# BATTERY SIZE OPTIMIZATION STRATEGIES FOR THE SOLAR POWERED LED LIGHTS

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## Abstract

Light emitting diodes (LEDs) are recently preferred for the implementations of low-energy consumption illumination systems because of their non-thermal light production effect. Solar rechargeable batteries can be used to power Light emitting diodes lights (LED-lights), but their costs increase with their charge storage capacity. Electric lights are often required to operate for a period that do not exceed 24 hours and are only mainly necessary to operate whenever there is a nearby person. In this study, a microcontroller that is interfaced with the Light Dependent Resistor (LDR) and a Passive Infra-Red sensor (PIR) will detect the presence of moving bodies and darkness to switch on LED lights for a predetermined period. The microcontroller code and hardware has been designed to optimize energy consumption by enabling low microcontroller clocking frequency and sleep mode features. A Data Acquisition System (DAS) has been used to assist with the evaluation of a solar site in question. The use of LDR, PIR, a DAS, low clocking frequencies and sleep mode feature of the microcontroller has made it feasible to use less capacity solar rechargeable battery for the supply of LED lighting system over longer periods.

**Keywords**:
LED Lights, Battery, Microcontroller, energy saving

## 1. Introduction

The world is showing a gradual shift towards the use of renewable energy. Amongst some of the factors in considerations is the environmental friendliness of solar energy as described in [1]. Photovoltaic energy is one of the easily acquirable energy [2] but its stability relies on both short term weather conditions as well as long term climatic conditions [3]. DAS systems were used in [4]and [5] to study the long term climate changes and short term weather conditions. Accurate meteorological data is a fundamental requirement for the design of photovoltaic systems [6]. Photovoltaic (PV) energy systems can be used as a primary electrical energy source when configured to work as stand-alone [7], back-up systems in hybrid mode and to supplement commercial energy supply for the grid connected systems [8]. In all applications that have been just mentioned, PV energy will provide cheaper and cleaner electricity.

## 2. Literature Review

### 2.1 Energy saving Light Emitting Diodes lights

LED- lights have gained applications that range from usage in small buildings to outdoors [9]. They tend to consume less power when compared to their thermal based counterpart. This research explored various techniques to enhance the operational duration of LED lights that are battery powered.

### 2.2 Battery powered illumination systems

LED lights are suitable to be powered from low voltage DC power sources [10], however commercially electricity is supplied as AC voltage above 100 V. In order to power LED lights with commercial electricity supply, the voltage supply is lowered to the required amount by an electronic circuitry which is integrated to the light bulb as illustrated in Figure 1. An exclusion of this voltage lowering circuitry may enable batteries to directly power these types of LED lights.

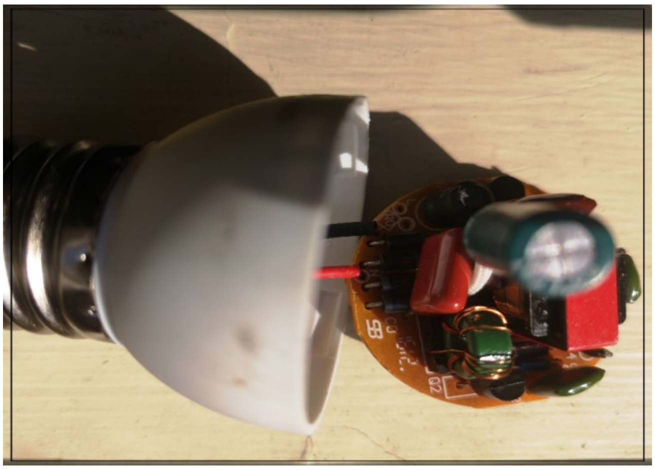

**Figure 1:** Internal structure of 230 V LED Light bulb

### 2.3 Motion controlled lights and day-night switching

It is not always necessary to keep lights in a bedroom or toilets ON. It is at times only necessary to use lights whenever it is dark and a room is not vacant. Motion detectors together with day-night switches may therefore incorporated to bedroom / toilet lights to control their ON/OFF times and ultimately reduce battery discharge durations. The significance of motion and day night controlled lights are described in [11].

### 2.4 Low clocking speeds for microcontrollers

As demonstrated in [12], the power of microcontrollers can be dropped up to 66.9%. by reducing the clocking frequency speed. Battery operating time will therefore be improved.

This research has considered the applications of LED lights, motion detectors and the effects of lowering microcontroller clock speeds; to recommend strategies that will be used to optimize the size of required battery.

