A CONCEPT OF LABORATORY TESTBENCH FOR INVESTIGATION OF LED DIMMERS

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Abstract – Основной целью данной работы является разработка испытательного стенда, пригодного для испытаний электронных балластов осветительных светодиодов. В статье оцениваются возможные конфигурации такого стенда, а также варианты его отдельных блоков. В статье также сравнивается энергоэффективность и управляемость понижающее/повышающего и понижающего преобразователей напряжения, работающих в качестве светодиодных балластов.

Keywords – Освещение, электронный балласт светодиодов, энергоэффективность.

REVIEW OF ADVANTAGES AND DRAWBACKS OF LED TECHNOLOGY

Artificial lighting is one of the most energy consuming areas in the world [1]. Therefore, increasing energy efficiency of lighting systems is very important and could give significant energy savings. The reduction of energy consumption can be achieved by two strategies: use of more energy efficient lighting technologies and use of intelligent lighting control solutions.

Implementation of LED luminaries gives the opportunity to implement both methods. As a rather new technology, LEDs provide higher efficacy [2] which also today is still increasing [3], better quality of light and are ecologically friendly. The life time of LEDs is significantly longer if compared to traditional lighting sources. They also do not emit IR-radiation and it is possible to use them in IR critical environments. Furthermore, the dimming of LEDs does not have negative impact on them.

The main disadvantage of LEDs is that they are currently more expensive than conventional lighting technologies. Other disadvantage of LEDs is their high heat sensitivity and need for a cooling system. LEDs are also low voltage elements and for this reason they require a special power sources (electronic ballasts), which makes lighting system more expensive. The main parameter is energy efficacy. LEDs have the biggest value of efficacy.

LIGHT REGULATION TECHNIQUES OF LEDS

LEDs are low voltage semiconductor devices that can be connected to AC network only through a converter that operates as voltage source or current source. At the same time there are three main methods of regulation of light intensity of LEDs: fluent regulation of LED’s current and flux, pulse mode regulation of LED’s current and flux, stepwise regulation, commutating LED groups. The comparison of the above mentioned regulation methods and both energy sources is presented in Table 1.

A. Fluent Mode Regulation

Fluent regulation of luminous flux by current regulation is a method when the value of luminous flux can be of any value between maximum and zero. This method has two significant disadvantages. Firstly, the LED brightness is not completely proportional to current. Secondly, not only luminous flux but also the wave length and therefore color of light are different at different values of LED current.

B. Pulse Mode Regulation

With pulse regulation method the value of luminous flux can be either the maximum value or zero. The average brightness of LEDs depends on the ratio of on-time to the switching period of LED. In this case the LED brightness can be adjusted by the most
common method – pulse width modulation (PWM). However, this method provides pulse pattern of instantaneous luminous flux. When the frequency of modulation is low, the pulsating character of light becomes visible to human eye. When the frequency is high a stroboscopic effect may appear [4] and [5].

C. Step Mode Regulation

With this method luminous flux changes stepwise over a range of fixed values between maximum and zero. Dividing LEDs in groups gives an opportunity to regulate brightness with a certain constant step.

Table 1

<table>
<thead>
<tr>
<th>Method</th>
<th>Source</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluent regulation</td>
<td>Current</td>
<td>● One source</td>
<td>● Current source should be regulated</td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
<td>● One source</td>
<td>● Voltage source should be regulated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>● Narrow usable voltage range</td>
</tr>
<tr>
<td>Pulse regulation</td>
<td>Current</td>
<td>● One unregulated source</td>
<td>● Current source, switch is needed</td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
<td>● One unregulated source</td>
<td>● Switch is needed</td>
</tr>
<tr>
<td>Step regulation</td>
<td>Current</td>
<td>● One source</td>
<td>● Current source, should be “n” number of switches</td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
<td>● Voltage sources for each group of LEDs</td>
<td>● should be “n” number of switches</td>
</tr>
</tbody>
</table>

As it is seen from Table 1, pulse mode regulation seems to be the most simple and useful method but it is necessary to take into account its disadvantages which are related to pulsating character of luminous flux (flickering, stroboscope effect). Fluent regulation and group regulation methods should be investigated more carefully. Preliminary comparison shows that both these methods have advantages and drawbacks.

DEVELOPMENT PROCEDURE OF THE TESTBENCH

This work is focused on elaboration of an easy reconfigurable testbench for investigation of light regulation methods for LEDs. Development of such testbench consists of several tasks. First, power of LED matrix and its configuration should be chosen. Second, the overall structure of testbench should be selected. Third, parts of the selected structure have to be chosen.

