# Economic Analysis of a Controllable Device with Smart Grid Features Applied to LED Street Lighting System

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*Abstract*—**Almost all luminaires that are used in street lighting system does not have communication, control and management infrastructure. Moreover, the artificial lighting system is responsible for the consumption of approximately 30% of all electricity generated in the world. Within this context, the LED technology offers flexibility and high efficiency, being suitable to be connected with smart devices, allowing the usage of possible alternatives to reduce energy consumption and providing significant economic saving. This work aims to perform an economic analysis of a controllable device with smart grid features applied to LED street lighting system in order to evaluate the efficiency of its usage as well as possible benefits on public lighting system and monitoring of low voltage grid parameters. The results have shown low payback periods and a promising internal return rate when compared with other applications, such as saving accounts. The smart grid features on the controller allows simple integration with renewable sources and central management and controlling lighting system.**

***Keywords— Economic Analysis, Power quality parameters, Smart grid, Smart lighting device, Street lighting system***

## I. INTRODUCTION

The conventional luminaires applied to street lighting system are not able to perform communication, control and management features [1]. Furthermore, the system is also not capable to measure useful information from the luminaire, i.e. energy consumption and detection of possible failures in the luminaire. In this sense, it is possible to notice that the large majority of street lighting systems were designed using old equipment and techniques [2]. However, due to the advance in science as well as the increase number of industrial researches regarding the development of modern devices and computational processes, the application of smart and communication technologies in the conventional street lighting systems provides prospects for monitoring, management and automation, allowing the interconnection of different intelligent devices.

It is noteworthy that the lamp needs to offer flexibility and high efficiency to accomplish the tasks received from the controller. Besides, for instance, it is not feasible to perform dimming control in high-pressure sodium lamps, which are the most common lamps used in the street lighting systems. In this context, the LED technology has the advantage to meet all the necessary requirements [3] and according to [4], its usage has gained notoriety due to its excellent photometric characteristics, such as high color rendering index (CRI), high luminous efficacy (lm / W), high mechanical strength, long lifespan (up to 100.000 hours) and reduction of light pollution [5].

It is estimated that about 30% of all electricity generated in the world is used to produce artificial lighting [6]. Therefore, it is possible to notice that artificial lighting systems represent a large potential for energy cost saving. Within this context, the usage of alternatives to reduce energy consumption in lighting systems could provide significant economic saving and reduction of environmental impacts. The so called intelligent lighting system is integrated with several devices, such as sensors, lighting fixtures, transceivers, energy meters, among other elements that allow measurement and controlling of the whole system through autonomous algorithm [12]. In this way, it turns possible the usage of available resources to optimize its functions as well as to solve inheriting issues in lighting systems.

With the insertion of smart devices in street lighting system as well as the integration of LED lamps, it is important to perform a deeply analysis to ensure both technical and economic feasibility of these types of prototypes. In this sense, this work aims to perform an economic analysis of a controllable device with smart grid features applied to LED street lighting system in order to evaluate the efficiency of its usage as well as possible benefits on public lighting system. This paper is organized as follows. In Section II is presented a detailed description of the developed intelligent device to be used in smart lighting application as well as to measure power quality parameters, which was proposed by the authors in [7]. It is proposed in the Section III two critical scenarios to economics assessment of the smart device in the street lighting application and they are evaluated using two different dimming strategies. In Section IV are shown the economic analysis concerning all the proposed scenarios and it is performed a brief discussion. Finally, in Section V are given the conclusions of this work.

## II. SMART MODULE FOR LIGHTING APPLICATION AND POWER QUALITY PARAMETERS MEASUREMENT

The proposed smart lighting device and all its sensors are well discussed by the authors in [7]. The main concept of the smart system is shown in Fig. 1. The smart module, represented by the number 2, is connected between the luminaire and the power grid and it has the prior function to receive commands from the central supervisory system, providing measurement data from the electrical network, such as sags, swells or possible failures as well as to perform automatic control dimming. In order to ensure an uninterrupted and isolated power source, this smart module has a backup battery, which is represented by the number 1, where it allows the system to maintain the communication with the central supervisory in case of failures, assuring the fault detection. The number 3 is the LED driver that is responsible to receive the control signals from the central supervisory and to deliver the respective and adequate power to the LED lamp.

