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Optoelectronics and optoelectronic devices

Design of a LED driver with a flyback topology for intelligent lighting systems with high power and efficiency

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Abstract. Considered in this paper are the parameters and characteristics of the developed highly efficient electronic control systems for powerful LED modules (drivers), built on the basis of a single-stage flyback converter with a nominal power close to 200 W. The results of experimental tests show that, at the nominal load, the minimum efficiency of the developed driver reaches 88.2% with the power factor above 0.97 and the coefficient of total harmonic current distortion close to 23.4%. With the maximum value of the efficiency factor of the developed system 90.3% and the supply voltage 240 V, the power factor is higher than 0.99, and the total harmonic current distortion is 3.6%. The values of current harmonics of the driver do not exceed the maximum allowable values defined by the current standards. Used driver construction topology enabled to reduce the cost of the final product due to the unification of the component base, which increases the availability and manufacturability of the design. The use of a modern element base made it possible to ensure the deviation of the output current from the set one by no more than 1% over the whole range of the operating voltage of the supply (180…250 V), which allows using the developed driver in intelligent lighting systems and lighting systems with a combined power supply.

Keywords: power LED, LED driver, high power factor, high efficiency, total harmonic current distortion, intelligent light system.

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1. Introduction

The development of modern semiconductor technology makes it possible to create energy-efficient intelligent high-power LED lighting systems. The main components of such LED systems, in addition to LEDs, are cooling systems, optical systems to form light streams, and electronic power supply systems (drivers).

Implementation of each component of the lighting system is an important scientific and technical task, and with an optimal solution, it allows one to improve quality indicators of the lighting system as a whole. In addition to high efficiency, intelligent lighting systems should provide adaptive properties, *i.e.*, be able to control the radiation power without significant loss of efficiency [1, 2].

One or several LED light sources [3] combined into clusters [4, 5] can be used in the design of intelligent lighting systems. At the same time, modern designs of LED cooling systems and LED clusters are built on the basis of two-phase heat transfer devices (for example, heat pipes [6], thermosyphons [7], *etc.*) and can have a lower cost as compared to widespread passive cooling systems [8], in which heat-conducting elements are made of homogeneous materials (aluminum, copper and their alloys).

Two-phase heat transfer devices provide compact dimensions of the cooling system and normal thermal modes of LEDs in a wide range of ambient temperatures. Recently, the transition to a modern solid-state gallium nitride semiconductor component base for special-purpose devices with increased heat generation has significantly intensified developments in the field of their cooling systems based on heat pipes [9, 10].

Since LEDs are point sources of concentrated light, computer-based methods of designing their optical systems allow creating the lighting systems with a given light distribution and those with a wide functional purpose.

One of the important components of LED lighting systems is the power supply system for LEDs [11]. Modern research of new materials for the construction of LEDs (such as macroporous silicon [12, 13], thin silicon structures [14], new light-converting materials [15]) technologies for their research [16, 17] and production technologies (for example, organic [18] and inorganic LEDs [19, 20]), expanding the scope of applications of materials used for the construction of white LEDs (radiation sensors [21, 22], silicon photo-multipliers [23, 24]) contributes to further increasing the power and reducing the cost of light-emitting diodes, but does not exclude the need to create power supply systems for them.

The development of technologies for production of power electronic components, in particular with the use of powerful gallium nitride transistors as power switches for the construction of drivers [25, 26], enables to reduce the size of electronic power supply systems for LEDs. Today, the pulsed power supply systems for LEDs using silicon power switches and usually built on the basis of forward [27, 28], flyback [29, 30], resonant [31, 32] or quasi-resonant [33, 34] topologies have become the most widespread.

The flyback type of topology is widespread in LED lighting systems [35, 36]. This topology has a number of advantages, namely: isolated input and output circuits, relatively simple design and low cost of electronic components, the ability to be integrated into the electronic circuit to ensure a high power factor (PF) [37]. Due to a number of features of this topology, it is mainly used for drivers with a power of less than 100 W.