A. Selection of LED Matrix

The number and configuration of LEDs have been chosen taking into account the following considerations. Firstly, the group method of light regulation requires sufficient number of LEDs. If the minimal step of light changes is about 5% (reasonable minimum for some street lighting applications) then the number of LEDs must be about 20. Secondly, available armature for the testbench is not very big and cannot dissipate power more than 20W. Thirdly, available LEDs are of 1W power. Taking into account possible hexagonal placement of LEDs the final configuration is 19 1W LEDs. The total power of such matrix is about 20W.

The placement of LEDs in the matrix must ensure symmetrical distribution of active LEDs when some of them are off. Fig. 1 shows two possible configurations of the matrix. The first one (Fig. 1-a) presents a full three level hexagonal placement of 19 LEDs intended for binary weighted groups (1, 2, 4, 8 and 4). Another configuration (Fig. 1-b) is aligned for equal groups of 2, 3, 6 or 9 (the figure shows 6 groups of three LEDs).

\[ \begin{array}{ccccccc}
  \text{a) } & 4' & 8 & 8 & 4 & 5 & 6 \\
  & 8 & 4 & 4 & 4' & 3 & 2 & 3 \\
  & 8 & 2 & 1 & 2 & 8 & 6 & 2 & 1 & 4 \\
  & 4 & 4 & 4 & 8 & 5 & 1 & 2 & 5 \\
  & 8 & 8 & 4' & & 4 & 3 & 6 \\
\end{array} \]

\[ \begin{array}{ccccccc}
  \text{b) } & 4' & 8 & 8 & 4 & 5 & 6 \\
  & 8 & 4 & 4 & 4' & 3 & 2 & 3 \\
  & 8 & 2 & 1 & 2 & 8 & 6 & 2 & 1 & 4 \\
  & 4 & 4 & 4 & 8 & 5 & 1 & 2 & 5 \\
  & 8 & 8 & 4' & & 4 & 3 & 6 \\
\end{array} \]

Fig. 1. Physical placement of LEDs in matrix: a) binary weighted groups; b) equalized groups.
B. Selection of Structure of the Testbench

First step of the laboratory prototype design procedure is selection of its overall configuration: monolithic or composite (composed of different blocks). The comparison of model types, their pros and cons are presented in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Type of model</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Monolithic</td>
<td>• Gathered scheme</td>
<td>• Poor possibility to research regulators</td>
</tr>
<tr>
<td></td>
<td>• Ready to use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High efficiency</td>
<td></td>
</tr>
<tr>
<td>Composite</td>
<td>• Easy reconfigurable</td>
<td>• Lower efficiency</td>
</tr>
<tr>
<td></td>
<td>• Convenient for research</td>
<td>• More complex construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Big size</td>
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The composite model shown in Fig. 2 has been chosen, because further research will be held on LEDs and their characteristics at the different methods of regulation. It consists of primary power supply, secondary regulator and the LED matrix. Such structure gives opportunity to investigate different regulators with different configuration of the LED matrix. One more expansion of the described ballast is a communication module that provides an opportunity of external control that is necessary for development of smart lighting system.

C. Choice of Primary Power Source

It is necessary to determine main parameters of the primary supply before designing it. Input voltage of this supply is AC grid voltage 220V. Since the buck converter has been chosen as the secondary regulator, the output voltage of AC (primary) power source should be 70V (19 series connected 1W LED – in the rated point of operation). Assuming the worst case efficiency of secondary regulator (90%) and primary power supply (90%) the power of supply is 20/(0.9*0.9)=25W. LEDs in the matrix are connected in series, therefore the current of the primary AC source is equal to the rated LED current 280mA (for 1W device). Modern equipment should consume a sinusoidal current. Primary power source with diode bridge and output capacitor does not satisfy this requirement. Therefore a PFC has to be included into the schematic. Power line and LED part should have galvanic isolation for safe use of AC power source. For this reason a flyback topology equipped with a power corrector has been chosen.

D. Overview of Luminous Flux Regulators

Pulse Mode Luminous Flux Regulators

Pulse regulators provide square shaped current pulses to LEDs. They can be divided into two groups: indirect voltage regulators and direct current regulators. In voltage regulator a controllable switch (MOSFET) is connected in series with LEDs. This configuration is a simplified voltage buck converter with PWM regulation utilizing the switch. In current regulator the switch is connected in parallel with LEDs and shorts them.