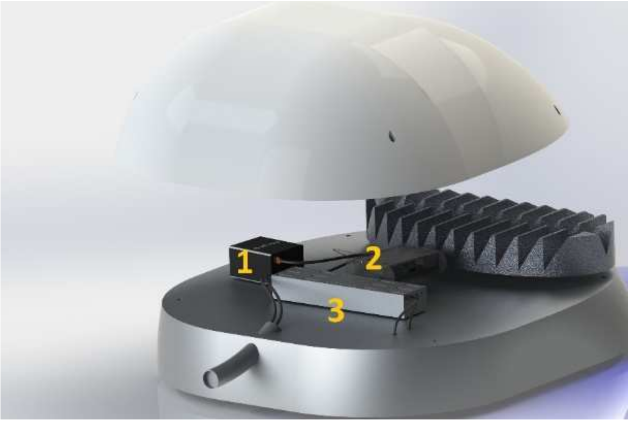

Fig. 1. Concept of the smart lighting system.

It is worth to notice that this smart module has several sensors, such as photocell to detect ambient light, presence sensor to detect pedestrians and voltage and current sensors to monitor the system operation. With the data acquired from the sensor and using the control interface, it is possible to operate remotely in order to manage and control the luminaire parameters as well as to provide information concerning the power grid. The smart module is responsible to analyze in real time the events from the power grid, such as sag, swell and possible failures. However, the harmonics are analyzed offline in the supervisory system.

The traditional lighting system only uses information about the amount of light to define the instant to power on and off the lights. Whereas, through the usage of this smart equipment, it is also possible to implement complex dimerization strategies that could change the luminaires behavior based on pedestrians detection, ambient light, time or network demand. Another intelligent feature includes the detection of defective lamps, which is based on the drained current and weather information measurement, such as temperature, humidity and solar incidence.

The acquired information received from the discussed module demands high computational effort and a huge memory capacity to storage. In this sense, the information stemming from both grid and luminaire are sent to a central supervisory system, allowing to save the data in a certain period of time for further analysis as well as to monitor possible failures in the system. Besides, it is possible to perform an automatic dimming in relation to a preprogrammed reference curve. The proposed architecture is presented in Fig. 2 and as can be seen, the modules are distributed in the streets and send information to the central controllers through ZigBee interface. These last ones are connected to a local Ethernet, using it to share the data coming from his zone to a central server. In this sense, technicians have the capability to switch off luminaires for maintenance. Additionally, the city hall may also be able to receive energy consumption reports and perform financial planning.

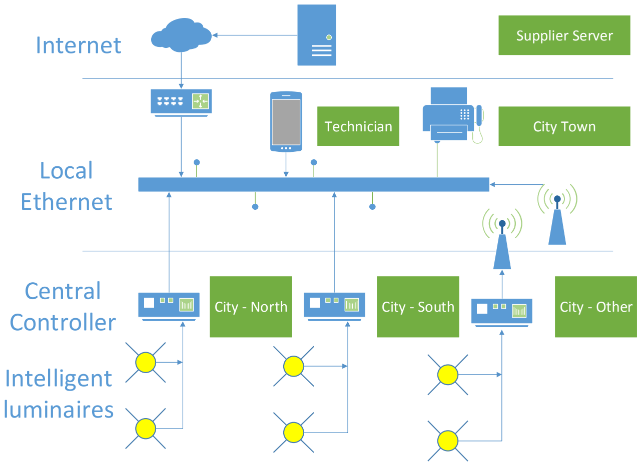

Fig. 2. Proposed architecture.

A diagram containing the luminaire controller schematic is shown in Fig. 3. The components were divided in accordance with their location level. The microprocessor TM4C123G is responsible to acquire and process the data stemming from the multiple sensors. Moreover, the same controller has a PWM interface for the luminaire driver and a ZigBee network interface. Other features include USB connection, real time clock, DALI transceivers and a backup battery.

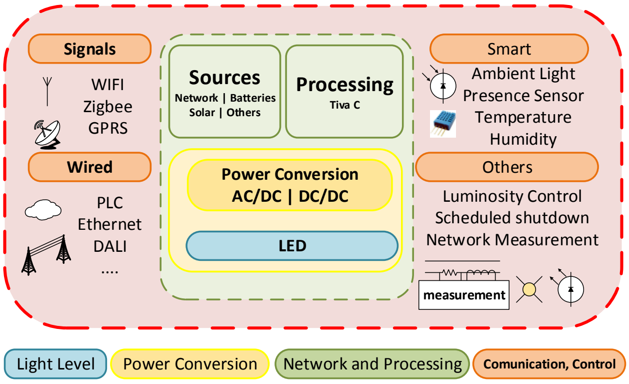

Fig. 3. Diagram of the electronic system.

