Solar Powered Traffic Sensitive Automated LED Street Lighting System

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Declaration

We do hereby declare that the thesis titled "Solar Powered Traffic Sensitive Automated LED Street Lighting System" submitted to the Department of Electrical and Electronics Engineering of BRAC University, is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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Abstract

Production and use of photovoltaic cells to generate electricity is an increasingly popular resource solution in Bangladesh currently. The focus of this project is to make the most efficient use of the energy received from the sun to power street lights in the city. Solar Panels mounted on the street lamps will collect the energy from the sun during day time, driving the LED lamps at night. The system we would be designing includes operation in the main streets of the major cities of Bangladesh which is to be equipped with solar powered street lamps effective in regulating the amount of load voltage depending on the intensity of traffic present. The project is about developing and fabricating the circuit that can charge the lead acid battery during day time by using solar energy as the source. The process, like most other photovoltaic systems theses days, would require the use of a microcontroller, namely PIC16F877A, to control many of the circuit functionalities including switching, controlling driver circuit, and integrating sensor output etc. The preferred lighting source is LED considering its photometrics such as efficacy, life span, cost, efficiency and power consumption. Since DC supply is being used, a DC-to-DC converter is employed to implement the LED. Traffic detection will be done through the concept of ultrasonic sensing using the Ping Sensor. In different seasons, the sun is incident on the earth's surface and thereby on the solar panels in different angles. Thus a mounting angle for the panels has also been determined which will allow optimum efficiency for all four seasons of the year.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

In this era of rapid developments and high demand towards energy, innovations can no longer suffice without sustainability. Dhaka being one of the most densely populated capital cities in the world, predictably, faces increasing constraints on its resources. Awareness on such topics has encouraged many renewable energy based innovations in the country. Bio gas cookers, solar water heating systems, solar-powered rickshaw etc are starting to make their place in the city. This drive towards sustainable energy is expected to bring the price of such 'green' technologies to affordable levels of the locals. The project involves an amalgamation of technology and sustainability in order to continue this drive.

The sun is a free resource with its unlimited supply of energy. While the supply of natural gas (which provides 89% of total power generation in Bangladesh) are increasingly getting depleted and unreliable for uninterrupted electricity supply, harnessing the energy of the sun efficiently, we believe, can sustain to provide for the electrical demands of the future in an economically viable way. [15]

This chapter introduces the project, with an overview of the project, the project objectives and scopes of the project. It also outlines the organization of this thesis paper.

1.2 Project Overview

The project is about developing and fabricating a photovoltaic system which collects energy from the sun during the day time and stores this in a lead-acid battery through a charge controller to drive LED street lamps at night. The charge controller circuit has been used to supply the battery with the maximum amount charge possible, while protecting it from overcharge by the solar panels as well as over discharge by the street lamps. An optimum tilt angle for the solar panels is determined which will help efficient energy collection all throughout the year to support the load at night. This mounting angle is determined with the help of MATLAB programs, according to the latitude and longitude of Bangladesh, and different meteorological angles. With the help of the output from Light Dependant

Resistors (LDR), the charging circuit is kept functional only during day time, during which time, the energy collected by the panel is supplied to the battery at a regulated amount. When the LDR signals night-time, the discharging circuit starts its operation. During this time, the discharge of the battery to the load is done through a driver circuit that maintains constant current through the LED lamps. Functionality of both the driver circuit and the charge controller circuit are controlled by the PIC16F877A microcontroller. For the charge controller circuit, the PIC detects the current and voltage of the battery and thereby, according to the state of the battery, it feeds back a Pulse-Width Modulated (PWM) flow of charge from the panel to the battery. The driver circuit operates similarly by detecting the current through the LED with the help of a current sensor, and thereby adjusting the value of PWM to the LED lamp. Brightness of the lamp also depends on the output of the Ultrasonic PING sensor, used to detect the volume of traffic present on the road. Depending on the voltage received from the PING sensor, the PIC microcontroller sets three different levels of brightness for the LED lamps. Thus the LED lamps operate with full power when there is high traffic density on the road, and with lower powers for lower traffic volumes. When night turns to day, the LDR will again signal this to the PIC and the LED and Ping sensors will become non-operation and charging will commence again.

1.3 Project Objective

The objective of this project is to develop smart, energy-efficient street lights that are powered by renewable energy and are operated at required intensities such that they are economically viable for the energy sector of Bangladesh. Outdoor lamps contribute to a major amount of electricity consumption from the main power lines of Dhaka city. While solar power acts as an alternative to conventional power supply to the street lamps, operating them in full power only when required adds a two-fold cost and energy saving scheme to this project. At empty streets with no or minimum presence of traffic, the street lamps need only operate at low threshold intensity. The project aims at limiting the large amount of energy wasted without purpose in such conditions by accomplishing automated detection, and powering the LED lamps with appropriate brightness level to provide illumination according to the amount of cars present on the road. It is also intended in the project to mount the solar panels at an angle that is optimum for the winter season, so that even during the short day hours of winter, enough energy is collected to support the load through the long nights.

1.4 Scope of Project

The scope of this project includes construction of the prototype of a solar powered outdoor LED lamp. A 12 V lead-acid battery supplies energy collected from a solar panel to LED lamps. The different components involved in the designing of this project includes a charge controller circuit and a driver circuit, both connected to an LDR circuit via PIC 16F877A microcontroller, which turns them on or off depending on day or night. For controlling the intensity of LED lights, each street light is equipped with a ping sensor which receives traffic information through ultrasonic waves and in turn sends voltage signal to the PIC 16F877A microcontroller attached to the driver circuit. The PIC 16F877A microcontroller also helps regulate the amount of charge flowing from the panel to the battery, and the current across the LDR. Several MATLAB programs have helped determine a fixed mounting angle for the solar panel. This mounting angle will ensure optimum energy collection such as to provide sufficient power to the street lamps during all four seasons of the year. However, the use of tracking or adjustable panels would have allowed higher energy collection, but at an increased cost. According to the Days of Autonomy, the system can power the street lamps for a maximum of 3 days without receiving energy from the sun.

1.5 Organization of this thesis

The thesis is organized in an order such as to provide the readers with a general understanding the different components present in the photovoltaic systems, before moving on to the details specific to the project. The following chapter introduces the different types of each component, their functions, advantages and disadvantages and their suitability to the project. These general discussions are followed by the chapter which details the comparison and determination of the optimum tilt angle for the solar panel. The same chapter also explains the different meteorological factors that affect the mounting angle of panels and the comparative study for tilt angle in different seasons. Chapter 4 provides a block diagram of the complete system along and outlines the different system parameters. It shows the calculations for determining the system size, and shows the relative decrease in required size by employing the traffic sensor. The last chapter gives a detailed explanation of how the project is implemented. It includes the circuit diagrams and explanation used to build the prototype of the street lighting system. The paper ends with the future aspects of this project following the results and discussions.

CHAPTER 2

SYSTEM DESCRIPTION

2.1 Introduction

A typical Photovoltaic system is made up of components such as Solar Panel, Battery, Battery Charge Controller, Mounting Mechanisms and connecting wires. In this chapter, the different components required by the photovoltaic system for this project will be discussed. The types, advantages, disadvantages, availability and economic value of the Solar Panel and Battery will be discussed. Charge Controllers and their types, operational stages of charge controllers and their chosen design are outlined in this chapter. The operating principle of the Ultrasonic Ping Sensor and how it is suited to our project follows the description of charge controllers. Lastly, a detailed comparison of lighting systems, and why LED is the best lighting option for this project will be given.

Various ways of electricity generation exists. But using solar cells to produce electricity has certain benefits, which are briefly explained below.

- Free Fuel: The main fuel for solar powered systems is the sun, which is available all around the world as a free resource. The environment effect is minimal as there are no harmful by-products.
- Independent Production of Electricity: In this process, electricity is generated independently without the use of fossil fuels and conventional electricity distribution lines.
- Low Maintenance: Since there are no rotating parts such as motors in a photovoltaic system, the maintenance is very simple.
- Added Benefit in determining location of installment: Conventional Power units needs to consider a lot of factors before setting up their centers, such as fuel supply, communication, drawing up electricity lines etc. But to install photovoltaic systems, the chosen location only needs to have abundant supply of sunshine.

- Easy to expand: According to requirements, the capacity of photovoltaic systems can be increased by adding solar modules. This is much less simpler and less costly than conventional power system.
- Maximum Dependability: As long as there is sunlight, the system will keep supplying uninterrupted electricity. Thus the risk of power cut is very low.

2.2 Solar Panels

The sun is a living fireball whose rays reach one side of the spherical earth during day time. Scientists have employed modern tactics to develop the solar cells that can directly convert the energy from sunlight to electrical power. Solar cell is an electronic device that converts energy.

The Greek term ‘Photovoltaics’ refers to the process of electricity generation from light. When a series of Photovoltaic or Solar Cells is put together, they form a Solar Panel. The panels absorb energy from the sun which is converted to electricity by the solar cells.

The main feature of photovoltaic cells is that we can get direct electricity when light is incident on them. Efficiency of this conversion mostly depends on the type of the solar panel. There are 3 types of commercially available solar panels used in standalone & grids connect systems. All three of them are based on silicon & can be classed into one of the three types. Main 3 types of solar panels are:

1. Polycrystalline Solar Panel
2. Monocrystalline Solar Panel
3. Amorphous Silicon ‘Thin Film’ Modules

(a) (b) (c)

Figure 2.1: Three major types of Solar Panels. (a) Monocrystalline, (b) Polycrystalline, (c) Amorphous

Since all 3 of them offer both advantages as well as disadvantages, there are a number of system specific factors worth considering while choosing the most efficient solar panels for solar powered systems. These factors may include solar panel cost, durability, longevity, warranty, size and wattage.

Monocrystalline solar panels are the most efficient and are among the smallest panels in size. However, these panels are very expensive, which makes it not suitable for the system that is being designed. These solar panels are typically used in high reliability applications like telecommunications.

The efficiency of amorphous modules to convert sunlight to electricity is half of polycrystalline or mono crystalline panels and requires twice as much roof space as an array with a similar rating using other the types. Even though the cost of these panels is low, amorphous would not be a good choice for the system to be implemented.

The efficiency of polycrystalline solar panels is very close to that of monocrystalline panels. It provides an excellent balance of performance and economic value, and therefore this type of solar panels is recommended mostly for use in a system as the one which is to be implemented. These panels are less costly than monocrystalline solar panels and provide performance near to monocrystalline solar panels.

Considering all the major factors of choosing the most efficient and economic solar panel, polycrystalline solar panel will be the best choice for the system.

2.3 Battery

In stand-alone systems, the power generated by the solar panel is usually used to charge a battery. The electricity produced by PV modules during the day is supplied to the battery and/or the load. The battery does not act only as an auxiliary support; rather it will provide energy to counter the fluctuations of load at any time. These fluctuations may result when the load demand is higher than the energy received from sun, or vice versa. Different types of rechargeable batteries or accumulators are available which can be used. These include the following:

- Lead Acid Battery
- NiCad (Nickel Cadmium) Battery
- NiFe (Nickel Iron) Battery

(a) **(b)** **(c)**

Figure 2.1: Three major types of Solar Panels. (a) NiCad, (b) Lead-Acid, (c) NiFe

Cadmium Batteries

Nickel-Cadmium (NiCad) batteries are very expensive, and disposing off Cadmium is hazardous. It has a low efficiency of 65 - 80% and non-standard voltage and charging curves may make it difficult to use in some equipments, such as standard inverters and chargers. Even though they have several advantages over Lead-Acid batteries, such as longer life span, and tolerance for higher discharge, NiCad Battery is not chosen for this photovoltaic system due to its high cost and limited availability.

Nickel Iron (NiFe) Batteries

The downsides of NiFe batteries include low efficiency which can go as low as 50%, even though typically the value is around 60 - 65%. It has a very high rate of self-discharge, high gassing and water consumption. High internal resistance means getting large voltage drops across series cells, and high specific weight or volume can reduce the overall efficiency of the solar system as much as 25%

In short, despite some advantage of long life and thousands of cycles, overall these batteries are a very poor choice for all solar applications where lead acid battery ensures a good quality with good features.

Lead acid batteries

These batteries will last much longer if not discharged too deeply. This is known as shallow cycling and greatly extends their life. Considering SOS and Depth of Discharge (DOD), Lead Acid batteries are the best choice for solar energy systems.

