Automatic Solar Street Light Design

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Abstract

Lighting plays a significant role in human lives, as it assists humans with better vision. Streetlights are essential for both safety and visibility at night. Like any electrical component, they consume energy and need to be switched on/off every day. It is essential to consider the optimal time for the lights to be switched on/off, the optimal control equipment and how to increase their efficiency. Various components are suitable for this task, but it is imperative to choose components that will deliver the desired results at minimal cost. This paper investigates controlling the street lights from one controller that uses Solar PV energy stored in a battery and the grid as a backup source. The source provided can supply power to all three streetlights from one supply instead of multiple power supplies and controllers. Furthermore, it is also possible to dim the street lights.

Keywords

Light dimming, streetlight, light sensing, motion sensing.

1. Introduction

The sun is the main natural source of visible light. The average time the sun is up is between 11.5 to 12 hours per day in South Africa [1]. Once the sun sets not all living organisms are able to see without the assistance of artificial illumination. Humans struggle to see during the absence of visible light as the human eye needs reflection of light to see. The light reflected by the stars and moon does not allow an average human eye to see objects that are 5km away clearly at night [2]. It has also been discovered that "proper lighting reduces road fatalities and accidents with pedestrians", thus streetlights are designed to help people have improved vision in the absence of sunlight [3].

Street lighting works as security measure to reduce crime. Areas with minimal illumination were found to have more security issues than well illuminated areas. As a result it was seen that there is a direct connection relationship between illumination and security. Security is very crucial for economic, industrial and social reasons [4].

The systems used to produce illuminations to the surroundings during night time are very important. The street lights' traditional approach of switching on/off at fixed times has been found to be an expensive method. This method employs either a timer or a physical traditional switch which is controlled manually [4]. The manual method has a lot of inconstancies as humans have to operate the switch. An automated system is more cost effective and reliable as works independent of human input. A timer based switch does not need humans to switch on/off. Yet again the timer has to be set for every season change [5]. The biggest problem with the timer based method is that it only turns on during set times. There are less labour issues related to automated system such as absenteeism, illness, strikes and labour costs. An automated system shall also be able to respond to a change in the environmental conditions.

2. Research Objective

The objective of this work was to build an energy saving streetlight controller that shall integrate both solar power and the power grid and use inductive sensing to control the streetlight's brightness.
The solar panel was connected to a storage battery to be able to use the energy at night. The controller was expected to monitor the battery levels and switch between the store energy and the power grid. The streetlight was primarily powered by solar energy stored in a battery and only alternates to the grid when the battery levels are very low. The solar panel and controller were to be designed such that they can be mounted onto the streetlight.

The controller shall be able to vary the brightness depending on the ambient light intensity, and if there is motion in its vicinity. The brightness shall vary from dim to maximum brightness in the event that there was traffic/motion around the streetlight. One controller shall be able to control at least three lights which will be varied dependent on the position of the object in motion.
The scope of the implemented design includes the following:

- Design and construction of a streetlight controller.
- The controller shall:
  - Monitor the ambient light
  - Monitor traffic or motion next to the street light.
  - Control at least 3 streetlights.
  - Vary the output load's light intensity
- Integration of AC and DC power inputs.

3. DESIGN SPECIFICATIONS

The system was required to achieve the following basics:

- Be powered by a PV solar system.
- Have a secondary back up source i.e. the grid for times when there is low power from the PV solar system
- The storage battery shall be rated at 12V
- Use the PV solar storage battery until the power decreases to 80%, else switch to the grid power.
- The lights will turn on only when the LDR network is less than 20% of the input voltage.
- The LED will brighten up when the PIR detects a high signal, otherwise be dim.

4. DETAILED DESIGN

Major and key components of the controller are discussed below:

4.1 Microcontroller

The Arduino Nano needs to be powered up at all times independently of the load sources. A 9V battery was used. This will help in reducing errors during the switching between the two power sources. The microcontroller can also be powered from a USB power outlet.

