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THE ROLE OF SMART LIGHTING IN SMART GRID IN THE CONTEXT OF SMART CITIES

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Abstract — Smart lighting is one of the key needs of everyday life for citizens. On the one hand, the presence of light is critical to provide security and safety. On the other hand, excessive usage of electrical energy influences greenhouse gasses increase. This white paper explores the importance of smart lighting in the context of smart cities. In particular, the importance of smart energy management of lighting and the choice of right technologies are discussed. Some possible technology solutions are presented and their performance are analyzed.

Keywords: smart cities; smart lighting; smart grid

I. INTRODUCTION

According to the World Health Organization (WHO), in 2012 around 7 million people died as a result of air pollution exposure – one in eight of total global deaths. This proves that air pollution is the biggest environmental health risk of the world [1].

Human activities, in particular the burning of fossil fuels, not only are a source of air pollution, but they release also sufficient quantities of carbon dioxide to affect the global climate. As a result of this, in addition to the direct effects of pollution on human health, the excessive production of greenhouse gases and the consequent climate changes have been indirectly related to deaths due to indigence, malnutrition and infectious diseases directly influenced by the climate, such as malaria. WHO has estimated that under the current conditions, these indirect effects could lead to 250.000 additional deaths per year between 2030 and 2050, with a significant increase in the cost of health, estimated to be 2-4 billion USD per year by 2030 [2].

Regarding this issues, in 2014 the European Council has proposed some energy objectives to be reached by 2030. The key targets are a reduction of at least 40% in greenhouse gas emissions (from 1990 levels), at least 32% share of renewable energy and an improvement of at least 32.5% in energy efficiency. [3]

Recently it was showed that street lighting is responsible for 6% of the greenhouse global gases emissions and for 19% of the total use of electrical energy [4]. From an economic point of view, street lighting is often the first or second largest local government energy use, typically accounting for 25–50% of a municipal energy bill. However, streetlights are essential to ensure safety in streets and to enhance security in homes and public areas. In addition, lights in cities had a crucial role in increasing work time, thus providing financial benefits for citizens.

Considering all these facts, it is evident that lighting energy management should be one of the key topic of smart cities, allowing the achievement of concrete objectives in the short and medium term, such as cost optimization, reduction of pollution, reduction of global warming and increasing the quality of life of citizens. For instance, it was calculated that saving 40% of electrical energy used in lighting could result in a reduction of 50% of all the greenhouse gasses produced in US [4].

This white paper describes smart lighting and the need for smart grid in Section II, the crucial role of smart lighting in Section III, and some promising solutions that can applied to improve efficiency so reducing energy consumption in Section IV.

II. SMART GRID AND SMART LIGHTING

The increased consumption of electrical power is producing enormous amount of CO2, thus challenging environmental sustainability. Besides, considering the shortage of fossil energy resources, the need for electrical power will be incremented even more than what is estimated. Therefore, the existing power grid needs to be smarter, more reliable, efficient, and secure, along with affordable energy generation, distribution, and consumption [5]. The main goal of smart grid is providing solutions for the abovementioned requirements by using advanced, information-based technologies [6]

Table.1 compares the main characteristics of future smart grid and traditional grid. As we can see, smart grid provides more flexibility to control the overall grid such as self-monitoring, self-healing, etc. Moreover, in smart grids we can identify a bidirectional flow of power and information between a decentralized power infrastructure and the final consumers. This is in contrast to what happens in traditional grids, in which there is only a unidirectional flow of power and the generation of electricity is often centralized.[6]

Advanced Metering Infrastructure (AMI) is an important part of smart grids. It provides two-way communication and integrates many advanced features and techniques such as advanced sensors, smart meters,

monitoring systems, computer hardware and data management systems. Moreover, AMI allows energy consumption data collection.

TABLE I. COMPARISON BETWEEN SMART GRID AND EXISTING GRID [6]

Existing Grid	***Smart Grid***
Electromechanical	Digital
Centralized Generation	Distributed Generation
One way communication	Two way communication
Hierarchical	Network
Few sensors	Sensors throughout
Blind	Self-monitoring
Manual restoration	Self-healing
Failure and blackouts	Active and Islanding
Manual check tests	Remote check tests
Limited Control	Pervasive control

Regarding the information flow, two different infrastructures coexist in the smart grid systems. The first one connects smart meters with data centers and the second one connects sensors with the smart grid control system. A mixture of technologies are used in the two infrastructures according to the amount of data that need to be transferred, including cellular networks, optic fibers, PLC and wireless communications (such as ZigBee, 6LowPAN, Z-wave, and others wireless technologies). [7]

Smart lighting is one of the possible application that could be implemented inside the smart grid infrastructure and it is made possible by the continuous exchange of information between sensors, distributed control systems and final actuators (in this case lamps).