Many types of lead acid batteries are used in PV systems each having different performance characteristics and specific design. They are mainly classified into 3 categories. They are:

SLI Batteries

SLI-(Starting, lighting and ignition) batteries are designed primarily for shallow cycle service, most often used to power automobile starters. They have few thin positive and negative plates per cell which are designed to increase the total plate active surface area. The large number of plates per cell allows the battery to deliver high discharge currents for short periods. While they are not designed for long life under deep cycle service, SLI batteries may provide up to two years of useful service in small stand-alone PV systems where the average daily depth of discharge is limited to 10-20%, and the maximum allowable depth of discharge is limited to 40-60%.

Motive Power or Traction Batteries

Traction or motive power batteries are very popular for use in PV systems due to their deep cycle capability, long life and durability of design. Motive power or traction batteries are designed for deep discharge cycle service; they are used in electrically operated vehicles and equipment such as golf carts, forklifts and floor sweepers. These batteries have a fewer number of plates per cell than SLI batteries; however the plates are much thicker and constructed more durably. Power batteries are used to enhance deep cycle performance.

Stationary Batteries

Stationary battery applications, as they are commonly float charged continuously, are used in un-interruptible power supplies (UPS) to provide backup power to computers, telephone equipment and other critical loads or devices. They may have similar characteristics like both SLI and motive power batteries, but are generally designed for occasional deep discharge, limited cycle service.

There are few types of lead-acid batteries which are

1. Lead-Antimony Batteries

2. Lead-Calcium Batteries

    a. Flooded Lead-Calcium, Open Vent

    b. Flooded Lead-Calcium, Sealed Vent

3. Lead-Antimony/Lead-Calcium Hybrid

4. Captive Electrolyte Lead-Acid Batteries

5. Gelled Batteries

Among these lead acid batteries, one has to be selected which with a 12 V rating for our PV system. Battery performance can be measured by considering the following factors:

- Capacity
- cut off voltage
- charging
- discharging
- rate of charging/discharging
- autonomy
- battery lifetime
- temperature effects

All the considerations are primary decisions and depending on the availability, cost and feasibility it will be effective practically. Solar panel wattage & battery voltage values are tentative and they are subject to change.

2.4 Charge Controller

Charge Controllers come into functionality since solar panels do not output a constant stream of voltage. The output from the panels are variable and needs adjustments before they are stored to the battery or supplied to the load. Charge Controllers work by mointoring the battery voltage. In other words, they fetch the variable voltage from the photovoltaic panels, condition to suit the safety of the storage lead-acid battery, and once full charge is reached, the controller can short the solar panel leads together to prevent further accumulation of charge in the battery. Charge Controllers, are therefore, mainly 'Choppers' or DC-DC Converters. The main functions of charge controllers are to prevent overcharging of battery from solar panels, overdischarging of battery to the load, and to control the functionalities of load.

2.4.1 Operational principles of charge controllers

Switches are used to operate Charge Controllers. The switch can be either a Relay or a solid state switch such as a MOSFET or power transistor. Relays contribute to less power loss due to their smaller resistence, but they have a limited life span. On the other hand, MOSFETS have a higher longivity, but also a higher rate of power loss in times of high current flow.

Control circuits are used to regulate the switching on-off of controller switches. One of the most popular techniques, and the scheme preferred for this system, is the Pulse Width Modulation (PWM). In this scheme, the switching time is determined by the percentege of the signal at high voltage. Loss is very less in this system, but the switch used has to be a MOSFET in order to use PWM.

Most controllers measure the amount of voltage in the battery and accordingly supplies current to the battery or stops current flow completely. This is done by measuring the Ah(Ampere Hour) of the battery, rather than looking at the State of Charge (SOC) of the battery. The maximum battery voltage allowed to reach is known as the 'Charge Set Point'. Factors such as prevention of Deep Discharge, Battery Sulfation, over current and short circuit current are also prevented through the controller. Deep discharge can be detected by the microcontroller and it will run an auto boost charge to keep the battery activated.

2.4.2 Charge Controller Designs

Depending on connections, charge controllers can be of two types:

- Parallel/Shunt Controller: the charge controller is connected in paraller with the battery and load.
- Series Controller: the charge controller is placed in series between solar, and battery and load.

The series controller has to handle the work at a lesser voltage than the shunt controller, and it also has less switching noise. Therefore, to sum it up, our preferred method of operation would be using a series controller and employing the Pulse Width Modulation (PWM) scheme as the switching technique. The temperature of the battery will also be maintained within a range of 15°C and 35°C, using a temperature compensator. The current rating of the charge controller will be kept 1.2 times higher than that of the panel for safety purposes. In our system, panel current has been calculatd to be 5 A, thus controller current will be 5*1.2=5.10A.

2.4.3 Types of Charge Controllers

Charge controller come in three general types which are discussed below.

1. Simple ON/OFF Controllers: These are simple controllers which use basic transistors and relays to control the voltage by either disconnecting or shorting the panel to the battery.
2. Maximum Power Point Tracking (MPPT): These types of controllers are highly efficient and provide the battery with 15-30% more power. MPPT Controllers track the voltage of the battery and match the panel output with this. This ensures maximum charge by converting the high output from solar panels to a lower voltage needed to charge the batteries.
3. Pulse Width Modulated Design (PWM): In this type, the controller continuously checks the battery voltage to alter the time and the width of the pulses of voltage it send to the battery. The name itself suggests that the width of the pulses is varied from a few microseconds to several seconds. It operates like a rapid on-off switch which breaks the panel current into pulses of constant frequency and sends a series of width-modulated pulse to the battery. This regulates the amount of charge flowing in the battery. In a discharged the battery, the width of the pulses will be on for almost 100% of the time, whereas in a fully charged battery, PWM as low as 10% may be provided. PWM offers inexpensive, yet more effective ways to control how the battery reaches full voltages without overheating.

2.4.4 3 Stage Charge Cycle

Most Charge Controllers can operate at more than three stages to complete the charging cycle of the battery. These stages vary according to different times and battery voltages. PWM can be employed to control the battery at these stages.

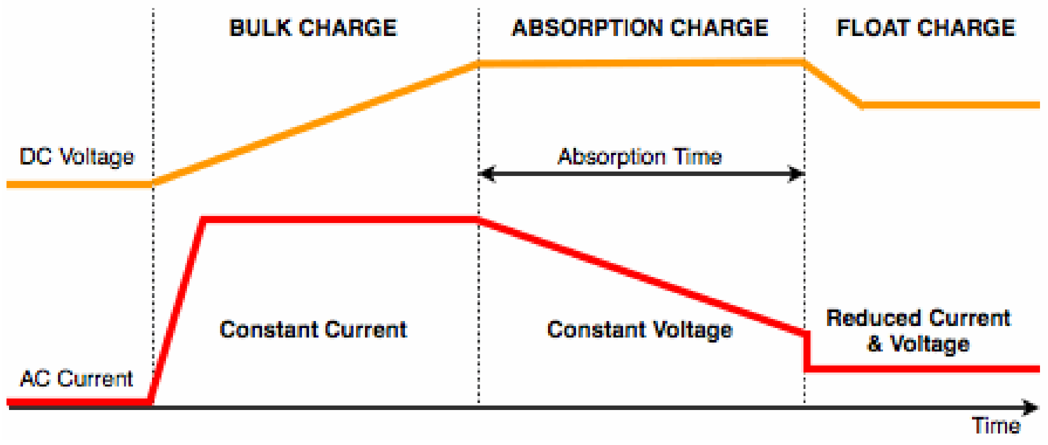


Figure 2.2: Three stages of a charge controller

BULK Stage: This is the first stage of the cycle which takes place when the battery voltage is low. Usually when power is drawn by the load from the battery, charge controllers begin bulk charging. In this stage, the maximum safe current is provided to the battery while voltage gradually rises to bulk level(14.4-14.6), which is 80-90% of fully charge level.

ABSORPTION: When bulk voltage is reached, absorption stage begins. During this, voltage is maintained at bulk for a specified time, for instance 1 hour, in order to safely charge the battery to 100%. As voltage remains constant, internal resistance rises and the current tapers off as the batteries charge up.

FLOAT: The voltage is lowered at float level (usually 12.6 to 13.2). Batteries draw small maintenance current untill next cycle at this stage. This level is important to keep a charged battery from being discharged, and as a result of this maintenance, the battery is likely to have a prolonged life.

2.5 Ultrasonic Sensor

2.5.1 Working Principle

A widely accepted sensor for obstacle/object detection that is used by many commercial products is ultrasonic sensor, more commonly known as ping sensor. However the fundamental function of the sensor is to determine the distance of an object and it can accurately measure how far the object is. Ping sensors have a very low range of from 3.3cm to 3m only but compared to many other sensors its pin configuration and working principle is relatively simple. Pin 2 is used to power up the sensor and pin 1 completes the internal circuit. Pin 3 is what sends and receives signals. Thus it can act as both an output and input pin.

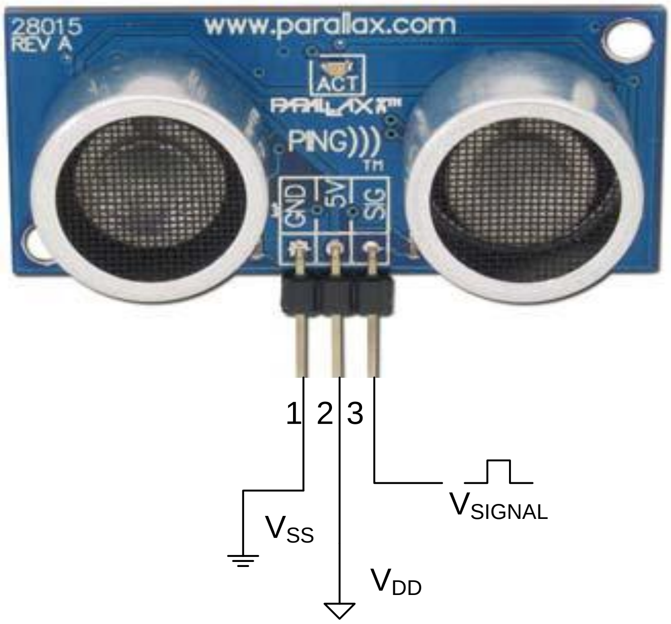


Figure 2.3: Ping Sensor with pin configuration

However before it can be fully functional it should be connected to an intelligent chip that can provide it with an initial trigger pulse. This external pulse is therefore provided by the microcontroller used in the system. This pulse is known as PULSEOUT and can be sent for as long 5µs to 15µs. After the sensor receives the PULSEOUT command from the microcontroller via pin 3 (Input pin), it waits for a further 20µs to let the micro-controller initiate a PULSEIN command which is generated as soon as the

PULSEOUT command is sent. As fig 5 shows, after waiting for 20µs, the sensor sends a sound signal of 40KHz known as chirp via pin 3(Output) and sets a high value in PULSEIN. Another variable is also initiated in the microcontroller. Let us consider the variable to be x. Every 5µs x increases by 1 as long as the PULSEIN has a high signal. As soon as the sound signal detects/hits an object/obstacle, the variable x stops increasing. For a 3m range, the maximum value of x can be 3600. If the final value of x is 3600 it means the object is 3m away. The lower the value of x, the nearer is the object and the distance can be easily calculated with the basic unitary method. However another there is another procedure that involves the PULSEIN. As the chirp signal hits an object, it is reflected off as an echo signal and is received by the ping sensor as in input again via pin 3 (Input) as shown in fig. 5. With the receiving of the echo signal, PULSEIN is immediately set to low. The PULSEIN therefore calculated the time elapsed between the sending and the receiving of the sonar pulse that is the round trip time. The longer the PULSEIN is set to high, the further is the object and this value is use to calculate the distance of the object with respect to the sensor using the speed of sound of 330m/s.

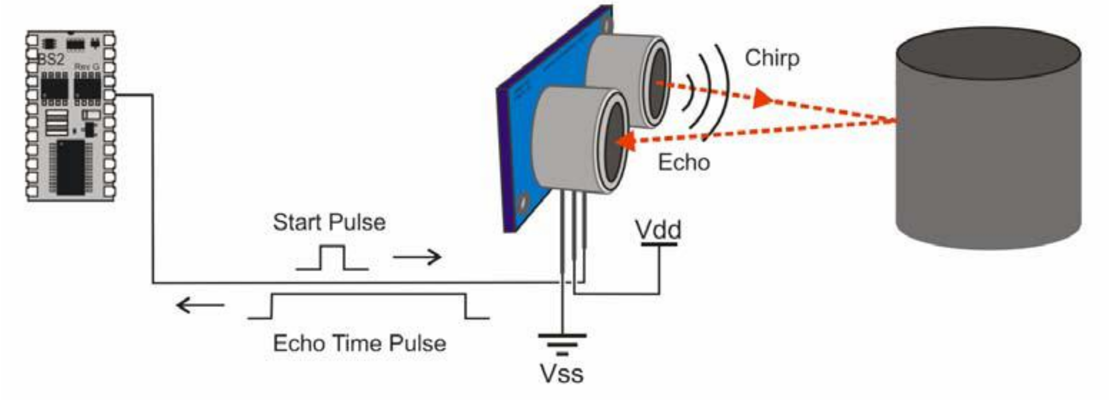


Figure 2.4: Working Principle

2.5.2 Physical Setup

The street lamp that will reach a vertical height of around **15m (??)** restricts the sensor to be mounted vertically along its height. Therefore for the sensor to be able to reach the traffic, it should be attached to the light pole at an angle considering the width of the street.

