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ORIGINAL RESEARCH ARTICLE

DESIGN AND IMPLEMENTATION OF SOLAR STREET LIGHT FOR SCARCELY ELECTRIFIED AREAS

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ABSTRACT

Streetlights are usually powered by alternating current supply from distribution stations of the utility companies. This invariably increases the demand for power distribution from utility companies. Recent developments, however, suggest the possibility of the use of renewable energy sources to power streetlights in order to reduce the demand on the consumption rate of energy on the utility companies. Accordingly, this work considered the design and implementation of streetslights in scarcely electrified areas powered by solar energy. Using tilted solar modules, energy efficient lamps, and structural anticorrosion parts, a standalone streetlight configuration with automatic switch ON/OFF mechanism was built. The results show that streetlight powered by solar source of renewable energy cheaply generates electricity directly from sunlight without emissions, noise, or vibration. Therefore, due to the inconsistencies surrounding the generation of electricity using fossil fuels, this work offers an alternative source to power streetlights thereby reducing pressure on the national grid.

1.0 Introduction

Traditionally, streetlights are powered by energy supply from the power grid. The constant outage and intermittent power supplied to consumers has often led to loss of lives and properties brought about by persistent darkness along major roads in cities as well as darkness within local communities. Recent advances in technology suggest the possibility of powering streetlight with renewable energy sources. Amongst the available renewable energy sources that can be used to power streetlights is solar power. Solar powered streetlights is the most feasible as they are independent of the utility grid, involves a minimized operation cost, requires much less maintenance compared to conventional streetlights, and eliminates the use of external wires, which invariably reduces the risk of accidents Nallapaneni et al. (2016), Nyemba et al. (2019). A solar cell (also called photovoltaic cell or photoelectric cell) is a solid-state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Photovoltaic (PV) is the field of technology and research related to the practical application of photovoltaic cells to produce electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight Nallapaneni et al. (2016), (Gang, 2014). Photovoltaic technology can be used in many electrical applications such as street lighting. Essentially, solar arrays generate electrical voltage and this voltage is used to charge a battery via a battery charger circuit. In contrast to burning of coal and other fossil fuel to produce electricity to power streetlights which often results in pollution including acid mine drainage, toxic waste, and air pollutants, solar powered street lighting is clean and free of pollution (Baburajan, 2017). The aim of this study is to consider the design and implementation of a solar powered streetlight to produce illumination at night and at dawn Bhairi et al. (2017) to increase the security of lives and properties of the people. To achieve this, a standalone solar powered street light with an automatic switch-on mechanism which activates the light as darkness approaches, and switches off as daylight approaches was implemented.

2.0 Materials and Methods

This section describes the design requirements for the proposed standalone solar powered streetlight. Additionally, this section also presents data collected from a solar panel installation designed to power a standalone streetlight located in a scarcely electrified area. In particular, the recorded data comprises of information of the voltage on the photovoltaic cells to generate the output power at a given time. To ensure consistency of the measured data, three days experiment were conducted each for no-load, system connected to battery, and system connected to street lamp. Using a multimeter, voltage from the panel on no-load, and when the panel was connected to a battery were recorded. Also, voltage measurements when the system powers the energy efficient lamp were recorded.

2.1 Design Specification

A stand-alone configuration was required.
An automatic switch-on mechanism was incorporated in such a way that the streetlight switches on when darkness approaches and switches off whenever it senses light.
The pole height would be about 30ft for adequate illumination.
A bulb rating of 32 watts was used.
A panel of 150 watts to withstand system capacity.
Presence of vented steel enclosed box which houses the battery and the solar charge controller.
An energy efficient lamp was required.

2.1.1 Composition of solar lighting system

Figure 1 shows the schematic diagram of a solar powered streetlight.

