitor $C\_{1}$, and input voltage. Thus with constant input voltage, capacitor ($C\_{1}$) and switching frequency, this converter will have a constant average current in its output and can be used as a constant current source. This attribute makes this converter suitable for LED driving applications.

# Simulation Results

To verify the analysis of the proposed converter, a simulation using Pspice software is performed. The input voltage and switching frequency are equal to 12 volt and 83KHz respectively. Other components in the circuit are listed below:

|  |  |
| --- | --- |
| $$C\_{1}=69nF$$ | $$L\_{1}=12μH$$ |
| $$L\_{2}=0.5mH$$ | $$L\_{3}=200μH$$ |

“Fig. 4”, shows the proposed converter in Pspice. This layout has been designed for 60 volts output voltage and 20 watts output power. Thus the output current is almost equal to 300mA.

 “Fig. 5”, shows the input current with respect to the gate-source pulse. As illustrated, input current begins increasing from zero when gate-source pulse is high. Thus, ZCS is achieved when the switch is turned on. Similarly, input current reaches zero when gate-source pulse is low. Thus, ZCS is achieved when the switch is turned off. Since ZCS is achieved for both turning the switch on and off, switching loss is almost zero.



1. Circuit Schematic in Pspice

|  |
| --- |
| (a) |
| (b) |

1. (a) Input Current and (b) Gate-Source Pulse

“Fig. 6”, illustrates the diode current and voltage. As illustrated, diode turn on and turn off occurs under ZCS condition.

|  |
| --- |
| (a) |
| (b) |

1. (a) Diode Current and (b) Diode Voltage

“Fig. 7”, illustrates the capacitor voltage. If the initial voltage in the beginning of mode I is equal to $-V\_{1}$, this capacitor will be charged to $2V\_{s}+V\_{1}$. When the switch is turned off, this capacitor will be discharged to $2V\_{out}-2V\_{s}-V\_{1}$, transfering its energy to the output.



1. Capacitor Voltage

# Conclusion

Since LEDs need to be driven by a constant current and the current through a LED string must be independent of the voltage across it, this paper has proposed a single, soft switched resonant LED driver circuit. High efficiency is achieved by reducing the switching loss through ZCS. The circuit provides a constant current independent of the output voltage. Using a single stage topology and reduced number of components, make this proposed LED driver suitable for cost sensitive applications. The presented simulation results verify the converter theoretical analysis.