2.5.3 Advantage

The advantage of an ultrasonic/ping sensor over other sensors for obstacle detection is that it is less complex, consumes power which is as low as 0.1W (20mA/5V), is compact , has a temperature endurance of up to 70^{o} C which is an additional advantage due to the hot summers in Bangladesh and finally is cost effective. In addition, as opposed to other sensors like laser, the ultrasonic signal can penetrate through any air condition (foggy, rainy, cloudy etc.) without hampering its performance.

2.5.4 Limitation

The acceptance angle or the beam width of the sensor is less narrow compared to the directive beams of many sensors. A directive beam accounts for a lower beam scattering and thus less power loss. However, ping, with its spreading beam, therefore lacks the benefits posed by direct beam sensors but considering all the major advantages, it can be accepted as a practical choice for both the lighting system prototype and final product. [13]

2.6 LED Lighting System

There is a wide variety of light sources for outdoor use and had been in use as street lights ever since the invention of street lamps. Incandescent, fluorescent, high intensity discharge (Mercury vapor, mercury halides and high pressure sodium), low pressure sodium and most recent LED are popular choices for street lamps. However for this purpose our aim is to exploit the chosen lighting, by maximizing its efficiency and minimizing its cost thus attempting to yield the best performance.

2.6.1 Selection of a light source for the solar powered street lamp

The performance of a light source is based on the photometry quantities. Thus for the project we have selected white LED considering its luminous efficacy (lumen/watt), luminous efficiency, lifetime, maintenance cost and color rendition and temperature. Power consumption is also a vital issue that should be kept in mind while choosing any lighting source. To illuminate a street, the approximate lumen that we are considering is 1200. However this is tentative and is subjected to lamp and battery wattage and other external factors.

Table 2. 1: Terminologies used to characterize lighting systems

Quantity	Symbol	SI unit	Symbol	Dimension	Notes
Luminous flux	Φ_v [nb 2]	lumen (= cd · sr)	lm	J	also called *luminous power*
Luminous intensity	I_v	candela (= lm/sr)	cd	J	an SI base unit, luminous flux per unit solid angle
Luminous efficacy	η [nb 2]	lumen per watt	lm/W	$M^{-1} \cdot L^{-2} \cdot T^{3} \cdot J$	ratio of luminous flux to radiant flux
Luminous efficiency	V			1	*luminous coefficient*

The color rendering index (CRI) (sometimes called color rendition index), is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. Color temperature is a characteristic of visible light that has important applications in lighting, photography, videography, publishing, manufacturing, astrophysics, horticulture, and other fields. The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source. Color temperature is conventionally stated in the unit of absolute temperature, the Kelvin, having the unit symbol K.

Cost of the lighting source is also a deciding factor. The cost can be either the initial installation expense or the maintenance cost. Some lighting types are cheaper in terms of either of the factors and sometimes in terms of both the factors. Color temperature and rendition defines the quality of a light where as lumen, efficacy and efficiency determines the light intensity.

2.6.2 Comparison among different lighting sources suitable for lighting streets

Table 2.2: Comparison of different lighting systems

Lighting Type	Efficacy (lumens/ watt)	Lifetime (hours)	Color Rendition Index (CRI)	Color Temperature (K)	Indoors/ Outdoors
Incandescent					
Standard "A" bulb	10–17	750–2500	98–100 (excellent)	2700–2800 (warm)	Indoors/ outdoors
Energy-Saving Incandescent (or Halogen)	12–22	1,000–4,000	98–100 (excellent)	2900–3200 (warm to neutral)	Indoors/ outdoors
Fluorescent					
Straight tube	30–110	7000–24,000	50–90 (fair to good)	2700–6500 (warm to cold)	Indoors/ outdoors
Compact fluorescent lamp (CFL)	50–70	10,000	65–88 (good)	2700–6500 (warm to cold)	Indoors/ outdoors
High-Intensity Discharge					
Mercury vapor	25–60	16,000–24,000	50 (poor to fair)	3200–7000 (warm to cold)	Outdoors
Metal halide	70–115	5000–20000	70 (fair)	3700 (cold)	
High-pressure	50–140	16,000–	25 (poor)	2100 (warm)	Outdoors

sodium		24,000			
Light-Emitting Diodes					
Cool White LEDs	60–92	25,000–50,000	70–90 (fair to good)	5000 (cold)	Indoors/ outdoors
Warm White LEDs	27–54	25,000–50,000	70–90 (fair to good)	3300 (neutral)	Indoors/ outdoors
Low-Pressure Sodium	60–150	12,000–18,000	-44 (very poor)(Monochromatic)		Outdoors

Since low pressure sodium, high density discharge and LED lamps are now a days in frequent use as street lights, these three will be compared in details to give a comprehensive idea of the typical lighting features, their advantages over each other , cost and power consumption.

(a) **(b)** **(c)**

Figure 2.5: Popular lighting system for street light. (a) LED, (b) HDD, (c) LPS

Although low pressure sodium LPS has the highest efficacy of up to 150 and sometimes more than 200, it has a short life span of about 18000 hours which is equivalent to 4.4 years and needs more frequent replacement than any of the other types thus increasing the maintenance cost. However the cost of a LPS is very low making it feasible for primary setup. However this light contains 0% mercury and can be disposed as non toxic waste. Also low pressure sodium does not require cooling down after returning from any temporary power failure or shutdown. Since LPS is monochromatic, its color rendering is very poor and it radiates a light which is peak to human eye sensitivity (Yellow of visible spectrum with wavelength 598nm). Besides its short lifetime perhaps its monochromatic nature is the biggest disadvantage. At night time when human eye sensitivity shifts from photopic to scotopic (night vision) the eye sensitivity peak shifts to a different wavelength thus creating a problem of obscurity which can prove to be fatal while driving at night. For street illumination of 1200 lumen and with a minimum efficacy of 60 lm/watt, we would require a lamp of around 20 watt. Although this is pretty low the other disadvantages are dominant.

High density discharge (HID) lights include three types of lighting sources – Mercury vapor, mercury halide and one of the popular choices for street lamps high pressure sodium lights.

Mercury vapor is the least energy efficient light with a slightly greater lifetime of 4.9 years that is 20000 hrs. It radiates a bluish-green light within the range 405nm-578nm. It has a fairly poor color rendering and with a lumen of minimum 25, it will consume greater power (48 watt) to illuminate a street with 1200 lumen. For mercury vapor lamps, its power consumption is a definite downside.

Mercury halide on the other hand has a broader color rendition as opposed to LPS, HPS and mercury vapor. With a lifetime similar to mercury vapor and with a minimum efficacy of 70 watt we will require a 17 watt lamp which is quite low compared to others, mercury halides are still less attractive alternatives to LPS, HPS and LEDs.

The last of the HID family is high pressure sodium lights (HPS) which has an approximate life span of 24000 hrs (5.8 years), higher than all the lights discussed so far. It has a good color rendition and emits light across the visible spectrum. The majority of the radiation falls within the orange tone (550nm-650nm). However with a high lifespan, a better CRI than LPS, a low cost and an efficacy close to that of LED, sodium lamps, although still an attractive option for street lighting, are being rapidly replaced by LEDs. This is because LED has the lowest power consumption, very energy efficient, has the highest life span of around 50000 hrs (12 years approximately) with no glare effect and toxic gas or UV emission. Because of its increased lifetime, the maintenance cost of a LED lamp is way cheaper when compared to its initial setup cost. Therefore in our project we have decided to implement LED as it is the most potential luminary in use today.

Table 2.3: High Pressure Sodium vs. LED lamp

Items	**High Pressure Sodium Light – HPS**	**LED Street Light**
Photometric Performance	Bad	Excellent
Radiator Performance	Bad	Excellent
Electric Performance	Electric Shock Easy (High Voltage)	Safe (Low Voltage)
Working Life	Short (5,000 hours)	Quite Long (>50,000 hours)
Working Voltage Range	Narrow (±7%)	Wide (±20%)
Power Consumption	Quite High	Quite Low
Startup Speed	Quite Slow (Over 10 minutes)	Rapid (2 seconds)
Strobe	Yes (Alternating Current Drive)	No (Direct Current Drive)
Optical Efficiency	Low	High
Color Index / Distinguish Feature	Bad, Ra <50 (The Color Of Object Is Faith, Boring, Hypnosis)	Good, Ra >75 (The Color Of Object Is Fresh, Veritable And Comfortable)
Color Temperature	Quite Low (Yellow Or Amber , Uncomfortable)	Ideal Color Temperature (Comfortable)
Bad Glare	Strong Glare (Dazzle)	No Harmful Glare
Light Pollution	Strong	No
Heating	Serious (>300°C)	Cold Light (<60°C)
Lampshade Turn Dark	Easy (Absorb Dust)	No (Static Proof)
Lamp Aging Turn Yellow	In A Short Time	No

Shockproof Performance	Bad (Fragile)	Good (No Filament Nor Glass)
Environment Pollution	Contains Lead Element Etc.	No
Maintenance Cost	High	Quite Low
Product Cubage	Big	Small (Slim Appearance)
Product Weight	Heavy	Light
Cost-Effective	Low	High
Integrated Performance	Bad	Excellent

For a required lumen of around 1200, a 20 watt LED will be feasible and energy efficient. But to allow any fluctuations in voltage, considering a 24w LED would be safer.

2.6.3 Light Emitting Diode (LED)

A LED device consists of cathode, anode, LED chip, wire bond, epoxy lens and reflectors. It comes in several colors which are predetermined by the semiconductor material used in manufacturing. The most common specification that comes with a small LED is its voltage and current rating. A forward voltage is required to initially drive the LED on and the maximum forward current rating limits the amount of current that can flow through it without damaging the LED. Another type of current rating can be given along with the LED that gives the value at which the LED will be brightest. However we should remember that the LED current is dependent on the ambient temperature and any change in voltage. A small change in voltage can lead to big change in current thus damaging the circuitry and the overall lighting system. To avoid this problem LEDs, with a DC power supply, require a driver circuit which will be discussed later in this section. For evading short circuit issues the LEDs are connected in series with a resistor. The calculation for the resistance is shown below:

$R= (Vs- V_{LED})/I_{LED.}$

V_{LED} and I_{LED} will be given by the rating on the LED lamp and the Vs which is power supply will be controlled by the driver circuit.

A complete LED lighting system consists of LEDs, optical system, thermal system and electrical system. This integrated successfully can provide good illumination besides being energy efficient and economically viable. LED produces directive light thus to fit it according to our purpose it might need several optical considerations and systems such as lens, reflectors etc. The performance of an LED is highly altered by the effect of its junction temperature, which in turn influences the LED current, light output and leads to a shorter life. A very good heat sink should be used to minimize the temperature. As mentioned earlier, a small fluctuation in voltage can lead to a huge change in LED current; we require a driver circuit to maintain a stable current all throughout. For this project we are taking into account a DC to DC converter (Switching regulator type).

There are 4 types of DC-DC converter:

- Buck
- Boost
- Buck Boost
- Flyback

Since we only want to limit the voltage to the maximum voltage supply in accordance with the LED current, temperature and light intensity required, a buck type converter is suitable. This type always yields a lower output voltage than the input and through pulse width modulation from a microcontroller, the on time of the voltage can be varied to achieve different intensities.

2.7 Conclusion

To design a complete photovoltaic lighting system sensitive to traffic, suitable components from the choices detailed above have been selected. During selecting the right system components, their parameters have been taken into account which can lead to achieving the most energy-efficient cost-effective system for use in Dhaka city. Thus factors such as availability, efficiency and response time have also been taken into account besides optimum energy production. The complete system will consist of a monocrystalline solar panel which will collect energy from the sun during day time. The panel will then feed the collected charge to a 12V Lead-Acid battery through a Series-Interrupting, Pulse Width Modulated type charge controller. This charge controller will regulate the amount of charge flowing from the panel to the battery during day time, and from the battery to an LED load during night. The LED will be connected to the output of the ultrasonic sensor. The sensor will detect traffic and depending on its output voltage, LED light will operate at a predefined intensity levels. Overall, these components are expected to satisfy the objective of this project to be energy-efficient.

