Energy Management System for Solar-powered Streetlighting Systems

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Abstract. Public lighting or street lighting systems are raised sources of light on the edge of the road or walkway, that is turned ON at night or during bad weather to lighten the streets and turned OFF in the morning. The major problem with streetlights is their excessive energy consumption as most of that energy is wasted because the streets are empty between about 11 pm to 5 am. This also leads to the rapid degration of the streetlights and increased cost of maintenance operations which constitute a financial burden to the municipality. This paper solves this problem by proposing an energy management system for solar-powered streetlights that in addition to turning the streetlights ON when places are dark, puts the streetlights in an energy-saving mode when there is no one on the streets. Vibration sensors are used as motion detectors. The study is focused on the second bridge on the River Wouri, Douala, Cameroon. Simulation of the work is done using Proteus Professional and the results obtained are compared with an estimated daily energy consumption of the existing streetlights on the bridge. It is seen that the energy consumption of the proposed system is 25740Wh, and this is far lesser compared to 187200Wh consumed by the existing system assuming each lamp is 150W.

1 Introduction

Streetlights have always been a top priority in the infrastructural development of every community as there is a need to identify people, vehicles, and other objects at night on the street to minimize accidents [1]. The purpose of streetlights is also to minimize theft. Since the introduction of street lighting, the technology has evolved over the years due to the need to reduce its energy consumption and extend its lifetime. This evolution has seen the development of light-emitting diode (LED) street lamps, which are more efficient, durable, provide high lighting quality, and consume lesser energy compared to the traditional high-pressure sodium (HPS) lamps [2].

As cited in [3], public Streetlights are responsible for 50 percent of the energy consumed in cities. This is very huge given the fact that most of this energy is wasted as the streets are empty in most parts of the night, usually from about 11 pm to 5 am. This, in association with poor quality lamps, leads to high maintenance cost of streetlighting systems and this is a financial burden to municipalities. Innovative approached have been proposed to break the cycle and reinstate affordable electricity services that guarantees security, and improve the maintenant cost of street lighting systems. Advancement in renewable energy technologies have also contributed to the gradual facing out of streetlight powered from conventional fossil-based sources. Street lighting have known considerable improvement with the improvement in the effeiciency of solar panels and the development of high quality light-emitting diodes (LEDs). Despite these develpments, the street lamps still remain fully lit all through the night, and this results in energy wastage which is unacceptable especially as the lamps depend on the energy produced by the solar panel and stored in the battery during the day.

Many pieces of research have been conducted to solve the problem of the excessive energy consumption of streetlights, with several solutions being the adjustment of the luminosity of the streetlights based on movements on the streets. For example, in [4], the authors presented a study that outlined a method for improving the energy efficiency in street lighting through the intelligent management of LED-based luminaires and traffic adaptation. They used radars as motion detection sensors as well as luminosity sensors to manage the operation of the streetlights based on traffic flow. The authors in [5] proposed an Arduino-based system to manage the intensity of streetlights based on movement on the streets, using infrared sensors like motion detectors. In [6], the researchers presented a reference design for remote streetlights management systems, which included the system's distributed deployment, server internal architecture, and technical solutions. In addition to the overall architecture solution, the paper successfully resolves several common Internet of Things (IoT) system issues

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like long-term connection maintenance between multiple terminals and the server, database performance issues due to the interaction of remote data, and the consistency of permission in multi-node terminal management. An IoT-based energy-efficient automatic streetlight is proposed in [7]. The system controls the brightness of the streetlights by using passive infrared (PIR) sensors for human detection on the streets and ultrasonic sensors for vehicle detection. The design and construction of an automatic street light control system is discussed in [8]. By using the global positioning system (GPS) to obtain date and time, as well as information about the system's location, the proposed electronic system could eliminate the shortcomings of previous systems like turning ON the streetlights at 6:00 pm when in some seasons places are still bright. The microprocessor evaluated and automatically recognized geographical regions, and retrieved appropriate data for dawn and sunset in the area, thereby, ensuring very exact ON/OFF mode of the lighting system. The use of a wireless sensor network (WSN) is proposed in [9] to control street lighting systems. The WSN node is the streetlight post. Arduino, PIR, LDR, and ultrasonic sensors were used as motion detectors, while a Raspberry Pi3 computer was the server. Nowabdays, new generations of automated solar streetlights have evolved with some being able to generate reports on the operation and lifespan of the streetlights.

