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Design and implementation of solar street light for campus environment

Achebe Patience Nkiruka
Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria
patug165@gmail.com

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Abstract

This paper has presented design and implementation of solar street light for campus environment. It is desired to develop a street light system that is powered by solar energy and that should automatically provide light without requiring manual (ON/OFF) operation for campus environment. In order to realize the objective of the paper, design analysis was performed and components purchased. A charge controller was designed using Circuit Wizard. The whole assembly was simulated with a voltage source representing a photovoltaic (PV) cell array, Battery source and a lamp integrated with charge controller circuit. The simulation results showed that the charging voltage, 14.9 V, greater than the battery voltage, 12 V, was obtained meaning that the charge controller regulated the output voltage of the solar panel well enough to charge the battery. It was also observed that the lamp effectively maintained an output voltage of 10 V with direct current of 4.3 A. This paper offer an advantage of an efficient solar street light system that minimize energy consumption and also eliminated the manual switching.

Keywords: Charge controller, circuit wizard, solar energy, solar street light, photovoltaic.

Introduction

One of the most important, and yet expensive, responsibilities of a city is to provide street lighting[1]. In typical cities worldwide, lighting is can account for 10-30% of the overall energy bill[1]. A particular concern that is of critical concern to public authorities in developing countries like Nigeria is the street lighting project. This is because of the strategic importance it offers to economic and social viability and stability.

An efficient design of a street light is capable of cutting street light costs drastically by reasonable percentage of about 25-60%[1]. Achieving this can reduce or eliminate the demand for new power plant and thereby making provision for unconventional energy using renewable source of energy solution for the population remote or rural areas. Another benefit of installing energy-efficient street lighting system is that the savings cost would also enhance cities to develop street lighting to other parts. This will lead to increase in access of lighting in low income and underserved locality within the municipal. This will also improve street lighting quality and service expansion and as such leading to improve safety conditions for both the movement of vehicles and humans during night fall. This invariably reduce traffic at night.

Most of the street lighting systems in recent time are utilizing a promising lamp made of light emitting diode (LED) for street lighting application. A combination of low powered LED, high illumination features with the present photovoltaic (PV) technology, has led to the development of PV powered street light using solar lamp.

Generally, solar street light systems are designed for outdoor purposes. This system is ideally suitable in places like campus, rural areas and highways where proper electrification is required for safety and security purposes. It is provided with a battery storage backup sufficient to operate the light for several hours (about 12 hours). It has an automatic ON/OFF time switching circuit that provide dusk to dawn operation and overcharge/deep charge prevention cut-off with LED indicators.

The remaining parts of this paper will focus on four main parts which are: review of related works, design methodology, results and discussion, and conclusion.

Research Motivation: The provision of street lighting is among the utmost costly tasks of a city. As a result of the strategic significant role it provides for commercial and public stability, it has become a critical concern for public authorities in developing countries[2]. Inefficient Street lighting causes significant waste of financial resources, and poor lighting system creates unsafe condition[2]. Hence, the need to have energy efficient system that will save costs by reducing the demand for new power plants and make available the capital for unconventional energy solution. This cost savings can as well enable municipalities (cities, towns, or metropolises) to develop street lighting to other parts, thereby providing right to use of lighting in areas occupied by low-income settlers.

Also, the Faculty of Engineering in the campus of Chukwuemeka Odumegwu Ojukwu University (COOU), Uli, often loss power during the night. This creates room for possible vandalism because security personnel could hardly notice the movement of persons with ill intention (hoodlums). Adequate surveillance and security is likely not possible in a situation of total darkness. Hence, the need for street lighting with renewable source of energy that will provide reliable and efficient lighting or illumination to aid security within the faculty in the night.

Statement of the problem: Recent practice in Street Lighting using Solar Powered LED is still considered to be non-cost effective especially in Nigeria. This is because most of the components required to design and construct a solar street light are virtually bought in the market and are very expensive. This probably will amount to increasing cost in all aspects of design and construction of such project with solar panel and battery taking up to 70% of the entire cost. Also, the LED lamps holder is affected as a result of the system size and weight on the structure. Utilizing sensing device and a miniaturized circuit for the charge controller can help reduce sizing of solar power system thereby having the power losses from point of generation to the load demand point. With this small sizing of the system, design and construction cost is optimized with less complexity in the structure to mount the system.

