Solar-wind power generation system for street lighting using internet of things

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Article Info

Article history:

Received Dec 22, 2021
Revised Mar 9, 2022
Accepted Mar 16, 2022

Keywords:

Battery
Easy electronic design automation
Internet of things
Net zero energy street lighting
Solar-wind

ABSTRACT

Every country is subsidising millions of dollars for street lighting as those are connected to the grid. Besides, the generation of electricity comes from fossil fuels with emissions of carbon dioxide (CO_2). Therefore, alternative generation of electricity can be done by using a hybrid system. Solar energy starts as the day begins, and the wind is accessible on the streets with a to-and-fro motion of the car. It does not rely on any factor. This hybrid system generates 12 V direct current (DC), whereas no alternating current (AC) converters are used, resulting in a reduction the system's cost. The control system was constructed based on internet of things (IoT) and included the most sophisticated battery charging system to improve the battery's cells' life cycle. The hardware system has been simulated using easy electronic design automation (EasyEDA) and incorporated with the printed circuit board (PCB) design. The prototype is constructed alongside collected data to compare with the theoretical basis towards net-zero energy street lighting (nZESL). The prototype was able to lead to nZESL and backup stability of the system is 10 hours per day, along with the validation of theoretical analyses and effectiveness of the system. The system has the potential to make a significant contribution to lowering CO_2 emissions and government subsidies for street lighting.

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1. INTRODUCTION

The Malaysian government spends 19 million US dollars a year on paying energy bills and streetlight maintenance costs on village roads nationwide, and 60% of light emitting diodes (LED) street lighting was achieved between early 2018 and mid-June 2019. Tenaga National Bhd replaced nearly 60% of Peninsular Malaysia's public streetlights with 90 watts of LED bulbs. As the government proved that those streetlights installed are energy efficient, the view is that the sources of generating electricity for those streetlights are not either green or renewable energy [1]. Although it is difficult to find alternative energy resources with the same efficiency and reliability as compared to conventional energy, it is also challenging to generate energy that is not involved in changing our climate. A hybrid solar-wind generation system can generate electricity both during the daytime and night-time [2]. As solar and wind are green energies, this system is implemented in street lighting to reduce electricity bills, carbon dioxide (CO_2) emissions, and improve the cities' air quality; thereby, authorities will no longer need subsidies [3]-[6].

This promoting system's greatest achievement is an inspiration to riders to use electric vehicles because they can have a hassle-free, uninterrupted trip wherever they go if this system is properly implemented according to its design uniqueness. The system will be a symbol of green for every country, reminding the citizen to be green and assisting the country in playing a vital role as a role model to the world [7], [8]. With fast economic growth, energy demand has risen year by year. Conventional energy is met with increasing tiredness. New renewable, clean energy is in desperate need. The future of wind and solar energy is the largest in the continuing growth of green energy and emerging energy technology and is of the greatest significance for progress. They are a clean and inexhaustible energy source. Second, it is a concern because the wind is prosperous when it's winter using a single sun or wind power, but there is a lack of solar energy; it's just the opposite when it's summer. Therefore, wind and solar energy can be very strong, complementary to each other [9], [10].

Three key meanings of a wind-solar hybrid streetlight are: i) Social benefit: The wind-solar hybrid streetlight is a high-tech, environmentally friendly device. The construction of wind-solar hybrid streetlights not only complies with the government's principle of environmental conservation but also reminds people to protect the environment [11]. ii) Economic benefit: It alone utilizes and generates electricity. We may obtain a long-lasting gain after the creation of a one-time investment. It saves a lot of manpower and financial capital to upgrade the conventional streetlight system laid on the underground cable power supply way. iii) Environmental benefit: In 10 years, each conventional streetlight spends 1825 kWh of energy. The standard coal consumption would be 7.3 tons, according to the standard thermal coal consumption (400 g/kWh) estimate. Furthermore, 876,000 tons of standard coal will be consumed by the city center in just 10 years. As a result, 3 million tons of carbon dioxide (CO_2), 17,500 tons of sulfur dioxide (SO_2), 13,000 tons of nitrogen dioxide (NO_2), and so much powder and impurities will be released. But emissions can be avoided by using wind-solar hybrid streetlights [12].