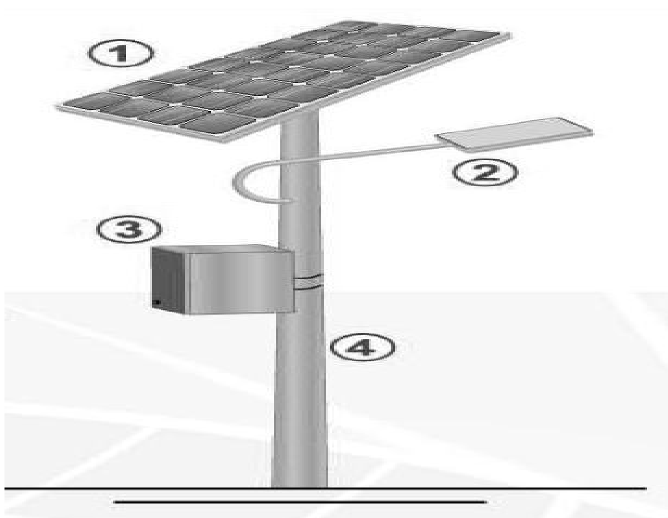

Figure 1: Schematic diagram of a solar powered streetlight

Key:

1- Tilted solar modules placed on a mounting structure facing the sun path.
2- Energy efficient lamp lighting unit suspended on a pole short arm.
3- Vented steel enclosure (contains the battery and the solar charge controller).
4- Structural anticorrosion parts consists of the pole, the affixing base, the short arm and the modules mounting structure as shown by Parise et al. (2014).

Assuming that the Lamp will be available for 12hours during the night, the specification of the calculated electrical devices is shown in Table 1.

Table 1: Specification of the calculated items required

S/n	Item	Power (watts)	Watt hour (Whr)
1	Lamp	16	16 x 12 = 192
2	Lamp 2	16	16 x 12 = 192
Total		32	384

2.1.2 Panel Rating

Assuming the sun will be available for 12 hours, the wattage of the panel is given by:

$$\text{Wattage of panel} = 384\text{watt}/\ 12\text{hrs} = 32 \text{ watt} \tag{1}$$

According to the wattage derived from (1), a panel above 32watts may be used.
Therefore, a panel of 150watts is implemented in this design.

2.1.3 Battery

The deep cycle battery was considered and used because of its reliability and durability compared to the dry, and the wet cell battery. To ensure battery longevity and to avoid damage, in this work, we recommend that ¼ of the battery capacity should be used. Thus,

$$384 \text{ x } 4 = 1536 \text{ watthour.}$$

Since the battery is 12 volts, for 200AH battery, $200 \text{ x } 12\text{volts} = 2400\text{whr}$. For 100AH battery, we have $100 \text{ x } 12\text{volts} = 1200 \text{ watthours.}$
Since a total of 1728whr is needed, a battery of 200 AH is proposed.

2.1.4 Controller

Solar charge controllers are designed to optimize the charging of the deep cycle batteries by the solar panels. Thus,
From

$$\text{P} = \text{IV} \tag{2}$$

$$\text{I} = \text{P/V} = 32/12 = 2.36\text{amps.}$$

Therefore, a controller called the HBSC51 of 5A rating is considered in this design.
In the worst-case scenario, when there is insufficient sunlight, we assume an increase of 15% of normal working condition for the panel, which gives $115\% \text{ of } 384 = 441.6 \text{ watts.}$

$$\text{Panel wattage} = 441.6 \text{ watthour}/12\text{hours} = 36.8\text{watts} \qquad ..(3)$$

Therefore, a 150watts panel can still be used to address the worst-case scenario, when there is insufficient sunlight.

2.2 Components Specification

2.2.1 The Lamp

The lamp specification is shown in Table 2.

Table 2: The Lamp specification

Rated voltage	12 volts DC (manufacturer's specification)
Watts rating	16 watts

Energy efficient lamps are considered for this design. Specifically, these energy saver lamps reduces energy usage to about 5 – 10 %. They are responsible for illumination and the watt rating is 16 watts. Two units of 16watts saver lamp are considered for this design. The watt power rating for both lamps equals 32-watts.

2.2.2 The Panel

The panel specification is shown in Table 3.