Review of Literature: The use of solar powered lamp street lights has attracted much attention and interest in literature as well as in industrial and commercial market. In recent application, high discharge (HID) lamps, which are usually high pressure sodium (HPS) lamps are being substituted with LED lamps of lower power[3] for energy-efficient and cost effective solar powered street light.

During day time, the Solar Panel generates the charging current for the battery. The charge controller regulates or controls the current for charging the battery. A control circuit using sensors such as Light Dependent Resistor (LDR) regulate or control the LED lamp operation. The entire components are then fixed on a rigid pole as represented in Figure-1. The PV panel is placed at the top of the pole minimize the chance of panel shading, if any.

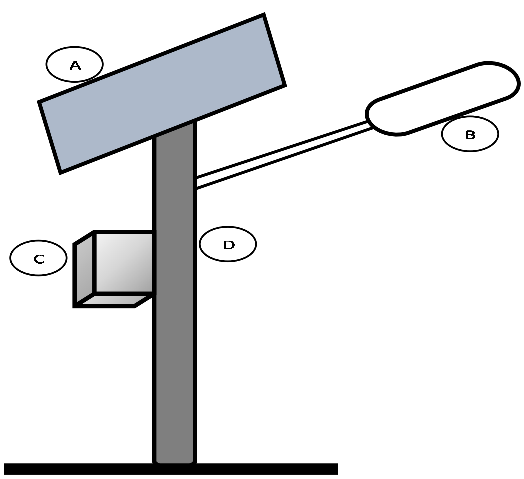

Figure-1: Schematic Diagram of solar powered LAMP Street Light System.

The labelled parts of Figure-1 are explained as follows: i. Solar modules place on mounting structure facing the direction of the sun. ii. Lamp lighting unit suspended on a pole short arm, iii. Vented steel enclosure (containing the battery and the solar controller), iv. Structural anti-corrosion parts consists of the pole, the affixing base, the short arm and the mounting structure.

Solar Energy and Application in Street Light: Solar panels consist of photovoltaic (PV) cells that are either serially connected or in parallel. It is a large area semiconductor p-n diode having its junction placed near the top of the surface[4]. Illuminating the cell brings about electron-hole pair generation as a result of the contact between the incident light energy and cell's atoms.

The electron-hole pair generated by the incident light energy (or photon) is separated by the electric field produced by the p-n junction of the PV cell. Drifting takes place, with holes drifting into p-region while electrons drifts into n-region.

The efficiency of conversion of photovoltaic cells is sated as the ratio of power output (electrical energy at the output) to the solar power impacting the surface area of the PV cell. The PV cell efficiency is generally below 30%[5]. The need to have more efficient and low cost solar panels has given rise to the different PV technologies[5]. Polycrystalline, thin films, Single-crystalline silicon, amorphous silicon, and semi-crystalline are the major types of solar panel.

In an attempt to explore the working principle of PV to generate electricity for street lighting using LEDs, some researchers have developed different design strategies for street light installation in various cities and communities. For instance, the significance of using light emitting diode (LED) as the lighting device for street light system powered by solar was well emphasized in Fathi and Chikouche[6], Guijian and Yingchun[7], Yongqing et al[8], and Mahto and Tiwari[9].

Kiong[3] presented a cost effective LED street light system powered by solar. An algorithm for LED light intensity control was proposed. Oke et al[10] designed and constructed a solar powered lighting system.

It stated that solar energy is harnessed for powering street light and almost 100% operation of the system is achieve without the involvement of manual operation for ON and OFF switching of the light whenever the sunlight comes or goes using Light Dependent Resistor (LDR). Mahto and Tiwari[11] designed and constructed a solar PV LEDs lighting system in which they stated that it is better than other lighting sources because it can be used for home appliance, residential and commercial process with some switching devices and with some controlling equipment. Priyanka and Baskaran[12] presented a remote streetlight monitoring and controlling system based on LED and wireless sensor network.

