

Choice of the Control Method for LED luminary in Intelligent Lighting System

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Abstract

In the context of Intelligent Lighting System various lighting devices and technologies are compared. For the most technically beneficiary and rapidly developing LED luminaries control and power supply methods are analyzed and experimentally tested. The optimal one is chosen. Outlines of the further research are defined.

Keywords

Intelligent Lighting System, LED, control methods, dimming, experiments

1. Introduction

Generally the concept of Smart Grid means enhancement of common electric grid with monitoring, analysis, control and communication capabilities in order to improve reliability, maximize throughput, increase energy efficiency, provide consumer participation in the energy distribution as well as allow diverse generation and storage options.

The devices of Smart Grid tend to be efficient in energy consumption field as well as “smart” enough to be able to decide whether the device is working usefully or not. A good example of where the Smart Grid concept should be introduced is an indoor and outdoor lighting. The lighting in municipal as well as in other buildings is often switched on almost all day long in the corridors and staircase, in spite of the need for illumination. The road lighting also is switched on constantly during the night time without any correction depending on traffic density and weather conditions. If the mentioned parameters were monitored and lighting levels were adjusted then the overall consumption of the lighting system could be reduced.

The main goal of the given work is to identify the approaches to the development the energy effective automatically reconfigurable energy systems for the effective control of lighting. This includes elaboration and analysis of power converters for LED luminaries, intelligent power units for integration of renewable energy sources and lighting systems as well as intelligent power modules with typical energy storage devices.

2. Lighting in modern society

The world electricity consumption for lighting in 2005 of 3418 TWh represents 19% of the world's total electricity consumption of 17982 TWh. Meaningful part of consumed electrical energy is spent for street lighting (for example, in Norway 3% of all electricity demand). At the same time for an average commercial building the lighting takes about 30-40% of its electricity bill [10][12]. It is seen that the problem of energy efficiency in lighting is important and topical.

The development of energy effective Street Lighting system is closely related to the three main goals of such systems: 1) providing safety for all type traffic users on road; 2) providing visibility of pedestrians and 3) providing safety for pedestrians. Traffic route lighting is designed for the worst case scenario, i.e. the maximum traffic density on the road. However, many traffic routes have high peak hour traffic for a very short period with substantially lower traffic flows for the remainder of the lighting cycle. In such cases a close examination of the traffic flow patterns and reasonable reduction of lighting at this time may lead to the significant savings in energy use and cost.

2.1. Proposed activities

One way to get some step closer to preserve the nature is to decrease electrical energy consumption produced by fossil fuels and improve the efficiency of electrical technologies. Since the lighting is widely used all over the world it is needed to improve the efficiency of lighting sources. The electricity consumption in Europe for street lighting alone is estimated to be more than 40 TWh annually. As it will be seen later an annual saving of about 30-50% is attainable by modernizing the luminaries and utilizing intelligent lighting technology.

Energy saving initiatives can be divided into the following groups:

- Replacing inefficient lamps – some lamps, such as incandescent, halogen or high pressure mercury lamps can be converted to a more efficient model such as high pressure sodium, metal halide, or LED;
- Improvement of a luminary characteristic – some luminaries may have more efficient light reflectors to direct light more precisely;

- Replacing of a magnetic ballast – new generation ballast can offer greater efficiencies and opportunity for dimming lights;
- Introduce a distance management for lighting control; this allows lighting to respond to individual conditions;
- Better use of existing infrastructure – some lighting applications need to be improved by adjusting color, lighting class, hours of operation; or complete removal.

2.2. Real Life Examples

There are quite a lot of examples of reduction the energy consumption for lighting needs [9]:

- Oslo, Norway – introduction of high pressure sodium lamps and intelligent street lighting system - the project involved the replacement of 10,000 units which was 15% of street lighting in Oslo. Estimated efficiency improvements are about 30%;
- Ann Arbor, Michigan, USA – Introduction of LEDs for street lighting purposes. Reduction in energy use by 50%;
- Los Angeles, USA –the project involved replacement of 140,000 street light fixtures with LED units. Designed to cut power use by 40%.

