

# Integration of Renewable Energy Sources and LED Luminaries in DC based Street Lighting Grid

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**Abstract** — the present paper deals with analysis of rapidly developing Solid State Lighting (SSL) technology capable to replace currently widely used High Pressure Sodium (HPS) lamps. The dynamics of electricity price and technology development is discussed and prognosis is drawn for the year 2015. The price per light is calculated for present LED luminary parameters and compared with expecting in 2015 year. The advantages of Direct Current (DC) lighting grid are proposed as well as connection of Renewable Energy Sources (RESs) to lighting grid is proposed.

## I. INTRODUCTION

The artificial lighting is one of major electrical energy consumers, which shares about fifth part of the global electricity market.

At the regular rise of electricity price, which is sensitive to variable prices for primary energy sources and rising mining expenditures, level of life and duty polices of each country, the total cost of consumed energy by any electrical appliance during its lifetime is getting more noticeable in contrast to initial expenditures. From this perspective, the efficiency of whole street lighting infrastructure should be optimized from the point of view of energy consumption minimization.

As the research results from [1] that saving 1 kWh of electrical energy, potentially could save the equivalent of 2 kWh of fossil fuel. It relates with the total system efficiency of energy delivery to end-user from mining site, which includes energy losses at middle stages, like use of energy during mining fossil fuels, energy conversion and transmission (mechanical and electrical) losses, as well as end-device efficiency. Consequently, locally generated energy (especially from renewable energy sources) is much preferable, because it excludes the major of mentioned losses.

For this reason, enhancement of street lighting infrastructure is an important task, leading to minimization of global energy demand and reduction of municipal expenditures on illumination of public places and streets.

## II. EXPENDITURES DYNAMICS

As it can be noted from the diagram below (see Fig. 1), the electricity price in Europe is rising rapidly, which can be approximated to the following diagram:

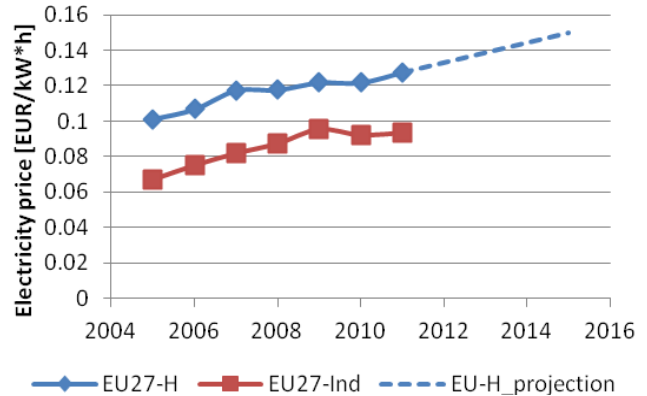


Fig. 1. Dynamics of average price for electrical energy in European Union for industries and households

In the year 2015, the price for electricity is expecting to be about 0.15 EUR/kWh, influencing the rise of expenditures for municipal organization, paying bills for lighting. On the other hand, prices per LED lighting are getting lower, while its efficiency is improving.

The rapid development of Solid State Lighting (SSL) technology and decrease of initial cost is described by Haitz's law [3] (see Fig. 2), who noticed that price/lumen relation is decreasing tenfold per decade, at the same time lamp's flux/package – increasing thirtyfold per decade.

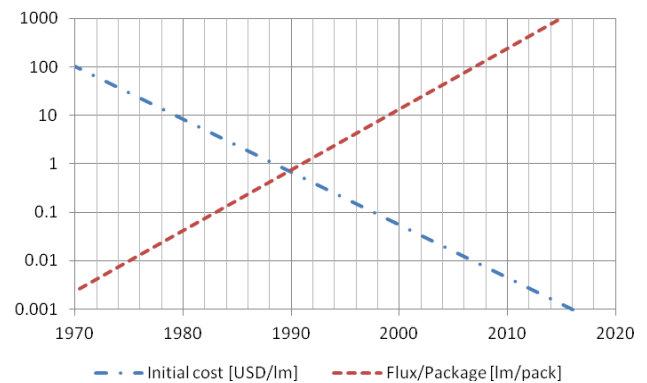


Fig. 2. Haitz's law, which approximates the price per SSL lamp's produced lumens

TABLE I

PRICE PER LIGHT COMPARISON FOR SSL AND HPS LIGHTING TECHNOLOGIES CONCERNING 2015 YEAR'S PRICES AND LED EFFICACY PROGNOSSES

Type of lamp	*Lamp cost (2012/2015) [EUR]	Lifetime [h]	Luminous flux (2012/2015) [lm]	Wattage [W]	Efficacy (2012/2015) [lm/W]	Price per light (2012) [EUR/Mlm*h]	Price per light (2015) [EUR/Mlm*h]
150 W Na (HLF-175MH150HPS)	71.14	24000	16000	186	86	1.512	1.744
2*80 W LED (LEDFFLA80392)	2*450/2*350	50000	2*5600/2*11000	2*80	70/138	1.859	1.088
400 W Na (RAB MEGS400SFQT)	229.80	24000	50000	464	108	1.207	1.392

\*www.1000bulbs.com (20.04.2012)

Thus it is reasonable to analyze the use of LED in street lighting making prognoses for price per light in 2015.