CHAPTER 3

DETERMINING THE OPTIMAL PANEL MOUNTING ANGLE

3.1 Introduction

The research involves an amalgamation of technology and sustainability. The focus of this project is to make the most efficient use of the energy received from the sun to power street lights in the city. Solar Panels mounted on the street lamps will collect the energy from the sun during day time, driving the LED lamps at night. During summer, the days are long and nights are short, whereas during winter, the scenario is the opposite. In different seasons, the sun is incident on the earth's surface and thereby on the solar panels in different angles. The incident angle also varies from sunset to sunrise. All these factors must be taken into account to determine a convenient tilt angle for the panel based on the latitude and longitude of Bangladesh, such that the angle allows optimum output for all four seasons, throughout the year. Thus minimum system size will be achieved for maximum energy collection.

3.2 Methodology

For maximum energy collection, panels should be perpendicular to the incident solar radiation. But the sun's position changes with different seasons, and so does the angle at which panels can collect optimum energy. There are three types of array mounting:

1. Fixed- mounted at an angle that will maximize the energy harvesting for the whole year.
2. Adjustable- further sub categorized into adjustable for 2 seasons, adjustable for 4 seasons and 2 axes. Their position can be adjusted whenever required. This is usually done at the start of each new season.
3. Tracking- an intelligent panel system which follows the path of sun all throughout the year. The angle of mounting is adjusted continuously from sunrise to sunset, and from season to season, in order to track the sun at all times.

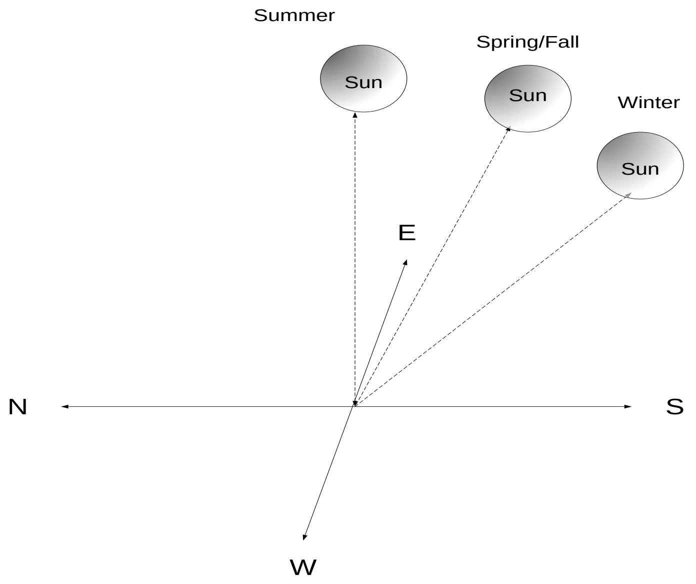


Figure 3.1: Position of sun at different seasons

What we have to keep in mind is that the panel should be pointed in a direction at which it can get the most from the sun. Although a tracker would negotiate automatically with the optimum direction to get the most of sunlight, implementing a fixed type needs to have a calculated angle since one tilt angle throughout the year must satisfy all the four seasons. Nevertheless keeping the economic factor in mind we have employed a fixed tilt angle to the mounted panel. The main task is to calculate the energy density or irradiation for winter summer spring and fall. However this required the understanding of the solar system that involves the relative position and also several angles concerning the Earth and the Sun. As the sun's beam moves through the atmosphere, the path covered by it varies depending on its angle with the vertical of the Earth, the Zenith angle. This path is thus expressed in terms of the **zenith** giving **air mass**. The **solar altitude** is another angle which is a complement of the **zenith angle** and all the three parameters mentioned effects the solar irradiance. Also the sun is not at a fixed position all throughout the year. It changes its position every season making an angle with the Earth latitude, thus giving us **declination angle. The hour angle** on the other hand determines the total no. of hours from sunrise to sunset. All the parameters discussed above are what finally decide the empirical formula of solar irradiance. The sun angle at sunrise and sunset is thus calculated using the hour angle formula and the solar irradiance equation is integrated over time i.e. the sunrise to sunset time to achieve the formula for solar irradiation. However before integration we have to consider the effective panel area as well.

The area varies, firstly with the angle of the sun's incident beam that changes from sunrise to sunset and secondly, with the relative position of the sun seasonally. As a result, except when the incident beam and the panel are perpendicular, the effective area in use is always less than the actual area and thus gives us an effective solar irradiation. The result of the integration will give us the solar energy density available for extraction by the panel every season. By comparing the effective irradiation i.e. the energy density per season at different mounting angles, the optimum angle was thus determined.

3.3 Calculation of the Cumulative Energy Density/Irradiation

3.3.1 Air Mass and Solar Irradiation

As sunlight travels through the space and into the atmosphere of the earth, it loses its energy because of the air mass. When the sun's rays passes through the atmosphere, much of it is scattered or absorbed by the atmospheric layers themselves. Depending on the length of path sunlight traverses through the atmosphere, the amount of absorbed or scattered sunlight varies. This path length is minimum with a vertical path directly to sea level and is designated an **air mass** = 1, expressed as AM1.

$$\mathrm{AM} = \frac{\mathrm{L}}{\mathrm{L_o}} \approx \frac{1}{\mathrm{Cos}\theta_Z} \qquad (1)$$

Where $\mathrm{L_o}$ the zenith path length is (i.e. normal to the Earth's surface) at sea level and θ_Z is the zenith angle in degrees.

At any other position, the path length is greater than the minimum path length (L_0) and is expressed as multiples of minimum path length.

Air mass is more conveniently expressed in terms of incident angle of sunlight, called the solar altitude,

$$\alpha = 90^\circ - \theta_Z \qquad (2)$$

$$\mathrm{AM} = \sec\theta_Z = \csc\alpha \qquad (3)$$

The zenith is a line normal to the Earth and the **zenith angle** θ_Z is defined as the angle between the sun and the zenith as shown in figure 3.2. **Solar Irradiance** is the measure of the power density of sunlight and is measured in W/m^2. With the sun directly overhead, only 70% of the initial sun irradiance of 1367 W/m^2 reaches the sea level of the earth. Thus the resulting irradiance is reduced to 1000 W/m^2, rest being absorbed by the atmosphere. However, for non-vertical sun angles, the rays of sun have to traverse extra distance through the layers of atmosphere resulting in a higher loss of intensity, and lower availability of solar irradiance. To enable the calculation of solar irradiance at any sun angle, following empirical formula has been proposed by [4] that relates solar irradiance with the altitude length air mass.

$$I = 1367(0.7)^{AM^{0.678}} \tag{4}$$

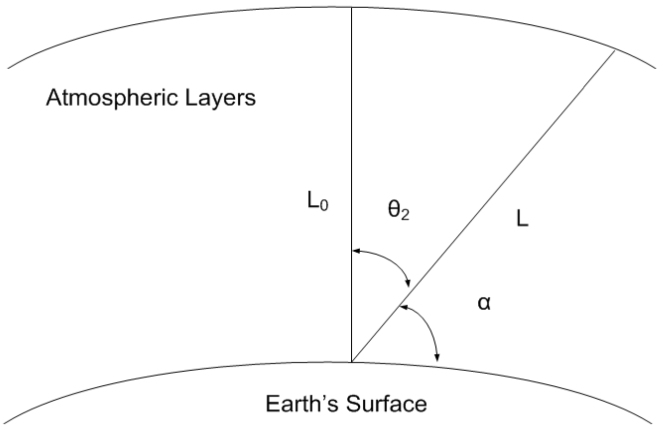


Figure 3.2: Distance travelled by the sun through the atmospheric layer

3.3.2 Position of the sun in different seasons and the declination angle

In the solar system, the Earth undergoes elliptical revolution around the sun in approximately every 365 days and a 360° rotation about its axis once per day. Therefore the position of the sun varies from day to day and from season to season. However the axis of the Earth is inclined by an angle of 23.45° to the plane of the Earth's trajectory about the sun as shown in figure 3.2. Because of this inclination the sun tends to be higher in the sky in the summer than in the winter which causes summer to have more sunlight hours and winter to have less sunlight hours. For the convenience in alignment of the earth about its trajectory, solar solstice and equinox are assumed to be around four particular days of the year since on those days the properties of the four seasons are chiefly evident. Summer and winter solstices happen to correspond to 21st June and 21st of December respectively where as spring and fall equinoxes correspond to 21st March and 21st September respectively. On the first day of summer, the sun positions itself vertically above the Tropic of Cancer, which is latitude 23.45° north of the equator whereas on the first day of winter, the sun is vertically above the Tropic of Capricorn, which is latitude 23.45° south of the equator. However on the first day of spring and the first day of fall, the sun is directly above the equator. As the season changes from fall to spring, the sun changes its position from directly above the equator to the south of the equator and from spring to fall it moves towards the north of the equator.

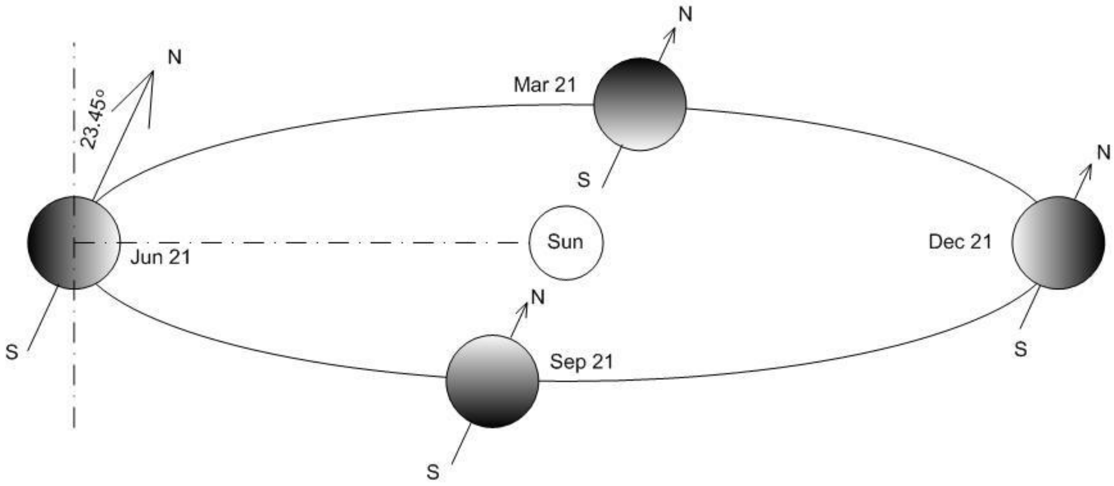


Figure 3.3: The orbit of the earth and the declination at different times of the year

The angle of deviation of the sun from directly above the equator that is 0° latitude is called the **declination.** For the purpose of sign convention, angles deviated or declined north of the equator are considered to be positive and angles deviated towards the south of the equator are considered to be negative angles. Thus at any given day of the year, n, the declination (δ) of the sun from the equator can be found from the equation given below [1],

$$\delta = 23.45^\circ \sin\left[\frac{360(n-80)}{365}\right]; \qquad (5)$$

where n= day of the year (i.e. January 1 means n=1).

For the simplicity of the equation it is assumed that there are exactly 365 days every year. Calculating and understanding declination angle is very important in order to find the location of the sun in the sky at any time of the day, on any day of the year and at any site in the world. When the declination is equal to the latitude of the location in question, the sun is located at its maximum point in the sky at solar noon.

Figure 3.4 illustrates the relationship among the declination angle (δ), the latitude (φ), and the zenith angle (θ_Z), for two different seasons, summer and winter.

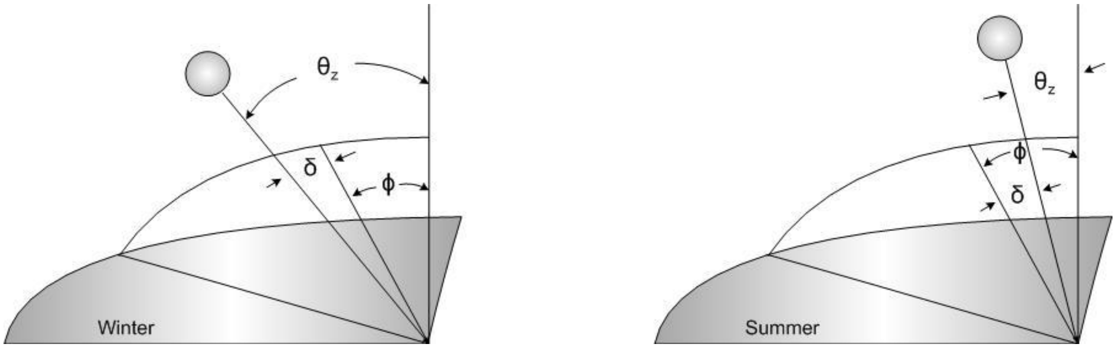


Figure 3.4: Relationships among θ, ϕ and δ at solar noon in winter and summer

Since the sun is upright above the Tropic of Cancer on the 21st June at solar noon it becomes apparent that,

$$\theta_z = \varphi - \delta \qquad (6)$$

where φ is the latitude and θ_Z is the zenith angle.

