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An Electronic Economic Controller for automatically adjusting the intensity of Solar-Powered LED Street Lightning Systems in rural areas

Shahriar Mahmud Kabir[1], Md. Abdullah Al Oafi Himon[1], Ahmed Al Mansur[1], Sakib Abdul Ahad[1], Md Hasan Rayhan Rabby [1]

1 Department of EEE, Green University of Bangladesh (GUB), Dhaka, Bangladesh

*Corresponding author's email: kabir@eee.green.edu.bd

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Abstract

Using photovoltaic energy for street lighting systems is increasing rapidly in rural areas. An economic and smart controller design for automatic intensity control of LED-based street lights is the main challenge. In this work, an electronic-based controller is proposed for controlling the LED light intensity automatically, considering vehicle movement and atmospheric conditions. A HC-SR501 PIR sensor is used for detection of vehicle movements and to assist the controller in making decisions regarding the brightness of the LED. The proposed LED is operated at three different energy levels, such as 0 W, 10 W, and 30 W. In the daytime, the load will remain off, and at night, the LED will operate at two power levels, 33% and 100%, based on the vehicle occupancy rate. In addition, the proposed controller will enhance the battery lifetime. Furthermore, the proposed work ensures significant savings in energy and operating costs and also favors environmental responsibility.

Keywords: solar power, led, streetlight, cost-effective, energy efficiency.

Highlights

- Automatic intensity control of LED street lights based on vehicle movement and atmospheric conditions.
- Energy-efficient operation with three different power levels for optimal lighting.
- Enhanced battery lifetime and significant savings in energy and operating costs.
- Environmental responsibility through smart LED street lighting technology.

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1 Introduction

BANGLADESH is a small country with a large population. Being a developing country, the need for energy in Bangladesh is huge. Approximately 60% of people in Bangladesh live in rural areas. Notable progress has been made, as 82% of this rural population now has access to electricity. However, an additional 18% of the population does not have this accessibility. In a country like Bangladesh, we need to look for other sources of energy. The most well-liked renewable energy source among them is solar energy, which is what we should focus on. Also, solar energy is a great choice for lighting Bangladesh's rural streets because of its decentralized nature, affordability, environmental friendliness, and low maintenance needs. Longer hours of illumination are one benefit of solar street lights, but they also promote community growth, safety, and security. With its reliance on renewable energy and effective batteries to provide reliable lighting in places with spotty grid connections, this option is especially important for rural development. The other thing we need to keep in mind is that we should think about how to use the energy produced more efficiently. By ensuring the efficient use of the electricity produced, we can overcome the scarcity of energy to a great extent. In our country, we use a good amount of electrical energy to light up the streets of towns and cities and also on highways at night. This project shows an alternative energy source for lighting the streets at night. Here we focus on solar energy to be used for streetlights. Conventional sodium lights should be replaced by LED lights because LED lights are more energy efficient. In this project, we want to have an automatic system capable of charging a rechargeable battery during the day using a solar module. This battery can later be used as the energy source for the LED street lights at night. Here, we would use a PIR (passive infrared sensor) to sense the light intensity of the outside environment. In this project, HC-SR501, PIR sensor has been used to sense different movements and make some decisions to adjust the LED street lights' brightness. Apart from that if this project idea is implemented in practical life, then it will reduce an enormous. pressure on grid energy which is now being used in streetlights in Bangladesh. And this unused grid energy can be used in other productive works.

A low-cost, Arduino-based micro-controller-based smart street lighting system was presented by Bhairi [1]. The main objective was to develop smart streetlights that were energyefficient to preserve energy in current lamps in rural, urban, and solely smart cities. An LED driver, an LED luminaire, a PV panel, a charge controller, a light sensor, a motion sensor, and an Arduino are all part of the system. The smart streetlight is regulated by the volume of traffic on the route as well as the time of day or night. In [2], it is investigated how traffic sensors and solar panel mounting angles affect the system requirements, such as size of panel and capacity of battery, for a solar powered street light system. An intelligent solar powered street light system has been proposed in [3], where to achieve the goal of effective utilization of available solar energy, an optimally sized lithium-ion battery bank is created and coupled with the street light system. The storage system is protected against overcharging and deep discharge circumstances by the smart control system. In [4], an antivandalism mechanism built into an Internet of Things (IoT)powered solar street lighting system emphasizes energy efficiency, automation, intelligence, power conservation, and the tracking and monitoring of vandalism. Particularly, the system is a freestanding self-powered solar PV system. It uses a lightdependent resistor (LDR) to automatically turn on and off the street light while also saving energy by using an infrared sensor (IR) and microprocessor to dim and brighten the LED as needed, extending the lifespan of the lighting module. In [5], a cost-benefit analysis of a solar-powered streetlight using a high-power LED as the light source is looked at. The recommendation to replace existing grid-connected streetlights with LED lights driven by solar energy is the focus of a case study for an engineering school. To evaluate their relative costeffectiveness, we do a life cycle cost analysis and a direct payback time calculation for both solar-powered and conventional grid-connected lighting systems. In [6], the affordability of solar-powered LED (Light Emitting Diode) street lights is a question that has been raised. The American University of Sharjah campus was chosen as the case study for analysis since it currently meets its lighting needs using conventional halogen lamps. The usage of traditional street lighting has resulted in the current unit tax of 0.45 fils/KW.hr (fils is the UAE currency subdivision). The annual cost of the institution is AED 373,852 (AED is the currency used in the United Arab Emirates).