Smart lighting is a generic term for a group a heterogeneous technologic solutions, with the common goal of increase energy efficiency, so reducing the negative impact of illumination on environment. It is based on the integration of various sensors, control systems with wide range of capabilities, and communication technologies.

This theoretically allows a precise control of every single lamp (e.g.: it can be switched on or off, the intensity and the colour of the light can be adjusted), regardless the number of lamps present in the system. These complex configurations are commonly called "light scenes" and clearly require a fine orchestration, made possible by the framework offered by smart-grids.

Bearing in mind the optimization problem that smart lighting tries to solve, research in this area is developing in four different, complementary and interconnected areas.

The first one is the Embedded Level, and it considers the lamp source itself. It has been shown that a correct choice of lamp technology (for example the use of modern LEDs) allows 50 to 70% of energy savings [4]. Moreover, an appropriate choice can significantly increase the life span of the lamps themselves, greatly reducing installation and maintenance costs. This is particularly true for street lighting, where replacement operations are particularly expensive.

The second area is known as System Level and it considers groups of lamps deployed in specific locations, which together form luminaries and lighting systems. For example, it is possible to control (i.e., turn on/off the lights) streetlights only when necessary, e.g., according with data retrieved by motion sensors. Chronological and astronomical scheduling is another example. It allows to control the lamps setting timers using information about the expected sunrise and sunset timing. Moreover it can be integrated with data produced by sensors such as ambient light sensors.

The third area is represented by the Grid Level. In general terms, studies in this area are intended to optimize management and monitoring of power sources, both from the point of view of energy generation plants and energy distribution network. Considering that street lighting is one of the main energy expenditures of the various municipalities and consequently it is a significant source of pollution, it is evident

that an optimization of energy production and the choice of the kind of energy source to be used (e.g. renewable sources), could have important benefits both in terms of costs and environmental quality.

The last main research area is known as Communication and Sensing Level, and it considers the framework that allows integration among the areas mentioned above. Here we take into account the systems of sensors used in smart-lighting (e.g. ambient light and presence sensors or scheduling systems) and the physical communication channels used to transfer data (e.g. PLC, wireless or cellular networks, …).

Smart lighting has many features that allows a more efficient use. Different strategies can be adopted to that purpose [8]. Some of these strategies can be summarized as follows:

- *zoning,* i.e. dividing an area in different, independently controlled zones;
- scheduling, when controlling the light remotely, switching them on/off based on time and season;
- *occupancy,* when turning the light on/off based on the detection of persons or vehicles in the area of interest;
- *daylighting,* in which lamps are controlled according to the light already present in the environment;
- *integrating,* especially used in indoor environments, which merges the lighting system with the Heating, Ventilation, and Air Conditioning (HVAC) and solar blind systems.

Considering these strategies, efficient energy management can be achieved.

Flexibility of smart grid enables the use of various technologies for smart lighting, as described in the following Section.

III. SMART LIGHTING TECHNOLOGIES

Although energy efficiency is a crucial factor in smart grid applications, achieving an efficient communication service is another important concern. Since smart grid can adopt various communication systems, it is important to understand the advantages and disadvantages of each of them when used for smart lighting.

TABLE II. COMMUNICATION TECHNOLOGIES IN SMART GRID [7]

Communication Technology	*Data-rate*	*Coverage range*	*Frequency*	*Limitation*
PLC	2-3 Mbps	1-3 km	1-30 MHz	Harsh, noisy channel environment
3G	384 Kbps-2 Mbps	1-10 km	1.93-1.98 GHz 2.11-2.17 GHz (licensed)	Costly spectrum fees
WiMAX	<75 Mbps	10-50 km (LOS) 1-5 km (NLOS)	2.5 GHZ, 3.5 GHz, 5.8 GHz	Not widespread
GSM	<14.4 Kbps	1-10 km	900-1800 MHz	Low data rates
ZigBee	250 Kbps	30-50 m	2.4 GHz-868-915 MHz	Low data rates, short range

Communication between electric utilities and smart meters can be achieved using either wired or wireless communication channels. Wired technologies exhibit advantages such as no dependency on battery and no interference issues. Conversely, wireless communications provides connection in unreachable areas at a low cost. Nevertheless, in wireless systems the signal at the receiver side can be low due to transmission path loss.

