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DEVELOPMENT OF A 20V–LED DRIVER BASED ON THE BOOST CONVERTER USING A FPGA MODULE

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ABSTRACT

We present the development of a LED (Light Emitting Diode) driver based on the boost power converter. Several DC to DC converter circuits were evaluated to determine their characteristics by varying the components and the duty cycle. The selected driver´s prototype was realized using a FPGA (Field Programmable Gate Array) module as the switching controller, wherein the implementation using Xilinx ISE14.6 and the measurements were successfully performed. The boost converter topology was investigated to achieve an optimal converter which showed a relatively high gain voltage. A duty cycle of 5% up to 20% was required to obtain the driver output voltage of 20V, revealing the efficiency of approximately 90%.

Keywords: FPGA module; LED driver; power converter

1. INTRODUCTION

Development of durable lamps with high light intensity and low power consumption has been reported in many publications (Narendran et al., 2004; Eichhorn, 2006; Han et al., 2012; Acharya, 2005). LED(Light Emitting Diode)structure has many benefits in comparison with conventional light bulbs. Using a high power LED or combining a number of LEDs could result in high intensity light; however, the dimensions would be expanded. Both methods still lead to self-heating of the devices, although the effect is still lower than the one with conventional light bulbs. To avoid premature damage on LEDs, a certain current level is required for emitting high intensity light.

The main component in LED system is the driver, where its design is normally compacted into a junction box with various features (DiLouie, 2004). The design of the converter circuit for the LED driver for high voltage (Hu et al., 2010) and power efficiency application (Leung et al., 2008) has been published. FPGA-based controllers for different types of power converters have been reported as well (Dousoky et al., 2009; Chu et al., 2008; Thangaveluet al., 2012).

LEDs can be triggered by a voltage regulator configured at a constant current. The linear voltage regulators can use voltage and constant current as their sources; however, the working principle of the linear regulator is not practical for high power applications, due to huge power dissipation and self-heating issues. Hence, the switching regulator will be more efficient for the LED driver. Determination of the working frequency of PWM (Pulse Width Modulation) in the regulator must be optimal, for instance, when the LED current increases, the driver must be optimized to match the real operating range and the specific application. Drivers which are 'smart' have also features for dimming and fixture remote monitoring (Signorino, 2009).

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This research is focused on the development of design and realization of the FPGA module as a switching controller of the power converter for the LED driver. The driver was specified for high power LEDs.This paper presents the implementation of FPGA based controller,in which the implementation using Xilink ISE14.6 was usedfor a boost converter and also the measurements for the three conditions were described.

2. EXPERIMENTAL

Before the implementation of the driver, several topologies of the converter were simulated using B2SPICE software. The value of the inductance, capacitance and the duty cycle were varied and the output voltages of the circuit were evaluated (Rif´an et al., 2013). Results of the model simulation showed that increasing the value of the capacitor decreased the output voltage, and increasing the inductance reduced voltage slope.

The calculation based on the mathematical equations to investigate the cuk and boost converter showed that the cuk converter required higher D than the boost converter in increasing the voltage. The equation of 1/(1-D) was applied for the boost converter and D/(1-D) for the cuk converter, wherein the duty cycle was represented by D (Microchip AN1207, 2009). However, at a relatively low value of D, relatively higher circuit efficiencies could be achieved

2.1. LED Control System

The scheme of the power LED control system is illustrated in Figure 1. The boost converter increased the voltage source that drove the serial seven LEDs up to 20 V. The output voltage of the converter was controlled by the duty cycle (D) of the PWM signal, where the LED current was maintained around 1 A. The LED current (ILED) was read by the current sensor and worked as a feedback signal (VSEN) to reach the nominal current of the LED.