Methodology

Technical Aspect: The method used in realizing the objectives of this paper are as follows: i. Purchasing of Equipment/ Components: The equipment could be purchased from a solar energy company or representative in Nigeria. Alternatively, it can be purchased from retail outlets. For instance, in this work, devices such as Solar Panel, Battery, components required to build the charge controller, and steels for fabrication were purchased from retail shops in Onitsha Main Market. An efficient and wiring connection is also an important part of the installation. ii. Component Testing: The solar panel and the components bought from the market are tested to ascertain that they are functioning properly. This test is based on voltage measurement and continuity. iii. Assembly of Component: The solar panel would be placed on metal structures of the top most point of the fabricated pole. Optimal angle of inclination and direction of sun light is considered. This enable maximum energy to be obtained. The designed charge controller is connected to the solar panel to regulate the charging current from the solar output to the battery. The arrangement for the electrical connection is represented in form of a block diagram in Figure-2.

Design analysis: The design analysis is considered here. In order to do this, the Bill of Quantities (BoQ), equipment specifications for solar panel and battery are presented in Tables-1, 2 and 3.

Battery Analysis: Installation rated capacity of battery = 12 V, 105Ah

Watt-hour of battery (W_B) = Rated voltage $\times$ Ampere-hour of batter (1)

Therefore, $W_B = 12 \times 105 = 1260\text{Wh}$

Load (lamp) capacity = 30W$\times$2=60W (two lamps are used with 30W capacity each)

Back up time (B_T) is given by:

$$B_T = \frac{W_B}{\text{Load}} \quad (2)$$

Therefore, $B_T = \frac{1260}{60} = 21\text{hour}$

This value is approximately equal to the specified battery hour (20 HR) by the manufacturer.

Charging current for battery (I_C):

The charging current should be one-tenth (1/10) of battery ampere-hour (Ah)[13].

$$I_C = 105 \times \frac{1}{10} = 10.5\text{A}$$

Charging time required of battery (T) is given by:

$$T = \frac{\text{Ah}}{I_C} \quad (3)$$

$$= \frac{105}{10.5} = 10\,\text{Hours}$$

The above value is for ideal case. In practice, due to losses (it has been noted that 40% of losses occurred during the battery charging), for this reason, charging time is taken as a value between 10 to 12 [13].

Table-1: Bill of Quantity.

Component	Quantity	Cost (Naira)
Solar panel	1	23,000
battery	1	46,000
Lamp (load)	2	23,000
Pole (two arms)	1	35,000
Cable	As per requirement	5,000
Charge Controller	1	20,000
Total	-	152, 000

Table-2: Solar Panel Specifications (Based on Nominal Rating).

Quantity	Symbol	Specification
Max. power (±5%)	P_{max}	100W
Current max power	I_{mp}	5.50A
Voltage max. power	V_{mp}	18.0V
Short circuit current	I_{SC}	5.90 A
Open circuit voltage	V_{OC}	21.05V
Max system voltage	-	$1000V_{DC}$
Cell Technology	MONO	-
Module dimension		1480*540*35

Table-3: Battery Specifications (ATOMZ Network Battery, M12V105AH).

Quantity	Specification
Voltage	12 V
Current capacity	105 AH
Flow voltage	13.6 V/unit (25^{o}C)
Temperature Compensation	-0.018 V/^{o}C unit
Charge current	0.25 C, A (max)

Instead of charging for 10 Hours, the charging time for 12V, 105Ah battery should be [13]:

The battery rating = (105Ah+Losses) (4)

$$= 105\text{Ah} + 105 \times \frac{40}{100} = 147\text{Ah}$$

Hence, battery charging time

$$T = \frac{147\text{Ah}}{12} = 12.25 \text{ Hours}$$

Solar selection[2]: Solar panel capacity, P_s is given by:

$$P_s = \frac{P_E \times N_{RT}}{T} \quad (5)$$

$$= \frac{60 \times 21}{12.25} = 102.8 \approx 100\,\text{W}$$

Charge Controller Design: The charge controller was initially designed using Circuit Wizard, a software for designing and analysing of electronic circuits. The designed and simulated charge controller is shown in Figure-3.