This is valid from spring to summer till winter (21st March - 21st September). Since for summer δ is positive and equal to latitude according to equation (6), θ_z zero is expected as the sun is at its highest with no angle difference between itself and the zenith line.

Also for winter, since δ is negative and equal to latitude this too yields the same reason as summer.

During summer, δ is positive and $\theta_z < 0$, while during winter, δ is negative and $\theta_z > 0$ due to increase in air mass and reduced solar irradiance. Thus on 21st June, $\delta = 23.45^0$ and θ_z is nearly equal to zero. On 21st December, $\delta = -23.45^0$ and θ_z equals 46.5^0.

3.3.3 Solar altitude α and the hour angle ω

Solar irradiance is a function of air mass (AM), while air mass is a function of the altitude α. The altitude α depends on the declination angle (δ), the time of the day and the geographical location of the site.

Solar altitude is given by [1]

$$(\alpha) = \sin^{-1}(\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega), \qquad (7)$$

where all the terms have their usual meanings and ω is the hour angle, as determined by the time of the day.

The hour angle as in solar altitude equation is the number of hours elapsed during the day from sunrise to sunset expressed in degree and can be calculated as below [1], $\omega = \omega_S - 15(t - T_{sr})$,

(8)

where t is the time of day on a 24-hour clock and T_{sr} is the sunrise time, ω_s is the sunrise angle and $-\omega_s$ is therefore the sunset angle. Fig.5 shows various sun angles that determines the final solar irradiation equation.

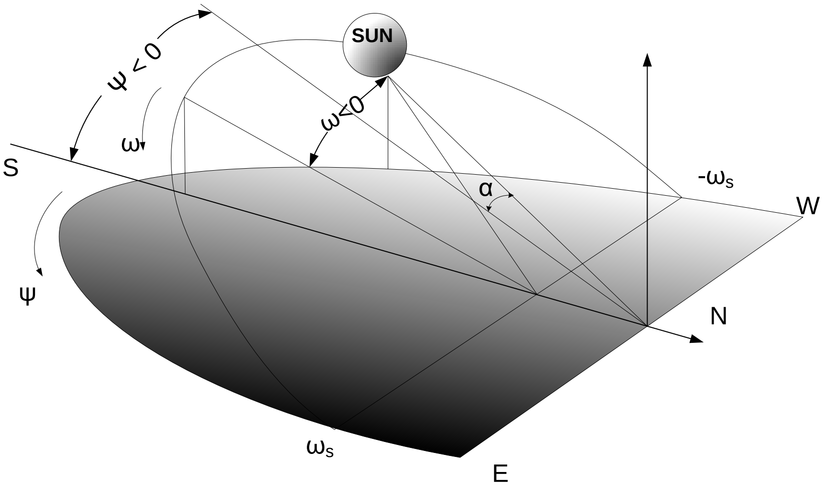


Figure 3.5: Sun angles, showing altitude, azimuth and hour angle

From the declination angle and the latitude discussed above, an expression for ω_s can be determined [1],

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \tag{9}$$

From sunset angle and sunrise angle, we can determine the number of hours during daylight which is required to calculate the total energy density.

3.3.4 Effective Area

The sun is not always incident perpendicularly on the earth’s surface, as seen from the discussions and figures above. Thus the effective area of the panel is always less than the actual area, unless the sun shines down perpendicularly. The area covered depends on two criteria. Firstly, the position of the sun changes from sunrise till sunset which causes the sun to be tilt at different times of the day thus creating an angle θ with the vertical. Secondly, during winter and summer the sun is declined away from the equator or 0° latitude which also causes the sun to tilt and cover the panel area inconsistently.

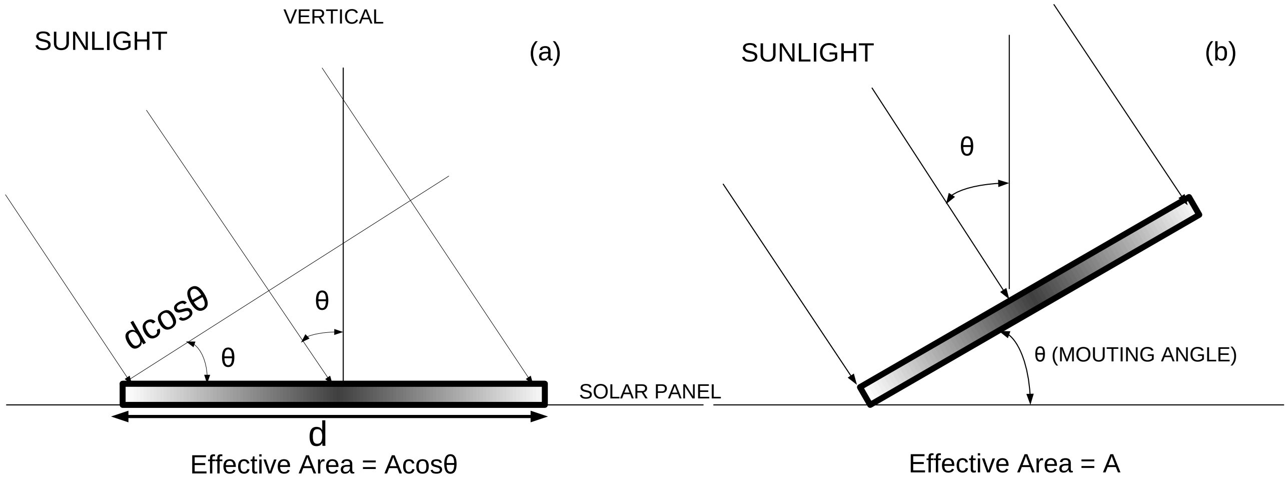


Figure 3.6: (a) Angle of Incidence of Sunlight and Effective Area (b) Optimization of Mounting Angle of a Fixed Collector

These factors should be taken into account while considering the effective irradiance that the panel can actually extract. The angle γ varies from 0° to 90° till noon and extends from East to West starting from sunrise. It is notable that only on spring/fall and at solar noon, γ is 0° thus utilizing the full area. At this occasion, effective area equals actual area. As γ changes in direction, eastward or westward, effective area decreases.

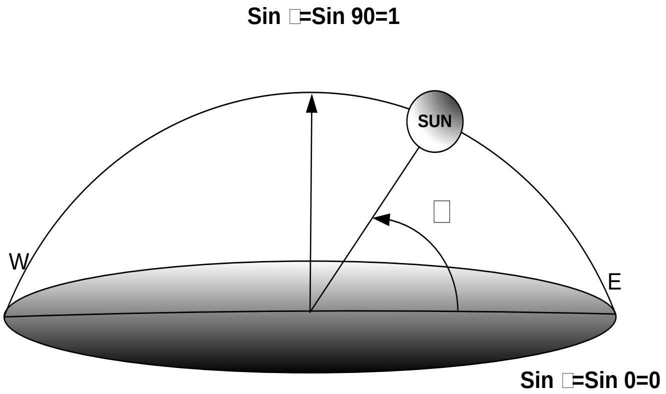


Figure 3.7: Variation of Sun's Position during the Day

As a result received intensity will be reduced. Using trigonometric formulae, we can derive that the effective area for reception of solar intensity or irradiance is given by:

$$\text{Effective Area} = A \times \cos\delta \times \sin\gamma, \tag{10}$$

where A is the actual area of the solar panel.

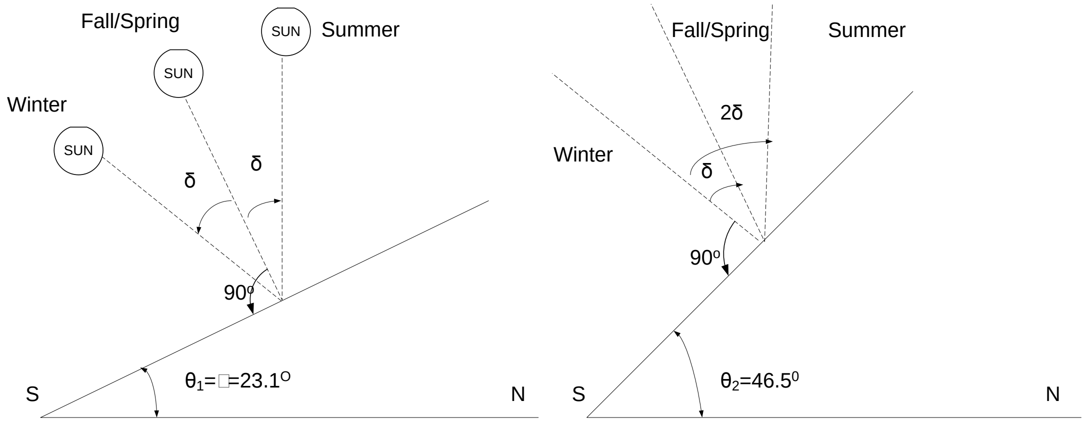


Figure 3.8: Angular Position of the Sun with respect to the panel for two different mounting angles θ_1 and θ_2 aligned for two different seasons spring/fall and winter respectively

In general, the panels are aligned for spring/fall to satisfy all the seasons. However we will look into both the winter and spring/fall mounting angle which will also be compared in section 3.4.

When $\theta=\phi=23.1^{o}$, aligned for Spring/Fall, the effective area during spring will be equal to the total area but during both summer and winter the effective area will be a multiple of Cos as shown below:

$$\text{Effective Area} = A \times \cos\delta \times \sin\gamma$$

When $\theta=46.5^{o}$ that is aligned for winter, the effective area during winter will be the actual area but during Spring/Fall,

$$\text{Effective Area} = A \times \cos\delta \times \sin\gamma$$

And during summer,

$$\text{Effective Area} = A \times \cos 2\delta \times \sin\gamma$$

Therefore the total intensity or irradiance can be calculated as follows,

$$\text{Effective Irradiance} = I \times \text{Effective Area}, \quad (11)$$

where the symbol I bears its usual meaning.

3.3.5 Cumulative Energy Density, Irradiation

Irradiation quantifies energy density of sunlight that is total energy per square meter per day. It is obtained by integrating total irradiance over daylight hours beginning from sunrise till sunset. Depending on various parameters and angles between the direct beam and the panel and Earth surface the total irradiation is obtained which is later converted to electrical energy in order to determine battery and solar panel size. Such angles and useful parameters are already explained which is finally incorporated to form the final equation used for obtaining the effective irradiation or energy density of solar radiation incident on our fixed collector.

$$\text{Total Energy} = \int_{T_{SR}}^{T_{SS}} A\cos\theta\sin\gamma\left(1367(0.7)^{AM^{0.678}}\right)dt \quad (12)$$

3.3.6 Energy Consumption by the LED lamp

The energy that can be successfully extracted by the solar panel will then be used to power the LED lamp at night.

The LED in place of common street lamps such as LPS and HPS already reduces energy consumption by 80%. However by integrating a traffic sensing system it can be made more energy efficient. LED lamps of 48 Watts have been decided to be used in the street lights and without the traffic sensing system the lamp consumes full 48W of power for its total hours of operational period during night time. This can be seen as per the equation below.

Without Traffic Sensor, the required Wh in a day is calculated as:

$$W_{without} = (48 \times h)\ \mathrm{Wh} \tag{13}$$

, where h is the no. of hours the lights remains on in a given day of the year.

With the Traffic Sensor installed, it can be approximated that the street light operates in full power for half of the operational time, in 2/3rd power for 1/4th of opertaional time, and in 1/3 power for the remaining quarter of operational time, in a given night of the year. Thus the watt-hour required can be calculated by:

$$W_{with} = (0.5 \times h \times 48) + \left\{0.25 \times h \times \left(\frac{2}{3}\right) \times 48\right\} + \left\{0.25 \times h \times \left(\frac{1}{3}\right) \times 48\right\}\ \mathrm{Wh} \tag{14}$$

$$= (36 \times h)\ \mathrm{Wh}$$

3.4. Results and Discussion

Fig-3.8 depicts the amount of cumulative energy density per square meter per day available from the sun in all four seasons for three mounting angles, 0^{o}, 23.1^{o} and 46.5^{o} calculated using Eq. (12). The three mounting angles are each optimized for the three seasons, spring/fall, summer and winter. Spring and fall is considered to yield the same output since on the first day of both the seasons the sun is located just above the equator with 0^{o} angle of declination, thus showing similar pattern in solar energy radiation. As expected, summer has the highest amount of energy as opposed to other seasons particularly when optimized of summer and spring/fall. Winter has the lowest of energy for tilt optimized for summer and spring.

