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Energy efficiency of lighting installations: Software application and experimental validation

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ABSTRACT

The rational use of energy and energy-efficient environmental public street lighting is an important topic. In the design of new public lighting installations, national regulations containing energy-efficient guidelines are already used. Nevertheless, either in new installations or in reconstructions of existing lighting, designers do not generally consider all the available means to save energy. In installations of street lighting, energy consumption can be reduced by reducing the losses in the conductors, associated with the efficiency of the equipment, allowing better use of the available energy. The losses in the conductors must be analysed in conjunction with all the loads that contribute to the current in the sections of the installed street lighting. When opting for more efficient lamps and luminaires or lighting control systems, the current decreases in the sections covered with the most significant power loss due to proportionality with the square of the current. This decrease, often forgotten, is considered in this work in the investment analysis of efficiency and sustainable street lighting via simulation and experimental results. This analysis, combined with the features and operating parameters of the electrical installation, accounts for all the gains that can make a difference in the choice of efficient street lighting.

1. Introduction

This paper presents a new software application and experimental validation to compare and choose the best investment in the solutions of street lighting installations. This analysis takes into account the decrease in the consumption of the lamps and the losses in the electrical conductors, which are usually forgotten. The power losses in the conductors, being proportional to the resistance and the square of the current, must be considered together with all the loads that contribute to the current in the sections of the installation, to account for all the gains that can make a difference in the choice of installation of efficient street lighting.

The choice of efficient street lighting is related to the following factors: price, power consumption, reduction of losses in the conductors, useful life and interest rate. This study will be based on a new way of thinking: from minimal investment cost to minimal life cycle cost.

At a time when the prediction for energy consumption is a global increase of 38.6% by the year 2030, the imperative to pursue energy-efficient improvements is clearly on the political agenda at all levels of government. Referring to the actions proposed, in 2008, a response document was produced by the IEA (International Energy Agency) to the document request for policy advice on energy efficiency across the Action Plan of the G8 in Gleneagles (Jollands et al., 2010). The recommendations for energy efficiency cover 25 fields of action in 7 priority areas: buildings, appliances, lighting, transport, industry, energy utilities and cross-sectoral issues. Decision makers and policy makers will be able to base their actions on real-world, real-time data. Households and companies will be able to react to market fluctuations by increasing or decreasing their consumption or production, thus directly contributing to increased energy efficiency.

Energy efficiency and consumption reduction in electrical installations and equipment have been the subject of investigation and research, from energy production to the final consumer. Public (predominantly street) lighting contributes 2.3% to the global electricity consumption; thus, energy-efficient programmes in this field are very welcome, since the possibilities for energy savings in

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Nomenclature

E_P	Illuminance in the point P
E_{av}	The average illuminance
L_v	Veiling luminance equivalent
TI	Glare upsetting/Threshold increment
L	Luminance
$\bar{L}$	Average luminance
η	Luminous efficiency
ε	Energy efficiency of the installation
S	Area
E	Medium level of service calculated illuminance
KC	Knot Connection
B	Branch
R	Net profit
D	Operation cost
V	Residual value
Inv	New investment
d	Monthly operating days
m	Months of annual operation
€	Cost of electricity
ΔP	Difference in cable losses
P	Power
$\Delta P[k, i]$	Difference in cable losses of the conductor of the output i of the distribution boxes K
$R[k, i]$	Resistance of the conductor of the output i of the Knot Connection
$I[k, i]$	Current of the conductor of the output i of the Knot Connection
N_i	Initial investment
O_i	Mean annual savings
SPP	Simple Payback Time
VAL	Net Present Value
IRR	Internal Rate of Return
I	Current
D	Operation cost
a	Annual interest rate
€	Electricity cost

street lighting are numerous and since some of them even enable reductions in electricity consumption of more than 50%.

The cable losses analysed regularly throughout the transport and distribution of energy are often overlooked as a component of the cycle of lighting systems and an available means to save energy and improve the overall performance of the installation of street lighting.