Pole Fabrication: A pole of diameter 1.14mm with the height of 45.75mm is used to hold the construction of the system and provides the necessary support. The solar panel base has a dimension of 15.25mm by 6.10mm and provides the support for the PV module panel. The lamp arm which provides support for lighting load is of dimension 6.10mm by 0.38mm.

Results and discussion

The presents the evaluation of the system performance based on simulation using circuit wizard and the simulation results obtained. In Figure-4, the simulation circuit environment is shown. Figure-5 shows the signal reading with circuit environment. The simulation results are presented in Figures-6 and 7.

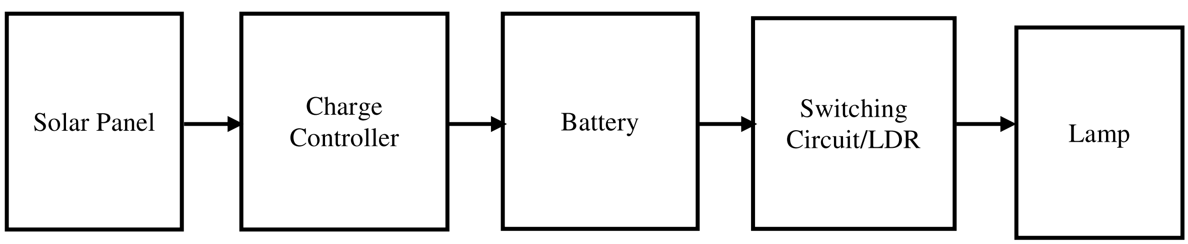

Figure-2: Block diagram of the solar street light arrangement.

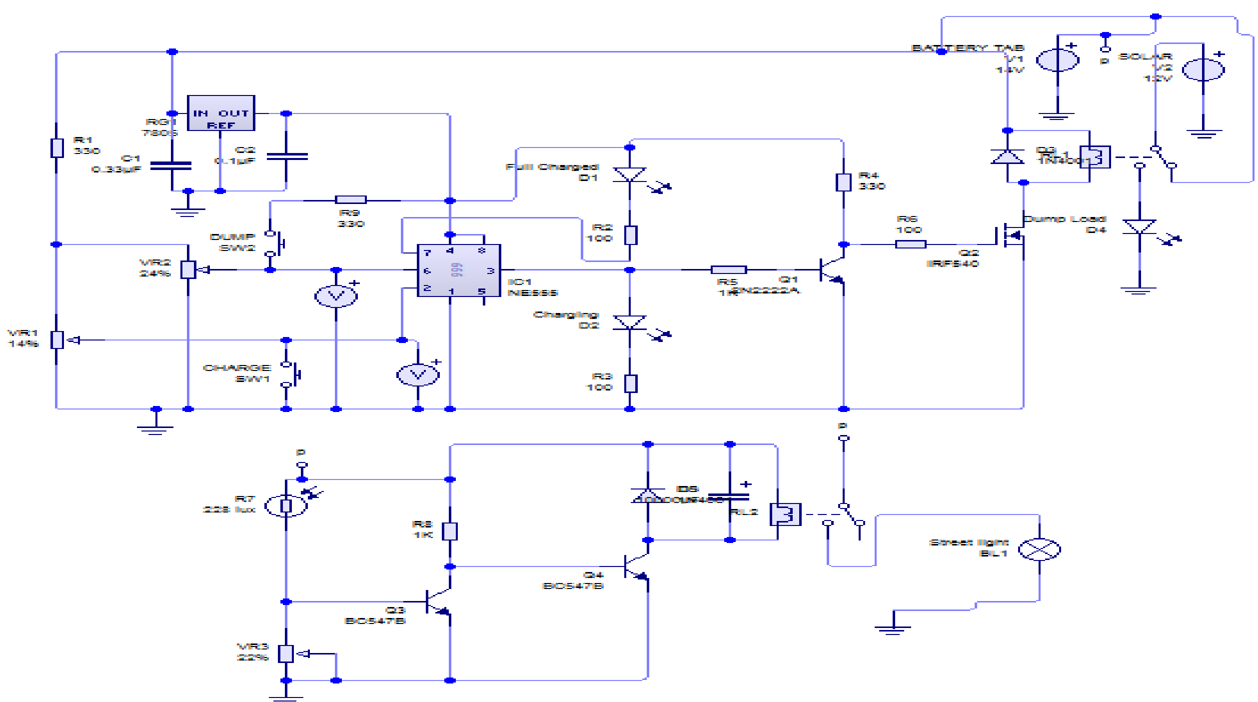

Figure-3: Charge controller circuit.