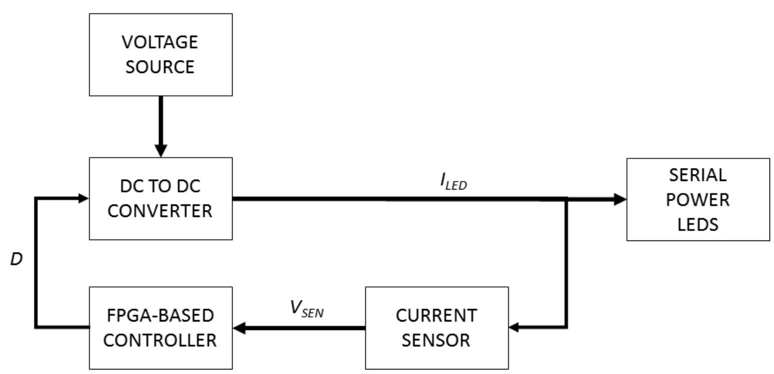


Figure 1 Scheme of the driver power LED system

2.2. FPGA Module

Figure 2 shows the controller system using a FPGA module. The system was designed and implemented into the development board Nexys-4 (Digilent) equipped FPGA Artix-7 (Xilink). Output of the current sensor, VSEN was converted to a digital signal through an ADC internal module (XDAC) which was set using a conversion speed of 1 MHz. To reduce the incoming noise, the average value of the ADC signal output was defined in a Low Pass Filter (LPF) digital module, and processed in the controller module. The filter ensured the stability of the control system. The average value of the LED current was calculated in the converter current module, therefore, it was monitored directly. The value represented the approximation of the actual current.