## 3. Methodology

### 3.1 Solar site evaluation and Light system design

In this study, solar energy is used to charge batteries that powers connected LED lights, it is therefore of great importance to first evaluate the solar energy profile of the host location. Several online data centers do provide solar maps of various geographical locations; example may be found in a study conducted by [13]. The problem with the data obtained from those sites is that it excludes factors such as shadowing created by nearby infrastructure and the locations are not exact. In this research, solar insolation profile shown in Figure 2 was built by using DAS based data logger [14].

An Arduino Uno based DAS was used to collect solar irradiance data. The collected data was uploaded to a program that was developed in LabVIEW called myPVsys, similar to PVsyst [15]. In MyPVsys, the solar curve is plotted and the effective Peak Sun Hours (PSH) is calculated. The load power consumption is highly influenced by the duration of illumination. The output of myPVsys is a trace that will follow:

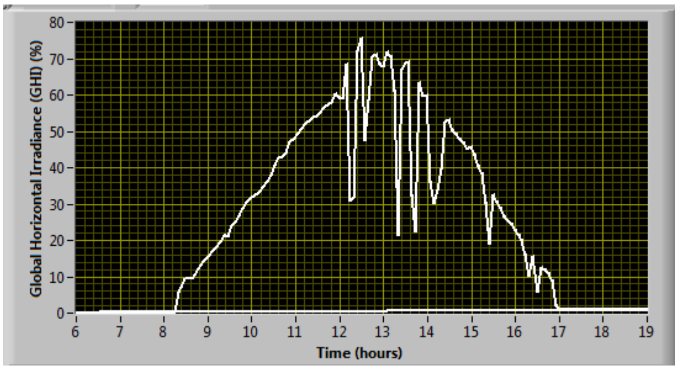


Figure 2: Solar profile obtained from Ramaphosa township in Boksburg, South Africa.

Figure 2 shows the solar insulation that was obtained on the 3rd of May 2020, from a region with GPS coordinates of -26.232590, 28.2409676. An effective PSH of 4.10 has been calculated from this output curve. Since the LED lights drawing 1.728 A were operated for 10 seconds and a maximum of 100 movements is expected within one night per week. The required charge ($Q_R$) can be calculated as follows:
$Q_R$ = 1.728 A x 10 /3600 H x 100 + Microcontroller 24-hour energy consumption. Since the microcontroller was consuming an average power of 10 mW at a clocking frequency of 1 MHz

$$Q_R = 10/3600\ H \times 100 \times 1.728\ A + 10mW / 6V \times 24\ H \quad (1)$$

$$=0.52\ AH$$

If the battery is allowed to discharge to a depth of 50 percent whilst the Days of Autonomy is set to one. A battery capacity of 0.52 x 2 = 1.036 AH is required. For that reason, a 6 V, 1.3 AH battery was selected and installed. If losses are ignored, the PV panel = 12 V* 0.52 AH/4.1 H = 1.5 W. A two-watt, 12 V solar panel was used for the purpose. The battery charging system current rating has to be at least 158.5 mA (1.25* 0.52 AH/4.1 H). Up to 250mA charging current was measured

## 3.2 Six volt LED light system hardware

Commercial six volt solar-rechargeable batteries are available on the shelf. Most microcontrollers are powered from 3.3 V or 5 V supply, therefore microcontrollers cannot be directly connected to the same available power source with 6 Volt DC powered LED light bulbs. Another challenge is a lack of six volts LED lights, which is addressed by re designing 12 V LED lights to operate at 6 V. To do this, size of current limiting resistor (s) are recalculated and replaced. It was also found that a 12 V light bulb can been successfully used with 6 V battery in anticipation to lower light intensity. A schematic diagram that illustrates the connections of the all the components that are used for the six volt LED light system is presented by Figure 3.

As illustrated by Figure 3, a 6 V battery supplies the microcontroller circuit via a diode bridge rectifier. The sole purpose of this rectifier it to reduce the maximum anticipated input voltage of about 6.4 V to 5.2 V and protect the circuit against accidental polarity reversal. The output of the motion detector is read by digital pin seven (D7) of the microcontroller and hard-wired to also activate the interrupt through digital pin zero (D2). The Light Dependent Resistor (LDR) that is used to detect darkness forms a voltage divider network with a 100 kΩ resistor and connect to analog input pin A0. The switching of LED lights is controlled by analog output pin A3 through a 1 kΩ resistor that connects to an NPN transistor. The emitter load for the NPN transistor is formed by a coil of five-volt single pole double trough (SPDT) relay.

