Comparison of Power Converters for LED Illuminants

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***Abstract* – The purpose of the paper is to investigate the various modulation types for control of transformerless non-dimmable AC/DC/DC converters in nominal operation mode intended for LED illuminants. A combined PWM (pulse width modulation) is investigated. The optimal selection of power converter inductor core is considered. The derived results lead to conclusions for improvement of the power converter characteristics. Furthermore, the DC link capacitor is reduced without significant effect on circuit performance. It is proven that utilizing combined PWM would result in less current ripple and improved power factor. Utilization of nanocrystalline materials additionally reduces losses in the examined power converter.**

***Keywords* – light-emitting diode driver, PWM control, buck converters, nanocrystalline materials.**

1. Introduction

Nowadays two main groups of LED (Light Emitting Diode) illuminants are in mass production – dimmable and non-dimmable [1], [2], [3], [4]. For both groups various power converter topologies could be utilized for AC/DC/AC converters [5]. All these circuits could implement a transformer or not.

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The transformerless AC/DC/AC power converters have better characteristics and are widely used for driving LED illuminants [6], [7]. However, these power supplies more or less affect the power factor of the grid [8]. On other hand, the growing amount of LED illuminants puts the question about their effect on the grid, the tendency for reducing the high harmonics in the supplied current and their total efficiency. New solutions are presented in [9] as a bias supply scheme for LED controller based on buck converter, as a LED driver with self-adaptive drive voltage [10] and symmetrical current-balancing circuit for LED control [11].

The purpose of the current paper is to investigate various modulation types for control of transformerless non-dimmable AC/DC/DC converter and the efficiency based on core type selection for the inductor. The obtained results are to lead to improvement of the characteristics of the investigated power converters.

The tasks to be solved are:

1. Selection of a wide spread LED illuminant with buck converter driver.
2. Realizing PSPICE simulations to compare the combined PWM control with the traditional one.
3. Analysis of the results and deriving conclusions on the investigated circuit.
4. Investigate the best core possibilities for the inductor of the converter.

2. Traditional buck converter with 50 kHz PWM

The investigated model of the device (Figure 1.) consists of three main parts with different functions:

- I part – grid rectifier with filtering capacitor;
- II part – DC/DC buck converter which matches the output voltage of the rectifier and the input voltage of the LED illuminant;
- III part – equivalent schematic of LED illuminant.

The rectified current is supplied to the buck converter that consist of power switch (transistor) T_1, rectifier diode D_5, accumulating energy inductor L_1 and filtering capacitor C_2. A specialized driver controls the power switch with pulses having 50 % duty ratio and 50 kHz frequency constant over time. In that case, big filtering capacitor C_1 is not needed, which compromises the quality factor of the whole system. The proposed equivalent schematic of the LED load models its specifics. The SPICE model of the investigated LED illuminant, given in Figure 1., is created based on the schematic of the chosen power converter and the equivalent schematic of the LED. The elements in the simulation model have the following parameters: V_i = 220 V/ 50 Hz; Transistor T_1 – IXGH40N60A; R_1 = 0,1 Ω, C_1 =1 μF, R_2 = 0,2Ω, L_1 = 435 μH, C_2 = 10 μF, V_{LED} = 48 ÷ 52 V, f_g = 50 kHz. The duty cycle range is derived from Equation (1).

$$D = \frac{V_{LED}}{V_D} = \frac{48\,V}{310\,V} = 0.16 \qquad (1)$$

, where D is the duty cycle, V_{LED} is the voltage over the load and V_D is the input voltage of the buck converter. The duty cycle range is in the range 0.1 to 0.6 depending on the necessary voltage for the LED load. The power transistor voltage, current and instantaneous power losses are given in Figure 2. The voltage over the load, load current and inductor current are given in Figure 3. It could be noticed that the proposed simulation model represents accurately the operation of the LED illuminant. The time diagrams reveal the workability of the circuit.