However, the modern component base allows one to design and manufacture of a flyback topology driver with high efficiency, power factor correction (PFC) and powers up to at least 200 W, which is typical for a number of modern LED light sources. It is also important that these drivers meet the requirements of standards regarding total harmonic current distortion (ITHD) (in particular, IEC61000-3-2 [38]).

In this work, the goal was to develop an efficient LED driver with a high power factor, power of about 200 W and to analyze its operation in various modes.

2. Design procedure and features of the flyback LED driver

LED drivers must have a long service life and provide high efficiency at significant power factor values as well as low harmonics factor values. Low manufacturing cost, availability of electronic components and reliability are important for the widespread use of the driver. It is advisable to predict the operation of the driver for a wide range of applications and its reliable operation under defined operating modes.

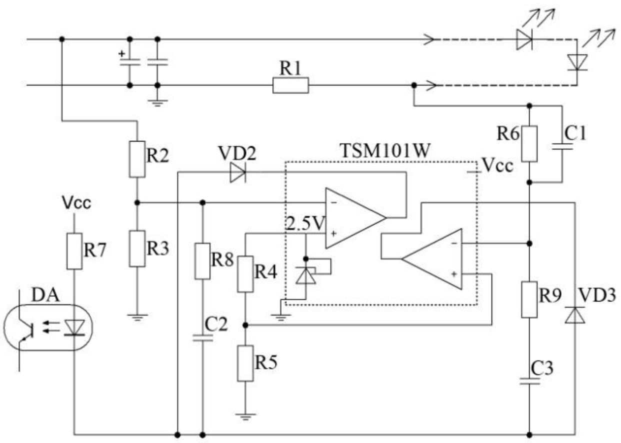


Fig. 1. Schematic diagram of the implementation of feedback output voltage and current.

In order to meet the above requirements, a galvanically isolated driver with a maximum power close to 200 W was developed. Its maximum output voltage was no more than 40 V, and the maximum output current was 5.5 A. During the design, it was taken into account that the driver should maintain the stability of its parameters in the voltage range of 180 to 250 V at the network frequency 50 Hz.

The driver was designed according to a two-stage conversion scheme. The first stage contains an active power factor corrector, and the second stage contains a step-down converter. This driver is galvanically isolated, which increases the safety of using the device by the consumer. The selected flyback circuit of the step-down converter allowed applying the minimum number of electronic components in its design.

Usually, one of the disadvantages of this topology with significant power is the high current and voltage of the clock transistor, however, optimization of the throttle design enabled to use a low-cost SPA17N80C3 transistor with a relatively low maximum current (17 A). Also, to unify the design, the throttles of the power factor corrector and the flyback converter were made on the same ferrite cores and frames (BH-PQ3230) without reducing the overall qualitative parameters. In addition, the same L6561 pulse width modulation (PWM) clock microcircuits are used in the two converters. In the design of the driver, protection against short circuit at the output and limitation of the output current and voltage are implemented.

Limiting the output current and voltage was carried out using feedback, which is implemented on the basis of the TSM103W microcircuit (Fig. 1). This microcircuit contains two operational amplifiers. An always stabilized voltage close to 2.5 V is applied to the input of one of them, and the output voltage of the driver is applied to the other input of this operational amplifier through a divider built on resistors R2 and R3. The operational amplifier is connected to the optocoupler through the diode VD2.