LED Groups Luminous Flux Regulators

With this method regulation of the overall luminous flux is done through separate powering of each group. Regulators for commutation devices can be divided into voltage and current regulators. Besides that equal group approach and weighted group approach can be emphasized. In case there are different numbers of LEDs in groups each group gets power from its own voltage source. Otherwise several voltage sources have to be utilized. In the case of current mode power supply the current source is the same for all groups, but each group has its own short-circuiting switch.
**Fluent mode regulators for initial debugging**

The last part of the chosen testbench topology is the secondary regulator of LEDs current. It may be built as a current source that has direct influence on the light produced by LEDs or as a voltage source that applies voltage to LEDs that, in turn, initiates LED current. Both approaches have their own pros and cons. However, at the initial stage, for simplicity and safety reasons voltage source topology has been chosen for initial debugging.

There are several well known topologies of switch mode voltage regulators such as buck, boost, buck-boost [6], SEPIC, Cuk [7] and flyback. With the chosen topology (primary power supply produces the maximal voltage of LED series) of the testbench only circuits with step-down capability are suitable. The set of such converters includes buck converters and buck-boost converters (like Cuk, SEPIC and flyback) in the buck mode of operation.

In order to find the most suitable solution buck and buck/boost converters have been developed (Fig. 3) and tested together with LED load.

![Fig. 3. Topologies of fluent mode regulators for initial debugging: a) buck; b) buck/boost.](image)

**EXPERIMENTAL COMPARISON OF FLUENT MODE REGULATORS**

The mentioned buck and buck-boost converters (in the buck mode) for fluent mode regulators have been developed, assembled and tested. These circuits have been studied from the point of view of their efficiency and controllability (with a digital control system) in two modulation modes: PWM and constant pause frequency modulation (CZFM) [8].

A. Comparison of efficiency

The experimentally obtained efficiency, duty-cycle and switching frequency is presented in Fig. 4 and Fig. 5.

![Fig. 4. Efficiency (a), switching frequency (b) and duty-cycle (c) of buck LED dimmer.](image)
losses are dominant. This dominance is also overwhelming due to the low duty cycle of the off state losses of the buck converter. Therefore, the on-state losses are elevated, but efficiency is rather small and switching frequency is higher. In this case, the relative impact of the on-state losses is negligible, but efficiency curves for PWM and CZFM are similar. The above mentioned assumption is also illustrated with duty-cycle and frequency graphs shown in Fig. 4-b,c and Fig. 5-b, c.

B. Comparison of controllability

The controllability is estimated with a set of parameters: 1) nonlinearity of control chain; 2) practical utilization of the duty-cycle and 3) its practical inaccuracy. The first parameter is important for estimation of stability of LED current regulator. It is defined as a root-mean-square declination of the actual regulation curve (Fig. 6) from the line connecting its end-points.
The practical utilization of the duty cycle is defined as a ratio of those values of the duty-cycle that actually affect LED current to the whole range 100%. This parameter is shown graphically in Fig. 6. Another parameter is the practical inaccuracy of the duty cycle that is defined as a ratio of technically achievable inaccuracy of the duty cycle to its practical span. The last two parameters show real performance of the control system of the dimmer.

From Fig. 6 a certain difference between calculated and experimental curve can be seen. It can be explained by non-ideality of real converters that is especially significant in the case of the buck-boost converter.

The above mentioned calculated and measured controllability parameters are presented in Table 3. As can be seen from this table, nonlinearity has no dependence on the type of dimming converter (although it is a little bit higher for buck-boost converter). Practical utilization of the duty cycle is better for buck converter supplied with input voltage equal to maximal operating voltage of the LEDs. Practical inaccuracy is reversely proportional to the practical span. For buck converter it is lower than for buck-boost converter.

### Table 4

<table>
<thead>
<tr>
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<th>Buck Calculated (measured)</th>
<th>Buck-Boost Calculated (measured)</th>
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<tbody>
<tr>
<td>NL</td>
<td>16% (12%)</td>
<td>18% (11%)</td>
</tr>
<tr>
<td>DSPAN</td>
<td>15% (17%)</td>
<td>5% (7%)</td>
</tr>
<tr>
<td>ADf</td>
<td>6.7 (5.9)</td>
<td>20 (14.3)</td>
</tr>
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</table>

**SUMMARY AND CONCLUSIONS**

In the paper a concept of laboratory testbench for LED dimmer research purposes has been presented. After brief analysis it has been concluded that the most suitable configuration of the testbench is a composite system (with LED matrix, primary power supply and a dimmer) that provides higher flexibility for further research. Stages of development of the testbench have been briefly discussed.

Various fluent mode voltage type LED drivers have been compared. Two of them (buck and buck-boost dimmers) have been experimentally investigated. It has been concluded that PWM/CZFM controlled buck dimmer provides better efficiency and is more controllable.

Finally it has been concluded that the developed testbench provides a good basis for future works focused on the experimental research of various LED light regulators.

**REFERENCES**