This work focuses on proposing an energy management system for solar-powered street lighting systems based on the movement of vehicles on the road. Vibration sensor are proposed as motion detectors. The second Wouri bridge linking Deido and Bonaberi in Douala, Cameroon, is used as a case study. The contribution of this paper to the body of knowledge is the use of vibration sensors modules, which each module made up of an SW-420 and an LM393 Comparator as motion detections unlike other research works that proposed passive infrared (PIR) and infrared (IR) sensors.

The rest of this paper is organized as follows; the next section is the methodology, which is followed by results and discussion, and then the conclusion and references.

2 Methodology

2.1 Study area

The second Wouri bridge in Douala, Cameroon is used as the case study area in this research. Douala is the economic capital of Cameroon, with a surface area of 210 km^2, and an estimated population of 2.768 million. The second bridge over the River Wouri that links the industrial zone and the agricultural production basins was commissioned in December 2018. The bridge curves gently. It is 760m in length, with 135m long spans, and has a railway line linking Deido to Bonaberi [10]. Fig. 1 shows a snapshot of the second Wouri bridge

Fig. 1. Second Bridge over the River Wouri [11]

2.2 Estimation of the energy consumption of Streetlights on the second Wouri bridge

The streetlights installed on the second Wouri bridge are high-pressure sodium (HPS) lamps, double-sided posts powered from the grid as can be seen in Fig. 2.

Fig. 2. The second bridge over River Wouri by night [12]

To estimate the total daily energy consumption of the streetlights on this bridge, it is assumed that the spacing between each post is 30m, and with that knowing that the full length of the bridge is 760m, the total number of lamps posts is obtained to be 52. Since HPS lamps are used, a typical HPS lamp can be on average rating 150W. For 12 hours of illumination, that is from 6 pm to 6 am the following morning, the total energy consumption, E_{total}, by the streetlights on the bridge can be obtained using equation (1).

$$E_{total} = N_l * P_l * t \quad (1)$$

Where N_l is the number of street lamps on the bridge, P_l is the power rating of each lamp, and t is the time of illumination.

Therefore, the total daily energy consumption of the streetlights is calculated to be 187,200Wh. It is seen that the total daily energy consumption of these streetlights is very huge. This is even worse as they are powered from the grid and hence serve as extra stress to the utility. This problem could be solved by replacing the streetlights with solar-powered LED streetlights and adding an energy management system (EMS) to them as proposed below.

2.3 Proposed streetlighting system with EMS

To solve the problem of high daily energy consumption on the second Wouri bridge, this research proposed the replacement of the existing streetlights with solar-powered streetlights with an inbuilt energy management system.

2.3.1 Replacement of the existing streetlights with solar LED streetlights

The existing streetlights could be replaced with the Luxtra 60W Solar LED Street Light shown in Fig. 3 below, which can provide up to 8000 lumens of luminosity. This is half the lumen of a typical 150W HPS streetlight (16000 lumens), but it is sufficient enough to keep the bridge lit enough.

Fig. 3. The Luxtra 60W Solar LED Street Light

The electrical characteristics of the Luxtra 60W solar LED street light is shown in Table 1.

Table 1: Electrical Characteristics of Luxtra 60W Solar LED Street Light

Characteristics	**Value**
Power	60W
Input voltage	24V
Battery	160Ah AGM
Solar panel	200W poly/mono
Luminous flux	8000 lm
Light source	LED

The block diagram of the solar streetlight is shown in Fig. 4. The solar panel charges the battery through a charge regulator. The charged battery is used to power the LED lamp at night when there is no sunlight.

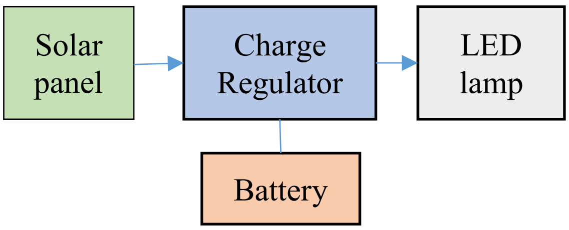

Fig. 4. Block diagram of the solar streetlight

2.4 Energy management system (EMS)

For a given solar streetlight, given that the energy produced by the solar panel to charge the battery to power the streetlight at night is intermittent, there is a need to effectively manage the energy stored in the battery. For each lamp post is installed an EMS which is made up of;

- An Arduino Pro Mini microcontroller that is the central processing unit of the EMS. It receives signals from the sensors and actuates the luminosity of the LED lamp accordingly
- The solar panel of the streetlight that is the light-sensing device of the EMS in addition to exercising its primary duty of power supply to the battery needed to power the lamp at night. It is used to detect night and bad weather.
- A vibration sensor module that measures the vibrations on the road to signal incoming vehicles. The module is made up of an SW-420 and an LM393 comparator. The vibration sensor here is used as the motion detector, unlike other research works that used passive infrared (PIR) and infrared (IR) sensors. The vibration sensor is installed on the road. Each time there is an oncoming vehicle at night, the sensor picks up the vibrations and sends a signal to the Arduino microcontroller

The block diagram of the EMS is shown in Fig. 5.