3. Intelligent lighting system

The definition of intelligent lighting assumes a total system with dimmable luminaries, advanced lighting control solutions, communication systems and administrative tools. The solution focuses on reducing energy consumption and high functional standard. It also, in most contexts, automatically declines the maintenance costs for the operator in combination with increased safety for the street user.

Introducing intelligent lighting means a more complex control of the system. In contradiction to the well known “on/off” technology, the intelligent street lighting requires more sophisticated analysis of the input parameters. The system should automatically react to external factors, such as traffic density and the weather conditions. For example, the level of lighting could be increased when there are a lot of cars travelling on a specific stretch of road. It is also possible to dim the lighting at night when fewer cars or other road users are on the roads or if the surface is covered with snow, but during rainy or fogged weather the lighting level should be increased.

Also Intelligent System can count the burning hours so that changes can be planned based on a statistical approach. Warning notifications can also be generated when the luminaries approach their end of life. The system can automatically report lamp failures. This results in eliminating the need to perform scouting activities to control the lighting.

Intelligent lighting concept is especially attractive in autonomous lighting systems because: 1) it reduces electricity demand due to improved functionality (as

explained above); 2) additionally it helps to choose the most suitable renewable energy source; 3) it allows implementation and smart utilization of energy storages.

This new technology is highly energy-efficient and therefore also cost-efficient because it provides light when and where it is needed most of all.

4. Comparison of lighting sources

The efficiency and performance of lamps has been improved dramatically during the last 30 years. Traditional gas discharge lamp control has become more efficient with the move from magnetic ballasts to electronic ballasts. At the same time the lamp technologies has evolved from High Intensity Discharge (HID) Mercury vapor to Sodium and metal halide. The current market of artificial lighting technologies has been widen by new technology – LED (Light Emitting Diode), which can be used to build very efficient and functional lighting source. At the given time lighting efficiency of the LED technology approaches 100lm/W. Therefore it could replace some traditional lighting sources like incandescent, fluorescent bulbs and in some applications even HID lamps, because HID lamps always require a reflector, which produces specific form of light beam for uniform surface illumination. On the other hand it leads to some “optical” losses and the real-life efficacy of the HID lamp can be smaller than it is shown in specification. In opposite to all other kinds of lamps LEDs have naturally directed light output that saves lumen losses in reflector.

Since the dimmable luminary is one of the major components of Intelligent Lighting system the various types of lamps were studied for this feature (Table 1).

The table shows that some types cannot be used in Intelligent Lighting system. Dimming of the HID lamps is limited due to the shift of color, reduced color rendering index (CRI) and increased flickering. One more drawback is inadvertent lamp shutdown, after which the lamp needs to be cooled down before reigniting (1-5 min), then needs to be switched at rated wattage for a minimum of 15 minutes before the next dimming. In general, dimming HID lamps much below 50 percent is not practically applicable. At the same time LED technology has no negative influence on dimming, even opposite, according to working characteristics of LED their efficacy is higher at reduced power. Beside that LED technology has other unique properties, like these: low voltage power supply, shock resistance, long life, instant starts-up and dimming for up to 100%, which make them indispensable in certain applications. Also this technology improves the color quality that makes it perspective in study and use.