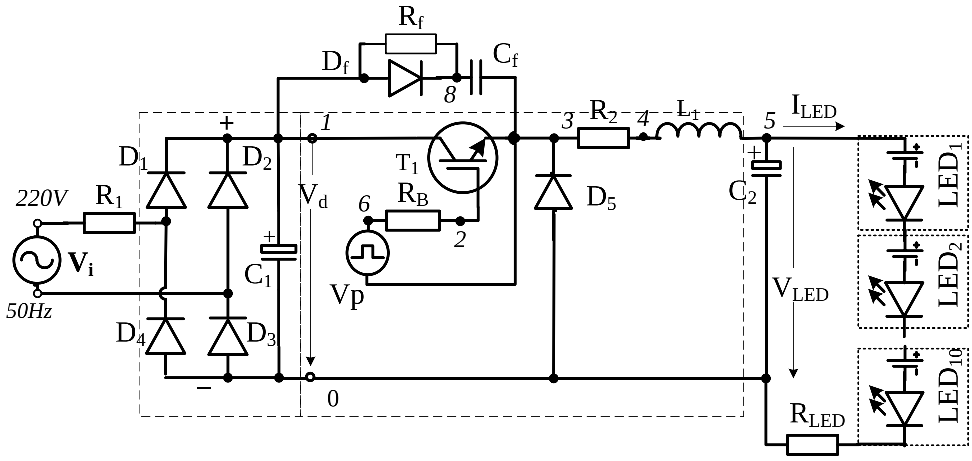


Figure 1. PSpice model of the BUCK converter used for LED driver

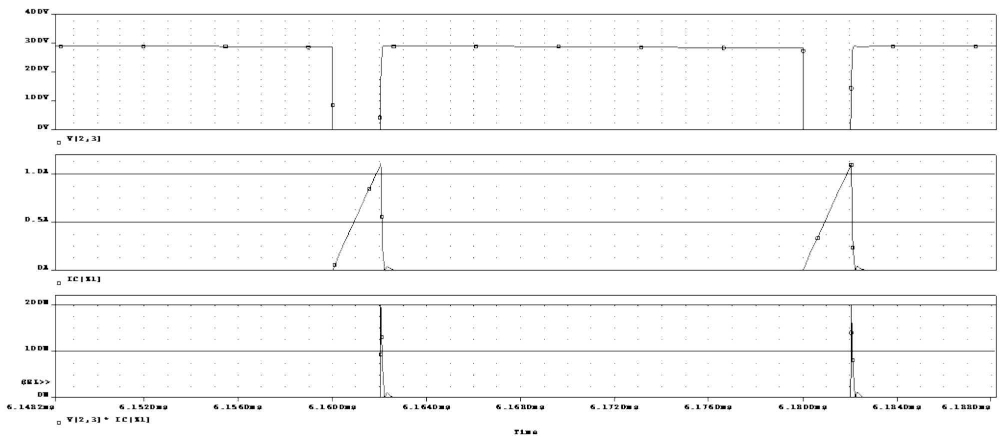


Figure 2. Time diagrams of power transistor voltage, current and instantaneous losses