##### References

1. Uddin, S.; Shareef, H.; Mohamed, A.; Hannan, M.A.; Mohamed, K., "LEDs as energy efficient lighting systems: A detail review," in *Research and Development (SCOReD), 2011 IEEE Student Conference on* , vol., no., pp.468-472, 19-20 Dec. 2011.
2. Aguilar, D.; Henze, C.P., "LED driver circuit with inherent PFC," in *Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE* , vol., no., pp.605-610, 21-25 Feb. 2010
3. Hui, S.Y.; Qin, Y.X., "A General Photo-Electro-Thermal Theory for Light Emitting Diode (LED) Systems," in *Power Electronics, IEEE Transactions on* , vol.24, no.8, pp.1967-1976, Aug. 2009.
4. Sauerlander, G.; Hente, D.; Radermacher, H.; Waffenschmidt, E.; Jacobs, J., "Driver Electronics for LEDs," in *Industry Applications Conference, 2006. 41st IAS Annual Meeting. Conference Record of the 2006 IEEE* , vol.5, no., pp.2621-2626, 8-12 Oct. 2006.
5. Yuequan Hu; Huber, L.; Jovanović, M.M., "Single-Stage, Universal-Input AC/DC LED Driver With Current-Controlled Variable PFC Boost Inductor," in *Power Electronics, IEEE Transactions on* , vol.27, no.3, pp.1579-1588, March 2012.
6. Chun-An Cheng; Chien-Hsuan Chang; Tsung-Yuan Chung; Fu-Li Yang, "Design and Implementation of a Single-Stage Driver for Supplying an LED Street-Lighting Module With Power Factor Corrections," inPower Electronics, IEEE Transactions on , vol.30, no.2, pp.956-966, Feb. 2015.
7. Chun-An Cheng; Hung-Liang Cheng; Chien-Hsuan Chang; Fu-Li Yang; Tsung-Yuan Chung, "A single-stage LED driver for street-lighting applications with interleaving PFC feature," in Next-Generation Electronics (ISNE), 2013 IEEE International Symposium on , vol., no., pp.150-152, 25-26 Feb. 2013.
8. Hongbo Ma; Wensong Yu; Cong Zheng; Jih-Sheng Lai; Quanyuan Feng; Bo-Yuan Chen, "A universal-input high-power-factor PFC pre-regulator without electrolytic capacitor for PWM dimming LED lighting application," in Energy Conversion Congress and Exposition (ECCE), 2011 IEEE , vol., no., pp.2288-2295, 17-22 Sept. 2011.
9. Yue Chen; Xinke Wu; Zhaoming Qian; Wenping Zhang, "Design and optimization of a wide output voltage range LED driver based on LLC resonant topology," in Power Electronics and ECCE Asia (ICPE & ECCE), 2011 IEEE 8th International Conference on , vol., no., pp.2831-2837, May 30 2011-June 3 2011.
10. Shrivastava, A.; Singh, B.; Pal, S., "A Novel Wall-Switched Step-Dimming Concept in LED Lighting Systems Using PFC Zeta Converter," in *Industrial Electronics, IEEE Transactions on* , vol.62, no.10, pp.6272-6283, Oct. 2015.
11. Tiesheng Yan; Jianping Xu; Xueshan Liu; Guohua Zhou; Jianlong Gao, "Flicker-free transformerless LED driving circuit based on quadratic buck PFC converter," in Electronics Letters , vol.50, no.25, pp.1972-1974, 12 4 2014.
12. Yi Chen; Yurong Nan; Qinggang Kong, "A Loss-Adaptive Self-Oscillating Buck Converter for LED Driving," in Power Electronics, IEEE Transactions on , vol.27, no.10, pp.4321-4328, Oct. 2012.
13. Yi Chen; Yurong Nan; Siheng Zhong; Qinggang Kong, "An input-adaptive self-oscillating synchronous boost converter for LED driving with ultra-low wide-range voltage input," in Energy Conversion Congress and Exposition (ECCE), 2014 IEEE , vol., no., pp.5243-5248, 14-18 Sept. 2014.
14. Qu, Xiaohui; Siu-Chung Wong; Tse, C.K., "Resonance-Assisted Buck Converter for Offline Driving of Power LED Replacement Lamps," in Power Electronics, IEEE Transactions on , vol.26, no.2, pp.532-540, Feb. 2011.
15. Cabral, H.G.; Marques, A.R.; Pedrollo, G.R.; de Faria, P.F.; dos Reis, F.S., "Performance comparison of Buck-boost family converters for driving led lamps," in Industry Applications (INDUSCON), 2014 11th IEEE/IAS International Conference on , vol., no., pp.1-8, 7-10 Dec. 2014.
16. Ying-Chun Chuang; Yu-Lung Ke; Hung-Shiang Chuang; Chia-Chieh Hu, "Single-Stage Power-Factor-Correction Circuit with Flyback Converter to Drive LEDs for Lighting Applications," in *Industry Applications Society Annual Meeting (IAS), 2010 IEEE* , vol., no., pp.1-9, 3-7 Oct. 2010.
17. Myungbok Kim; Daeyoung Im, "A modified forward converter with a capacitive output filter for isolated LED lighting applications," in *Telecommunications Energy Conference (INTELEC), 2011 IEEE 33rd International* , vol., no., pp.1-5, 9-13 Oct. 2011.
18. Chin Yuan Hsu; Yu Liang Chang, "A single stage single switch valley switching Flyback-Forward converter with regenerative snubber and PFC for LED light source system," in *Intelligent Green Building and Smart Grid (IGBSG), 2014 International Conference on* , vol., no., pp.1-6, 23-25 April 2014.
19. Baek, Jae-Il; Kim, Jae-Kuk; Lee, Jae-Bum; Youn, Han-Shin; Moon, Gun-Woo, "Integrated Asymmetrical Half-Bridge Zeta (AHBZ) Converter for DC/DC Stage of LED Driver with Wide Output Voltage Range and Low Output Current," in *Industrial Electronics, IEEE Transactions on* , vol.PP, no.99, pp.1-1.