Table 1. Comparison of Different Light Sources [1][8][11]

Lamp technology	Efficacy (*) [lm/W]	Life time [hours]	CRI	Available Dimming Level [%]	Dimming Influence	Startup time
Incand.	10-17	1k	100	100	Positive: lifetime extending	Instantly
Halogen	12-20	2k	100	100	Negative: lifetime shorten - halogen cycle doesn't work	Instantly
FL	20-60	10-20k	80	10	Neutral	1-5sek
MV	25-40	14-20k	80	50	Negative: Lifetime shorten; Color shifting	5-7min
MH	35-50	10-15k	60-90	50	Negative: Lifetime shorten; Color shifting	2-5min
HPS	55-65	24-32k	40	80	Positive: Lifetime extending	5-10min
LED	65-75	50-100k	70-90	100	Positive: Efficacy risen, Lifetime extending	Instantly

* – Typical expected performance in real-life applications. Based on mean lumens, and including ballast/driver, thermal equilibrium and typical fixture Coefficient of Utilization losses.

5. Comparison of LED luminary dimming methods

LEDs themselves are low voltage semiconductor elements (diodes) that are not directly compatible with common AC networks. Therefore some converter is always required to supply LED luminary.

If the luminary must provide some constant amount of light its power supply must ensure the corresponding constant current of the LEDs. This can be done with some traditional equipment like voltage source and series balancing resistor or current regulator (more efficient and preferable solution).

Light dimming is only possible with more complex power supply. Preliminary analysis revealed three basic light control approaches: 1) regulation of value of LED's current; 2) pulse width modulation of the current; 3) grouping and sectional powering of LEDs. Besides that it is possible to combine the first two approaches with the third one.

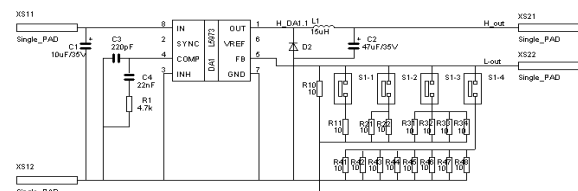
A. Regulation of current

The current regulator of the luminary may be based on a typical closed loop that includes a current feedback with current sensor, error amplifier, some PI or PID regulator and power converter. It is, however, more difficult to find an integrated solution for such current loop while discrete implementation is bulky because of the measurement of current. That is why it was decided to adopt an existing voltage regulator to the discussed application [3].

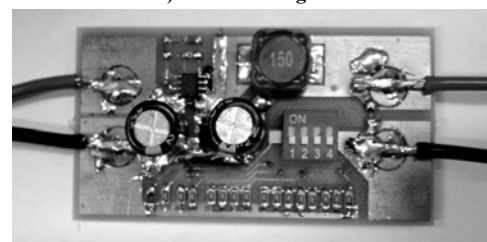
Such voltage regulators are also based on the closed loops, but they include voltage feedbacks. The sensor of the feedback is usually a voltage divider that in steady state ensures 1.235V in its midpoint. The upper and lower parts of such divider may be chosen quite arbitrary, but their ratio defines the output voltage. The divider may be described as the

branch with constant current that is set by means of the lower resistor at the level of $1.235V/R_{LOW}$. Then the upper resistor may be even non-linear, for example, series of LEDs – its current will also be stabilized [4].

The proposed example (Fig. 1) is based on the integrated circuit L5973. In order to adjust the current from 0.35A to 2.8A (for tested 70W luminary), lower resistor is changed from 3.5 to 0.44 Ohm ($1.235/0.35$ and $1.235/2.8$ – respectively). Power losses in the lower resistor are changed from 0.43 to 3.46W (less than 5%) that is acceptable for laboratory purposes.



a) electrical diagram



b) laboratory example

Fig. 1. The current regulator of LED luminary that is based on an existing integrated voltage regulator.

B. Pulse with modulation of current

This approach is based on the phenomenon of inertia of the human eye. If a luminary is blinking fast enough then such blinking is recognized as dimming. The depth of the dimming depends on the duty cycle of the signal (Fig. 2-a). There are several possible realizations of this approach.

Direct PWM signal may be applied to the transistor commutating DC voltage to the connected in series LEDs and balancing resistor.

Inverted PWM signal may be applied to the transistor short-circuiting the series connection of LEDs.