Table 3: The panel specification

Rated voltage	18volts DC
Watts rating	150 watts
Current rating	8.28amps (manufacturer's specification)

2.2.3 The Battery: Battery specification is shown in Table 4.

Table 4: Battery specification

Capacity	200 AH
Voltage rating	12 volts

2.2.4 The Controller: Controller specification is shown in Table 5.

Table 5: Controller specification

Rated charge current	5A
Rated load current	5A
Voltage	12volts

The solar streetlight controller described in this work was designed to achieve a 150W solar energy battery charger, and a 32W lamp driver. During the daytime, the controller preserves the electric energy gathered by the solar module (PV module), then stores it in the battery. In the evening, the controller uses the battery energy to power the streetlight. Solar controllers of solar photovoltaic systems were used for the coordination of solar panels, batteries and work load. It is a very important photovoltaic system component. The solar street lamp controller has the following basic features (Shahriar and Hosseini, 2019), overload protection, short circuit protection, reverse-discharge protection, reverse polarity protection, lightning protection, voltage protection, overcharge protection, and power load restoration. A typical solar charge controller indicating normal working condition is shown in Figure 2.

Figure 2: Solar charge controller indicating normal working condition

2.2.5 Characteristics of the controller

Control unit: This characteristics uses a micro controller unit and professional software as the control center to fulfill intelligent system control.

Charging mode: The charging mode employs the use of pulse width modulation to achieve high efficiency charging. This invariably boosts recovery and float charging-auto-work for battery long life.

Self-protection: The self protection characteristics protects the controller against overload, outside and inside short circuit, reverse connection, thunder and lighting, PV panel reverse current, over charging and discharging etc.

LED indication: The light emitting diode (LED) indicates if the system is charging, overcharged, fully charged, power low, over – discharged, over load, and short circuit.

2.3 The System Main Block Diagram

The block diagram of the controller is shown in Figure 3. The microcontroller unit (MCU) provides a real-time system monitoring for the controller. These includes:

● Error detection/protection for solar module output voltage, battery voltage (UBAT), LED lamp voltage (ULED), battery charging current (IBAT), and LED lamp current (ILED).

● System self-recovery (Safa, 2017).

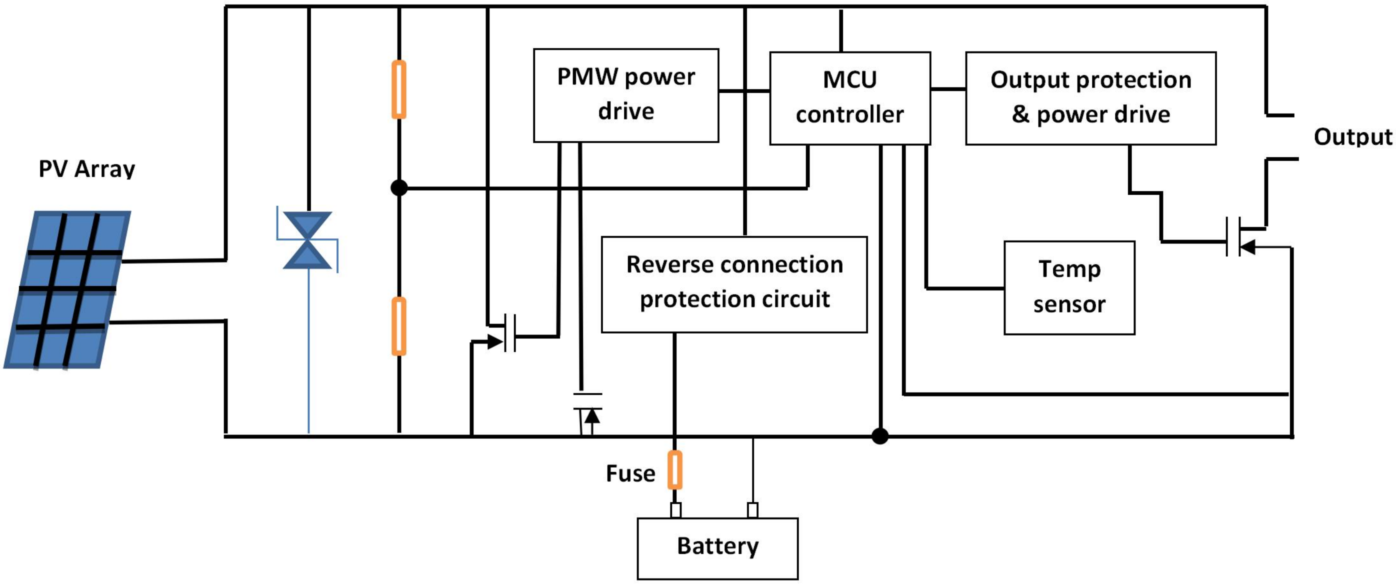

Figure 3: Block diagram of a controller

2.4 The PV Cells

From the calculation above, we consider the use of a panel of 150watt rating. It consists of a solar module which is connected to form a DC power producing unit.