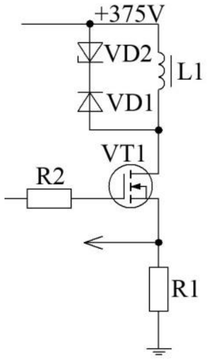
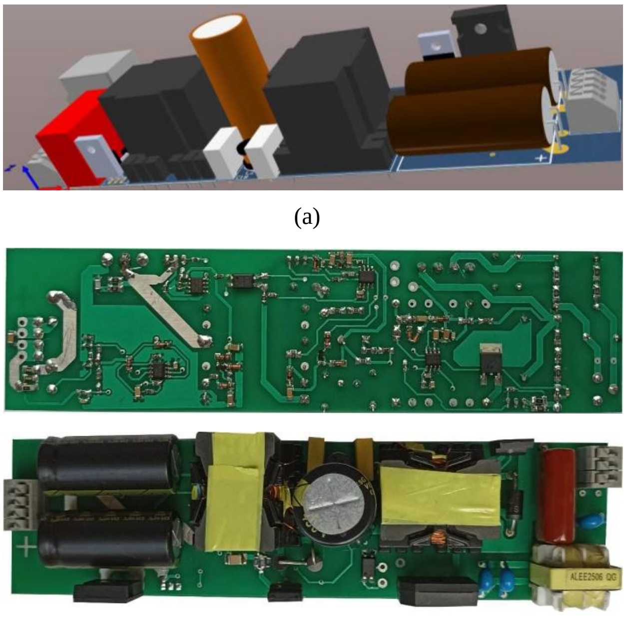


Fig. 2. Schematic electronic diagram of the section of the current-limiting transistor.

By opening the optotransistor, the optocoupler provides reducing the width of PWM pulses generated by the timing microcircuit. The clock microcircuit allows limitation of the value of output voltage on the driver up to 40 V. Another operational amplifier in this microcircuit is used in the circuit limiting the output current up to 5.5 A, one of the inputs of which is supplied with a stabilized constant voltage from the divider R4, R5, and the other – with the voltage from the current regulator resistor R1.

The output of the operational amplifier is connected to the optocoupler through the diode VD3. Diodes VD3 and VD2 are necessary to solve the potentials of two operational amplifiers. To prevent the driver from entering the generation and the smooth increase of voltage and current at the output, pairs of resistors and capacitors R8, C2 and R9, C3 are installed, they set the feedback integration time constant.

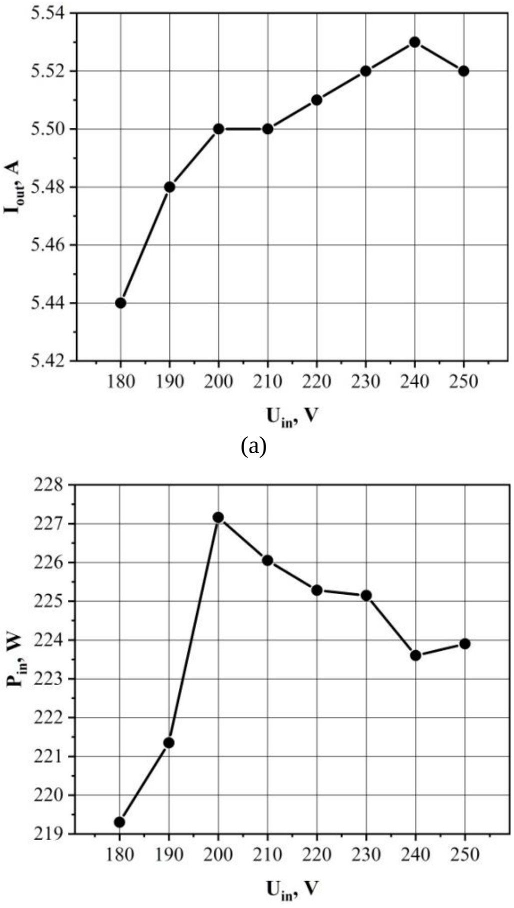


(a)

(b)

Fig. 3. Computer model (a) and photo (b) from two sides of the experimental sample of the developed driver.

The secondary converter provides protection for the maximum peak value of the current through the clock transistor (Fig. 2), which allows to protect the transistor and select the optimal operating mode. Limiting the peak power can be considered a secondary task of this protection.



(a)

(b)

Fig. 4. Dependences of the output current I_{out} (a) and power consumption P_{in} (b) on the input voltage of the driver supply U_{in}.