Direct PWM signal may be used as enable signal for the current stabilizing IC [4][5].

For laboratory testing (Fig. 2-b) the first approach was used. PWM signal was taken from a laboratory signal generator and through a driver circuit applied to the transistor.

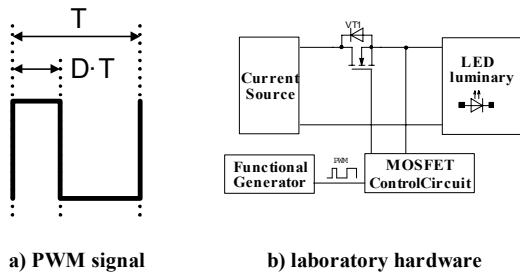


Fig.2. The current regulator of LED luminary that is based on an existing integrated voltage regulator.

C. Commutation of groups

If the luminary contains few lighting devices (for example, several LEDs) they can be switched on and off separately or in groups thus providing several steps of lighting. Utilization of the binary weighted groups gives more levels of lighting with more constant step between levels. Of course, each group of LEDs requires its own power supply that, however, may be less complex (3 laboratory power supplies were used in the experiments) [6].

Since in the given research 7 LEDs are used it is efficient to use groups of 1, 2 and 4 diodes (Fig. 3-a and Fig. 3-b). Then there are 7 available levels of power and 7 levels of brightness (Fig. 3-c).

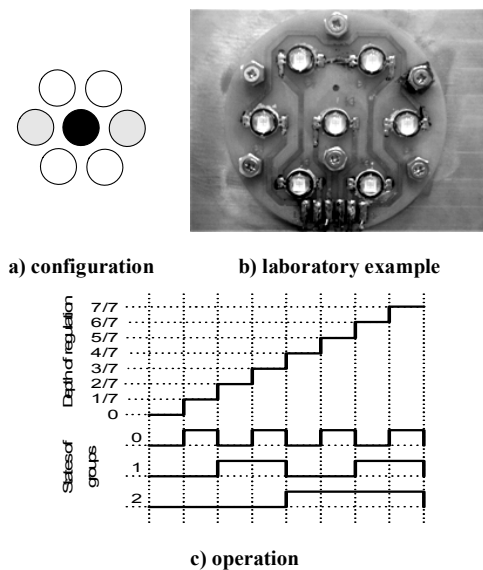


Fig. 3. Grouping of lighting elements in the 70W 7 LED luminary.

6. Experimental Results

The mentioned approaches were tested with 70W LED luminary that consists of 7 W724C0 LEDs (2.8A, 10W ~80% of which is released as heat), the corresponding heatsink and connectors available for each binary weighted group of LEDs. The experiments were made in order to find the most energy saving and cost effective solution, as well as to uncover the properties of dimming methods and their efficiency.

The current regulation, current PWM and group switching methods were tested with 1/7, 3/7 and 5/7 of the parameter. Then the current regulation method requires $2.8/7=0.4A$, 1.2A and 2.0A levels of the current, PWM – $100/7 \approx 14.3\%$, 42.5% and 72.5%, values of the duty cycle, but for the group switching – 1, 3, and 5 elements powered with rated current of 2.8A.

Typical light distribution over the explored surface is presented in Fig. 4. As it was expected the measured brightness is maximal just under the luminary and drop significantly (about 20% per 1m) across the distance. No other significant light spots or shadows are found. In whole this is typical lighting picture for luminary without reflectors, diffusers or other light equalization means.