Graph output shows although we receive less solar power during summer and spring the difference between winter energy and energy during other seasons is much less at 46.5 degree than other mounting angles. At other mounting angles the difference in solar energy density among different seasons is greater than the tilt angle maximized for winter.

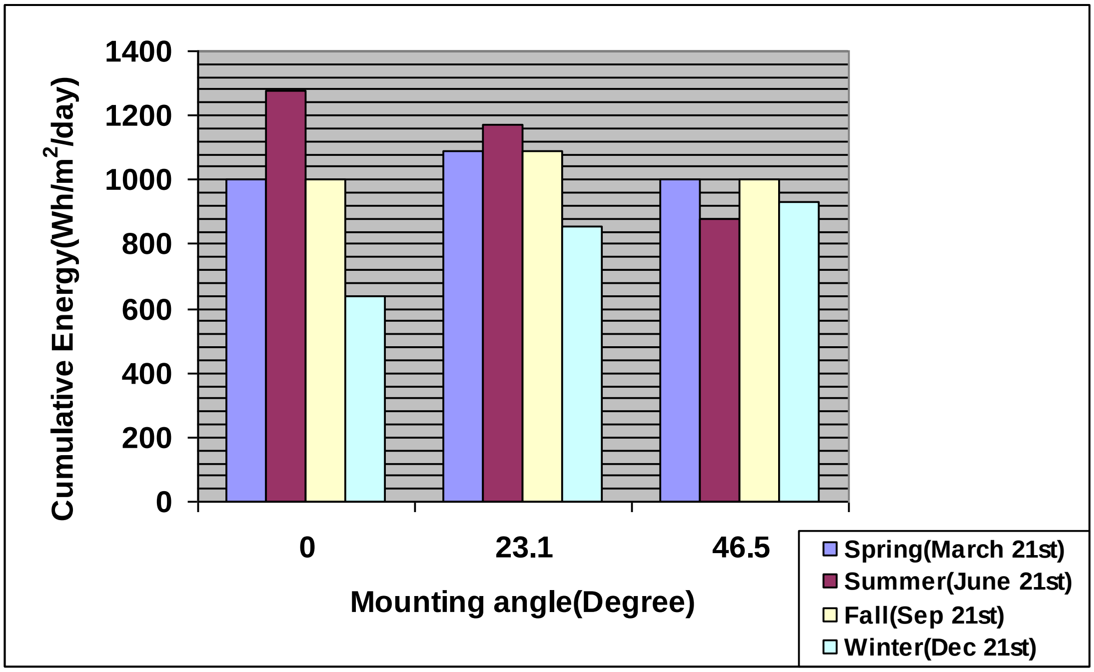


Figure 3.9: Cumulative Energy Output of Solar Panel in W/m^2 per day in different seasons at different mounting angles

Fig-3.9 represents the energy consumption by the street lamp per night, as calculated using Eq (14). The blue line shows energy consumption at night when a traffic sensing system is not in action while the red line shows energy required by the LED lights when a traffic sensing system is incorporated. Naturally the latter requires less energy to power the lights as the driver circuit is depended on the output of an ultrasonic sensor which measures traffic volume. Depending on the traffic volume the LED acts according thereby consuming less power when traffic is low. The solar energy extracted and converted to electrical energy is used up in driving the LED lights used as a luminary. In this project we are considering a LED bulb set of 48W that has to be powered for an average of 13 hours per night. However the exact value of the numbers of hours to be consuming energy can be found using the equation for Ws. Without the traffic sensing system, 48W of power is required by the LED for that many no of hours. However if we are incorporating the traffic sensing system, as per our microcontroller algorithm, the maximum of the power will be consumed for half of the time while for the rest half the power consumption will vary.

Total number of hours =H

Power of an LED lamp=48 W

Total Energy Consumption without traffic sensing system=48 $\times$ H Wh

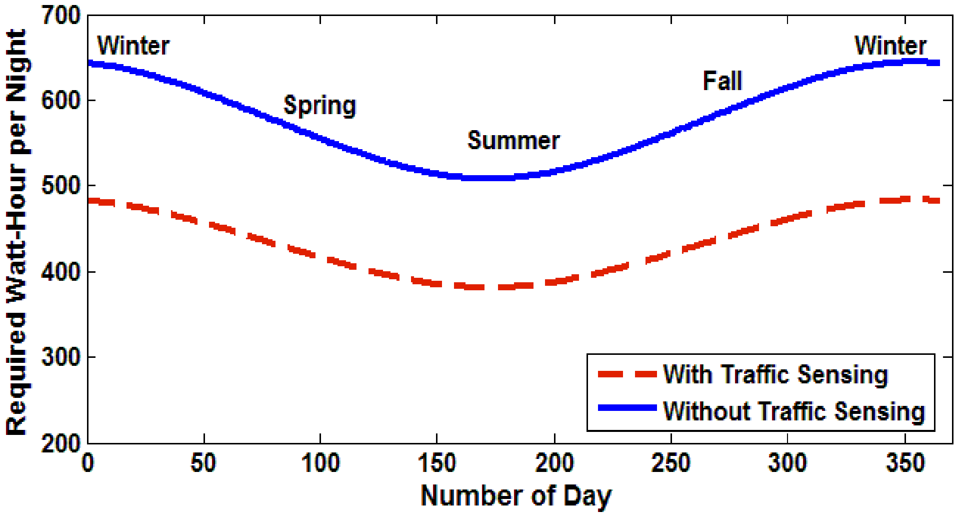


Figure 3.10: Energy Required to Light LED Lamps per Night at Different Times of the Year

3.5. Conclusion:

Considering all the above calculations and data from graph, it can be concluded that using solar street lamps in conjunction with traffic sensor can considerably reduce the amount of energy consumed, and thus be energy-saving and cost effective at the same time. It is also seen that since the mounting angle is decided basing on winter, all the other seasons can meet their maximum requirements easily.

CHAPTER 4

CALCULATION FOR SYSTEM SIZE

4.1. Introduction

Calculations now need to be done in order to determine the parameters for a photovoltaic system to power the LED street lamps. The system will require a solar panel for the collection of sun energy, and a battery as a storage area for the collected charge. Energy will thus be collected through the photovoltaic panel during day time, and be stored in the battery till it is drawn by the street lamps at night. If size of system is too larger than required, there will be wastage of energy as well as economic resources. On the other hand, if too small a size is employed, it will not be possible to collect the maximum energy of sun that reaches earth and therefore the system will be inefficient. As a result the size of the batteries and photovoltaic panels needs to be determined as to achieve maximum utilization of the system, based on the findings of the energy received from the sun and the energy required by the LED street lamps.

4.2. Methodology

The use of Light Emitting Diodes (LED) in place of common street lamps itself reduces energy consumption by 80%. LED lamps of 48 Watts have been decided to be used in the street lights. As seen earlier, without Traffic Sensor, the required Wh in a day is more than that of the lighting system with a traffic sensor attached. It can be seen that there is a decrease in required power by the street lamps if Traffic Sensor is used in conjunction with the lights. These results have also been reflected in Fig-3.8.

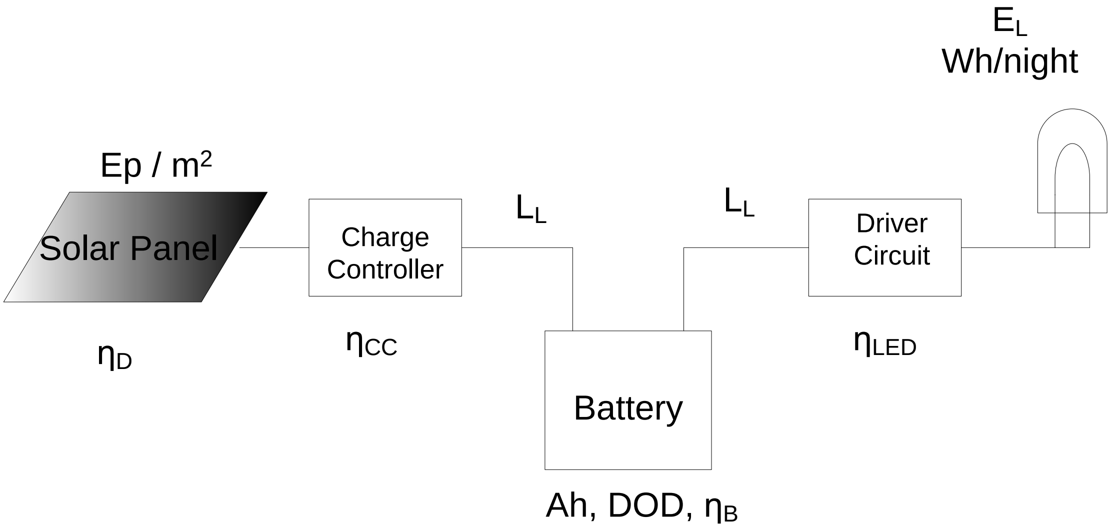


Figure 4.1: Block diagram of a LED lighting system showing system parameters.

Fig-4.1 shows a block diagram of solar powered street light system. The energy collected from the solar panel is stored in the battery through the charge controller during the day. The charge controller adjusts the variable output from the panels before supplying it to the battery. The battery supplies it to the load at night, through the driver circuit, which maintains a stable current through the LED. All the system components have some internal loss and thereby they do not have 100% efficiency. There is also additional line loss where wires connect the different components. We will determine the battery capacity and the panel size in Ah and m^2 respectively. Values for use in these calculations are taken from Fig-3.8 and Fig-3.9.

4.3. Calculation of Battery Capacity

In Fig-4.1, E_L denotes the total energy in Wh required by a LED lamp per night. If L_L is the line loss from battery to LED and η_B is the Battery efficiency, the energy that should be supplied is given by:

$$\text{Energy} = \frac{E_L \times (1 + L_L)}{\eta_B \times \eta_{LED}} \text{ Wh} \tag{15}$$

To ensure the supply of energy during the cloudy and rainy days, battery should store more energy than obtained by the above equation. Number of such days is called days of autonomy.

Therefore the maximum number of days that the battery can drive the load without receiving energy from the source, namely the panel here is 3 days. The DOD is the maximum limit of discharge for a battery. We also have to take in account the efficiency of the driver circuit, to which charge passes from the battery before driving the LED, denoted by η_{LED}. Considering 3 days of autonomy, line loss and driver circuit efficiency the total energy to be supplied to the LED is thus given by:

$$E_T = \frac{3 \times E_L \times (1 + L_L)}{\eta_{LED}} \text{ Wh} \tag{16}$$

Now, considering the battery efficiency and the depth of discharge, the maximum energy that could be stored in the battery is given by:

$$E_S = \frac{E_T}{\eta_B \times DOD} \text{ Wh} \tag{17}$$

where E_S is maximum energy that can be stored in battery.

Therefore the battery capacity in Ah is simply calculated by dividing E_S by the voltage rating of the battery as shown below:

$$\text{Battery Capacity} = \frac{E_S}{\text{Battery Voltage}} \text{ Ah} \tag{18}$$

4.4. Calculation of Panel Size

The panel size can now be determined with the help of the total energy required, calculated in the previous section. To find the size of the solar panel required, we need the new parameters η_D, known as the Derating factor. The Derating factor results in loss of efficiency of the panel due to long time of use, layers of dust and wear etc. The efficiency of the charge controller also needs to be taken into account since charge is stored in the battery through the charge controller. From figure-4.1, we can see that the maximum energy received in the photovoltaic panel is denoted by E_P.

$$\text{Maximum Energy received from the sun} = E_P \text{ Wh}$$

If E_T is the total Energy required by the LED light in Wh/night, if the line loss from battery to panel through the charge controller is L_L and the charge controller efficiency is η_{CC} and the derating factor is η_D we get:

$$\text{Panel Size} = \frac{E_T \times (1 + L_L)}{\eta_D \times \eta_{CC} \times E_P} \text{ m}^2 \quad (19)$$

In the above calculation, three different values of E_P are taken for three different mounting angles during winter. This value is the same during operation with traffic sensor and that without traffic sensor, since the received energy does not depend on the sensors.