## III. CRITICAL SCENARIOS OF ECONOMICS ANALYSIS

To perform the economic evaluation were proposed two basic scenarios. The first one consists of the installation of smart module for lighting application and power quality parameters measurement proposed in [7] in lampposts that already have LED lamps. The second is the replacement of the high-pressure sodium (HPS) and high-pressure mercury (HPM) lamp in street lighting by LED lamps with the correspondent smart module. Note that these lamps where chosen due to their extensive use in Brazilians street lighting systems [10]. Finally, two dimming cases were considered, where the first one regards the full operation of the lighting system during the period of 6 pm to 12 pm and with 50% of dimming from 12 pm to 6 am. In the second, it is considered 50% of dimming during the period of 6 pm to 6 am and full operation only when there is detection of pedestrians.

The first methodology for dimming is adequate to be used in places where there is a few or almost no presence of people after a certain time (e.g. midnight). This condition could occur frequently in universities and squares, when after a specific period the lighting system has the primary function to provide security. However, the other dimming methodology is quite suitable in situations that the pedestrians' traffic could not be expected consistently, such as streets and avenues in central areas. In this case, there is occasional flux of pedestrian due to the function of various activities, being extremely hard to determine a safety and specific period of time to proceed with dimerization. It is noteworthy that exists a time hysteresis that the lamp is turned on, which is suitable in cases that the pedestrians' traffic varies in a short period, with the aim to not affect the luminaire lifespan. Additionally, in these localities, it is possible to determine a maximum traffic level of pedestrians that the system implementation is not feasible.

For a dimming process based on hours, it is possible to easily determine the lighting system consumption just by relating the number of hours that the system remains in a certain lighting state with the required power, which results directly in the consumption of a certain period.

However, it is not an easy task to calculate the system energy consumption as a function of the pedestrians' traffic. It is necessary to perform traffic estimation in the area to be evaluated, allowing the determination of the time in each dimming state, respectively. In this way, it is intended to use a factor, which represents the percentage of time that the system operates with pedestrians' traffic, called in this paper by "T".

The T factor determines which value of traffic is feasible to implement dimming control. To understand the variation of the results based on this factor, the economic parameters are analyzed in the range between 10% and 90% of traffic. A brief summary of the proposed cases is shown in Table I.

As can be noticed in the equations presented in the Table I, one of the parameters is the number of hours that the luminaire remains switched on and this value can be determined through the number of sunshine hours that could strongly influence the economic outcome. The experimentation analyses were performed in the city of Juiz de Fora, Brazil. For this city, the number of hours varies between 10 am and 30 minutes on the winter solstice (June 21th) and 13 hours and 10 minutes on the summer solstice (December 21th). Therefore, the simulations have been carried out between these two extremes time periods

TABLE I. STUDY CASES.

| Case | Dimming Methodology | Consumption period |
|---|---|---|
| Lighting System that already has LED array | - Until 24h: 100%<br>- After 24h: 50% | Consumption = number of hours at 100% · power at 100% + number of hours at 50% · power at 50% |
| Replacing the high-pressure sodium lamp (HPS) | - Until 24h: 100%<br>- After 24h: 50% | Consumption = number of hours at 100% · power at 100% + number of hours at 50% · power at 50% |
| Replacing the high-pressure mercury lamp (HPM) | - Until 24h: 100%<br>- After 24h: 50% | Consumption = number of hours at 100% · power at 100% + number of hours at 50% · power at 50% |
| Automated Lighting System that already has LED array | - Dimming in function of pedestrians' traffic | Consumption = (1 − T) · nighttime · power at 100% + T · nighttime · power at 50% |

The both electrical and photometric parameters of the LED array used in these experimentations are compared with HPS and HPM lamps and are also presented in Table II. Despite of the higher scotopic response given by some HPS lamps, the LED technology has an spectral power distribution that matches with the photopic response of the human eye, allowing lower wattage as well as best reproduction of colors [8].

TABLE II. LAMP PARAMETERS.

| Parameter | LED | HPS | HPM |
|---|---|---|---|
| Wattage | 63 W | 70 W | 80 W |
| Lamp | 52 lm/W | 85 lm/W | 46 lm/W |
| Lifetime | Up to 50.000h | 28.000h | 16.000h |
| CRI | >80 | 23 | 48 |
| Luminosity | 3225 lm | 6000 lm | 3700 lm |
| Model | Epileds | SONT70W PLUS [9] | HPLN80W-IMP[9] |

Due to the recent nature of LED technology, it is expected a great development in the next years concerning its efficiency, as shown in the Fig 4. Thus, the last analysis performed in this paper consists in change the LED efficiency to understand how this value could affect the economic feasibility. Besides, this analysis also helps to predict how this system could be useful in the future.