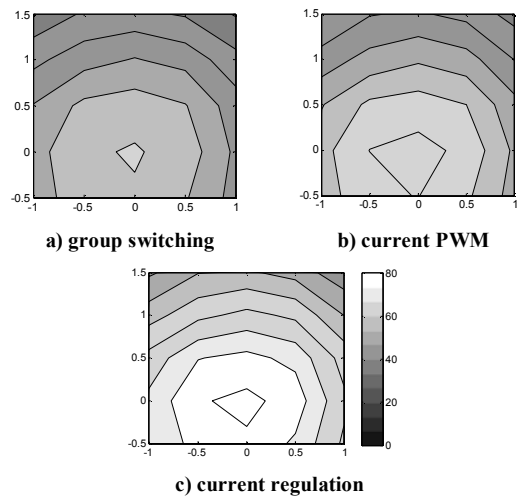


Fig. 4. Lighting at 3/7 of control parameter taken with different type of the dimming

The similar picture could be presented for the other values of the regulation parameter. However, it is more important to compare brightness at different control approaches and at different levels of the corresponding control parameter that is done in Table 2. It is seen from this table that switching of groups and PWM provide quite linear regulation (9% and 8% respectively) while current regulation is highly non-linear (24%). This phenomenon could be explained by non-linear lighting characteristic of LED itself. At the same time the current regulation approach gives more light at the same level of the control parameter.

Table 2. Average brightness [Lx] at different power supplies

Value Type	1/7	3/7	5/7
Group switching	16.4	49.8	74.9
Current PWM	17.0	54.4	91.7
Current regulation	25.2	66.4	95.2

Another table (Table 3) represents the operating temperature of LED package. It shows that in PWM and current control modes the temperature depends on operation parameter, but in group switching mode operating LED temperature is about 100°C.

Table 3. LED working temperatures [°C] at different power supplies

Value Type	1/7	3/7	5/7
Group switching	96	96	103
Current PWM	36	51	79
Current regulation	42	63	79

The next significant comparison is a comparison of the consumed power (Table 4). From this table it is seen that current regulation consumes less power for the same level of control parameter. PWM approach is the most power consuming. However, it must be noted that these data depend a lot on the power calculation methodology and other PWM methods may be more effective.

Table 4 Consumed power [W] at different power supplies

Value Type	1/7	3/7	5/7
Group switching	11.2	32.0	51.4
Current PWM	10.8(10.5)	38.3(34.9)	71.8(59.9)
Current regulation	8.5	28.0	49.2

Conclusions

So far the described experiments demonstrate the effectiveness of the current control method. This conclusion has two sides. The first one, the lower is current the higher is efficacy of diodes [lm/W]. The second – lower current leads to the reduced operating temperature of LEDs and, hence, to higher light output (smaller losses). The efficiency of all control methods is summarized in Fig.5.

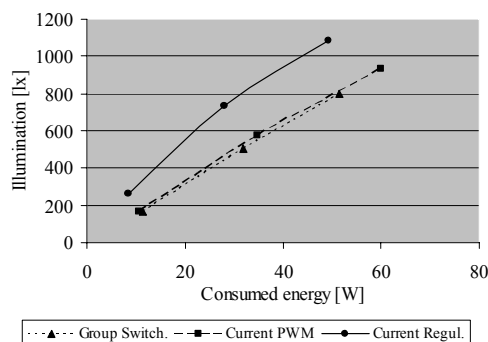


Fig. 5. Efficiency of dimming control methods

All LEDs have the same drawback – their lifetime directly depends on the operating temperature.

Therefore the current control and PWM approaches are more preferable also from this point of view.

Besides the dimming capabilities LED luminaries have an advantageous control characteristic – small reduction of illumination corresponds to significant reduction of consumed electrical energy (Table 5).

Table 5. Energy savings by dimming SON and LED luminaries[7]

Reduced Illumination by %	Energy Savings (SON) %	Energy Savings (LED) %
10	6	18
20	16	30
30	24	45
40	32	55
50	40	65

These data mean that the same dimming realized with LEDs has more than 50% higher energy saving effect if to compare with SON lamps.

The results of the conducted experiments confirm the advisability of utilization of LED technology in Intelligent Lighting Systems. They also allow recommending the development of power converters and information support for Lighting Systems with LEDs.

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