According to Ronay and Dumitru [13], an intelligent street lighting system is powered by photovoltaic (PV) with energy storage while LED is controlled by a dimming circuit to reduce energy consumption and only the lighting intensity will be increased when vehicles are present; otherwise, it will be dimmed. Kovács *et al*. [14], the paper is motivated by applying renewable energy-based street lighting with optimization control to determine when to sell and buy electricity to and from the grid under a time-of-use tariff (ToU), and also considering the forecasting of energy generation and consumption. Tukymbekov *et al*. [15], the most pressing issue is supplying energy to the street lighting system during inclement weather. The autonomous street lighting system is proposed with adaptive energy consumption that relies on weather forecasting. Energy generation of solar panels can be assumed using long short-term memory (LSTM) based on weather and solar radiation forecast data for the upcoming days [16]. Edison *et al*. [17] presented an internet of things (IoT) framework-based smart and intelligent street lighting system, which consists of an IoT sensor-based smart electric pole with a controller for adjusting LED bulbs.

After a thorough review of the literature, most studies have been conducted based on a PV power system for street lighting, whereas those systems are not enabled to lead to net-zero energy street lighting (nZESL). Therefore, this paper proposes a hybrid energy system (solar and wind) for street lighting with energy storage, whose controller communicates with the mobile operating application via a communication protocol to allow remote control. This research work provides a comprehensive analysis of the nZESL technique. The hardware system is analyzed in simulation and verified by experimental results. The findings of this study indicated that a hybrid energy system with energy storage and its control method is adequate for obtaining nZESL.

The remaining of the paper is organized as shown in: In section 2, introducing research instruments and collected data with design technique of proposed system hardware. The parameters of prototype validation and observation is discussed in section 3. The conclusion presented in sections 4.

2. RESEARCH METHOD

2.1. Solar and wind energy

Malaysia is formed like a crescent, with Peninsular Malaysia (West Malaysia) and the states of Sabah and Sarawak on the island of Borneo (East Malaysia). Statistics indicate that in the equatorial region, Malaysia has an average solar radiation of 400-600 MJ/m^2 per month as shown in Figure 1. During the Northeast monsoon, it is higher, while during the Southwest monsoon, it is lower [18]. Besides, an average hourly wind speed of 2.07 m/s and 1.52 m/s respectively, January and April are the windiest and calmest month in Kuala Lumpur [19].

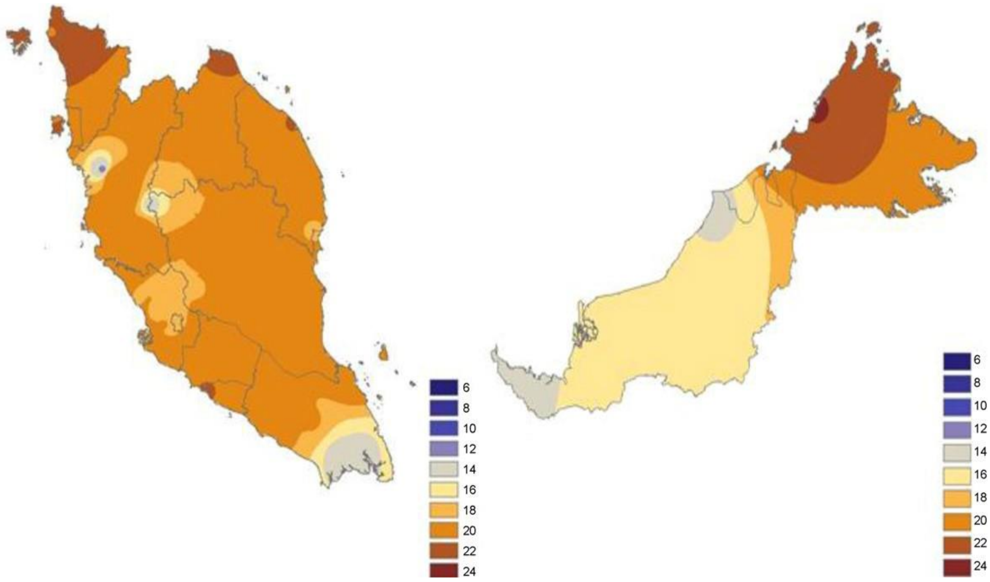

Figure 1. Annual average solar radiation in Malaysia (MJ/m^2/day) [18]