Moreover, with the growing researches related to the development of efficient designs for LED drivers, the relative cost of manufacturing is reducing quickly, as shown in Fig. 5. It is observed that there is a strong tendency to decrease its manufacturing costs until the year of 2020, expected to be around 30% of the actual manufacturing cost.

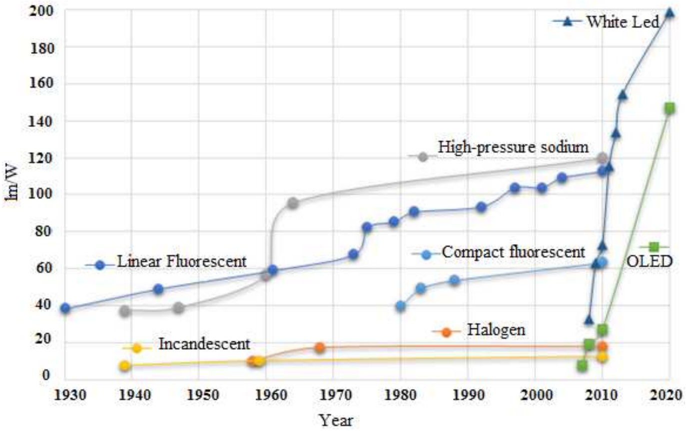

Fig 4. Comparison of luminous efficacy between main lighting technologies and LED. (Adapted from [11]. 2020 projection).

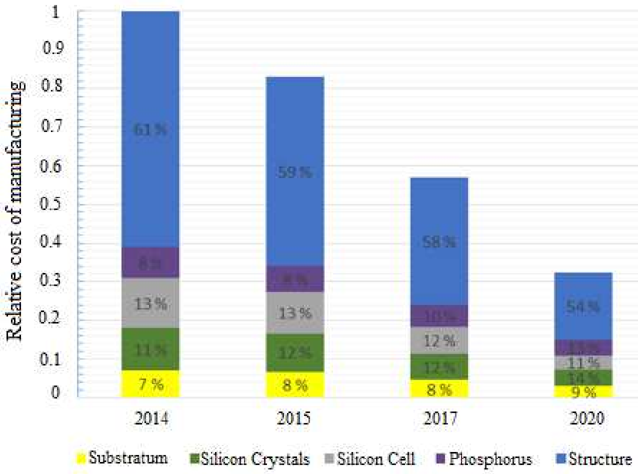

Fig. 5. Projection of relative cost of manufacturing of an LED luminaire [13].

For the analysis regarding the payback of the investment, it was performed a comparison between costs and benefits produced over the prototype lifespan. The cost analysis consists of a detailed survey of prototypes cost as well as the study of main economic indicators, which are the payback and internal rate of return (IRR).

The payback period is calculated by the simple relation between the total investments divided by the generated savings each month, computing how long is possible to obtain profits from this system, as shown in (1).

$$Payback\ period = \frac{R_j}{C_T} \qquad (1)$$

Where $R_j$ is the gross revenue of the project in the year ($/year) and $C_T$ is the total cost of the project ($).

The IRR is the flow rate capable to balance the benefits with the negative flow of investments and this calculation rate is presented in (2). It is possible to notice that a large value of IRR represents a good investment. In addition, in order to give a reference to provide comparisons, in Brazil the saving accounts have shown IRR around 7%.

$$\sum_{j=0}^{n} R_J + (1+i)^j = \sum_{j=0}^{n} C_J + (1+i)^j \qquad (2)$$

Where $R_J$ is the annual revenue of the project in the year j ($/year), $C_J$ is the total cost of the project ($) and n is the project lifespan (years).

## IV. RESULTS AND DISCUSSIONS

To evaluate the proposed analyses, it is important to first establish the cost of the presented system. It is noteworthy that even though the power quality features brings several benefits to utilities and consumers, it is not easy to quantify their economic evaluation and therefore, it is not considered in this study. In this way, the considered costs include the necessary value to implement only the dimming control, which in the first and fourth scenarios are enough. However, in the second and third scenarios, the economic parameters could change due to the costs concerning the installation of the LED luminaires.