2.5 Installation of the System:

In general, it is known that the sun rises from the east; the panel is therefore placed towards the east as early as 7am for the day's reading. From a theoretical point of view, it is known that the optimum panel angle which maximizes the yearly average irradiation lies between 30° and 40°, which is generally close to the latitude angle Liga et-al. (2018). Therefore, the panel is placed 30° facing the east.

The installation procedure of the system is listed below:

Prepare the 1.5mm wire

Connect the 1.5mm wire from the battery port on the controller to the battery, noting carefully the + and – pole of the connection.

Connect the wire from the PV port on the controller to the PV panel. When the connection is right and the panel gets the sunlight, the charge indicator on the controller comes on.

Connect the two 16watts energy saver lamps to the load port on the controller.

We consider a height of 30ft for the pole for adequate illumination. A typical installation diagram is shown in Figure 4.

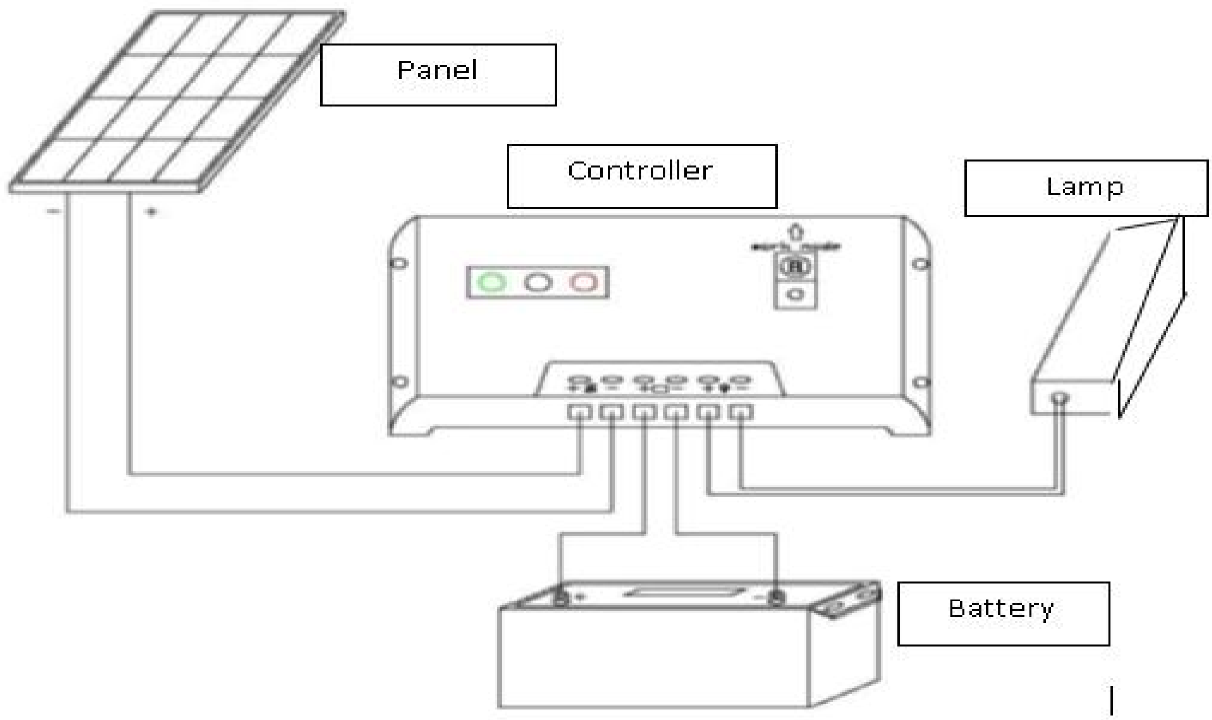

Figure 4: Installation diagram of the solar powered streetlight

2.6 Operation of the System

When light fall on the solar panel, voltage is induced. If the system is properly connected, the green LED is activated indicating that the system is working perfectly. When the battery voltage is in normal condition, the state LED lights up in green; state LED flashes slowly in green when the battery is fully charged. When the voltage of the battery is low, the yellow LED is activated. When the voltage goes down continually to an over-discharged state, the system state LED lights up in red and turns off the output at the same time. Upon re-charging, the battery voltage recovers from the over discharged return voltage, and the system automatically becomes operational.

The Load LED lights up when the load is connected. If the load current is 1.25 times higher for 60 seconds or 1.5 times higher for 5seconds than the rated current of the controller which is 5A, the trouble LED flashes slowly in red to show overload, and the controller shuts down the output. When the load short circuit happens, the trouble LED flashes quickly, then the controller shuts down its output. When this happens, the load at fault is disconnected.

2.7 Problems and Troubleshooting of the PV system

Probable problems of the PV system, and troubleshooting options are presented in Table 6.

Table 6: Probable problems and possible solutions

Problems	Troubleshooting
The charge LED indicator (green) is not activated when sunlight gets to the PV panel.	Check if the cable of the solar panel is connected properly.
The charge LED indicator flashes quickly.	System over voltage or open circuit of the battery. Check if the battery is connected to the system cable properly or check for any charging circuit damages.