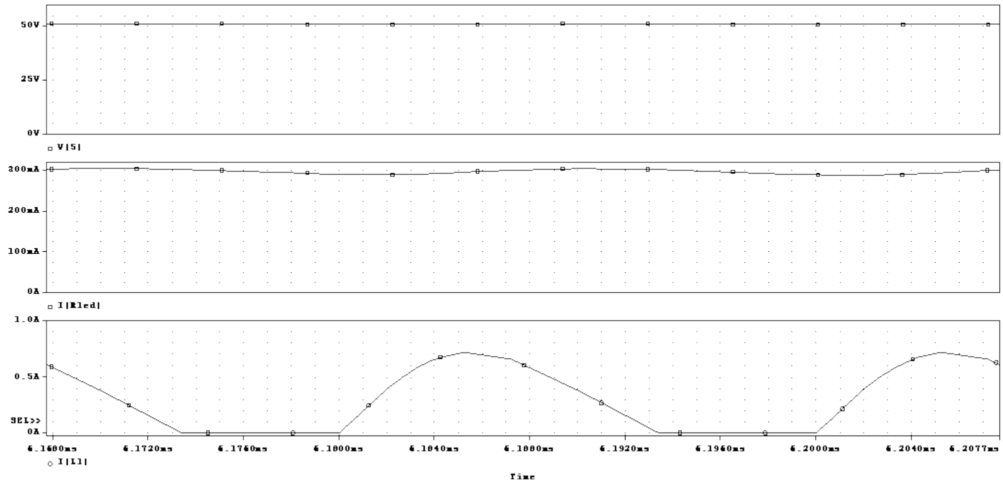


Figure 3. Time diagrams of voltage over the load, load current and inductor current

3. Buck converter for LED driver based on combined PWM control

The same schematic for a buck converter is used as previously discussed in Figure 1. An improvement is introduced to reduce significantly the filter capacitor value to around 1μF. The difference is in the transistor T1 driving voltage modulation. The modulation itself is a combination of 50 kHz PWM, where the duty cycle is changed according to 50 Hz sine wave. The time diagrams of the rectified input voltage are given in Figure 4. As a result, the obtained modulation has fixed pulse width and amplitude following the rectified input voltage pattern. After a series of simulations, utilizing this modulation, it is estimated that better results are obtained, if the pulse width is additionally changed according to the sine waveform. So, considering the 50 Hz half-wave the middle pulse has the biggest amplitude and duration, and in the beginning and the end of the half-period it is the opposite. The investigated combined pulsed sinusoidal PWM is given in Figure 5. The obtained pulses are combined with 50 kHz pulses and the result, given in Figure 6., is used to control the same buck converter. The operation of the buck converter with both types of modulation is investigated using PSPICE simulations.