By replacing all traditional lighting in AUS with LED (Light Emitting Diode) lighting, this project aims to reduce energy expenses on campus. It then seeks to ascertain the financial benefits of implementing these solar-powered LED lights. A techno-economic feasibility assessment of a smart streetlight (SSL) system is presented in [7] in the setting of rural India. A case study is considered of the distant Indian village of Khurhaan to assess the proposed SSL system. The outcome indicated that switching to SSL over the traditional street light system results in 91,506 cost savings yearly. LED lighting technology is a contender since it outperforms HPS lamps in terms of energy and financial savings. If a solar power system (PV) and LED bulb are used for street lighting, the savings and local impact may

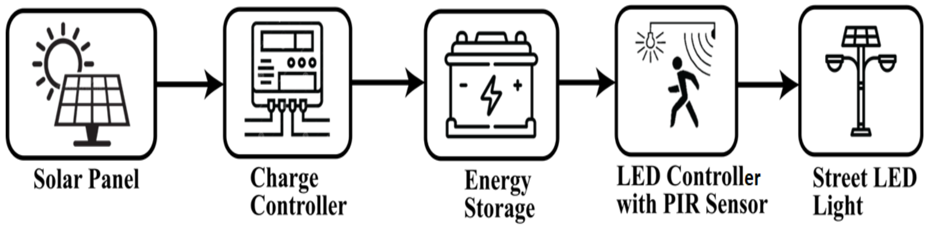

Fig 1. Block diagram of the proposed methodology

be improved and increased. This study makes recommendations and illustrates the local effects of solar-powered LED street lighting on the Sultanate of Oman. As a case study, the findings and analysis are made for one of Sultan Qaboos University's (SQU) key roads [8]. Solarpowered electricity can be produced and stored in batteries with the use of a charge controller. A non-traditional source of energy is solar power. There are instances when the streetlight is not switched on or off at the proper times. Even during the day, there are streetlights, albeit occasionally they are not switched on at night. The cost of street lighting will directly increase in situations like these. In [9], the solar streetlight study's objective was to build a system that consumes the least amount of electricity while still operating at optimal efficiency. In [10], a solar-powered street light system is suggested using lead-acid batteries that have been charged by solar panels to power LED-based lighting systems. The design includes an automatic on/off switch for the streetlights as well as a charging switch for the backup batteries. Although switching to an LED street lighting system is anticipated to result in higher initial installation costs, the savings realized from lower maintenance costs are substantial.

2 Methodology

Fig 1 shows the proposed methodology. Few pieces of literature have already shown the automated intensity control circuit in [11]–[17]. In this study, the first block comprises a solar panel that is used to capture the sun's rays and transform them into electricity. Table 1 shows specifications of the solar panel model. And the second block comprises a charge controller, which is an electronic instrument that operates the power entering the rechargeable battery from the solar panel. The third block comprises a rechargeable battery, which is the lead-acid type of battery that solar power systems most frequently use.

Table 1. Specifications of Solar Panel Model.

Parameters	Specified
Model Types	40 Watt Mono-crystalline
Voc	22.2 v
Vmax	18.2 v
Imax	2.2 A
Isc	2.37 A

It has a low energy density, low efficiency, a high maintenance demand, lasts longer, and costs less than other battery kinds. Table **??** shows specifications of a rechargeable 12V lead acid battery. The fourth block consists of an LED controller with a PIR sensor. In this work, a 7812 voltage regulator integrated circuit is used, which is a very popular and affordable option in electronics because of its simplicity, set output voltage, and dependability. Its broad working temperature range and low dropout voltage add to its adaptability. And, a passive infrared (PIR) sensor detects and measures the infrared light emitted by any object in its range of view.

Table 2. Specifications of Rechargable 12V Lead Acid BATTERY .