The load LED indicator lights up but there is	Check if the load is connected to the system

no power output.	properly.
The load LED indicator flashes quickly and there is no power output.	Check the output circuit. If over load occurs, remove the load and push the button. The controller returns to its operational state.
The load LED indicator lights up slowly and there is no power output	Possibility of system overload. Disconnect some load and push the button again to reactivate the controller.
System state LED indicator flashes red color and there is no power output	Over discharge of the battery. The controller resumes its operation after battery charge is complete.

3.0 Results and Discussion

For analytical simplicity, the practical test was carried out over a period of nine days. The components were tested together as a system, and multimeters were used to measure the voltage on each of the component. Multimeters were set to DC at 20 volts range to take the no-load reading on the panel. The no-load reading is obtained when the battery is not connected. This provide the voltage reading on the panel obtained directly from the sun rays. Also, multimeters set at DC 20 volts range were used to obtain the reading on-load. The reading on-load show how the battery is being charged by the solar panel. In this case, the battery must have been connected to the controller to be charged. The last set of readings were taken during the dusk. We are determined to know the rate of discharge of the battery when the bulbs (32 watts) are connected, and when there is no supply of voltage from the panel. The multimeter is also set at DC 20 volts range to obtain relevant values. We ensured that the right connection of the components that make up the solar streetlight which include the panel connection to the controller. Also, the battery and the load (32watt bulb) are connected to the right slot on the controller. The controller helps to regulate the voltage that charges the battery, and to turn on the lamp when there is low voltage from the panel.

3.1 Voltage from the Panel (on no-load)

Upon the installation of the PV system designed to power the streetlight, voltage measurements were obtained. Using a multimeter, voltage from the panel on no-load for three days were recorded as shown in Table 7, 8, and 9.

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Voltage from panel measurements for no-load experiment for day one is shown in Table 7.

Table 7. Time and voltage readings for day one (7/12/2019)

Time (am-pm) (minutes)	Voltage on panel (volts)
7:30	17.20
8:00	17.37
8:30	17.98
9:00	18.22
9:30	18.58
10:0	18.62
10:30	18.98
11:00	18.50
11:30	18.91
12:00	18.74
12:30	18.15
13:00	18.45
13:30	18.52
14:00	18.41
14:30	18.52
15:00	18.55
15:30	18.48
16:00	18.43
16:30	17.77
17:00	17.34
17:30	17.40
18:00	14.00
18:30	5.70

Voltage from panel measurements for no-load experiments for day two is shown in Table 8.