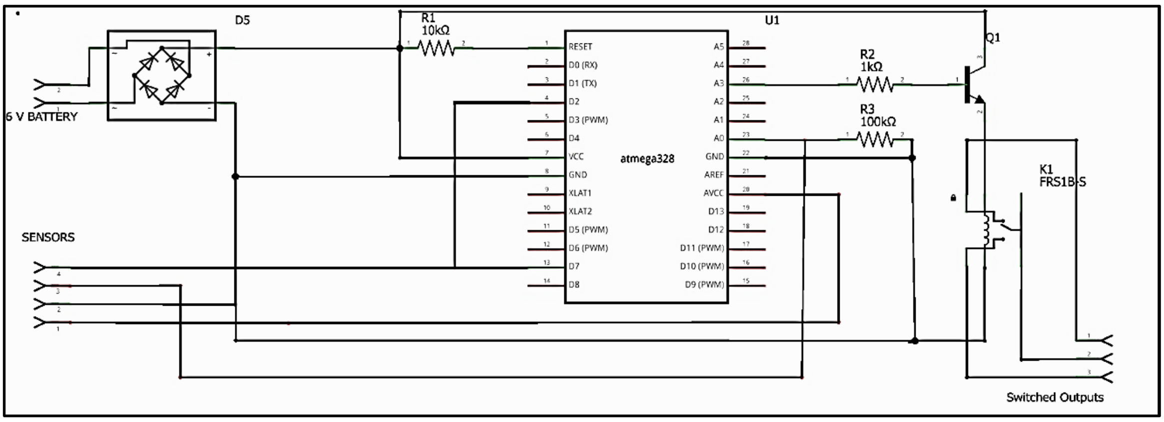


**Figure 3:** Schematic diagram of a six volt LED light system.

### 3.3 Six-volt LED light system software

System software has a responsibility to control switching durations based on a given input conditions. It should execute this processes whilst optimizing the battery used as a means to preserve battery charge and ultimately avoid blackouts. Some of the considerations are to employ sleep modes and lower clocking features of the atmega328 microcontroller [16]. Figure 4 and Figure 5 highlights all these considerations. Five volt based Atmega328 microcontroller can be found in most of the Arduino Uno development boards, however the majority of them are configured to operate at clock speeds of 16 MHz and above. It is already stated that the power consumption can be reduced by dropping the microcontroller's clocking frequency. To make Atmega328p microcontroller compatible to a 1 MHz clock, they have to be reprogrammed by using a newly reconfigured IDE with a submenu shown in Figure 4.

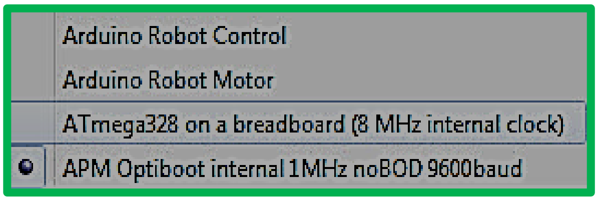


**Figure 4:** Arduino IDE programmer options modified to support 8 MHz and 1 MHz

Arduino IDE libraries have been amended to enable reprogramming of Atmega328 with a bootloader that supports 1 MHZ as shown on Figure 4. After burning a 1 MHz bootloader to the microcontroller, a sketch that execute activities illustrated by Figure 5 was written to the microcontroller chip via its serial port.