2.2. The empirical algorithm for the proposed system

Solar and wind energy are readily available, environmentally friendly energy sources driven by the sun and wind, respectively, that can be used to generate power directly. On the other hand, renewable energy is intermittent. Therefore, the correct configuration would not only make the solar-wind LED streetlamp system's work more reliable but will also reduce the cost. The method of measuring the configuration of the solar-wind LED streetlight system is connected to the following factors [9], [12], [17]:

i) Power extracted by the wind turbine is $P_W = 0.5 \times A \times C_P \times \rho \times v^3$
Where, C_P is the power coefficient and is given by $C_P =$ Power in the wind turbine/Power in the air
The value of C_P is limited by Betz limit to 0.593
Power in the air $= P_{air} = 0.5 \times A \times \rho \times v^3$
Where, ρ is the air density in Kg/m^3 = 1.3
A is the area swept by the rotor in m^2
v is the wind speed in m/s
The swept area A is given by
$A = \pi r^2$ where, r is rotor blade diameter in m

ii) Power of solar cell components = Total power of LED lamps × Electricity time × Loss coefficient (1.6~2.0)/Local peak sunshine time.

iii) Battery capacity = Total power of LED lamps × Electricity time × Rainy days × System safety factor (1.4~1.8)/System voltage.

iv) The cumulative electricity produced by this system is equal to the electricity generated by the solar panel and the electricity generated by the wind turbine. It can be interpreted mathematically as total generated power (T_P) = Power generated by solar panels (T_s) * loss + Power generated by wind turbines (T_W) * loss

v) To design the battery charging circuit, emphasized five criteria as shown in: i) Low voltage protection, ii) Overvoltage protection, iii) Battery cut-off circuit, iv) Backward current protection, and v) Over-current discharge protection.

vi) Finally, the proposed system configuration introduces a cloud server via remote XY mobile application.

vii) To prevent overcharge and over-discharge of the battery, the battery is generally charged to about 90%. Discharge remaining 5%~20%.

2.3. Electronic design automation (EasyEDA)

EasyEDA is a web-based EDA tool package that allows hardware engineers to design, simulate, exchange, and debate schematics, simulations, and printed circuit boards both publicly and privately [20]. The proposed system has been simulated by using EasyEDA and associated with Eagle software for the design of a 3D view of the printed circuit board (PCB). After selecting the model of all components and adding them in order to prepare the simulation. Two boost converters have been used to make a stable 18 V direct current (DC) and proceed to LM317 to maintain either 14.9 V or 15 V for charging the 9 AH lead-acid battery. The Arduino Uno is associated with another external electronic step-down circuit, and it has been powered from the battery bank.

2.4. RemoteXY

Using a cloud server to connect RemoteXY allows you to control the device from anywhere if there is an internet connection. The ESP8266 module will be set up as a client in order to connect to a wireless fidelity (Wi-Fi) network. A unique registration token is required for each device that is registered on the RemoteXY cloud server and must also specify this token when connecting to the device from a mobile application. Tokens are created in the RemoteXY site's personal cabinet. The access point must be connected to the internet. The RemoteXY library ensures that the device has registered on the cloud server correctly. The mobile application will communicate with the cloud server rather than the device directly. As a result, the device will be accessible via internet from anywhere [21]. The proposed system is encountered mainly to preserve data privacy and security as the system is dependent on a third party's cloud server and mobile application for controlling the street lighting. This may be developed by purchasing the hosting domain of a cloud server from the registered service provider according to requirements, with self-developing web or mobile applications that can provide more privacy and security of data in the case of street lighting control.

2.5. Arduino Uno and Arduino IDE

The Arduino Uno is a microcontroller board that uses the ATmega328P microcontroller. It contains 14 digital input/output pins, 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an in-circuit serial programming (ICSP) header, and a reset button. Writing code and uploading it to the board is simple with the open-source Arduino software (IDE). Any Arduino board can be used with this software [22].