In power production, transport, distribution and final consumption, various aspects have been particularly highlighted: environmentally and economically efficient production and dispatch; distributed generation and significant impacts on the operational characteristics of transport and distribution networks (Alvarez-Herault et al., 2012); dimensioning of the section of the conductor selection circuit to reduce the power consumption and optimize the operating distribution systems; reduction of distribution losses by reducing the reactive power optimization with capacitors placed on the distribution lines and layout optimization for radial distribution (Pires et al., 2012); use of superconducting power transmission (Vysotsky et al., 2011); and the circuit design of industrial and residential electrical installations (Parise and Parise, 2011).

Also noteworthy is the study and development of efficient equipment in power consumption (Lobão et al., 2014), in particular industrial induction motors (Hamer et al., 1997), to be responsible for much of the energy consumption.

In the case of outdoor lighting, two situations can be identified: on the one hand decorative lighting, for which the aesthetic component is the main objective rather than obeying the requirements of lighting and energy, and on the other functional lighting for outdoors (streets, roads, squares, etc.).

Functional lighting accounts for a significant weight of energy consumption and contributes to the security of persons and property. Various aspects have been the subject of study and research.

From the aspect of security, there are regulations and national and international standards, which contain the values and rules to be complied with: the Document of the Reference for Energy-Efficient Public Illumination in Portugal, norm EN13201 and CIE 115:2010, among others (CEN Publication EN 13201, 2003; CIE Publication No 115, 2010).

With respect to energy efficiency and reducing the consumption of street lighting installations, we can separate the study into three aspects: one that includes the technological development of lamps and luminaires, as mentioned in Kostic et al. (2009), Hermoso Orzáez and de Andrés Díaz (2013), Sadhan Mahapatra and Chanakya (2009), Mahlia et al. (2011), Mockey Coureaux and Manzano (2013) and Sperber et al. (2012); another that includes the study and development of systems for the control of lamps and luminaires that under the project conditions allow the reduction of power consumption, for example the use of equipment that allows the variation in the luminous flux as a function of time and traffic conditions on the roads (Xiao et al., 2010; Burgos-Payan et al., 2012; Yan et al., 2009; Parise et al., 2013; Siddiqui et al., 2012); finally, we may consider integrating the two previous aspects into the installation of the whole system, for the purpose of classification of a public lighting installation from the point of view of energy and lighting (Radulovic et al., 2011; ADENE, 2011), into which we can integrate the present study.

In a street lighting installation, the reduction of energy consumption in order to improve energy efficiency has to contribute to the efficiency of the real lamps and losses in the cables of the installation, normally themes that are studied separately. It is intended to connect these two aspects of research, including, in the economic analysis, the influence of efficient lamps and the losses they cause in the installation. The selection of the connection between optimal cables and the influence of efficient lamps will also be demonstrated experimentally, in addition to the simulation results, providing an economic analysis. This paper is structured as follows. Section 2 presents a description of the formulation. Section 3 explains the economic evaluation. Section 4 illustrates the software application. Section 5 presents the results obtained in simulation and the experimental results. Finally, concluding remarks are given in Section 6.

2. Formulation

Good quality lighting design contributes good efficiency from the point of view of energy, security and illumination. The lighting class is not always identical for all the hours of the night. Therefore, it is up to the planners and designers, together with the entities responsible for public lighting (municipalities and dealership networks), to determine the selected classes throughout the night.

Illuminance is the ratio between the luminous flux emitted in all directions by a light source $\partial\varphi$ incident on an element surface and the area ∂A of this element. The unit is the lux (lx).

The illuminance at point P, E_P, of the road surface can be calculated using as a reference the representation of Fig. 1 and the light intensity I (cd) in a graph typically provided by the manufacturer of the luminaire used.

$$E_P = \left(\frac{I_{\bar{\gamma}}}{d^2}\right)\cos\gamma \qquad (1)$$