Hour Rate	Battery's Capacity
20 hour rate (0.45A)	9.0 Ah
10 hour rate (0.83A)	8.3 Ah
5 hour rate (1.44A)	7.2 Ah

Electricity generated by the solar panel during daylight hours is processed by a charge controller device and then stored in the rechargeable battery (Fig. 2). One of the

Fig 2. Proposed outlook of this study

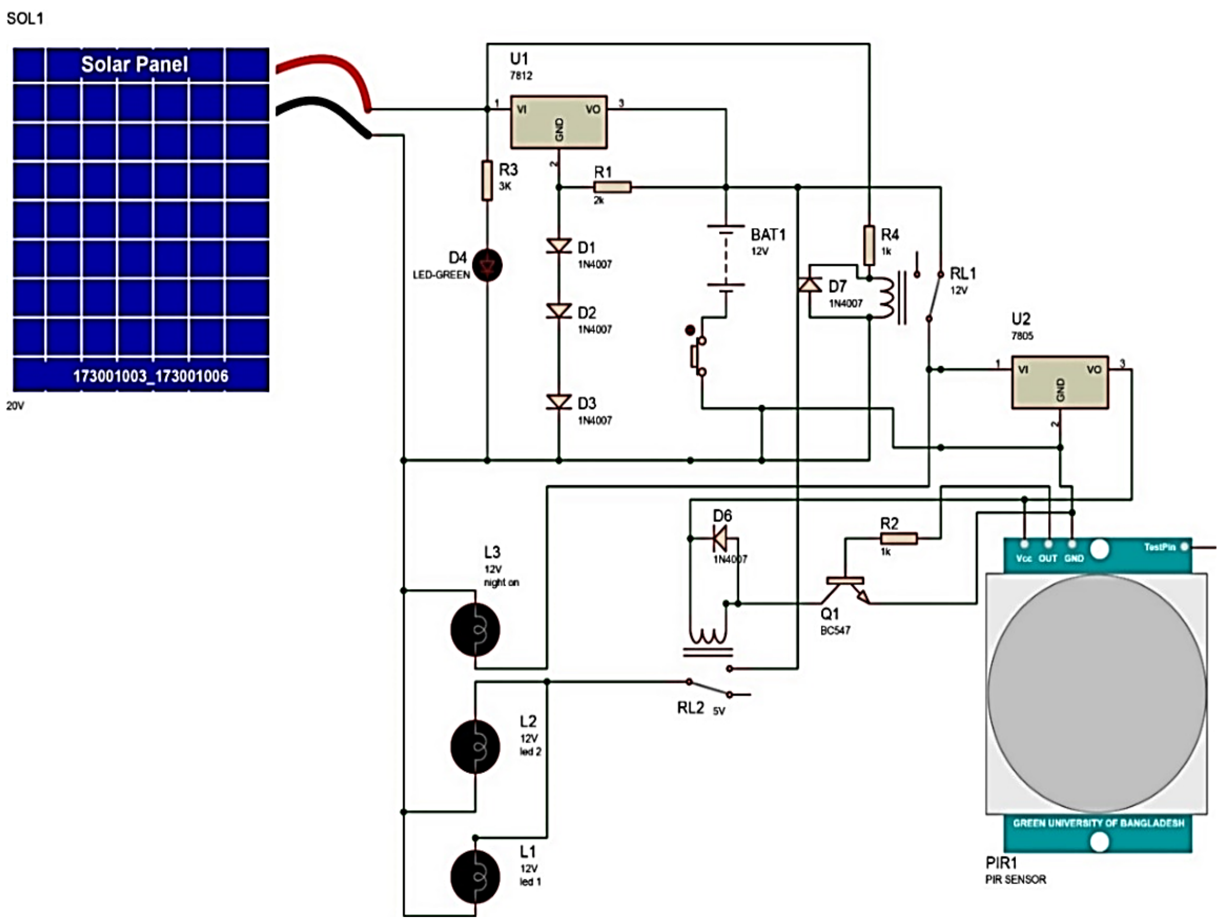

Fig 3. Proposed circuit diagram of this study

Table 3. Performance Comparison of the Proposed Method with other Related Works

Reference (Year)	Specification of Sensor	Key findings
Nor Elisya Kuamthab, 2021 [9]	PIR motion sensor automatic controlled, self-powered	Arduino UNO Rev3 is used.
Nurulazlina Ramli, 2018 [18]	IR sensors control the light intensity.	Arduino UNO Rev3 is used.
Proposed Method	PIR sensor senses motion and controls light intensity while the solar panel used as PV sensor for switching the system.	No Arduino microcontroller is used.

three 33.33% bright LEDs will turn on if there isn't any motion during the night. The motion sensor turns on and instructs the streetlight to be turned up to 100% brightness whenever it detects a moving object, such as a human or a vehicle. Battery-powered electricity is usually utilized to run streetlights. The streetlights will automatically switch to electricity from the utility source when there is cloud cover and not enough battery life.