2.6. Hardware design technique

The virtual block diagram of the prototype and how the system works with wireless communication control remotely are shown in Figure 2. Renewable energy is uncertain with respect to climate change. To fill this gap, a battery bank with two Zener diodes is used for both generation sides, which ensures the system stability and allows the generating voltage to pass from 8.2 V/15 V as shown in Figure 3. To make the constant voltage for both sides, two boost converters have been utilized, which lead to 18 V, and LM317 is implemented to secure 15 V for battery charging, as a 12 V/9 AH battery is used in the system. To protect the system from reverse voltage, two blocking diodes are used in the system. When the battery is fully charged, the MOSFET is responsible for disconnecting from the main circuit via a 12 V relay. A step down 12 V/5 V converter is used to plug in the Arduino Uno with ESP8266 to connect to the cloud server. The streetlight is powered from battery bank using 5 V relay, which is controlled by Arduino Uno based on the response of the ESP8266.

Figure 4 shown the PCB has been designed for ancillary components and the remaining ones, such as Arduino, ESP8266, step-up converter, and step-down converter, are available in the local market at a reasonable price as compared to self-designing. Tactlessly, this circuit has integrated with other essential components to make the whole circuit more state-of-the-art.

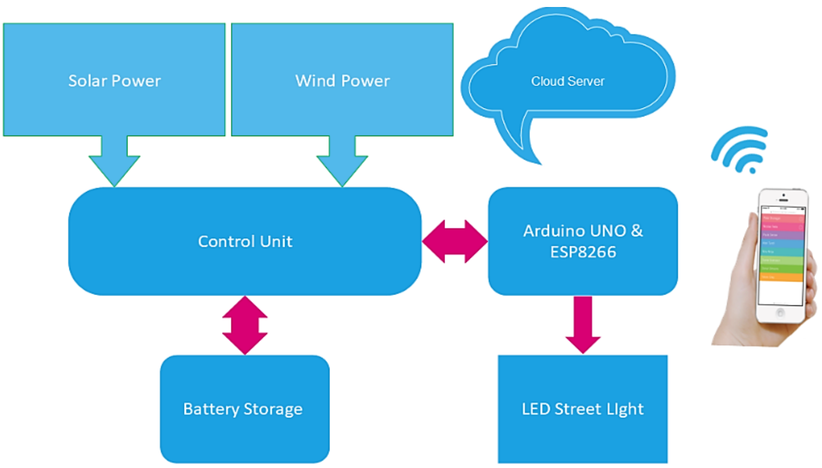

Figure 2. Block diagram of the proposed system

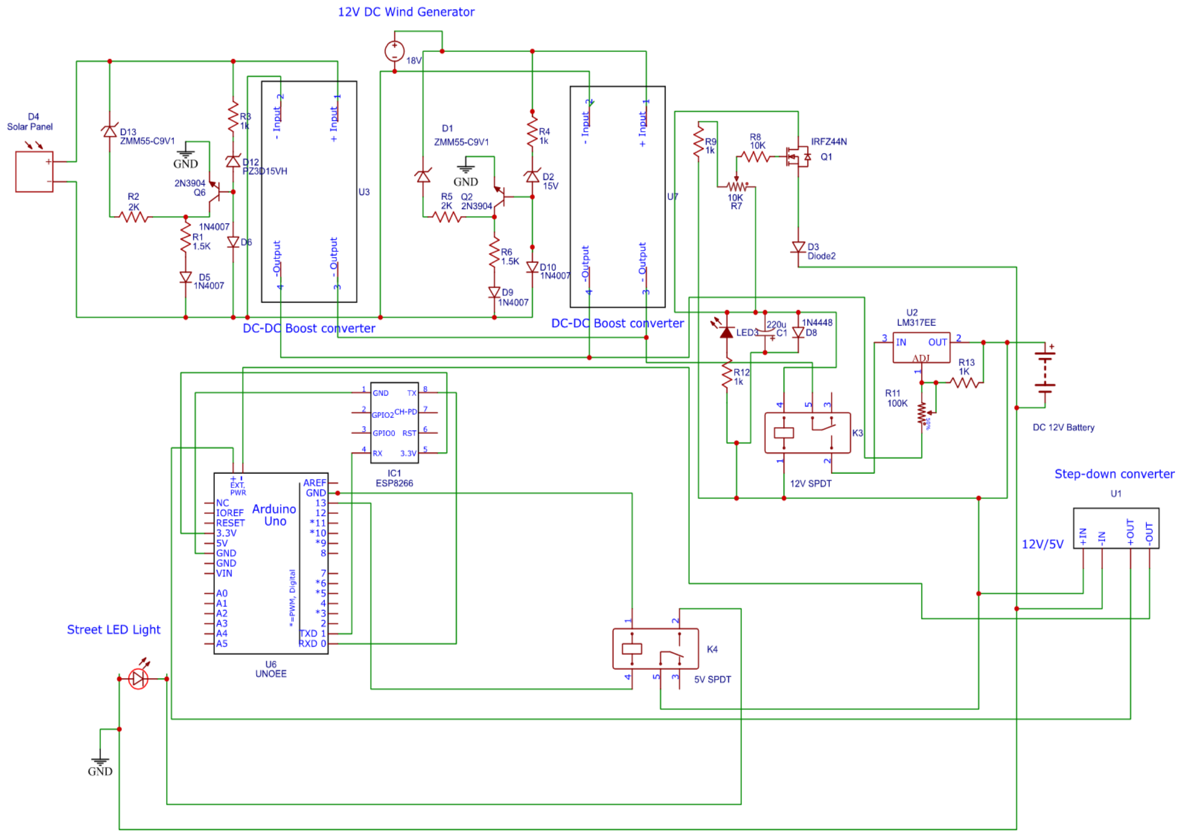

Figure 3. Schematic diagram of the proposed system using EasyEDA

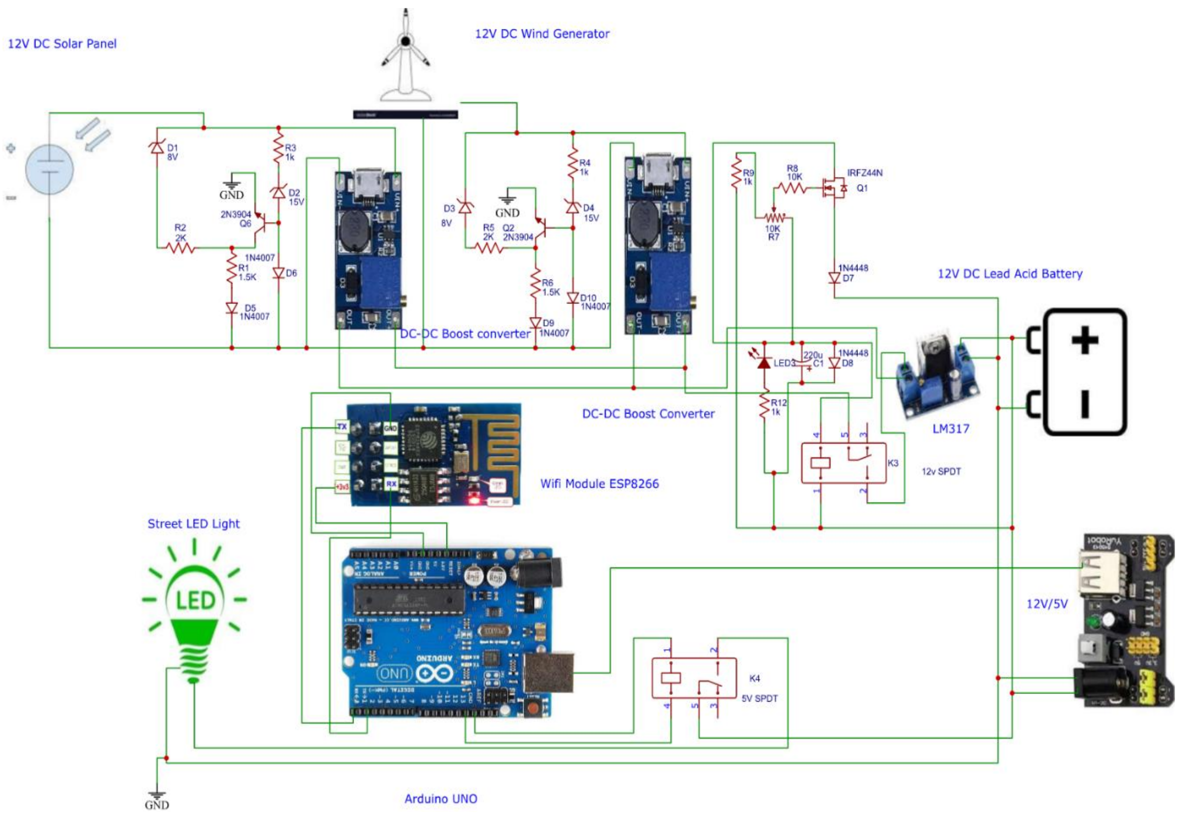

Figure 4. Circuit design model using EasyEDA

A three-dimensional view is shown in Figure 5 to identify the defect in the PCB design, along with consideration of durability to maintain the reliability of the circuit. It has also been taken into account to make the system more primitive and robust as well.