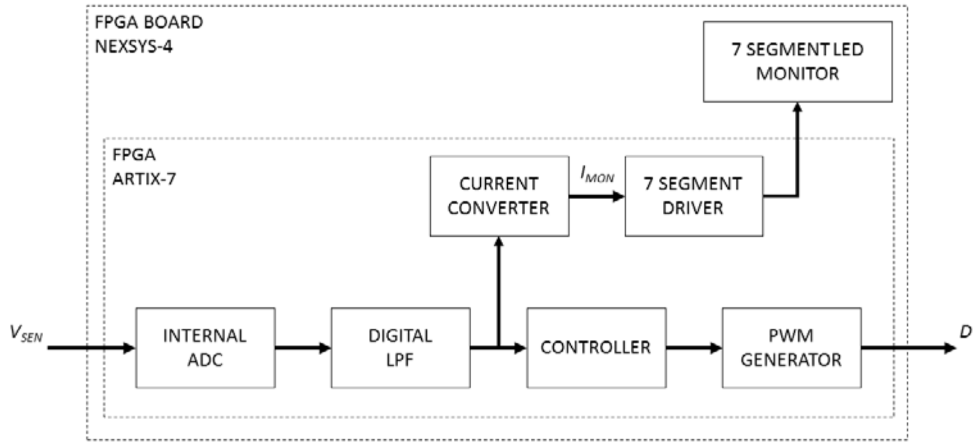


Figure 2 FPGA-based controller system

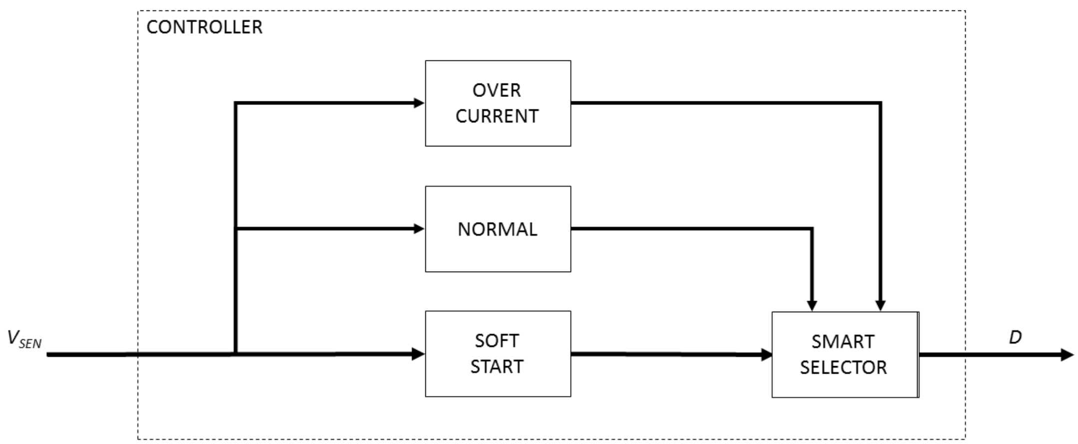


Figure 3 The controller core

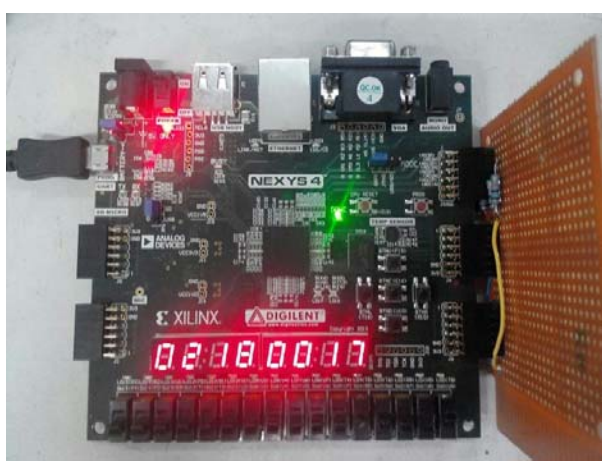


Figure 4 FPGA board showed the measurement of the current sensor with resistor 0.1 Ohm (output ~0.5A) at PWM duty cycle of 1.7%

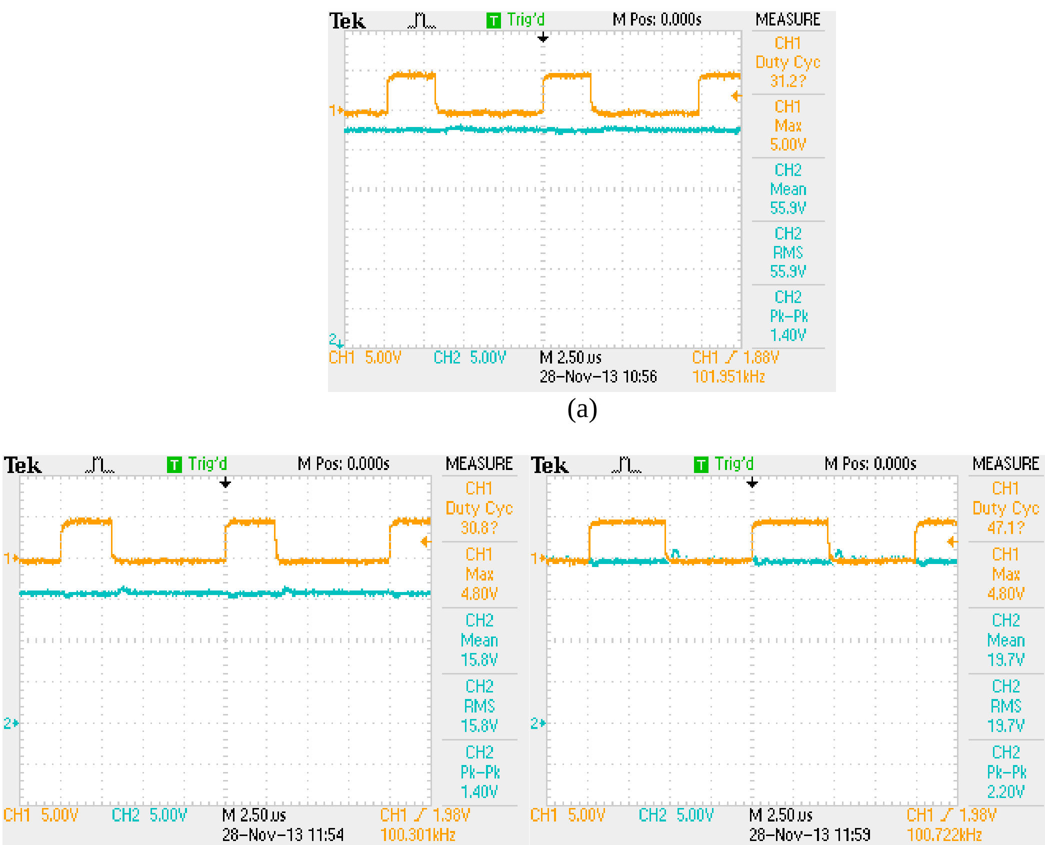
The design of the controller core is shown in Figure 3. As the switch was turn on, to protect the LED against the inrush current, the Soft-Start module increased the current gradually until it reached (close to) the nominal value. The Normal module controlled the LED current using a conventional linear control system (PI type). If the current was above a certain threshold level, the Over-Current module took over the control function to decrease the duty cycle. The Over-Current module had the highest priority, and the Normal module had the lowest one. The Smart Selector module worked to determine the value of the duty cycle according to the priority.