In the Table III is shown the cost of each components of the control system as well as its total cost. It was not considered manufacturing costs since these values could strongly change in relation of the number of the units produced. As the final cost of the prototype will change in accordance with several factors, it was considered in this economic analysis a cost of $220, which corresponds to the value of a similar product found in the market, referred in [14], without the Brazilian importation duties and taxes.

Considering that the LED lamp can operate during 50.000 hours, it was possible to set the evaluation of the system in 12 years.

TABLE III. COSTS OF THE PROTOTYPE SYSTEM .

| **Part** | **Units** | **Unit cost** | **Total cost** |
|---|---|---|---|
| Microcontroller | 1 | $12,99 | $12,99 |
| ZigBee | 1 | $37,95 | $37,95 |
| Board | 1 | $2,07 | $2,07 |
| Luminosity Sensor | 1 | $2,08 | $2,08 |
| Presence Sensor | 1 | $16,04 | $16,04 |
| Connectors | 10 | $0,40 | $4,00 |
| Resistor | 40 | $0,10 | $4,00 |
| Capacitor | 10 | $0,40 | $4,00 |
| Box | 1 | $34,56 | $34,56 |
| Others | 1 | $15,00 | $15,00 |
| Total | $132,68 | | |

The economic parameters are estimated based on the proposed scenarios of the Table I and the lamp parameters of the Table II, which are presented in the Table IV. It is noteworthy that the usage of dimming control around 50% percent of time presents a low payback time and an interesting internal return rate when is compared to the return of saving accounts.

TABLE IV. ECONOMIC INDICATORS OF THE MAIN SCENARIOS.

| **Scenario** | **IRR** | **Payback** |
|---|---|---|
| Lighting System that already has LED array | 5,5% | 10,5 years |
| Replacing the high-pressure sodium lamp (HPS) | 13,5% | 7,2 years |
| Replacing the high-pressure mercury lamp (HPM) | 23,8% | 5,0 years |

For the fourth scenario, the values were analyzed in relation of the time percent that the system is under traffic at night. The results are presented in the Fig. 6. Considering the life time proposed of 12 years, the economic feasibility could be restricted to a traffic percentage of 70% of time operation. This high value indicates a strong economic potential for this kind of system. Nevertheless, on the IRR side, the economic viability is restricted to the maximum of 30% of traffic during all night, which gives an IRR larger than saving accounts.

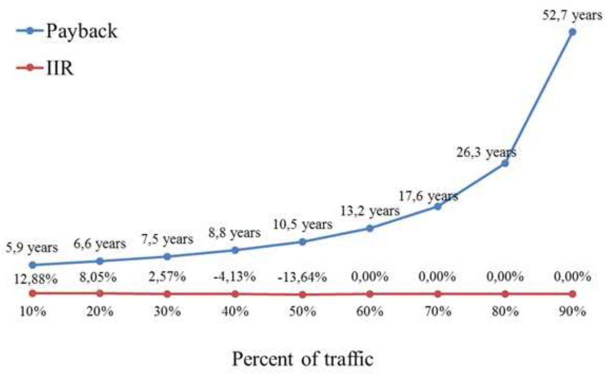

Fig. 6. Payback and IRR for fourth scenario considering the pedestrians' traffic variation.

The manufacturing cost is affected by many reasons, i.e. the number of units produced, technological maturity, cost reduction of components, project optimizations, among others. Considering that is important to evaluate the system economic parameters by changing the cost of the dimerization system, the Fig 7 shows the IRR of the first three scenarios regarding the project cost reductions up to 40% and in Fig. 8 is presented the evolution of payback time in the same conditions.

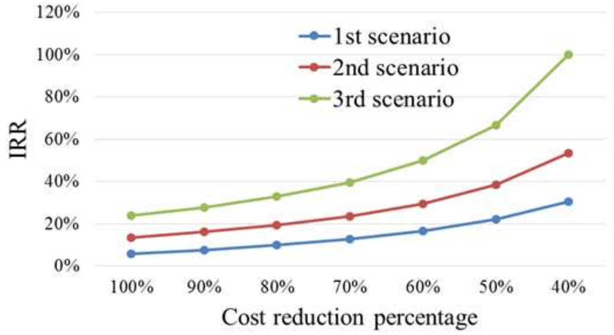

Fig. 7. IRR considering cost variation of the control system.