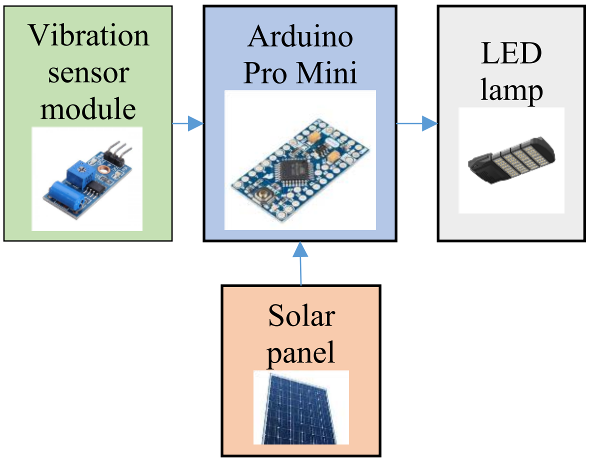

Fig. 5. Block diagram of the EMS

2.4.1 Operation of the EMS

The operation of the EMS for a single solar streetlight is shown in Fig. 6.

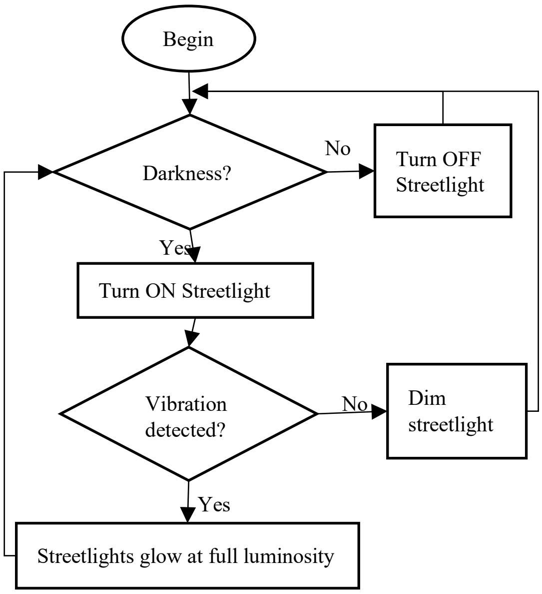

Fig. 6. Operation of the EMS

The solar panel is responsible to detect darkness (be it night or bad weather) and this leads to the powering ON of the streetlight. At this instance, the vibration sensor module is equally activated and begins to sense vibrations on the road. If there is no vibration, this means that there is no vehicle on the bridge and hence the streetlight is dimmed. The moment vibrations are captured, this is seen as an oncoming vehicle, and streetlight is actuated to fully glow. It should be noted that, in as much as the solar panel is producing (meaning daytime), the vibration sensor module is kept OFF.

2.4.2 Simulation of the EMS

The EMS is modeled and simulated using Proteus Professional software as shown in Fig. 7. The system is built following the characteristics of the Luxtra 60W Solar LED Street Light. A 4x4 LED matrix is used to represent the LED lamp.