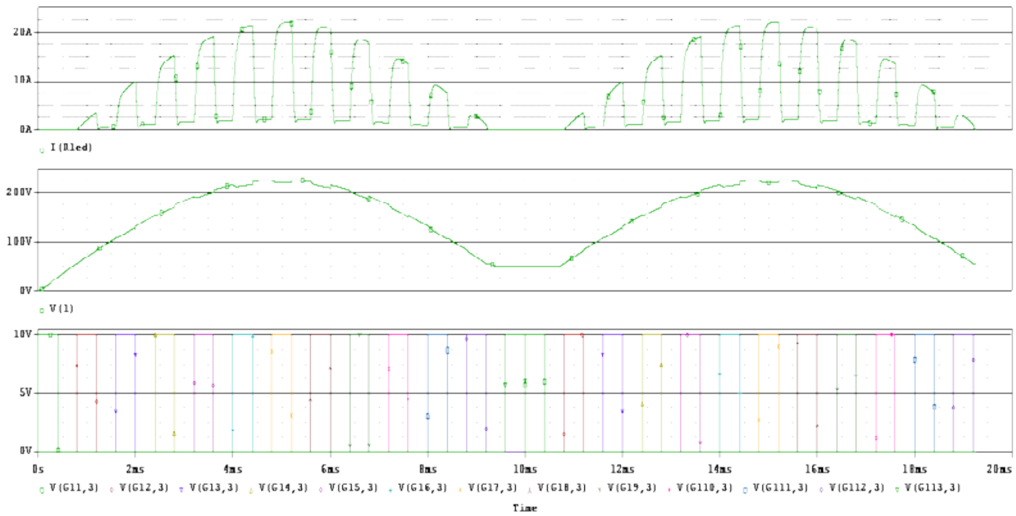


Figure 4. Time diagrams of the investigated pulse-sinusoidal modulation

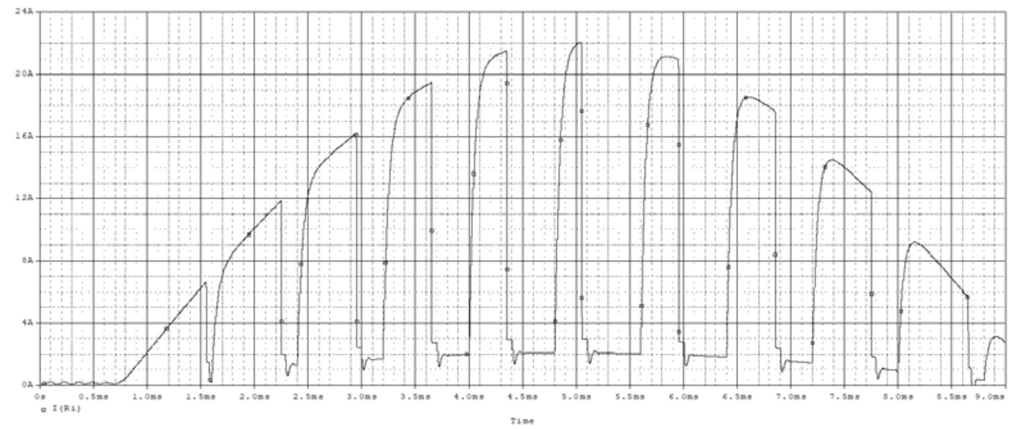


Figure 5. Input current utilizing pulse-sinusoidal PWM

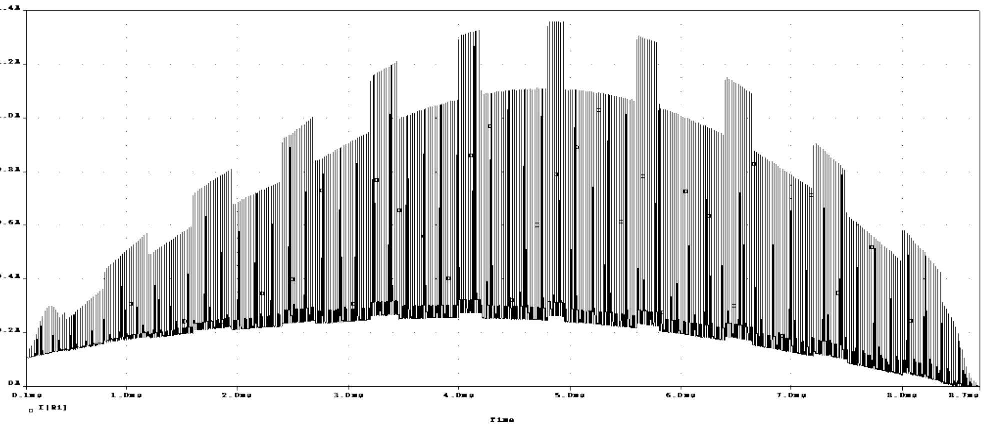
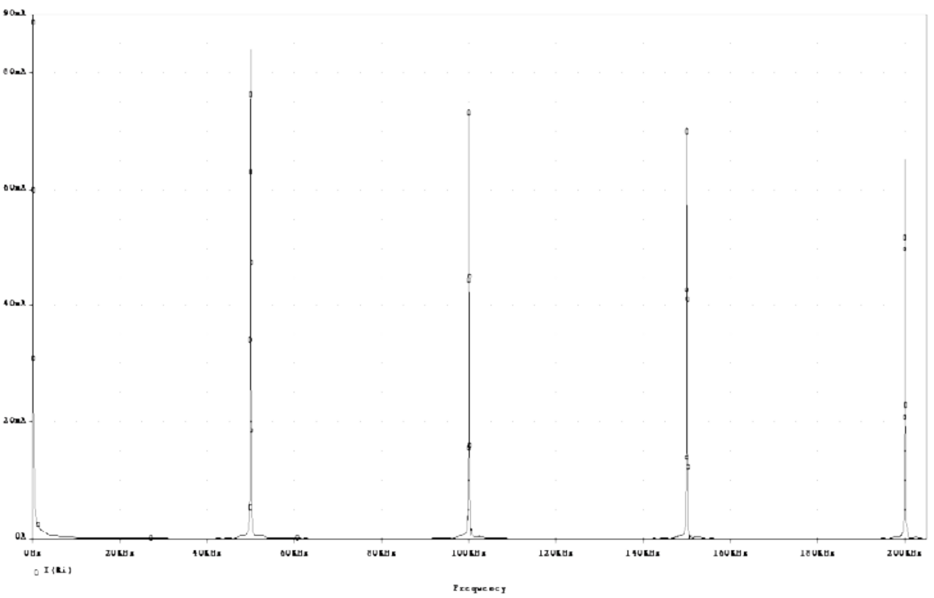