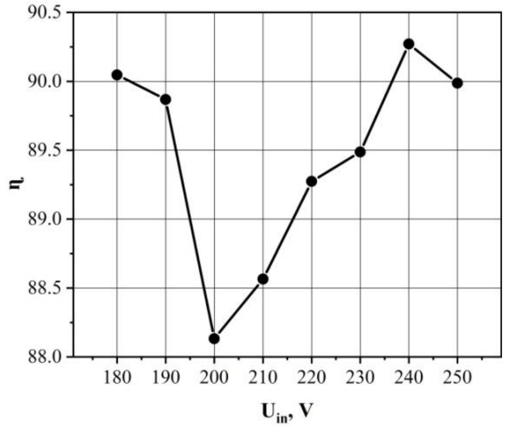


Fig. 5. Dependence of the efficiency factor η of the driver on the change in the input supply voltage U_{in}.

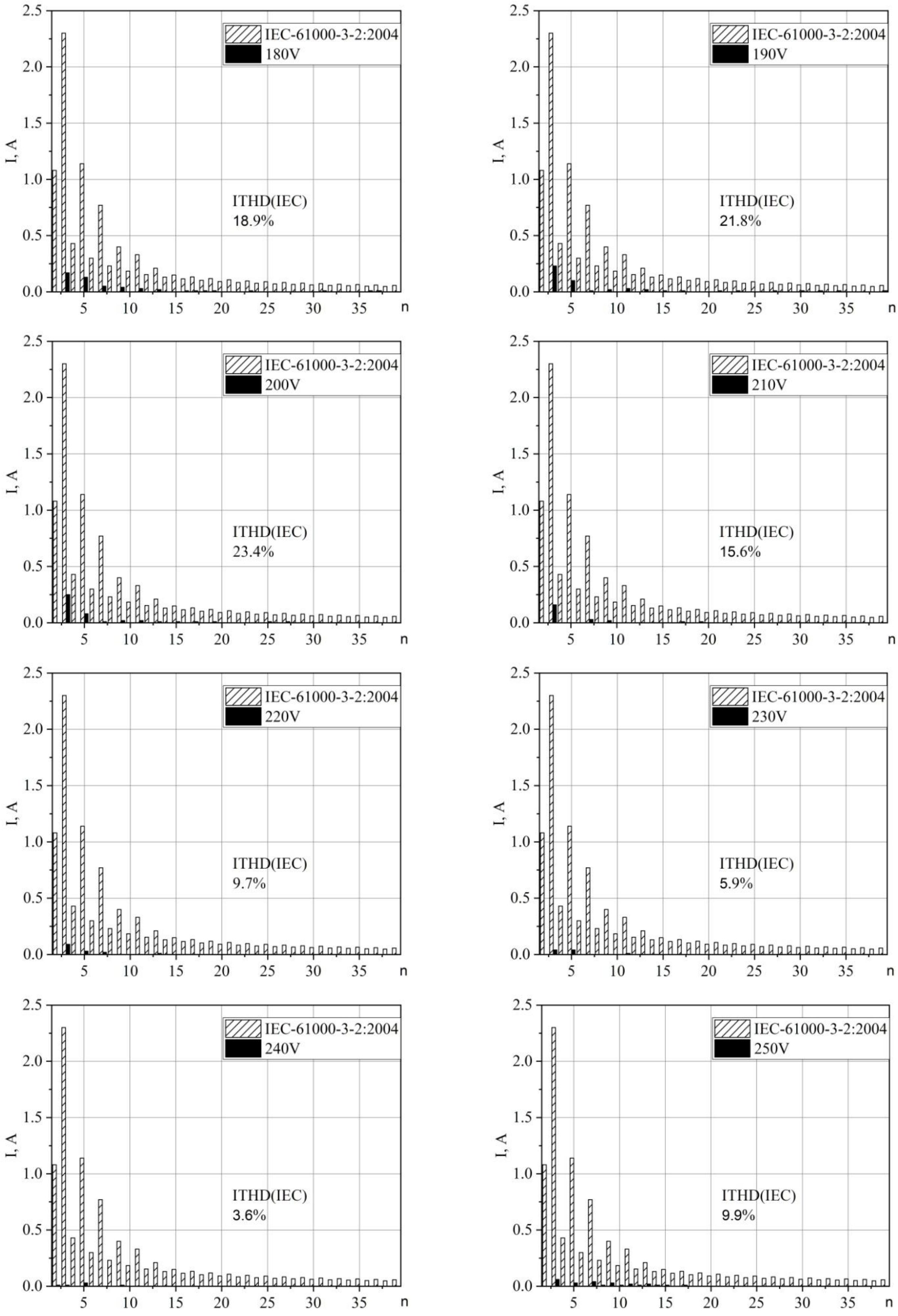


Fig. 6. The magnitudes of the current harmonics of the driver relative to the maximum allowable value according to the IEC-61000-3-2:2004 standard under the driver supply voltage from 180 to 250 V.

As can be seen from Figs 1 and 2, the current through the transistor VT1 to "ground", when it is opened, flows through the resistor R1. The voltage from this resistor is fed to the comparator (microcircuit L6561), which, when the threshold voltage value is reached, gives a prohibition signal to open the transistor. Accordingly, the value of the resistor R1 can be used to adjust the maximum peak value of the current through the transistor, which allows protecting the transistor at peak currents, to limit the maximum power of the driver, to select the optimal PWM frequency and width of the clock pulses by the microcircuit, as well as to protect the driver from short circuits at the output.

Since the developed driver can be part of lighting systems that need to change their light flux, in the driver it is provided an input for a PWM control signal, which can be used to change the value of the output current.

3. Hardware prototype and experimental results

In this work, an experimental sample of the developed driver was made, which is shown in Fig. 3, and its functioning was investigated under various operating modes.

To check whether the driver characteristics meet the requirements, the driver parameters were studied using the following equipment: Tektronix DMM4050 precision digital multimeters and a PF9811 power meter, and an Agilent 6812B AC alternating current power supply was used for its power supply. A LED module [4] with the maximum power 300 W was used as a load.