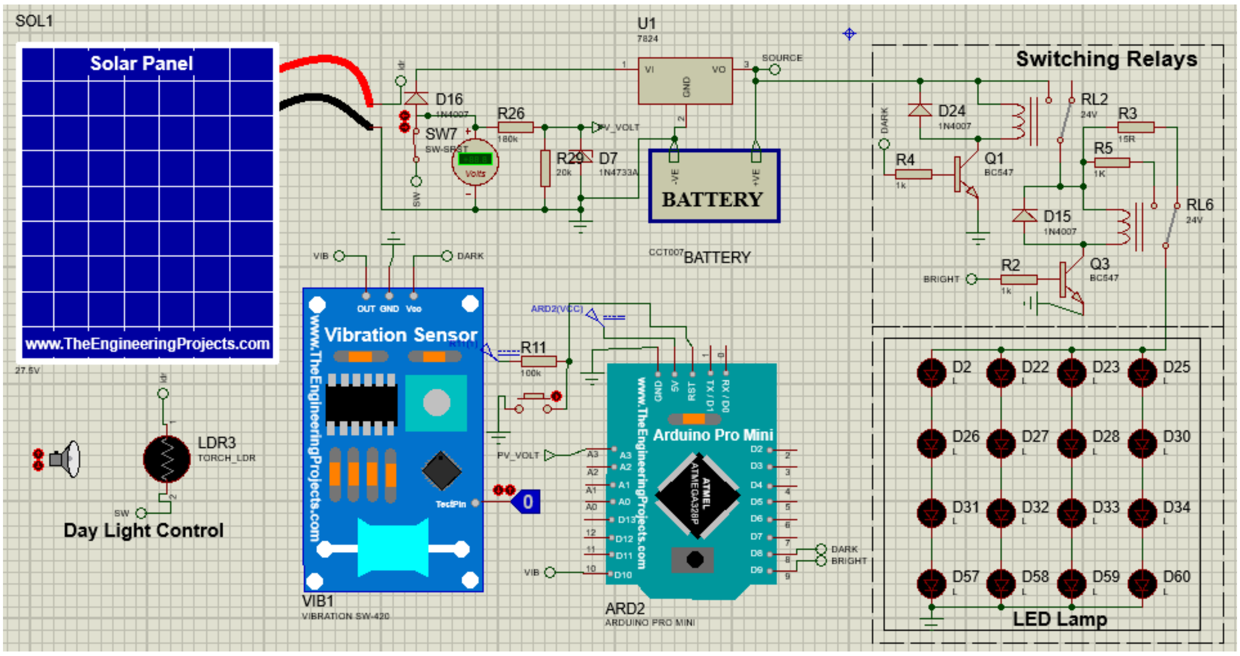

Fig. 7. Simulation of the EMS of a single solar streetlight

3 Results and Discussion

The simulation of a single solar streetlight with the proposed EMS was done in Proteus Professional and the results are presented in this section.

3.1 Automatic ON/OFF of the LED lamp based on the solar panel production

The Arduino microcontroller measures the voltage produced by the solar panel to determine whether it is daytime or night or bad weather. Solar panels do produce power when exposed to daylight. An exposed solar panel will stop producing power only at night or during bad weather conditions. This is the principle used in the utilization of the solar panel to automatically turn ON/OFF the LED lamp. In the simulation, the variation in the power production of the solar panel is accomplished by utilizing a light-dependent resistor (LDR) coupled with a torch. When the torch is taken away from the LDR, it is seen as darkness as the resistance of the LDR get very high to around 1 MΩ and the output voltage of the solar panel drops to a very low value of 0.54V. This being picked by the microcontroller leads to the automatic disconnection of the solar panel from the rest of the system, and this is accompanied by the lamp being turned ON in dimmed mode as can be seen in Fig. 8. These actions are proceeded by the activation of the vibration sensor module. When the torch is brought closer to the LDR, it is daytime and the resistance of the LDR drops to a few ohms and the output voltage of the solar panel automatically increase to 24.1V as seen in Fig. 9. The Arduino upon measuring this actuates the connection of the solar panel to the rest of the system and the battery begins to charge. At the same time, the lamp is turned OFF.

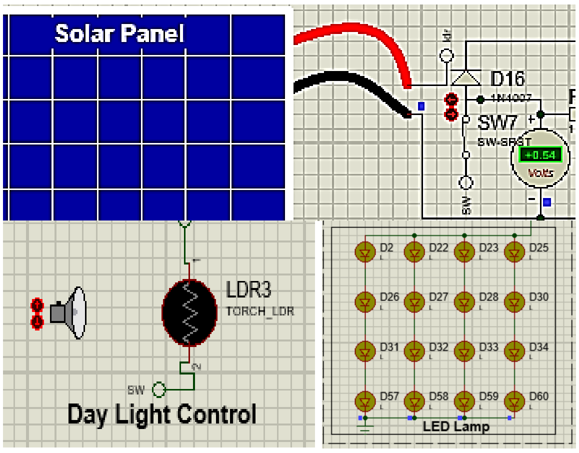

Fig. 8. Streetlamp comes ON when the solar panel stops producing power

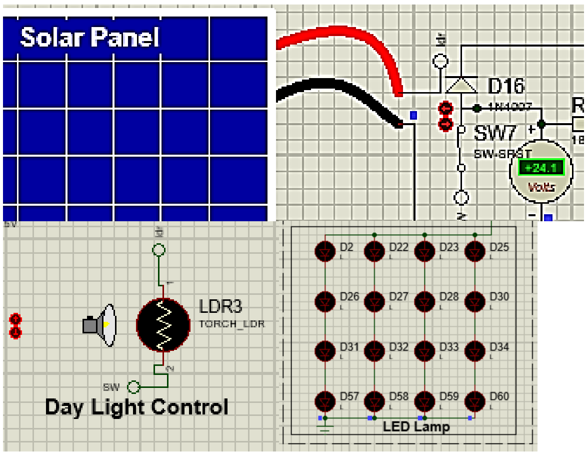

Fig. 9. Streetlight OFF as the solar panel is producing meaning that it is daytime and the sky is clear