Figure 6. Input current utilizing combined PWM



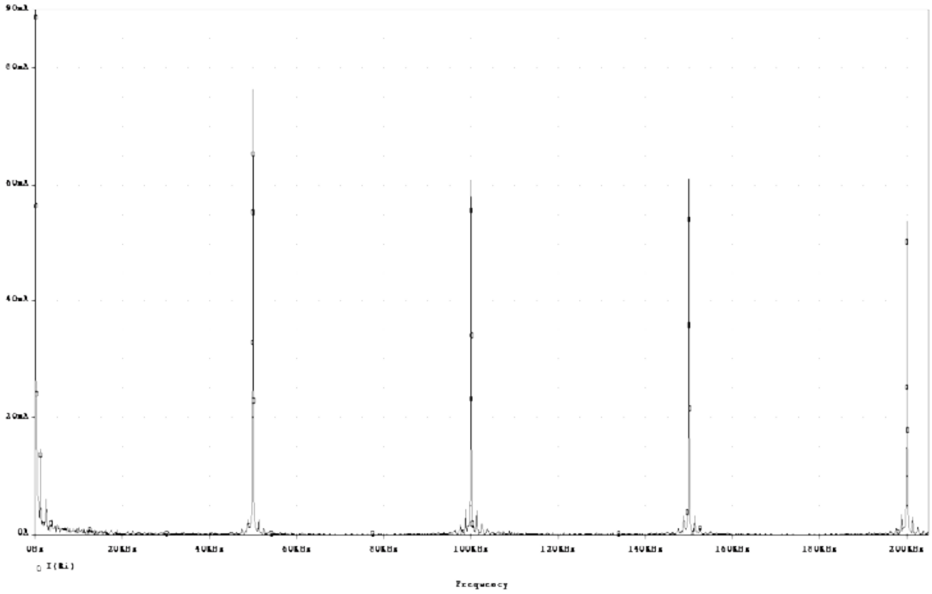


Figure 7. Grid current spectrum for buck converter with: a - conventional PWM 50 kHz; b – combined PWM

