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Original Research Article

Engineering design and assessment of a demand-sensitive LED streetlighting system

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ABSTRACT

A solid-state lighting technology was demonstrated at a US Navy Research Center in Maryland – where light-emitting diode (LED) luminaires were substituted for existing high pressure sodium (HPS) streetlighting units, and an intelligent lighting control system was deployed. This paper summarizes the prudent engineering design and implementation of the demand-sensitive feature of the LED streetlighting system at Naval Surface Warfare Center (NSWC) Carderock Division that provides an annual average electricity and CO_2 savings of 74%. In addition, technical system performance and life-cycle assessment of the HPS and the new LED systems are discussed. Best practices and field experience that can help with other similar smart lighting implementation elsewhere are also summarized.

Introduction

This paper describes the technology implemented in the demonstration project entitled "Bi-level demand-sensitive LED street lighting systems", which was deployed at a US Navy Research Center in Maryland. The objective of the project was to replace a set of high-pressure sodium (HPS) streetlights at NSWC-Carderock with a more energy efficient and intelligent street lighting system based on solid-state lighting technology (or light emitting diode – LED).

Light emitting diode (LED) is emerging as the most energy efficient technology for lighting applications. Most of the existing applications focus on replacing existing streetlighting units with more energy efficient LED streetlighting system without any type of control to take advantage of its usage pattern. Examples include roadway lighting in Philadelphia, PA [1], walkway lighting in New York City, NY [2], roadway lighting on Golden Gate Bridge, CA [3] and roadway lighting in Portland, OR [4]. Findings from these projects indicate that the potential for energy savings of energy efficient LED-based systems is as much as 50% compared with that of the traditional high pressure sodium (HPS) lamps. One interesting feature of LEDs is the ability to reduce their illumination level without any significant impact upon life and color [5,6]. As a result, we have seen some LED demonstration projects explored dimmable features of LEDs with occupancy sensors, mainly for parking garages [7,8]. At present, LED lighting systems have become more commonly accepted and selected municipalities have already upgraded their streetlighting systems to LED, such as in Arlington, VA [9].

Most publications in the literature focus on methodology for indoor lighting control, e.g., methods for illumination control taking into account natural light [10–12], sensor network control for LED lighting system [13], and sensorless illumination control [14]. Some publications discuss energy saving potentials of selected outdoor lamps [15] and their lighting control drivers [16,17]. To the best of our knowledge, the use of intelligent control and communication network to enable the demand-sensitive feature of LED streetlighting systems has not been discussed in the literature.

The highlight of this work is the integration of the demand-sensitive feature onto the intelligent control of LED systems that are suitable for streetlighting applications. This was uniquely accomplished through a creative engineering design in integrating traffic sensors and smart server to perform area light control. This paper documents the technology development, assessment of the performance and cost-benefit analysis of the demonstrated system, as well as summarizes field experience that can help replicate this deployment in other facilities around the U.S. and elsewhere.

Technology description

The demonstrated technology is a smart bi-level demand-sensitive LED lighting system for outdoor street lighting applications

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that allows dimming as well as traffic sensing capability through a centralized controller. The highlights of the demonstrated system include the following characteristics:

- Use of LED light fixtures for energy savings, improved light quality, and infrastructure savings;
- Integration of streetlight controllers to enable bi-level and demand-sensitive features;
- Integration of traffic sensors for detecting moving traffic to minimize light output during low demand periods;
- Use of a smart server to perform area light control.

The demonstrated system comprises four main components: (1) LED light fixtures; (2) streetlight controller; (3) traffic/photocell sensors; and (4) a smart server, as shown in Fig. 1.

The system has been designed such that all LEDs are turned ON after the sunset, and their light intensity is dimmed at night to allow additional energy savings. Several traffic sensors are deployed to provide detection of foot and vehicle traffic at the demonstration site. These sensors provide inputs to the smart servers to allow turning up the light intensity of the LED units to 100% for about five minutes when foot/vehicle traffic is detected. LEDs are turned OFF simultaneously at sunrise.