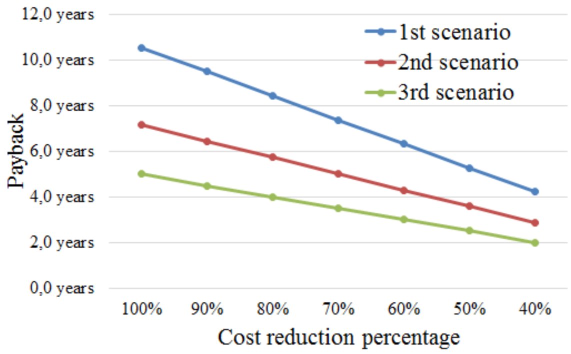

Fig. 8. Payback considering cost variation of the control system.

Note that the payback time behaves linearly when considering the system cost reduction, while the IRR varies dramatically, being more beneficed by it. Although the 40% reduction seems larger, the prototype costs are higher than wholesale.

According to Fig 4, the perspectives have shown that the efficiency of LED lighting can increase up to 200 lm\W in the next 10 years and concerning this prediction, it is important to evaluate the economic parameters in these situations.

The Fig. 9 exhibits the IRR for the dimming control regarding the actual efficiency until 180 lm\w. In the Figure 10 is performed the same analysis for the payback time. It is observed that by enhancing the efficiency, the feasibility of the diming in comparison with other technologies is increased, as expected. However, it is also possible to notice that if the LED efficiency increases too much, there are just a few margin of gain to dimming control, reducing strongly the economic feasibility of this strategy.

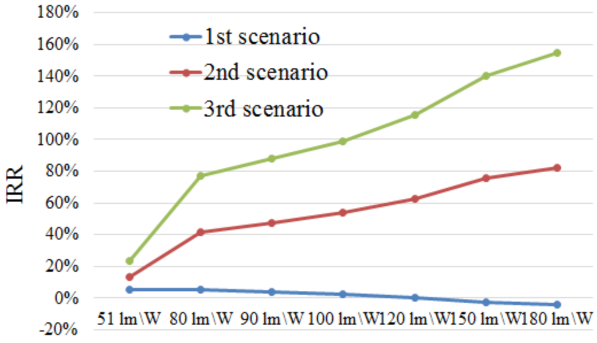

Fig. 9. IRR variation considering the improvement of LED efficiency.

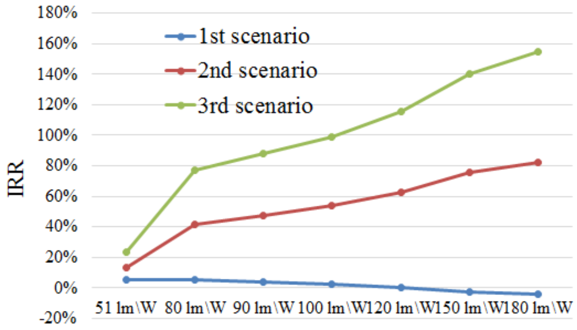

Fig. 10. Payback variation considering improvement of LED efficiency.

Additionally, there are other advantages of dimming control that is not referred in this work, such as the increase in lifespan due to the reduction of the produced heat, possibility of power factor control, novel possibilities of dimming strategies that are suitable in specific places, among others.

## V. CONCLUSIONS AND FUTURE WORKS

This paper has presented a brief review of an economic analysis for dimming control of LED lamps applied to public lighting systems. By comparing the LED with conventional lighting systems, it has been demonstrated in this work the economic feasibility of this technology, which has provided an actual payback time between 4 and 10 years.

Moreover, it has been performed an assessment of dimming control considering the future improvement projection of LED technology and the cost reduction of the control system. It has observed that the reduction of the control system cost can strongly affect the system feasibility, producing payback times lower than 5 years when considering reductions about 40% on the prototype cost.

On the other side, the increased efficiency in LED systems can reduce the margin of gain when compared with conventional LED lighting systems. In this case, it would be also necessary higher cost reductions of the prototype to make the technology viable.

Besides the advantage of the use of dimmer controllers, as the one proposed in this work, the proposed technology has the capability to add several other functionalities, such as power quality analysis, power factor control, implementation of complex and specific dimming strategies, integration with renewable sources and others. All these features carry out a large portion of economic benefits that will be considered in future works.

## ACKNOWLEDGMENT

The authors would like to thank the Federal University of Juiz de Fora, CAPES, FAPEMIG, CNPq, INERGE and the Brazilian Government for all financial, technical and scientific support on this work.

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