Table 4.1: Specification of System Parameters

System Parameters	L_L	η_{LED}.	η_B	DOD	η_D	η_{CC}
Specification (%)	1	95	80	80	90	95

4.5. Results and Discussions

The calculations for the two different conditions of operation with and without traffic sensor can be summarised and tabulated in a table to show the relative energy saved by using traffic sensors to detect traffic density and monitoring the lights. In the table, the different values of battery capacity, and the panel size are shown for three different mounting angles ‘0°’, ‘23.1°’, and ‘46.5°’, calculated using equations no. 18 and 19, for december 21 of winter. The values of E_P used to determine the panel size have been taken from Graph-1, and are 638.5, 854, and 928.5 respectively for 0°, 23.1° and 46.5°. It can be seen from the percentage comparisons that we can minimize system size by approximately 33%, for both panel and battery, by employing the traffic sensors in the road to determine the intensity of the LED street lamps.

At 46.5°, the panel size required for a system without traffic sensor is 4.07 m^2, whereas, a system with traffic sensor installed will require a panel of 3.06 m^2, which saves about 33% of the area. The battery capacity requirement is also reduced by 33.2% from 266.62 Ah to 200.17 Ah by the use of traffic sensors. Looking at the changes with respect to the mounting angle, it can be seen for the case without traffic sensor that panel size is reduced from 4.43 to 4.07. This shows that about 9% reduction in panel size can be brought about by mounting the panel at 46.5°, instead of the general practice at 23.1°. The battery capacity has no change with respect to varying mounting angles, since it does not depend on the energy collected by the panel in different seasons.

Table 4. 2: Panel Size and Battery Capacity for three different mounting angles in winter, and their percentage difference for operation with, and without, traffic sensor.

Mounting Angle, θ (degree)	Panel Size (m^2)			Battery Capacity (Ah)		
	With Traffic Sensor	Without Traffic Sensor	% Difference (%)	With Traffic Sensor	Without Traffic Sensor	% Difference (%)
0^0	4.44	5.92	33.3	200.17	266.62	33.2
23.1^0	3.32	4.43	33.4	200.17	266.62	33.2
46.5^0	3.06	4.07	33.0	200.17	266.62	33.2

4.6. Conclusion

Considering all the above calculations and data from the graphs, it can be concluded that using solar street lamps in conjunction with traffic sensor can considerably reduce the amount of energy consumed, and thus being energy-saving and cost effective at the same time. The calculated system parameters and the meteorological data confirms that the system size will be efficient enough to provide full-time operation of load at nights during all seasons of the year. It is due to the fact that the mounting angle is decided basing on winter, and therefore, all the other seasons can meet their maximum requirements easily. This optimum system size is efficient both in terms of energy, life-cycle, and economic factors.

CHAPTER 5

HARDWARE IMPLEMENTATION

5.1 Introduction

This chapter is the product and incorporation of all the previous chapters discussed so far. After an intensive research on all the available techniques and components, to meet the requirement of the desired lighting system and to satisfy the prime objective of the project, suitable methods and components were selected and implemented through electrical circuits. The circuits are such so that these yield maximum output with minimum system requirements. The final product i.e. the complete solar powered traffic sensitive LED lighting system is therefore an integration of all the individual circuit and is tested under certain experimental conditions and limitations. Although the actual street light could not be developed because of time restraint, a prototype is built and all the experimental measurements are thus selected in proportion to the size of the prototype.

5.2 Solar Powered Traffic Sensitive Automated LED Street Lighting System

5.2.1 Panel, Charge Controller and Battery

The charging of the battery is a very important part of any PV system. Among the 3 types of charge controlling mechanism, the PWM type charge controlling has been applied effectively to the battery charging unit. Figure 5.1 shows the charge controlling circuit that charges the battery from 0 volt to 14.4 V according to the stage charging cycle shown in figure 5.2. The circuit uses a feedback mechanism where the panel provides voltage to the battery and the battery's voltage level is fed into an ADC channel of the microcontroller AN0 pin as a feedback. This voltage is then converted into a digital value between 0 and 1023 which is then compared by the conditions programmed in the microcontroller to yield a suitable PWM through pin 17. Then the PWM equivalent to the digital voltage value is fed into the base of the BJT NPN transistor Q_1 through a 220k resistor. This PWM is however interpreted as an average DC voltage equivalent to the PWM percentage by the base of the BJT. Which means a higher PWM will have longer ON time and therefore the voltage at the BJT will be higher. Now if the voltage at the base is high, the BJT turns on and goes into saturation with the voltage at the collector being 0.2 volt. Since this voltage is considered as a low level the PMOS turns on and provides a high voltage at the positive terminal of the battery. The voltage is not immediately stored; rather the panel gradually supplies the voltage through the 22k resistor. This means the continuous solar energy from the panel is now pulsed by varying the ON OFF time of the PWM. With a higher PWM, the ON time will be longer; therefore voltage will be stored in the battery for a longer time thus resulting in a greater battery voltage. The reverse is true for a low PWM.

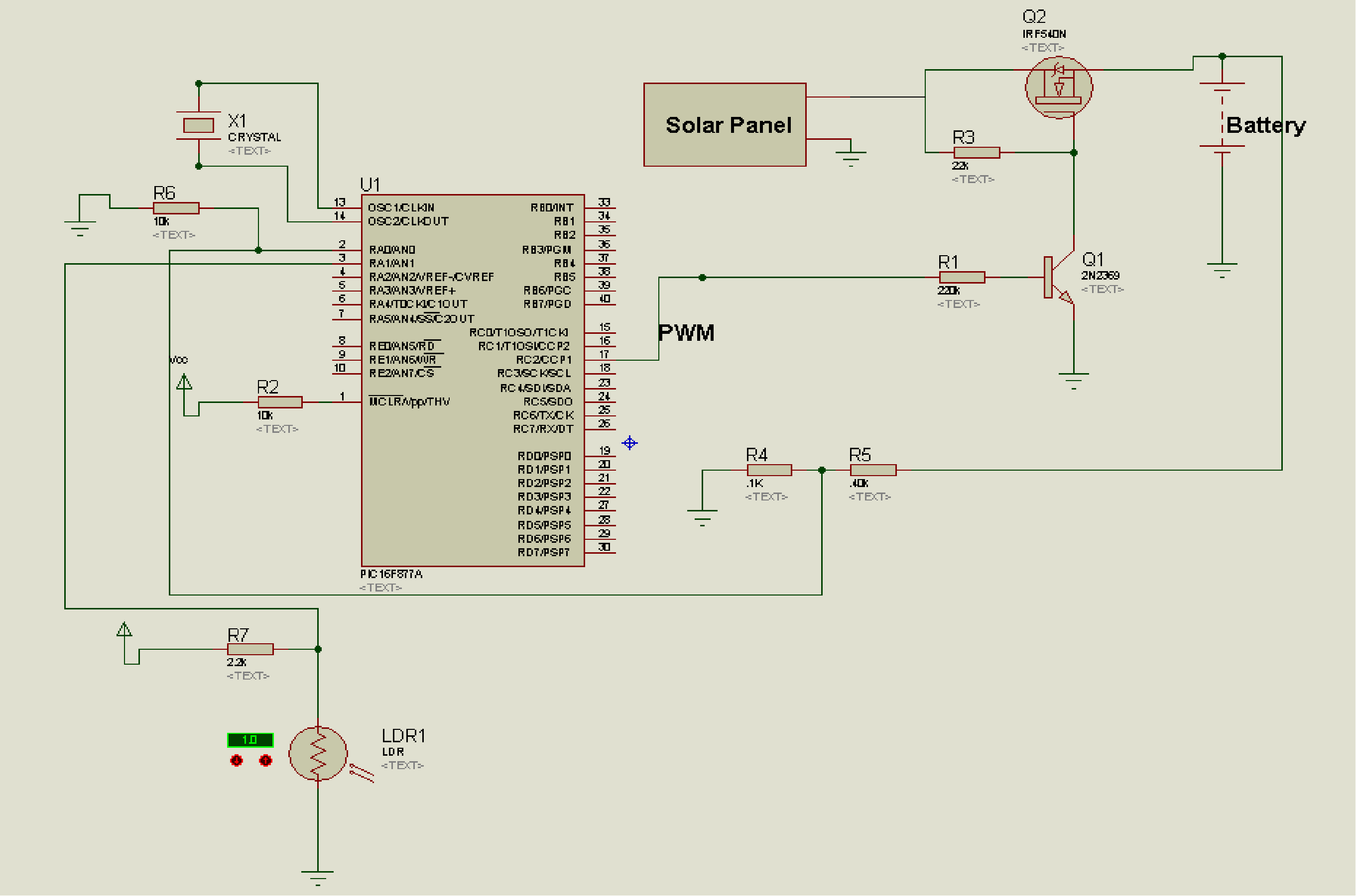


Figure 5.1: Circuit for Battery Charge Control via Solar Panel

The LDR on the other hand controls the operation of the battery. During daytime, the LDR sends a voltage V_L at the microcontroller ADC pin AN1. This voltage is lower than the threshold voltage that marks the boundary between day and night time and indicates that the battery can now be connected to the charge controller circuit. However, when the V_L value is higher than the threshold, it indicates night time and the battery is disconnected from the charging circuit and is connected to the load that is the driver circuit. The other connections are basic microcontroller connections required to power up the microcontroller and to stabilize its output.

Like all modern charge controllers, three stages of charging have been used by the Pulse-Width Modulation technique to develop the charge controller in this project. The 3-stage controller ensures maximum possible charge to be fed to the battery during the day, and details of each stage have been described in section 2.4.4.

The microcontroller in our charging circuit has been coded as to let the charge controller supply the maximum possible current to the battery till it reaches the bulk voltage of 14.4 V. The battery will thus receive a 100% PWM till it reaches the bulk voltage and the voltage is gradually increased while the current is held constant at its maximum value. This can be seen in Fig 5.2. When the bulk voltage is reached, the microcontroller signals the charge controller to reduce percentage of PWM and adjust it to a constant absorption voltage of 14.4 volts by taking continuous feedback voltage from the battery’s present voltage. At the same time the current will gradually decrease to a value less than 1% of the battery capacity. At this stage the battery reaches 100% charge and the voltage is allowed to drop till 13.6 V, which is considered as the float level in this implementation. During the float level, a low PWM is supplied to keep the battery from discharging and maintaining it till the next cycle begins.

The maximum current safe for the battery is generally considered to be 25% of the battery capacity in amp-hours. We have seen in section 4.3 that the required battery capacity was found to be 200.17 Ah for operation of the system with traffic sensor. Thus a maximum of 50 A could be allowed to flow through the battery during the bulk stage. Since the battery capacity has been calculated for the original system, the battery Ah value for the prototype would be lower. For the prototype, a 3 W LED has been considered in place of a 48 W LED to determine the energy required by the lamp per night which in turn is a parameter in the equation to calculate battery capacity. [14]

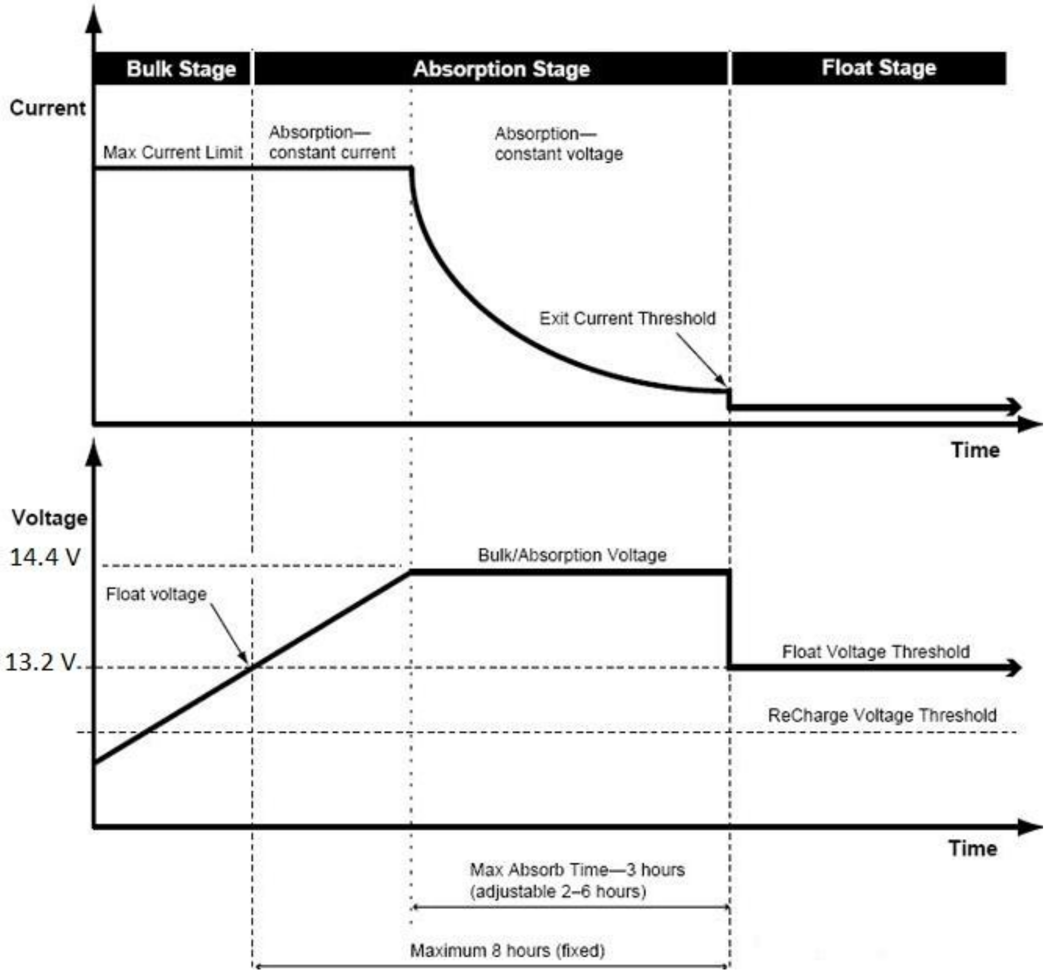
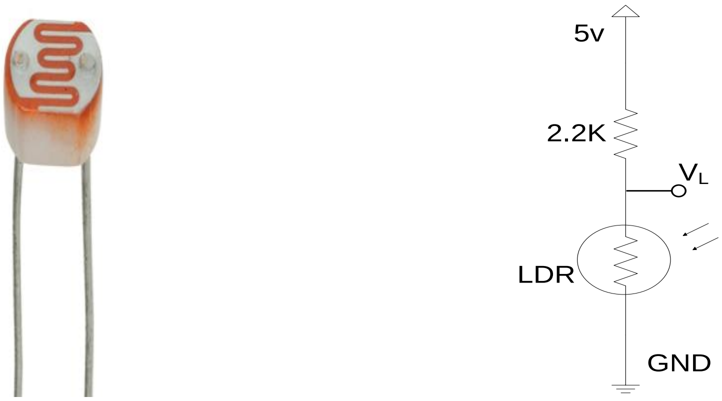