As a result of this research, the dependence of the change in output current and power consumption on the input voltage was obtained, which are presented in Fig. 4. The data of measurement results were recorded after stabilization of the temperature of the driver components at a constant temperature of the surrounding environment (22 °C), but not earlier than after 1800 s of system operation at the set mode. The system components were assumed to have reached temperature stability, if the readings did not change by more than one unity of measurement within 900 s.

From the obtained dependence of the output current on the driver supply voltage, it can be seen that the change in the output current is 1% of the set output current of 5.5 A, and the change in the input power over the whole range of input voltages is less than 4%. These parameters allow using the developed driver in systems that require a stable power supply, in particular, in intelligent lighting systems and lighting systems with combined power supply [39].

Since the efficiency of the lighting system largely depends on the efficiency factor of the driver, the dependence of the efficiency factor on the change in the input voltage was investigated, which is presented in Fig. 5.

The dynamics of the change in efficiency factor from the input voltage showed that the minimum value of the efficiency factor is 88.2% at the supply voltage 200 V, and the maximum one is 90.3% at the voltage 240 V. These fluctuations in the efficiency factor of the driver can be explained by a change in its operating mode, namely: by a change in the conversion frequency and the value of current through the clock transistor. An increase in the conversion frequency leads to an increase in switching losses, since each of the transistors and diodes have parasitic capacitances.

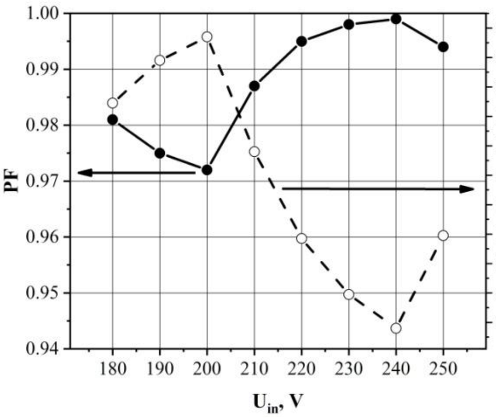


Fig. 7. Dependence of the PF and ITHD of the driver on changes in the input voltage of the power supply network.