The Department of Energy USA (DoE) has launched the project entitled CALiPER (Commercially Available LED Product Evaluation and Reporting) aimed to benchmarking of commercially available SSL products, providing detailed test results and real parameter comparison with those, mentioned in specification. At the given time experts from DoE prognose, that SSL technology will remain rapid development and by the year 2015 commercially available LED luminaries with efficacy of 138 lm/W (see Fig. 3) will be on the market [4][5].

The “cost of light” [6] is calculated by using the following formula (1):

$$C_{light} = \left( \frac{1000}{\Phi_{lm}} \right) \cdot \left( \frac{C_{inst} + C_{lamp}}{T_{lamp}} + P_{lamp} \cdot C_{electricity} \right), \quad (1)$$

where  $C_{light}$  is price per light [EUR/Mlm\*h],  $\Phi_{lm}$  - luminous flux [lm],  $C_{inst}$  - installation cost (50 EUR),  $C_{lamp}$  - lamp's cost [EUR],  $T_{lamp}$  - lamp's lifetime [h],  $P_{lamp}$  - lamp's wattage [W],  $C_{electricity}$  - price for electricity [EUR/kWh].

As it can be noticed from the table (see Table I), the price per light for LED luminary in the year 2015 will be significantly decreased, showing direct competitiveness for currently widely used High Pressure Sodium (HPS) lamps, which development has reached it maximum already.

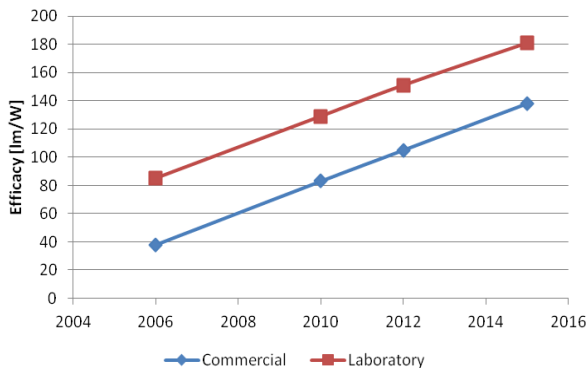


Fig. 3. USA DoE prognoses for LED warm white light efficacy

### III. ADVANTAGES OF DC LINK FOR STREET LIGHTING INFRASTRUCTURE

Concerning advantages that have been drawn in the previous chapter, it may be assumed that SSL is going to be the replacement technology in the lighting sphere in the nearest future. Another assumption can be drawn on base of the fact, that LEDs are DC load, what for street lighting grid could be supplied with DC voltage.

In this case configuration of LED luminary could be as it is drawn below (see Fig. 4).

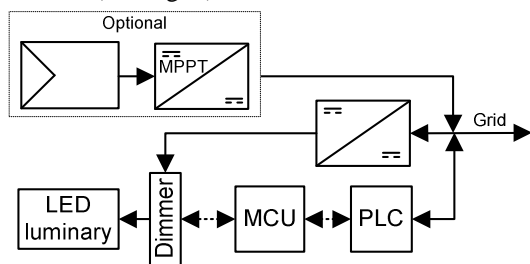


Fig. 4. Configuration of street lighting unit

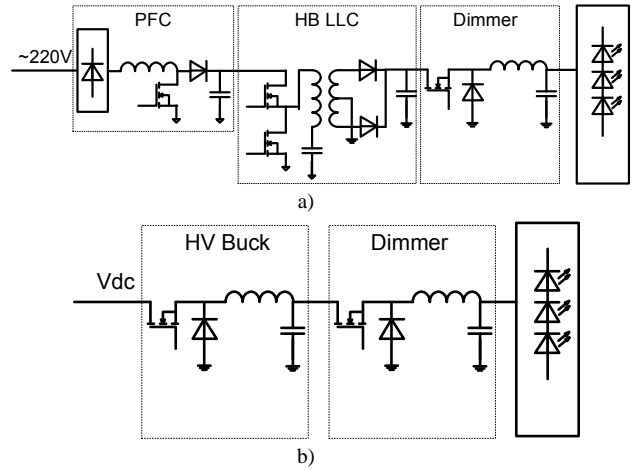


Fig. 5. Schematic of LED luminary PSU for AC(a) and DC (b) grids.

It could greatly reduce the elements count in the luminary's power supply unit (PSU) (see Fig. 5), because it contains only primary DC/DC converter adjusting grids DC voltage to admissible value, which further is regulated by dimmer, which is controlled by microcontroller unit, which communicates over power lines. The comparison of basic element count is provided below (see Table II).

TABLE II

BASIC COMPONENTS OF AC AND DC GRID'S POWER SUPPLY UNITS

	AC PSU	DC PSU
Switches	4	2
Diodes	8	2
Inductors	2	2
Capacitors	3	2
Transformers	1	0

Currently used electrical switching boxes allow only connecting street's grid to utility grid. In case of DC link, it should contain main Power Factor Correction (PFC) converter capable to supply all the luminaries installed on a given line. The total efficiency of proposed system could be slightly higher than currently used. On the other hand, other advantages bringing with DC lighting grids should be mentioned:

- Simple installation of RES to the grid;
- Easy communication over DC link;
- Smaller EMI/EMC problems.