Performance of some technologies are presented below and in [9]

A. Powerline Communication

Power Lines Communications (PLCs) are wired communication systems that enable data communication over existing power cables. Since it is possible to use the already available infrastructure, PLC is a particularly suitable choice in the case of smart lighting. Thus, the main advantage of this approach is the low installation cost.

Amongst the known disadvantages of PLCs are a harsh and noisy channel, high sensitivity to disturbances and small bandwidth. Moreover, due to the broadcasting feature of PLC (the signal is sent to all devices connected to the network), security concern is a relevant issue.

B. Cellular Network Communication

Various cellular networks are available for smart lighting such as 2G, 2.5G, 3G, WiMAX, and LTE.

Since cellular networks has already existed, there is no installation cost. Moreover, it is possible to send large amount of data with secure data transmission.

The main disadvantage of cellular network is the low reliability of connection. Indeed, due to the huge number of network customers, network congestion can be excluded so that and service quality is not ensured. Communication costs should be also taken into account.

C. Wireless Mesh

Mesh wireless networks consist of set of nodes where each node is dynamically connected with as many other nodes as possible and cooperate with them to efficiently route data from/to users. Mesh networking has features such as redundancy, self-healing, self-configuration, effective maintenance costs and load balancing. Moreover, the coverage range can be extended simply by adding new nodes.

Some disadvantages of mesh networks depend on signal fading, interference and network capacity. However, they are usually able to ensure reliable and flexible routing. Moreover, a control center is often needed to manage the network.

D. ZigBee

ZigBee has many good features for smart grid such as low power usage, low bandwidth requirements, low installation and operation costs and simple, robust and easy network implementation. Unfortunately, mainly due to the simple and cheap hardware, ZigBee exhibits some limitations such as small memory size, low processing capability and high sensitivity to interference from other devices in the same transmission medium.

Considering all the above technologies, different solutions for smart lighting have been investigated.

IV. SMART LIGHTING SOLUTIONS

One of the first solutions proposed to implement smart lighting is the replacement of old lamps with new technologies based on the more efficient LED technology. A study in Taiwan has shown that replacing mercury vapor lights with LEDs could save 50% electricity with a high acceptance level of the general public [10]. The lamps structure itself should also be optimized. For instance, to avoid the phenomenon known as "wasted light" or "lost light", outdoor lighting should be fully shielded and directed only where needed. Quite surprisingly it has been estimated that 30% of street lighting is wasted, which corresponds to 22,000 gigawatt-hours per year (or 15.5 million metric tons of greenhouse gases) in the US [11].

Other studies have been done to demonstrate how an optimized lamp design could reduce energy waste, increasing the efficiency of lighting. For instance, a new lamp design called Total Internal Reflection (TIR) has been proposed [12]. It combines LED technology and special lens in order to collimate light in parallel beams, which can be easily directed only in the area of interest. LEDs array and lens are mounted inside a reflecting cavity, which further “recycles” light, so increasing the optical efficiency. Moreover, researchers analyzed different street pole arrangements (central, zigzag, and single-side) and determined the optical utilization factor, defined as the ratio of the light flux on the street target region and the total one emitted by the lamps. They found that this new design allows an efficient and homogeneous distribution of light. In addition, the computed efficiency indexes are high (up to about 80%), even compared with those reported in previous top level designs, which ensure an efficiency of about 45%.

Another promising smart street lighting solution has been implemented in Malaysia [13]. Accordingly, street lighting is turned on only when a wireless sensor network detect the presence of persons. In the low traffic street of Shah Alam in Malaysia, that solution allowed to save approximately 60% of energy and around 40% the electricity bill.

Another aspect that should be considered is related to the operational costs of smart lighting solutions, which could often be optimized using innovative approaches. For example, optimizing standard

PLC technology, authors were able to remotely turn on the lamps using zero energy wake up receivers, thus eliminating power consumption during standby mode. Indeed, in standard PLC hardware designs, modems need to be constantly active to be able to detect the driving (i.e., switch on/off) signal. Even though the wasted power in PLC modems is small when the light is turned off (about 0.5 W), considering the number of lights in a city, the required total power becomes significant. For instance, a medium size city could require about 30,000 streetlights, which result in about 15 kW of wasted standby power. In the proposed architecture the modem is by default turned-off and special hardware turn it on by exploiting the energy associated with the electric signal encoding the control information. After the modem activation, the signal can be decoded and the lamp can be activated [14], [15].

CONCLUSIONS

This white paper illustrated the great relevance of smart lighting in the context of smart cities. In particular, their contribution to the city energy consumption and the need for an efficient energy management of lighting have been discussed. Moreover, some relevant technology solution have been analyzed, thus providing guide lines for the identification of the best choice for a given situation.

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