Considering that the designed driver has a high power, it is important to ensure a high PF and a low value of the total harmonic current distortion (ITHD) over the entire input voltage range. This will enable to reduce the load on the power grid due to the reduction of the reactive component of consumption.

On the territory of Ukraine and Europe, the values of ITHD are regulated by the standard IEC-61000-3-2:2004. When developing modern drivers, it is important to compare the values of the current harmonics of the driver with the maximum allowable values according to current standards. For the developed driver, the measured values of current harmonics are adduced in Fig. 6.

In Fig. 6, it can be seen that under the supply voltage 200 V, the maximum value of the current harmonics coefficient is 23.4%, at the same time, none of the harmonics exceeds the maximum allowable value according to the IEC-61000-3-2:2004 standard.

As a result of studies of the PF and ITHD, the corresponding dependences were obtained and presented in Fig. 7.

As can be seen from Fig. 7, due to the use of an active corrector of power factor, the minimum value of power factor is 0.972 at the voltage 200 V and the maximum value is 0.999 at the voltage 240 V. At the same time, the harmonics factor was no more than 24% over the whole investigated range of input voltages.

4. Conclusions

In this work, an efficient driver for LED light sources based on a flyback converter of the power 200 W has been developed and implemented, which is close to the maximum possible power for this type of topology typical for the driver construction.

To increase the availability and manufacturability of the design, a unified component base has been used, which enables to reduce the cost of the final product without significant changing the characteristics.

The results of experimental studies show that under nominal load, the minimum efficiency of the developed driver is about 88.2% with a power factor higher than 0.97, and total harmonic current distortion of 23.4%. With the maximum efficiency factor of the developed power supply system of 90.3% under the voltage 240 V, the power factor was higher than 0.99, and the coefficient of nonlinear distortions was 3.6%.

The values of the total harmonic current distortion of the driver do not exceed the maximum allowable values set by the valid standards on the territory of Ukraine and Europe.

The deviation of the output current from the set value does not exceed 1% over the whole operating voltage range (180…250 V), which allows using the developed driver in intelligent lighting systems and lighting systems with combined power supply.

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Розроблення світлодіодного драйвера за зворотноходовою топологією для інтелектуальних систем освітлення з високою потужністю та ефективністю

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Анотація. У даній роботі розглядаються параметри і характеристики розроблених високоефективних електронних систем керування потужними світлодіодними модулями (драйверів), побудованих на основі одноступеневого зворотноходового перетворювача з номінальною потужністю близькою до 200 Вт. Результати експериментальних випробувань показали, що при номінальному навантаженні мінімальна ефективність розробленого драйвера становить приблизно 88.2% з коефіцієнтом потужності вищим ніж 0.97 і коефіцієнтом нелінійних спотворень струму 23.4%. При максимальному значенні коефіцієнта корисної дії розробленої системи 90.3% і напрузі живлення 240 В коефіцієнт потужності перевищує 0.99, а коефіцієнт нелінійних спотворень струму – 3.6%. Величини струмових гармонік драйвера не перевищують максимально допустимих значень, установлених діючими стандартами. Використана топологія побудови драйвера дозволила знизити вартість кінцевого виробу за рахунок уніфікації елементної бази, що сприяє підвищенню доступності та технологічності конструкції. Використання сучасної елементної бази дозволило забезпечити відхилення вихідного струму від заданого не більше ніж 1% у всьому діапазоні робочої напруги живлення (180…250 В), що дозволяє використовувати розроблений драйвер в інтелектуальних системах освітлення та системах освітлення з комбінованим електроживленням.

Ключові слова: потужний світлодіод, світлодіодний драйвер, високий коефіцієнт потужності, високий коефіцієнт корисної дії, коефіцієнт нелінійних спотворень струму, інтелектуальні системи освітлення.