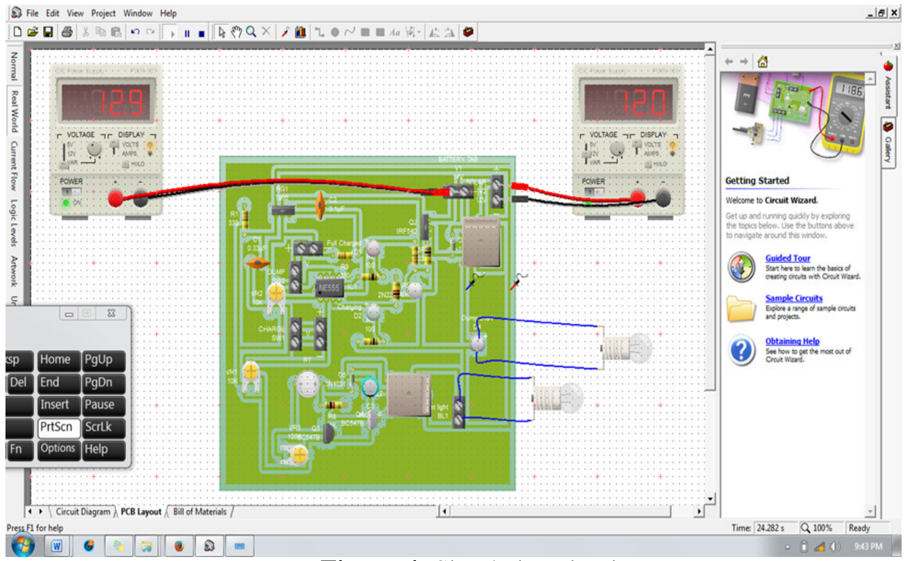

Figure-4: Simulation circuit.

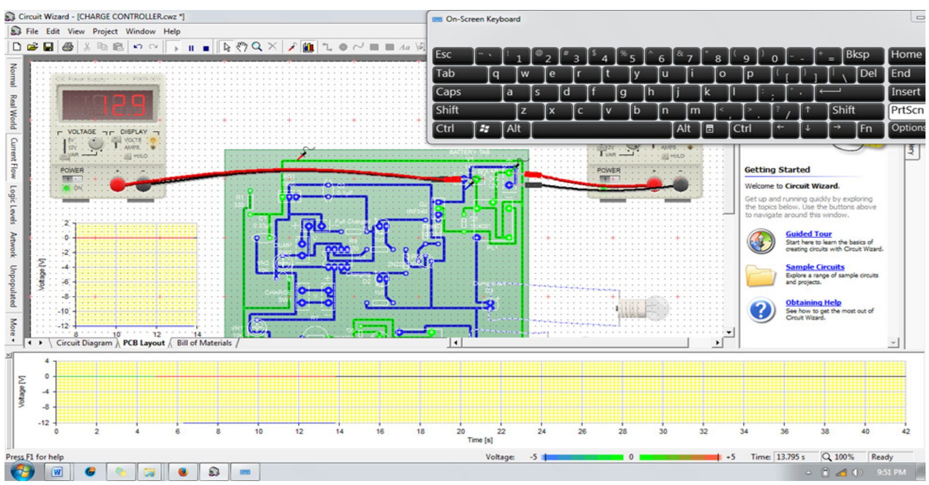

Figure-5: Circuit signal reading with simulation environment.