### IV. CONNECTION RES TO STREET LIGHTING DC LINK

Installation of local electricity generation from renewable energy sources, such as wind turbines, Solar panels, are good solutions for preserving the global climate changes caused by greenhouse gases, mainly produced in electricity plants. However, its connection to utility grid requires in most cases two stage power conversion – for wind turbine it is required AC/DC (with PFC and MPPT) and DC/AC converters, due to changing frequency of wind generator; for PVs – DC/DC (Boost and MPPT) and DC/AC.

Concerning the fact, that both mentioned RESs in most cases contain DC link in the power converter, the connection to the DC grid of RESs could be much more convenient, excluding the problem of designing EMI/EMC filters for each of low power RES, capable to smooth generated low current sinus.

In this case, the main PFC converter should be capable of transmitting energy in both directions, because generated electricity from RESs could be displaced in phase with lighting load (especially in case of PVs), or, when lighting load is smaller than the generated power, excess of energy could then be transmitted to the utility grid.

The potential of RESs even in Eastern Europe is high enough to promote its use. The average energy generated by 45 W Solar panel (monocrystalline cells) acquired in 2011 in Riga is presented in the table below (see Table III). As it can be noted, energy, yearly generated by Solar panels with nominal power equal to half of mentioned LED power, is comparable with yearly consumed energy by 100 LED luminaries dimmed by night down to 30% from the nominal power. The diagram below (see Fig. 6) shows yearly average generated and consumed energy.

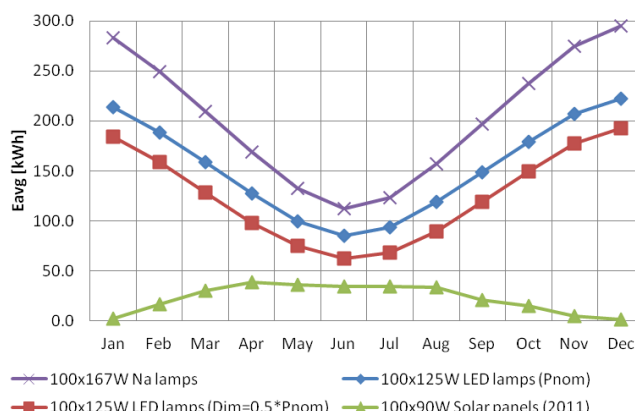


Fig. 6. Average energy per month for a given street in Riga

TABLE III

COMPARISON OF AVERAGE ENERGY USE FOR STREET ILLUMINATION CONSISTED OF 100 POLES FOR HPS AND LED LIGHTING TECHNOLOGIES AT FULL POWER AND DIMMED BY NIGHT (FROM 0:00 TILL 6:00) AND AVERAGE GENERATED ENERGY BY 100 STATIONARY 90 W PV PANELS.

	167W HPS Eavg [kWh]	125W LED Eavg [kWh]	125W LED Eavg (Dim=0.2*Pnom) [kWh]	125W LED Eavg (Dim=0.3*Pnom) [kWh]	125W LED Eavg (Dim=0.5*Pnom) [kWh]	125W LED Eavg (Dim=0.75*Pnom) [kWh]	Eavg PVs (2011 year) [kWh]
Total	2441.0	1842.1	1296.2	1364.5	1500.9	1671.5	268.3
Jan	283.3	213.8	165.8	171.8	183.8	198.8	2.3
Feb	249.8	188.5	140.5	146.5	158.5	173.5	16.8
Mar	209.9	158.4	110.4	116.4	128.4	143.4	29.8
Apr	169.1	127.6	80.2	86.1	98.0	112.8	38.5
May	132.4	99.9	59.5	64.6	74.7	87.3	36.3
Jun	112.4	84.9	48.8	53.3	62.3	73.6	34.6
Jul	123.6	93.3	53.8	58.7	68.6	80.9	34.6
Aug	157.2	118.7	72.1	77.9	89.6	104.1	33.2
Sep	196.9	148.6	100.6	106.6	118.6	133.6	20.5
Oct	237.3	179.1	131.1	137.1	149.1	164.1	15.2
Nov	274.4	207.1	159.1	165.1	177.1	192.1	4.7
Dec	294.7	222.4	174.4	180.4	192.4	207.4	1.8

## V. CONCLUSIONS

The paper discussed the potential of SSL technology in the nearest future to replace nowadays widely used HPS lamps. As the electricity price is rapidly rising, the total cost of consumed energy by luminaries during its lifetime is getting more noticeable in contrast to initial expenditures. Concerning Haintz's law, which describes precisely enough the development of SSL technology for over last 50 years, the prognosis for year 2015 is drawn, approximating the electricity price and LEDs parameters. The use of DC link as interface in street lighting infrastructure is described as preferable, due to a lot of advantages, concerning simple connection of RESs to the DC grid, improving total efficiency of the street lighting, more reliable communication.

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