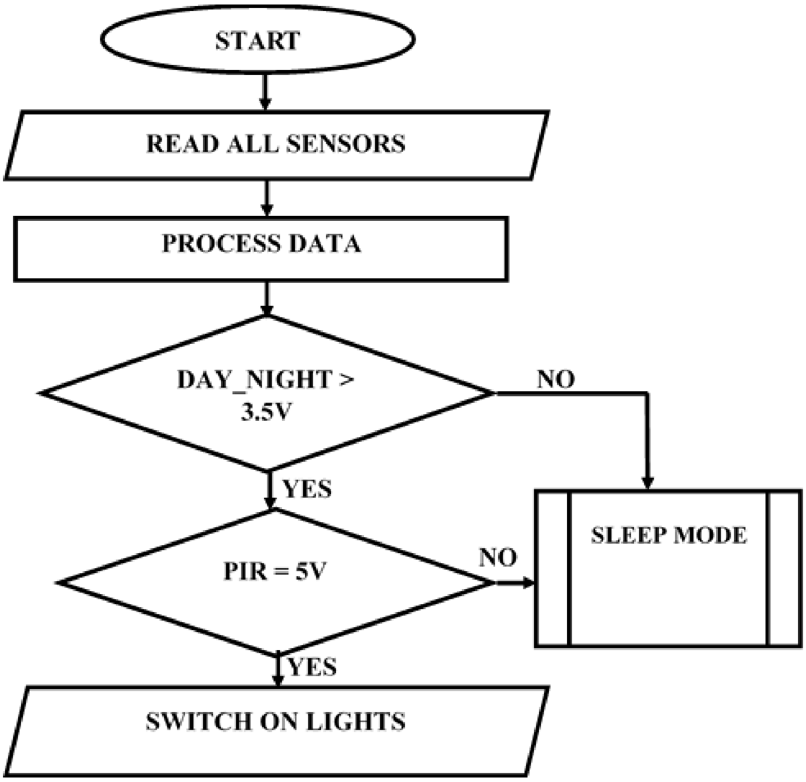


**Figure 5:** LED light system software algorithm

## 4. Results

### 4.1 Comparison of battery operational durations

Table 1: battery operational duration results (operate ='✓' and non-operation = '×')

| | | |
|---|---|---|
| **96 hrs.** | ✓ | × |
| **84 hrs.** | ✓ | × |
| **72 hrs.** | ✓ | × |
| **60 hrs.** | ✓ | × |
| **48 hrs.** | ✓ | × |
| **36 hrs.** | ✓ | × |
| **24 hrs.** | ✓ | ✓ |
| | ✓ | ✓ |
| **Duration** | **1 MHz with sleep mode** | **16 MHz without sleep mode** |

In this study a system that operate with an internal clock of 1 MHz and features a sleep mode was observed to operate continuously for four nights from a single charge cycle. Under similar conditions, 16 MHz externally clocked system without a sleep mode could only manage to operate for one night. It is because the system without sleep mode continuously draws higher currents even if they are not in use. The results presented here are also subjected to changes in the frequency of movements around PIR. High frequency movement will result to lower operational nights.

### 4.2 Weekly performance, where Days of autonomy (DOA) is four.

Days of autonomy is the numbers of the days that a solar system is expected to work without significant sunlight. It is clear that the 1 MHz system will be able to cope under the conditions of Table 2, where weather conditions are given in the last row of the table. Table 2. illustrate an example of weekly LED lights operations.

Table 2: Comparing 1 MHZ clocked with the 16 MHZ clocked processors over an 7-day duration

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | ✓ | ✓ | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ | ✓ | ✓ | ✓ |
| 22 | ✓ | ✓ | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ | ✓ | ✓ | ✓ |
| 20 | ✓ | ✓ | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ | ✓ | ✓ | ✓ |
| 18 | ✓ | ✓ | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ | ✓ | ✓ | ✓ |
| 14 | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | |
| 6 | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × | × | × | ✓ | ✓ | ✓ | × |
| 4 | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × | × | × | ✓ | ✓ | ✓ | × |
| 2 | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × | × | × | ✓ | ✓ | ✓ | × |
| | 1MHz | 16MHZ | 1MHz | 16MHZ | 1MHz | 16MHZ | 1MHz | 16MHZ | 1MHz | 16MHZ | 1MHz | 16MHZ | 1MHz | 16MHZ |
| Time(h) | Day 1 | | Day2 | | Day3 | | Day4 | | Day5 | | Day 6 | | Day7 | |
| |  | |  | |  | |  | |  | |  | |  | |

## 5. Conclusions

From the results that were obtained in this study, it is clear that the operational time of a battery used to power LED lights was optimized by:

- A careful study of the location's solar insulation profile.
- Incorporating PIR and Day- night switches to detect the necessity to switch on lights
- a use of microcontroller to control the LED lights switching activities.
- Lowering the clock frequency of the microcontroller whilst utilizing sleep feature.

Considering all this factors will benefit the designers to use smallest and cheapest battery for their illumination tasks.

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## Biography

**Nkateko Eshias Mabunda** is a senior lecturer at the university of Johannesburg (UJ). He completed his National Diploma and BTech degree in Electronics Engineering at Nelson Mandela Metropolitan University (now called NMU) in 1996 and 1998 respectively. During the year 1998, he also joined Telkom as a Technician for Operations. In 2001, Telkom SA appointed him as a site manager until end of 2002. In his managerial career for Telkom, he looked after the operations, installations and maintenance of equipment within a satellite access node (SAN). He started his lecturing career in December 2002, when he joined NMU. In 2006 he joined UJ as a lecturer in the Department of Electrical and Electronic Engineering Technology (DEEET). During his current career with UJ, he obtained the following degrees with them: MTech Electrical Engineering degree in 2015 and a Doctoral degree in Electronics/ Electrical Engineering in 2018. He is a registered Professional Engineering Technologist with the Engineering Council of South Africa and a member of IEEE. He has published seven international conference papers related to his doctoral work and one journal paper.