3.2 Variation in the luminosity of the lamp

The streetlight is brightened when motion is detected on the road by the vibration sensor module. When motion is detected, the vibration sensor sends a logic 'high' signal to the Arduino and the streetlight is brightened as shown in Fig. 10. When no motion is detected, a logic 'low' signal is sent to the Arduino and the streetlight is dimmed as shown in Fig. 11. In this mode, its energy consumption is considerably reduced ¼ of its full consumption.

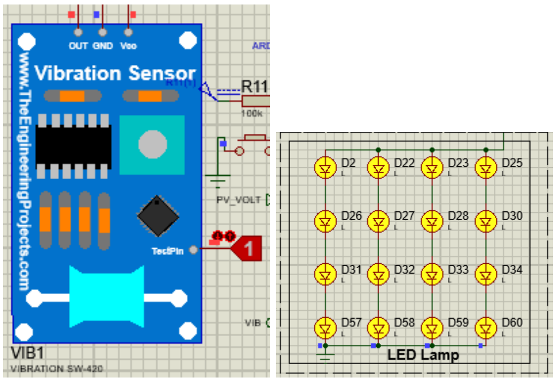

Fig. 10. Vibrations detected, lamp glow

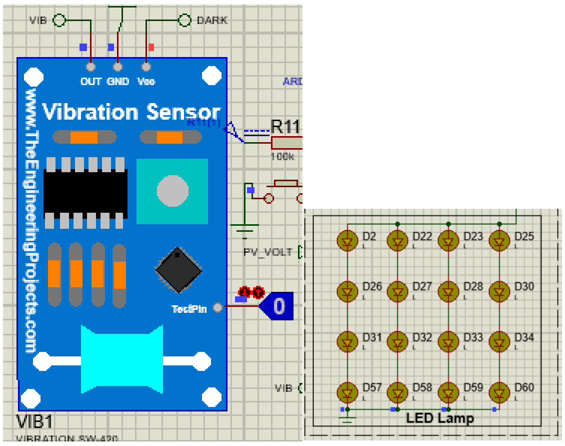

Fig. 11. No vibration detected, lamp dims

3.3 Energy-saving of the proposed solar street lighting system with EMS in place of the installed streetlights on the second bridge of the river Wouri

Assuming the solar streetlights with the EMS are dimmed to ¼ of their full luminosity for 5 hours every day (from 12:00 midnight to 5 am), and glow fully through the other parts of the night till 6am, the approximate daily energy, E_{daily} consumed by the streetlights on the bridge daily can be obtained using equation (2).

$$E_{daily} = N_l * P_l * (t_g + 0.25 * t_d) \qquad (2)$$

Where N_l is the number of solar lamps on the bridge, P_l is the power rating of each lamp, t_g is the time the lamps glows fully, and t_d is the time the lamps are dimmed.

$$E_{total} = 52 * 60 * (7 + 0.25 * 5)$$

$$E_{total} = 25740Wh$$

This is far lower than the approximate energy (187200Wh) consumed by the grid-connected HPS streetlamps in used. This means that 86.25% of energy is saved by using solar streetlights with the proposed EMS to lighten the bridge in place of the existing HPS lamps.

In addition, the proposed scheme is solar-powered hence releasing stress from the grid. Futheremore, the utilisation of the EMS will make the lamps not to operate at full capacity all the time thererby prolonging their lifetime, and in so doing reducing their maintenance cost of the streetlighting system.

4 Conclusion

This research proposed an energy management system (EMS) for solar-powered streetlights. The second bridge on the River Wouri was used as the case study. An estimate of the daily energy consumption of the existing streetlights on the bridge was done, and this was found to be 187200Wh, and this is very significant. This work proposed the replacement of the existing streetlights with Luxtra 60W Solar LED Street Light, with the proposed EMS installed. The EMS made use of vibration sensor modules to detect the presence of vehicles on the bridge to control the luminosity of the streetlights. An estimate of the daily energy consumption of the proposed solar street lighting system with the EMS yield 25740Wh and this is very much smaller than the actual estimated daily energy consumed by existing streetlights on the bridge. This, therefore, means that tremendous energy will be saved if the proposed solution is adopted to effectively light the bridge and in so doing reduce stress on the grid. The implementation of this proposed solution will necessitate effective collaboration between the utility company and the transport sector.

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