Table 8. Time and voltage readings for day two (8/12/2019)

Time (am-pm) (minutes)	Voltage on panel (volts)
7:30	17.10
8:00	18.50
8:30	18.50
9:00	18.90
9:30	18.80
10:0	18.80
10:3	18.70
11:00	18.50
11:30	18.60
12:00	18.30
12:30	18.44
13:00	18.49
13:30	18.58
14:00	18.55
14:30	18.54
15:00	18.30
15:30	18.34
16:00	18.18
16:30	17.86
17:00	17.41
17:30	17.22
18:00	12.18
18:30	6.21

Voltage from panel measurements for no-load experiments for day three is shown in Table 9.

Table 9. Time and voltage readings for day three (9/12/2019)

Time (am-pm) (minutes)	Voltage (volts)
7:30	17.15
8:00	18.30
8:30	18.38
9:00	18.98
9:30	19.10
10:0	18.70
10:30	18.65
11:00	17.43
11:30	18.56
12:00	18.62
12:30	18.76
13:00	18.59
13:30	18.68
14:00	18.84
14:30	18.52
15:00	18.22
15:30	18.07
16:00	17.81
16:30	17.48
17:00	16.98
17:30	16.42
18:00	14.03
18:30	13.48
19:00	3.27

3.1.1 Observation for No-Load Testing

As can be seen in Tables 7, 8, and 9, an increase in the sun's intensity results to a corresponding increase in the voltage obtained from the panel. This can be seen during the peak period where the sun intensity is high between the 9:00 hours and the 10:30 hrs. For the three days' experiment for no-load, the peak voltage is found between the stated period.

3.2 Voltage measurements when system is connected to the Battery

Voltage measurements when the battery was connected to the panel were recorded for three days as shown in Table 10, 11 and 12.

Voltage measurement for on-load experiment for day one is shown in Table 10

Table 10 Time and voltage readings for day four (10/12/2019)

Time (am-pm) (minutes)	Voltage (Panel) (volts)	Voltage (Battery) (volts)
7:30	12.64	12.67
8:00	12.73	12.69
8:30	12.86	12.72
9:00	13.01	12.92
9:30	13.05	12.98
10:00	13.19	13.00
10:30	13.02	12.97
11:00	13.06	13.02
11:30	12.99	12.97
12:00	13.00	12.96
12:30	13.20	13.01
13:00	13.02	12.96
13:30	13.07	13.04
14:00	12.97	12.92
14:30	13.08	12.95
15:00	13.01	12.99
15:30	12.96	12.92
16:00	12.95	12.91
16:30	12.92	12.89
17:00	12.90	12.87
17:30	12.87	12.84
18:00	12.82	12.81
18:30	12.76	12.77
19:00	0.97	12.44

Voltage measurement for on-load experiment for day two is shown in Table 11

Table 11 Time and voltage readings for day five (11/12/2019)

Time (am-pm) (minutes)	Voltage (Panel) (volts)	Voltage (Battery) (volts)
7:30	12.80	12.68
8:00	12.84	12.80
8:30	12.98	12.91
9:00	13.04	12.95
9:30	13.13	13.06
10:00	13.10	13.07
10:30	13.10	13.07
11:00	13.11	13.07
11:30	13.11	13.08
12:00	13.11	13.11
12:30	13.14	13.11
13:00	13.74	13.11
13:30	13.12	13.10
14:00	13.14	13.13
14:30	13.14	13.12
15:00	13.08	13.05
15:30	13.04	13.03
16:00	13.01	13.01
16:30	13.03	13.02
17:00	12.96	12.97
17:30	12.94	12.91
18:00	12.86	12.89
18:30	12.81	12.83
19:00	0.10	12.80

Voltage measurement for on-load experiment for day three is shown in Table 12

Table 12 Time and voltage readings for day six (12/12/2019)

Time (am-pm) (minutes)	Voltage (Panel) (volts)	Voltage (Battery) (volts)
8:30	13.38	13.38
9:00	13.98	13.96
9:30	19.10	13.45
10:00	18.70	13.34
10:30	18.65	13.36
11:00	17.43	14.13
11:30	18.56	13.22
12:00	18.62	13.24
12:30	18.76	13.36
13:00	18.59	13.27
13:30	18.68	13.17
14:00	18.84	13.32
14:30	18.52	13.28
15:00	18.22	13.23
15:30	18.07	13.21
16:00	17.81	13.22
16:30	17.48	12.23
17:00	16.98	13.22
17:30	16.42	13.14
18:00	14.03	13.25
18:30	13.48	13.17
19:00	3.27	12.71

3.2.1 Observations for on-Load Testing

As can be seen from Tables 10, 11, and 12, it is observed that immediately the battery is connected, there is a drop in voltage from 18 volts to between 13 and 14 volts.