Fig. 3 depicted the complete circuit diagram of this study. This circuit design features a solar panel with a 15v output for charging the 12V battery, we constructed a charge controller using the 7812 voltage regulator IC, 2K, and three diodes. As a charge indication, we have directly linked a green led to a solar panel using a 3K resistor. Then, to switch the first LED, a 10W 12V LED, we connected a 12V relay to the solar panel using a 1K resistor. This represents the system's 33.33% illumination condition. The relay will activate when the sun is out, disconnecting the led connection from NC to NO. Now, we have taken a 12V output from the 12V battery and converted it to a 5V output for powering the PIR sensor using a 7812 voltage regulator IC. After attaching a 1k resistor to the PIR sensor output, we switched a 5V relay using a BC547 transistor, which activated two more 20W 12V LEDs. All LEDs will remain off during the day as our output result. And 1led will turn on when it becomes dark out. Additionally, when there is a movement under the PIR sensor, another 2 LEDs will also light on as a result of the system receiving a signal from the PIR sensor, which triggers the relay to turn on the LEDs.

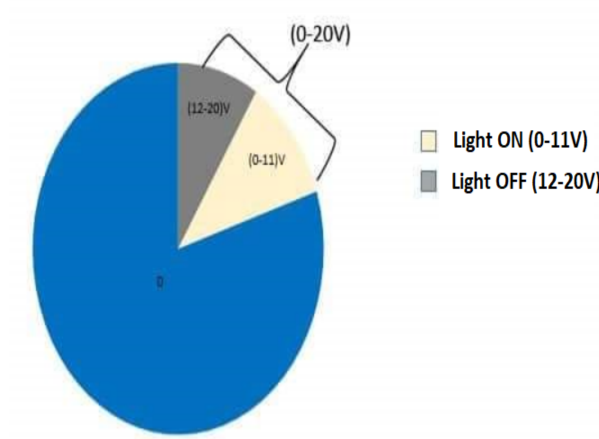

Fig 4. LED Operating (on/off) voltage range

3 Experimental Results

In this work when the battery is charging during the daytime, all led will stay off. At night time LED brightness will be in a 33.33% state when there will be no motion happening. But LED brightness will be in 100% state when there will be motion happening. Because the PIR sensor senses the motion and gives a signal to the system then the relay turns on and the LED turns on 100%. Fig. 4 shows how wireless sensor networks are being used for energy-saving applications like light control. For the proposed LED street lighting system, the light will be ON when the amount of fog is high. The light will be ON for 0-11v and the light OFF for 12-15v when there is no fog and the sun is shining.

The vehicle occupancy rate obtained through equation 1 is shown in Fig. 5.

$$\text{Occupancy Rate} = \frac{\text{Total used LED Power}}{\text{Total available LED Power}} \quad (1)$$

When at night time the vehicle availability is zero then the street light will be dimmed at 33.33% and when the vehicle accessibility is higher, the street light intensity will

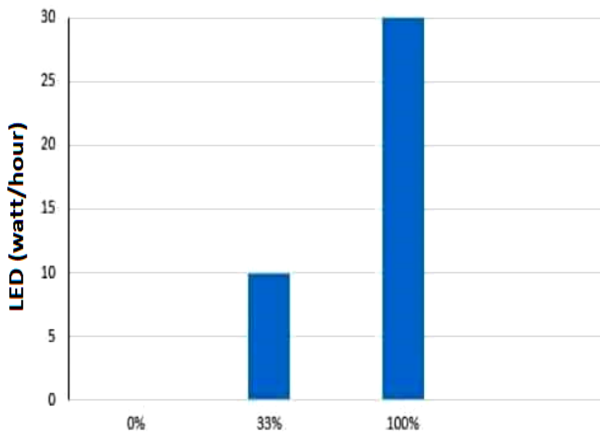

Fig 5. Vehicle occupancy rate

be 100%. This is cost efficient as suggested by a few literary works. [18]–[20]. In [9] and [18] related works, the Arduino Uno Rev3 is used while our method used PIR sensor with transistor, which minimizes the cost. Table 3 shows a comparison with other works in terms of novelty and cost minimization with our proposed method.