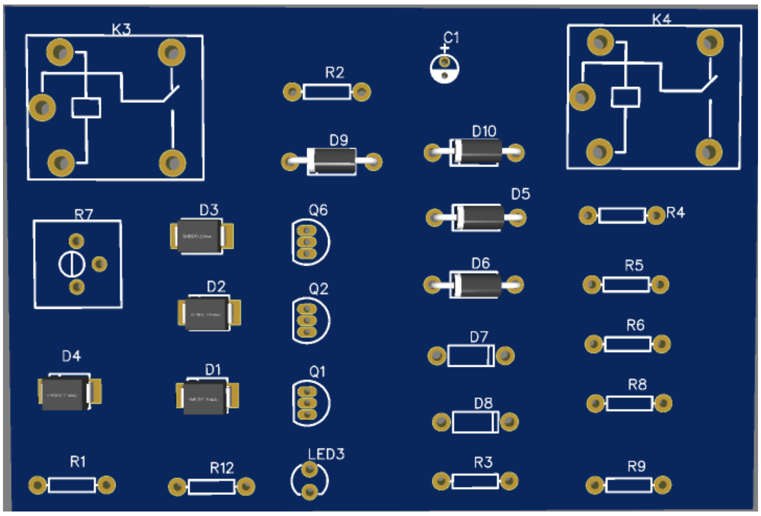

Figure 5. 3D view of PCB

3. RESULTS AND DISCUSSION

As can be seen from Figure 6, the final experimental setup with all components integrated and the detailed parameters of the proposed system are listed in Table 1. The IoT-based circuit can be controlled remotely from anywhere and at any time [23]-[25]. The proposed system generated a voltage of 15 V to 23 V during solar peak hours and 10 V to 12 V during wind peak hours, respectively, whereas about 7 V to 10 V and 5 V to 7 V during off peak, as shown in Table 2.

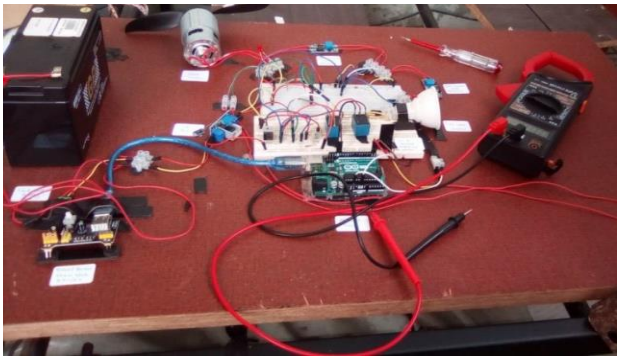

Figure 6. Experimental setup

Table 1. System parameters for experimental tests

Parameters	Value
Solar panel	18 V/10 W
Wind turbine	18 V/1 W
Boost converter	18 V
Relay	12 V/5 V
Microcontroller	Arduino Uno
Wi-Fi module	ESP8266
LM317	15 V
Step down converter	12 V/5 V
Battery	12 V/9 AH
LED	12 V/5 W