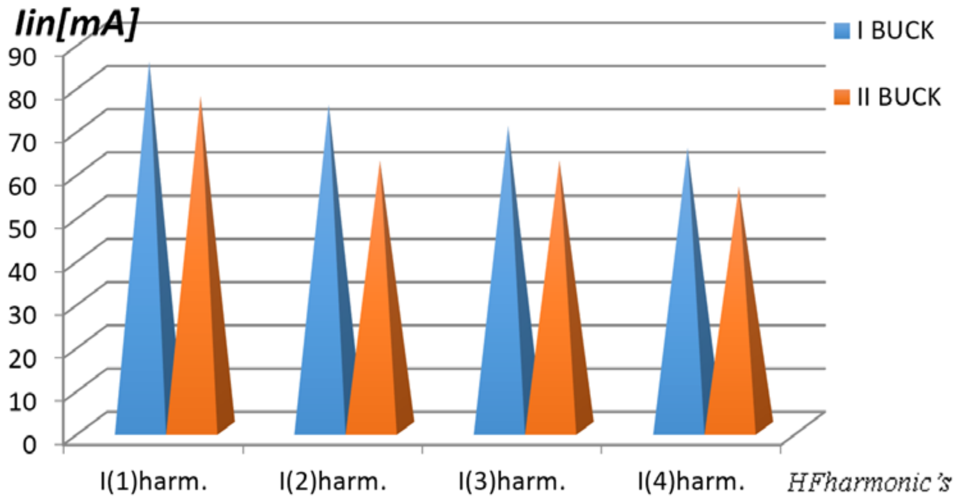


Figure 8. Diagram of the harmonics for the two types of modulation

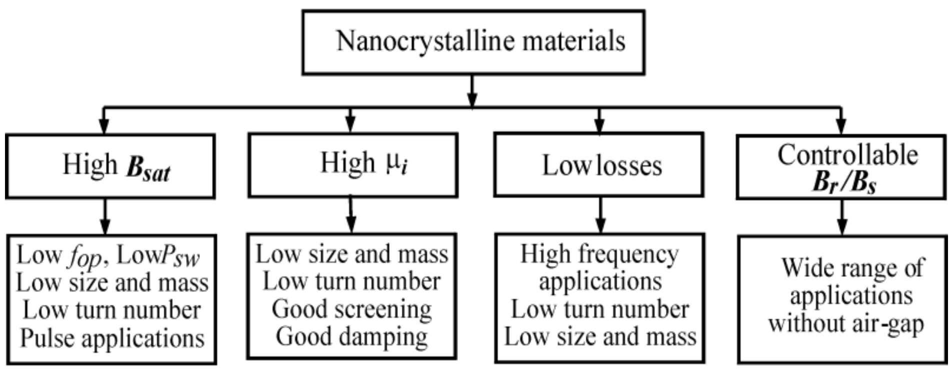


Figure 9. Features and proper applications of nanocrystalline materials.

The first order and the high order harmonics of the current, consumed from the grid, are obtained for conventional PWM with 50kHz switching frequency and for the combined input current modulation. The resultant grid current spectrum is given in Figure 7a. and 7b.

The harmonics amplitude reduction when using combined PWM to drive the power converter can be clearly noticed. A comparison between both types of modulation: BUCK I with conventional 50 kHz PWM and BUCK II with combined PWM, is given in Figure 8.

Up to 10 % and more reduction is available at the 4th harmonic which indicates an improvement in quality factor. This is extremely important especially with the elevated requirements for quality of the consumed energy, which is monitored by different government organizations.

4. Arguments for choosing optimal material for the inductor of the converter

Optimizing the design of the inductor in the circuit is closely related to an optimal choice of the magnetic material for core. In [12] the possible magnetic materials are considered and compared in the respect of use in such circuits. The compared materials are: ferrites (3F3), powder materials (sendust MS and Hi-Flux™ HF) and amorphous materials (Microlite 245). Design recommendations are derived based on the well known Fast Design Approach [13].

Further, nanocristalline materials have to be considered (VITROPERM500, NANOMET, FINEMET ets.). The advantages of the nanocrystalline materials are that they combine both high permeability typical for amorphous materials and low losses of ferrite materials; using them allows reduced size and weight of the components and the material reveals high aging stability and reliability. The advantages, corresponding features and applications of nanocrystalline materials are summarized in Figure 9.

Final design recommendations are derived based on the comparison of three different materials for the cores:

- DC choke design based on ferrite cores leads to higher copper losses and thus, deteriorated heat transfer reduced the design optimisation;
- DC choke design based on powder type toroids - core losses are dominant [12];
- Using nanocristalline cores proved decreased losses and volume, but the price is higher.