4.2 Sensors

4.2.1 LDR

Since an LDR varies its resistance with change in incident, it was used to detect how much ambient light is available. Out of this property, a voltage divider was used get voltage variations during different times of the day. A 10k LDR was used as it is readily available. Since the Arduino Nano has a 10bit processor, the analogue reading ranges from 0 to1023 at 5V input. At sunset, the analogue reading is expected to be at most 511 at a voltage of 2.5V. In Figure 1 below, R1 represents the unknown resistor that shall work with the LDR.

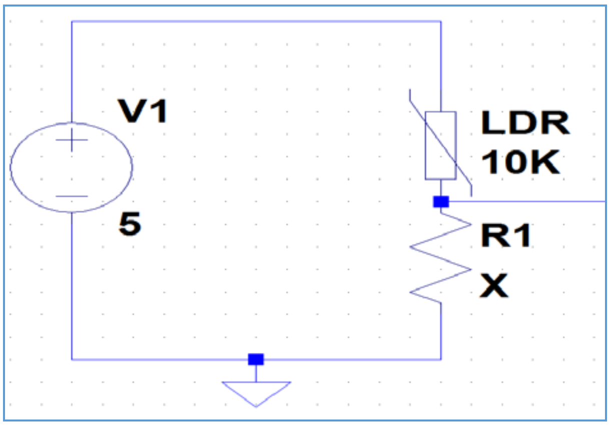

Figure 1: LDR voltage divider

Using the voltage divider rule, the resistance value was calculated

$$\frac{V_o}{V_{in}} = \frac{x}{LDR+x} \quad (1)$$

$$x > \frac{V_o}{V_{in} - V_o} LDR \quad (2)$$

$$x > \frac{2.5}{5 - 2.5}(10k) \quad (3)$$

$$x > 10k\Omega \quad (4)$$

The closest resistor value greater than 10kΩ is 12kΩ . Hence R1 was a 12kΩ resistor.

4.2.2 PIR

A Digital PIR motion Sensor was used. Since it is compactible for Arduino, it needs no additional components. It was very much important not to go above the rated voltage of 5V, else the motion sensor module will break. The sensor will detect infrared generated by motion with its view field. Motion detection will be used to control the output light intensity.

4.3 Load

The main power consumer of the project is the output LEDs. Three LEDs were used. Each is rated at 12V, 4W, 480mA. Each LED will be connected to a MOSFET to be able to do fast switch. This reduces switching loses as the might vary its brightness several times in a single night. An IRF510 MOSFET was used. Ohm's law was used to calculate the value required current limiting resistors. An LED act as a short circuit once it reaches its forward voltage. Each LED will be limited to 100mA.

$$R = \frac{V}{I} = \frac{12}{100 * 10^{-3}} = 120\Omega \quad (5)$$

As result 3*120Ω resistors were needed for current limiting resistors. The total current consumption is given by

$$I_{TOTAL} = 3 * I_{LED} = 3 * 100mA = 300mA \quad (6)$$

Power consumption due to LEDs was then given by

$$P_{TOTAL} = V * I_{TOTAL} = 12 * 300mA = 3.6W \quad (7)$$

4.4 Power Source: Solar Powered Battery and Grid

As it was discussed above, the system had to have two power source, a 12V battery which was charged by a PV solar panel. A solar regular was used to couple the solar panel and 12V battery to avoid overcharging. The regulator was not built from first principle but were purchased as a complete item. It does not form a key part of the controller. The selected battery has a battery capacity of 7A.h. With the total current being 300mA, the amount time the battery can last can be calculated as:

$$q = I * t \quad (8)$$

$$7 = 0.3 * t \quad (9)$$

$$t = 23.3\ hours \quad (10)$$

A fully charged battery could go for at least two full nights.

4.5 Relay

A relay operates as an automatic switch. It has three pins on the output, namely:

- Com: common node
- NC: Normally closed
- NO: Normally Opened

The relay was triggered by the Arduino Nano with a 5V signal.