The proposed prototype was validated by comparing the real time results with the hardware simulation results as well, which shows the system is optimal with the minimization of initial and maintenance cost. A solar panel and wind turbine are placed accordingly to receive the maximum solar radiation and air speed, respectively. The system relies on the surrounding location and a lead-acid battery was used for energy storage in the system. Notably, lead-acid battery charging followed constant current and constant voltage (CCCV) rules precisely to maintain the health of the battery's cells and improve its reliability. Infiltration care was also deemed during the installation of the battery for safety purposes. Battery charging started at 9 AM on the 18th of October and ended at 5.3 PM, and it took about 8.3 hours to be fully charged, thus turning on the streetlight at 7 PM using RemoteXY mobile application via ESP8266. The prototype was consecutively observed to verify the stability of the system as shown in Figure 7. If the system runs 10 hours daily, there is no possibility of being down the system as it has taken substantial care during the selection of every component. On the contrary, the luminance of LED light was decreasing as both voltage and current are inversely proportional. Finally, the LED was turned off at 5 AM using remoteXY mobile application. The working hours can be increased using compact size of renewable energy resource (RER) and battery storage.

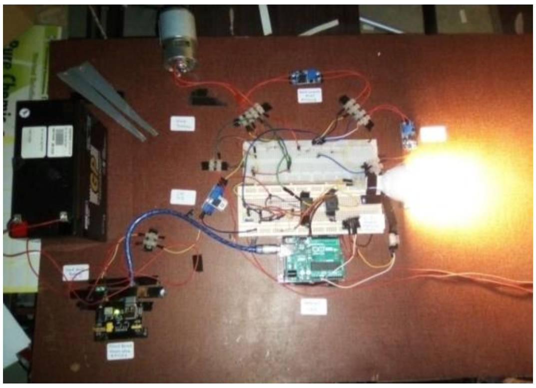

Figure 7. Continuously observation

Consecutive rainy periods have been considered in the proposed system during the case study period, so the system will be able to back up as well. However, it shows the climate of Malaysia is superior to installing the hybrid system as the principal feasibility of this proposed system is that during rainy airspeed, the wind turbine is enabled to generate the DC. In contrast, at other times, the solar panel will be enabled except at night times. The hybrid system generates only 12 V to 15 V DC; after that, it has been used to boost the converter to retain 18 V and proceed to LM317 to maintain 15 V for the purpose of battery charging. Energy storage will be used when both systems cannot generate electricity.

Table 2. The stability of prototype is verified with experimental results

Solar peak-off-peak	Wind peak-off-peak	Boost converter and LM317	Charging hours	Back up hours
23 V/15 V – 10 V/7 V	12 V/10 V – 7 V/5 V	18 V/15 V	8.3	10

As consecutive rain occurs in Malaysia, the great advantage is to get rid of solar panel cleanness and improve the lifespan of the system. However, the lead-acid battery has been used in the proposed system because of its cost-effectiveness, though its weight is higher as compared to the lithium-ion battery. The lithium-ion battery can be used as an alternative to the lead-acid battery if the system only needs a few watts. This may be an inexpensive, reliable, durable, and compact size of the battery as compared to the lead-acid battery. As the proposed system will require more power to turn on the 60 W to 80 W LED light, the best choice is to select a lead-acid battery, although the charging time of a battery is too long but economical. The most challenging part of renewable energy is storing the energy, even though it is still the most primitive form of energy storage, the lead-acid battery. Well-designed and installed, it will reduce the compact size of the battery and minimize the maintenance cost.

4. CONCLUSION

This research demonstrates an optimization design of solar-wind hybrid streetlights. The hardware design of the experimental system with a reduced number of total component devices leads to cost-effectiveness and backup stability of the proposed system at 10 hours per day with real-time control of street lighting. The experimental validation revealed that the adopted technique is effective in achieving nZESL. After the battery is fully charged, the excess generation can be shared with the neighbouring poles or grids. The way of generating electricity does not have any waste whatever is generating, can be implemented in the system. As the proposed system was limited to avoid complexity, in the future, this system will move to intelligent lighting for the smart city and will include closed circuit television (CCTV), Wi-Fi, lighting emitting diode television (LED TV), and charging stations to encourage the electric vehicle riders as well as that is the best way to bring the whole country into a Wi-Fi zone. An LED TV will be used to raise awareness among pedestrians, and CCTV will assist the intelligent officer in finding the cases out. The system will have a smart sensor to know the amount of electricity generated, and recording data can be sent to a controller in real-time to identify which poles are not capable of generating electricity during peak hours. It will also be easy to respond to maintenance quickly.

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