Approximately 75% of the population lives in 87,000 villages in Bangladesh. The majority of these communities are located in low-lying places away from main routes, and they usually have fields and rivers surrounding themselves. We can implement the proposed work in those rural areas. Some of the possible areas have been mentioned in Table 4. In addition, the proposed project could easily be adjusted for use in various Bangladeshi rural areas.

Table 4. Possible Area in Bangladesh where can implement Solar-Powered LED Street Lightning Systems .

Serial No.	Areas
01	Hatiya
02	Maheshkhali Island
03	Sonadia
04	Urir Char
05	St. Martin's Island
06	Bhola Island
07	Manpura Island

4 Conclusion

In this work, the PIR Sensor is implemented for the automatic intensity control circuit of LED street lights satisfactorily. This circuit design is very cost-effective as well as energy efficient. The system is working, turning the LED lights ON at night and turning them OFF in the daytime automatically.
Also, for the PIR sensor, our system can sense motion and control LED brightness by 33.33% or 100%. Due to both cost and energy-efficient, it is very much acceptable for commercial use. Using solar energy has a number of clear benefits. Solar energy production produces no carbon emissions after installation, making it a pollution-free energy source. Moreover, there is the possibility of a return on investment; this is not the case with continuous energy bill payments. This system has fully automated, simple in design, low cost, fast response, and high-efficiency circuit. Switching has a very short rise time, stand-alone, and energy savings. Also, the proposed system can be improved as the charging system can be smarter by using Arduino. Charging time can be decreased by using fast charging technology.

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Shahriar Mahmud Kabir received the M.Sc. in Electrical and Electronic Engineering (EEE) from Bangladesh University of Engineering and Technology (BUET) in 2013 after earning a B.Sc. in the same field from Ahsanullah University of Science and Technology (AUST) in 2008. Currently, he is pursuing his Ph.D. degree in Electrical and Electronic Engineering (EEE) at Bangladesh University of Engineering and Technology (BUET). He can be reached at Green University of Bangladesh (GUB), Assistant Professor, Department of Electrical and Electronic Engineering (EEE), Dhaka-1207. Email: kabir@eee.green.edu.bd

Md. Abdullah Al Oafi Himon was born in Cumilla, Bangladesh, in 1994. He received the B.Sc. in Electrical and Electronics Engineering degree from Green University of Bangladesh (GUB) in 2018. Currently, he is pursuing his M. Sc. degree in Electrical, Electronic and Communication Engineering (EECE) at Military Institute of Science and Technology and as of January 2019, he is working at Green University of Bangladesh (GUB) as a lecturer in Electrical and Electronic Engineering department. His research interest includes Antenna, image Pro-cessing, Machine Learning.

Ahmed Al Mansur was born in Dhaka, Bangladesh, in 1986. He received an M.Sc. in Electrical and Electronic Engineering (EEE) from Islamic University of Technology (IUT), Gazipur under the OIC, in 2011 after receiving the B.Sc. in EEE from Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh, in 2008. He has completed his Ph.D. Degree from IUT in 2019. In several national and international journals and conferences, he has published over sixty research papers. Since 2020, he is working at Green University of Bangladesh (GUB) as an Associate Professor in the Department of Electrical and Electronic Engineering. In 2011, he worked as a lecturer at Prime University (PU) in Bangladesh. His research focuses on modeling and simulating power electronic circuits and electric drives, as well as the application of power electronics and renewable energy. He is a life member of the Bangladesh Electronic Society as well as a member of the Institution of Engineers (IEB), Bangladesh. He is an Associate Editor of GUBJSE and the Moderator of the Green University Robotics Club. He has been serving as TPC Co-Chair at the STI Conference since 2019 and as an Advisor to the IEEE PES GUB student branch chapter since 2020. He has been a senior member of IEEE since 2021 and currently holds the role of Educational Activities Coordinator of IEEE PES SC-Bangladesh Section in 2023.

Sakib Abdul Ahad was born in Mymensingh, Bangladesh, in 1991. He received the B.Sc. in Electrical and Electronic Engineering (EEE) from Green University of Bangladesh (GUB) in 2018. Currently, he is pursuing his M. Sc. degree in Electrical, Electronic and Communication Engineering (EECE) at Military Institute of Science and Technology and working as a lecturer of department of Electrical and Electronic Engineering in Green University of Bangladesh (GUB) from April 2019. His research interests include signal processing, image Processing, Machine Learning and deep learning. He can be reached at sakib1991991@gmail.com

Md Hasan Rayhan Rabby was born in 1998. He received his B.Sc. in Electrical and Electronic Engineering degree from the Green University of Bangladesh in 2022. His research interests are in solar systems and solar charger development.Currently, he is working as a technical staff (freelancer) at National and International Event Management.