The peak voltage occurs between the hours of 12:30 and 13:00.

It is observed that when the battery is fully charged, with the controller connected, the voltage supplied to the battery is cut off thereafter we could only obtain the no-load voltage as it can be seen from 9:30 hours on day six.

It was observed that when it is getting dark specifically between 18:30 hours and 19:00 hours, the controller automatically switches on the 32watts lamp.

It is also observed that the battery charges effectively when the voltage output from the panel exceeds 12 volts.

3.3 Battery Voltage discharge when connected to Lamp

Voltage measurements when the Lamp is connected to the battery were recorded as shown in Table 13, 14 and 15.

Voltage discharge measurement for Lamp-Battery connection experiment for day one is shown in Table 13.

Table 13: Time and voltage readings for day seven (27/12/2019)

Time (pm-am) (minutes)	Voltage (Battery) (volts)
19:00	12.72
19:30	12.75
20:00	12.70
20:30	12.69
21:00	12.68
21:30	12.68
22:00	12.65
22:30	12.64
23:00	12.63
23:30	12.62
00:00	12.60
00:30	12.59
1:00	12.58
1:30	12.56
2:00	12.55
2:30	12.54
3:00	12.53
3:30	12.52
4:00	12.50
4:30	12.48
5:00	12.47
5:30	12.31
6:00	12.28
6:30	12.27
7:00	12.22

Voltage discharge measurement for Lamp-Battery connection experiment for day two is shown in Table 14.

Table 14. Time and voltage readings for day eight (28/12/2019)

Time (pm-am) (minutes)	Voltage on Battery (volts)
19:00	12.44
19:30	12.45
20:00	12.45
20:30	12.42
21:00	12.38
21:30	12.36
22:00	12.34
22:30	12.32
23:00	12.30
23:30	12.28
00:00	12.26
00:30	12.24
1:00	12.23
1:30	12.23
2:00	12.22
2:30	12.21
3:00	12.20
3:30	12.20
4:00	12.19
4:30	12.17
5:00	12.15
5:30	12.12
6:00	12.10
6:30	12.08
7:00	12.11
7:30	12.13

Voltage discharge measurement for Lamp-Battery connection experiment for day three is shown in Table 15.

Table 15 Time and voltage readings for day nine (29/12/2019)

Time (pm-am) (minutes)	Voltage (Battery) (volts)
18:50	12.46
19:00	12.49
19:30	12.50
20:00	12.46
20:30	12.42
21:00	12.38
21:30	12.38
22:00	12.34
22:30	12.32
23:00	12.31
23:30	12.29
00:00	12.26
00:30	12.25
01:00	12.23
01:30	12.22
02:00	12.21
02:30	12.20
03:00	12.19
03:30	12.19
04:00	12.18
04:30	12.16
05:00	12.13
05:30	12.11
06:00	12.09
06:30	12.08
07:00	12.06

3.3.1 Observation on Battery Discharging Rate

From the discharge information as shown in Tables 13, 14, 15, when the load is connected, there is a sudden drop in voltage which later increases for a while and remains stable before discharging with a considerable constant discharging rate.

There is an increase in voltage at 6:30 hours due to sunrise thus, the controller cuts off the supply to the load and then charges the battery.

4.0 Conclusion

This work considered the design and implementation of a solar powered streetlight to provide illumination along streets, houses, and on roads during nighttime and at dawn thereby increasing security and safety of lives and properties. Due to the inconsistencies surrounding the generation of electricity using fossil fuels, this work offers an alternative source to power streetlights thereby reducing pressure on the national grid. Results obtained showed that the solar source of electricity generation through the use of solar panels (Photovoltaic modules) cheaply generate electricity directly from sunlight without emissions, noise, or vibration.

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