Building Block 1: LEDs for streetlighting applications

In general, three major lamp types are common for outdoor lighting applications: high intensity discharge (HID), fluorescent, and incandescent. Among these, HID lamps are the most prevalent technologies being used for streetlighting applications. The most common HID lamps are mercury vapor (MV), metal halide (MH) and high pressure sodium (HPS). Of these three types, HPS and MH are predominant. MH lamps offer superior color quality with a bright white light output, while most HPS lamps offer greater efficiency at the expense of color rendering by producing an amber light [18].

Light emitting diode (LED) sources are well on their way to becoming the most energy efficient technology for outdoor lighting applications. Compared with their HID counterparts, LEDs can deliver comparable luminous efficacy, have longer life, provide better light quality and have instantaneous responses [18]. In addition, LEDs contain no mercury, thus minimizing disposal issues. Note that the study from University of California, Irvine [19] reveals that some colored LEDs may contain metallic toxicants, such as lead and arsenic. However, the study did not find lead in any of the blue or white LEDs. Also, according to the Pacific Northwest Pollution Prevention Resource Center (PPRC), currently LEDs are not classified as hazardous waste, and are disposed of in regular landfills [20].

Recently, induction lighting has become a light source of interest for many outdoor lighting applications. Similar to LED, induction lighting lamps deliver high energy efficacy (lumens/watt), and a high color rendering index (CRI) [18,21]. Manufacturers claim an operating life of more than 60,000 h, but this claim is yet to be proven. Some disadvantages of induction lighting include the following points: (1) induction lighting requires special housing because the shape of the lamp is large. This can be a challenge for retrofit applications; and (2) the induction lighting contains mercury, unlike LEDs which are mercury-free. This mercury content in induction lighting raises disposal issues.

For these reasons, LEDs have been chosen as the preferred technology for this demonstration project. Characteristics of various light sources, including LED, HID and induction lighting, are summarized in Table 1.

Building Block 2: streetlight controller

A streetlight controller acts as an interface between the LED light fixture and the smart server (to be discussed under Building Block 3). This building block allows polling information, such as failures, alarms, voltage, current, power, energy and number of burning hours, from the streetlights, and allows implementation of dimming command for light control according to signals from the smart server. The streetlight controller selected for the project is from Echelon. One streetlight controller is required for each LED luminaire.

Building Block 3: traffic/photocell sensor

Traffic sensors are placed on the roadway to allow detection of moving traffic (both vehicular and pedestrian). In general, the vehicles' headlights allow visibility only about 100 m ahead [22]. Turning up the streetlight intensity once the vehicle is at least 100 m ahead of the first light pole will help improve the visibility beyond that provides by the headlights. Traffic sensors selected for the demonstration is a set of passive infrared (PIR) motion transmitters and one receiver. The project also requires an event counter to record on/off transitions of motion transmitters. A photocell sensor is also used to turn ON and OFF all LED luminaires at sunset and sunrise respectively.

Building Block 4: smart server

The smart server is responsible for recording lamp status, energy use and operating hours from the streetlight controllers; collecting data from traffic/photocell sensors; and controlling the light status (ON/OFF/dim) via streetlight controllers. The smart server selected for the demonstration is from Echelon.

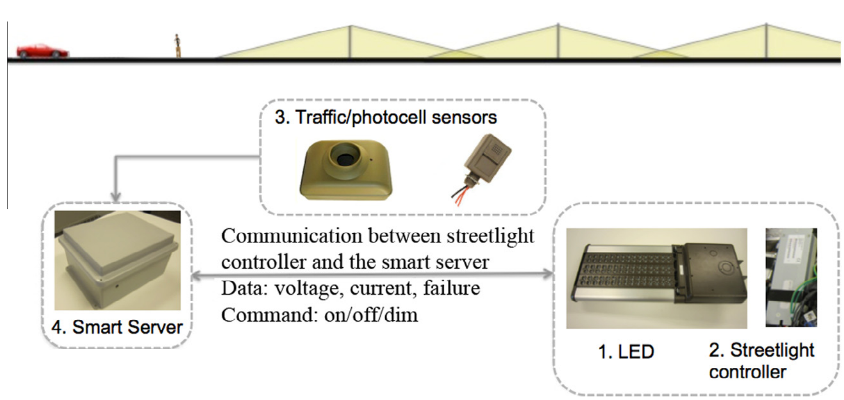

Fig. 1. Technology overview.