5. Conclusion

The different modulation types for transformerless non-dimmable LED driving AC/DC/DC power converters are investigated in nominal operation mode. The following conclusions are made based on the simulation analysis:

1. The high frequency switching of the power converter allows proper operation of the output filter with lower filtering capacitor values;
2. The utilization of combined PWM type results in lower ripple and better power factor;
3. The utilization of nanocrystalline materials allows additional reduction of the losses in the investigated power converter.

The obtained results lead to possibilities to improve the characteristics of the investigated power converters.

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References

[1]. Hwu, K. I., Tu, W. C., & Lai, C. Y. (2014). Light-emitting diode driver with low-frequency ripple suppressed and dimming efficiency improved. *IET Power Electronics*, *7*(1), 105-113.

[2]. Camponogara, D., Ferreira, G. F., Campos, A., Dalla Costa, M. A., & Garcia, J. (2013). Offline LED driver for street lighting with an optimized cascade structure. *IEEE Transactions on Industry Applications*, *49*(6), 2437-2443.

[3]. Chiu, H. J., Lo, Y. K., Chen, J. T., Cheng, S. J., Lin, C. Y., & Mou, S. C. (2010). A high-efficiency dimmable LED driver for low-power lighting applications. *IEEE Transactions on Industrial Electronics*, *57*(2), 735-743.

[4]. Pinto, R. A., Cosetin, M. R., Roncalio, J. G., Melo, M., Marchesan, T. B., Alonso, J. M., ... & do Prado, R. N. (2011, November). High-power-factor street lighting system to supply LEDs without energy consumption during the peak load time. In *IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society* (pp. 2947-2952). IEEE.

[5]. Sebastian, J., Fernandez, A., Villegas, P., Hernando, M. M., & Ollero, S. (1999, March). Design of an AC-to-DC converter based on a flyback converter with active input current shaper. In *Applied Power Electronics Conference and Exposition, 1999. APEC'99. Fourteenth Annual* (Vol. 1, pp. 84-90). IEEE.

[6]. Pereira, D. D. C., De Paula, W. J., Almeida, P. S., Soares, G. M., Braga, H. A. C., Tofoli, F. L., & Camponogara, D. (2016, June). Analysis of the low-frequency output current ripple in a buck-based LED driver under distinct control techniques. In *Industrial Electronics (ISIE), 2016 IEEE 25th International Symposium on* (pp. 442-447). IEEE.

[7]. Chen, W., Li, S. N., & Hui, S. Y. R. (2010, September). A comparative study on the circuit topologies for offline passive light-emitting diode (LED) drivers with long lifetime & high efficiency. In *Energy Conversion Congress and Exposition (ECCE), 2010 IEEE* (pp. 724-730). IEEE.

[8]. International Electrotechnical Commission. (2005). *Electromagnetic Compatibility (EMC)—Part 3-2: Limits for Harmonic Current Emissions (Equipment Input Current⩽ 16 A per Phase)*. IEC 61000-3-2.

[9]. Deng, J. (2013, November). A novel self bias supply scheme in LED lighting. In *Solid State Lighting (ChinaSSL), 2013 10th China International Forum on* (pp. 178-181). IEEE.

[10]. Hu, Y., & Jovanovic, M. M. (2008). LED driver with self-adaptive drive voltage. *IEEE Transactions on Power Electronics*, *23*(6), 3116-3125.

[11]. Choi, S., & Kim, T. (2012). Symmetric current-balancing circuit for LED backlight with dimming. *IEEE Transactions on Industrial Electronics*, *59*(4), 1698-1707.

[12]. Valchev, V. C., Todorova, T. P., & Van den Bossche, A. (2017, September). Comparison and design of DC chokes based on different magnetic materials. In *Scientific Conference Electronics (ET), 2017 XXVI International* (pp. 1-4). IEEE.

[13]. Valchev, V. C., & Van den Bossche, A. (2005). *Inductors and transformers for power electronics*. CRC press.