Since both the normally closed and normally opened and not be operation at the same time. The following configuration shall be followed:

- Com: LEDs positive node
- NC: battery (primary source)
- NO: grid (secondary source)

A diode will be connected to the NC and NO node to avoid the sources charging each other during the source swapping phase. Below is a picture of the circuit diagram:

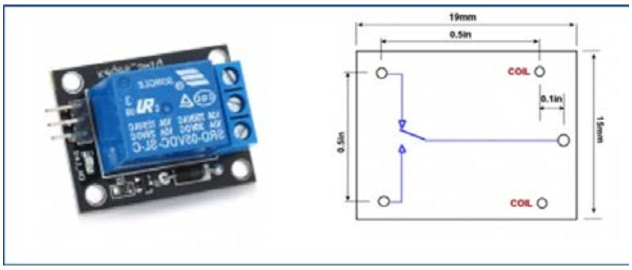

Figure 2: Relay and a circuit diagram [1]

5. OBTAINED RESULTS

Figure 3 below illustrates the power consumption and required voltage as a function of the output of the microcontroller to switch the MOSFET.

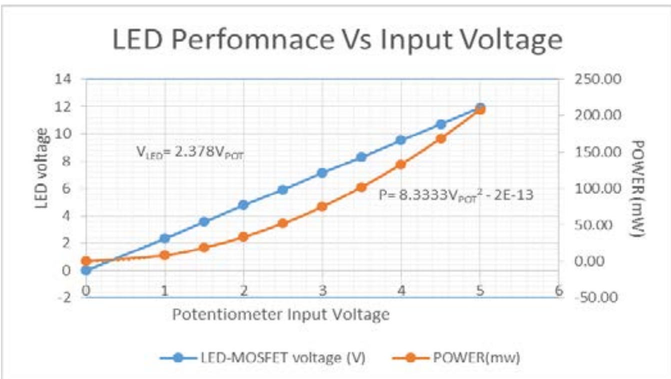

Figure 3: Load performance as a function of Arduino voltage

The x axis determines how dim the switch has turned the LED. The corresponding voltage across the LED and power are shown in the figure above. It is then seen that when the LED operates at full load only 0.2W is consumed from each LED. If the LED was to be dimmed to 80% only 0.15W would be consumed.

Figure 4 gives the relationship of the measured voltage across its terminals to the voltage read by the microcontroller.

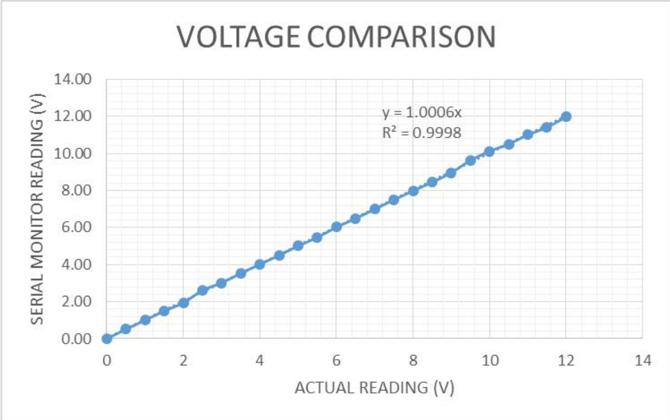

Figure 4: Voltage comparison between Serial Monitor and Battery.

From Figure 5 above it is evident that there is a very strong correlation (R2=0.9998) between the actual voltage read across the terminals of the power source and the voltage read by microcontroller which was then displayed on the Serial Monitor.

The microcontroller's readings are not always 100% accurate. There is a small voltage variation. This can be used as a very good approximation, as the gradient is (m=1.0006≈1). This implies that there is almost a 1:1 relation between the measured and actual voltage. It is a great indication that the subsystem passed the test. Dimming the LEDs reduces the power consumption.

6. CONCLUSIONS

In this work, a grid connected solar powered automatic street light controller was designed and implemented. The solar system automatically charges the battery and this now powers the street lights (LED's). The chosen LEDs only turns on at very high voltages. They only work when the battery is at least 80% full. This implies that after the system has drained 80% of the 12V battery, it is then supposed to resort to the grid. The major short coming of this system is that it uses a relay which is a hard and slow switching device. This quickly drains the 9V battery used to power the controller as a standalone system. Future work is currently ongoing to improve the efficiency of the system.

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