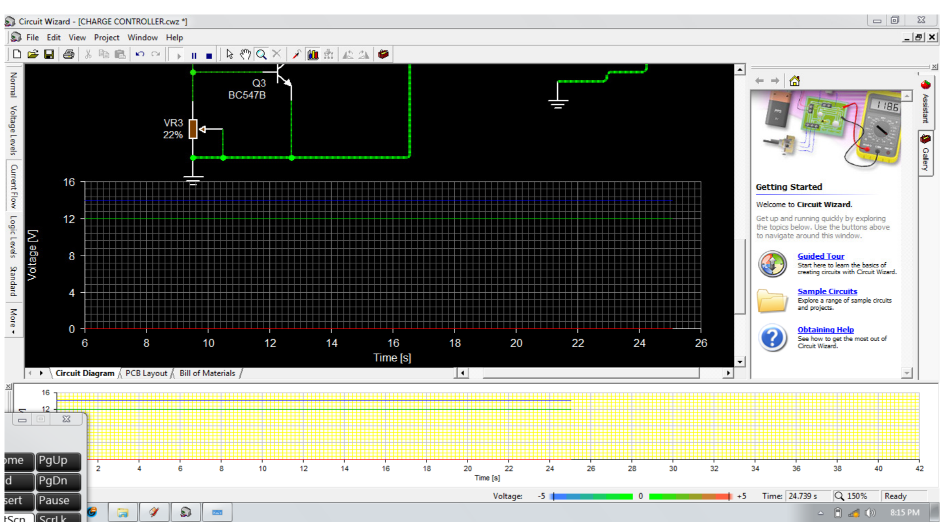

Figure-6: Simulation results for solar charging voltage, battery voltage and ground voltage.

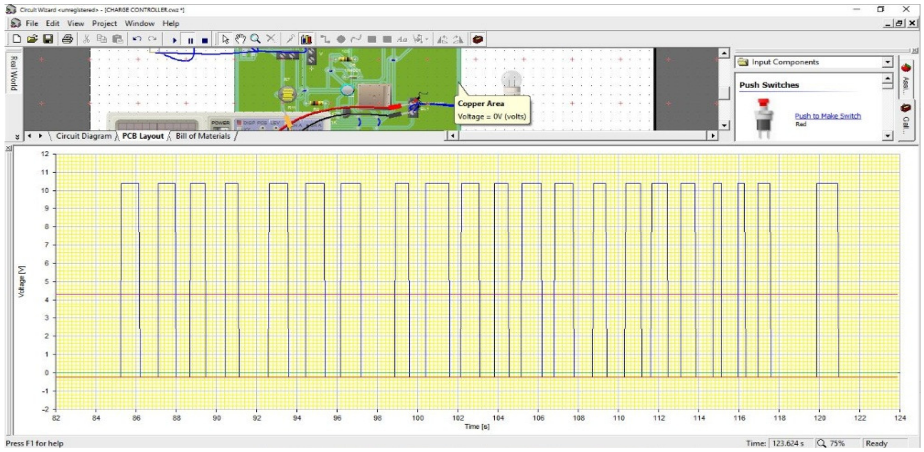

Figure-7: Solar lamp output.

The simulation results in Figure-6 shows the solar voltage (blue line), the battery voltage (green line), and the gound voltage (red line). Charging begins at 6 seconds. The charging voltage from the solar PV is 14.9V which is greater than the battery voltage, 12V. This difference in voltage between the sPV cell and the voltage of battery brings about a potential difference that makes charging current to flow from the solar panel to battery.

In Figure-7, the output voltage is maintained at a level of 10 V. The current is maintained at 4.3 A, indicated by the red line.

Conclusion

This work has presented design and construction of solar power street light. It was designed and constructed so as to eliminate the traditional use of inverter or public power supply sources. Street lighting required the use of charge controller to control the battery charging rate so as to prevent from damaging. It has a sensor that functions to automatically switch the lamps at the appropriate time. The switching mechanism is achieved with light dependent resistor (LDR), which triggers the system including a charge controller. The entire system was built around the concept of energy conservation using low energy lamp (LED), which also enhanced battery performance efficiency unlike the fluorescent lamp that might cause the battery efficiency to reduce. Furthermore, using solar panel eliminates the use of inverter as the power generated by the PV cells is a direct current (D.C.) and charges the battery. The improvement of this paper is on the use of cost effective system that eliminates the use of inverter and utilizes low energy lamp to provide illumination for campus environment during the night.

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