Figure 4 showed the FPGA board for the measurement of the current sensor at 1.7% of duty cycle of PWM. The module showed the ADC output value which corresponded to the current value of approximately 0.5 A (at the current sensor resistance of 0.1 Ohm).

3. RESULTS AND DISCUSSION

The measurements were performed for the driver´s circuit using LEDs as load, and using a dummy load resistor. At first the measurements were taken for the no-load driver´s circuit. All the tests on those three conditions were performed to obtain the output voltage of the driver. The following figures show some measurement results.

The output of the boost converter of 55.9V was obtained at duty cycle of 31.2% for the no-load driver´s circuit (Figure 5(a)).



(a) (b) (c)

Figure 5(a) The result of the circuit measurement using no load at a duty cycle of 31.2%, the output voltage Vo of 55.9 V was obtained. The test with dummy load indicated (b) at a duty cycle of 30.8%, Vo of 15.8V; and (c) at a duty cycle of 47.1%, Vo of 19.7V

For the test using a dummy load resistor, output voltage of 15.8 V and 19.7V, at a duty cycle of 30.8% and 47.1%, respectively, were achieved (Figures 5(b) and 5(c)). The input voltage of 12V resulted in ripple voltages inthe range of 0.3V–0.8V (peak-to-peak), with no spike. Therefore, to obtain the maximum voltage deviation of 0.2V (peak-to-peak) for LED, it required a series of LEDs.

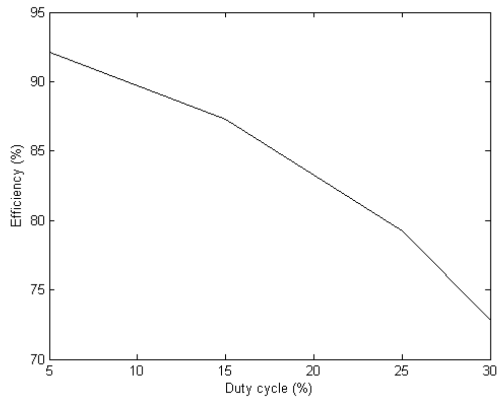


Figure 6 Efficiency as a function of the duty cycle of the boost convert

For the measurement using LEDs (seven lamps connected in series) as the circuit load, the duty cycle of 5% up to 90% was applied, increasing 5% each step, wherein the output voltage of 20.5V and efficiency of 90.5% were achieved.

The measurement results for the efficiency as a function of the duty cycle is plotted in Figure 6. It indicated that the efficiency decreased as the duty cycle of 30% was reached, meanwhile higher efficiencies of more than 80% were achieved at the duty cycle relatively small (less than 20%). Hence, during the measurement, the input voltage was controlled (with minimal value in increment), while the output voltage remain fixed, to obtain relatively high efficiencies. Efficiency is defined as the comparison of the LED power and the source power. Thus, the duty cycle was changed by varying the input voltage, since the output was fixed.

4. CONCLUSION

The FPGA module was used as the converter switching controller. The FPGA-based power LED driver was successfully designed and implemented. The boost converter was selected as the optimum power converter for the driver, from which the measurement results indicated relatively high gain voltage. The measurement using a series of LEDs as load resulted in the output of 20.5V.

The value of the battery voltage should be considered to be able to obtain the duty cycle of 10% (i.e. high efficiency). Based on the mathematical equation (i.e. 1/(1-D) for the voltage ratio of the boost converter), if the D is 10% , then the voltage ratio Vo/Vi would be around 1.1; and if the Vo of more than 20V is required, then the source voltage Vi is 18.5V. Therefore, the battery voltage for the driver should be selected at around 18V.

5. ACKNOWLEDGEMENT

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