Figure 5.2: The 3 charging states in the battery

5.2.2 Light Dependent Resistor

A light dependent sensor is used in the lighting system to allow the LED bulbs and battery to function according to the time of the day. That is the battery should start charging when it is day time while LED bulbs will be switched of, during night time, the battery should start discharging to and thus the LED should be on. Keeping the LED bulbs and battery functional when not required will unreasonably consume power. According to figure 5.2, the supply voltage is connected to the LDR which acts as a voltage divider circuit. The voltage drop across the LDR decides the time of the day. After several experiments, an average threshold voltage is decided which acts as a boundary between day time and night time. During day time, when light intensity is high or detectable, the current through the circuit increases. Therefore the voltage drop across the 2.2k ohm resistor will be greater than that of the LDR.

The supply voltage will thus be divided in a ratio such that LDR voltage V_L is lower than the threshold value thus indicating day time. This analog V_L goes as an input to both micro-controller 1 and micro-controller 2 in the LED driver circuit and charge controller circuit respective in the analog pins. The analog pins of the micro-controllers convert the value to digital and each IC interprets the digital value separately. For the charge controller circuit, a low $\mathbf{V_L}$ commands the circuit to start charging the battery while disconnecting the LED bulbs from the system and a high $\mathbf{V_L}$ value activates the LED bulbs to operate fully according to the sensor input and disconnects the battery or the charge controller circuit. Figure 5.2(b) shows how the LDR is used in a voltage divider circuit to produce $\mathbf{V_L}$ across it. The 2.2k resistor is used for safety purpose so that even when the current from the light intensity is too high, it can be limited through the high resistance and prevent the circuit and the LDR from burning.



(a) (b)

Figure 5.3: (a) LDR (b) LDR circuit

5.2.3 Ping Ultrasonic Sensor

As discussed in chapter 2, to make the lighting system traffic sensitive, a ping sensor was incorporated with the LED driver circuit. Although the general purpose of the ping sensor is to measure how far an object is, the lighting system only requires it to detect any traffic passing by. In this system there will be 2 traffic levels: 'no traffic volume' and 'high traffic volume'. With every traffic level, ping sends corresponding signal to our programmed microcontroller which produces matching pulse width modulation to the LED driver circuit to be discussed later. As per the programming in microcontroller 2, the ping will be provided with the trigger PULSEOUT signal by the microcontroller for 5µs and the ping waits for 20µs before it starts sending out its chirp pulse. After 20µs, as it sends the chirp it continues till

3m when no traffic is detected. This indicates a 'no traffic volume' level and therefore based on the PULSEOUT command or the x variable, the micro C program generates a corresponding low voltage. This analog low voltage is then fed into an ADC pin of the micro-controller. The task of an ADC is to convert any input analog voltage to a digital value within a range of 0-1023. This will be discussed later in the micro-controller section. However the converted digital value will accurately reflect the low voltage and thus will yield the corresponding PWM. Therefore the two different traffic levels will produce two different PWM. The 'no traffic volume' level will have the lowest PWM of 72% and the 'high traffic volume' level will have the highest PWM of 90%. The LED lamp will respond according to the received PWM which will be discussed in detail with a circuit diagram in the next section.

5.2.4 LED lighting system

LED bulbs are a very ideal choice for any energy saving lighting system. Not only it consumes less power but it also has a very high life time which means it does not need frequent replacement thus saving huge amount of maintenance cost. However LED bulbs cannot be directly connected to a voltage supply as maintaining the current through the LED is very crucial and prevents the LED lamp from overheating. Fig 5.3 shows the driver circuit required to switch on and off the lamp efficiently. The N-Type MOSFET acts as a switch while the Zener diode always limits the input voltage to the NMOS gate to 5v. The 0.75Ω resistance at the source of the NMOS is kept low so that minimum voltage is dropped across the drain and the source of the MOSFET. The system must contain a 12 volt LED lamp of 48W to satisfy the standard amount of intensity required to light any street in Dhaka but for the prototype, a 3W 12 volt LED bulb is used for the simplicity of the circuit. A 48W LED bulb therefore produces at least 2880 lumen considering a minimum efficacy of 60lumen/W. To operate efficiently The LED however will respond to two parameters, firstly the input voltage from the ping sensor circuit and secondly the LDR voltage $\mathbf{V_L}$. As mentioned earlier, the analog voltage from the ping sensor which is fed into the micro-controller's analog pin 1 is converted to a corresponding digital value which generates the parallel PWM in the PWM1 pin (pin 17) of the microcontroller which in turn is connected across the Zener diode as shown in fig 5.3. The corresponding PWM will be averaged out as a DC voltage equivalent by the LED causing the LED to have different intensity level. For a 72% PWM for no traffic, the LED will be dim while for a PWM of 90% for high traffic volume, the LED will have the brightest intensity. Since the LED is not a linear device, the % of PWM is not directly proportional to the average DC voltage equivalent. This means if the total voltage supplied to the LED is 12 volt, a 50% PWM does not correspond to half the supply voltage i.e. 6 volt. To summarise, whenever ping detects traffic, the LED will glow brightly and stay on for 10s. After 10s if it does not receive any further signal from the ping sensor indicating ‘High traffic volume’, it will automatically receive a PWM of 72% from the LED and will be set to a dim intensity. This traffic sensing allows the lighting system to save energy unlike the traditional street lamp, which is always in its full operation mode irrespective of the traffic passing by. The comparison is explained elaborately in chapter 4. The LDR on the other hand feeds its analog $\mathbf{V_L}$ value into a second analog pin (pin 2) of the micro-controller which is similarly converted in a digital value and is compared with the C program in the microcontroller. A threshold value is set as a boundary between day time and night time. If the digital value at pin 2 is less than the threshold value, the program generates the low PWM and vice versa. The PWM is output at pin 17 for both the LDR and sensor and works simultaneously.

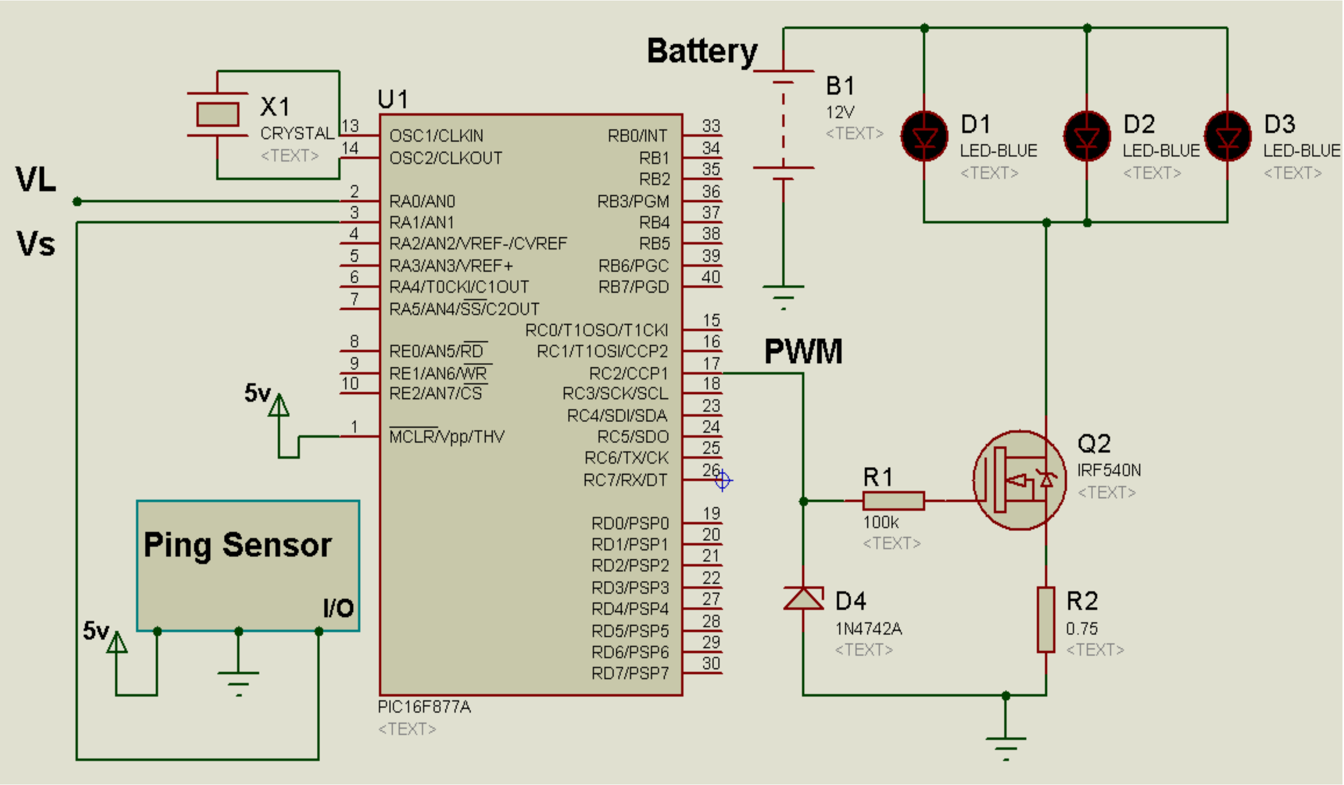


Figure 5.4: Traffic Sensing LED Driver Circuit

5.2.5 Microcontroller

Microcontrollers are programmable compact integrated circuits used in embedded systems that opt for intelligence. In this solar powered traffic sensitive lighting system, a PIC microcontroller of 16F series is used. Compared to all other microcontrollers, the 8-bit 16F877A has a higher performance and 40 peripherals used for interfacing with other software or hardware. Of them 33 are I/O pins with 5 I/O ports. The pins that have been widely used throughout the system hardware implementation are the I/O pins, ADC (Analog to Digital Convertor) pins/channels and PWM pins. In total there are 8 10-bit ADC channels and 2 PWM pins. The use of the pins varies according to the micro C coding in the microcontroller. Figure 5.5 shows the physical structure of PIC16F877A and Figure 5.6 shows its pin configuration.

Figure 5.5: PIC16F877a Microcontroller

The basic circuit is quite same for all series of microcontroller. To power up the chip, a supply voltage is given at any one of its two available V_{DD} pins and the either of its V_{SS} pin is to b grounded. Pin 1 is always set to high through a 10K resistor and pin 5 known as V_{REF} is also set to high directly. The operating speed of this microchip is 20MHz but according to the need of the code and the interfaced device's response time, a 4MHz or a 20MHz could be used. For the ping sensor, a 20 MHz crystal oscillator (clock) is used since it needs to be very fast while operating. However for the other circuits, a 4MHz oscillator will suffice. Above everything, the most vital issue that should be prudently handled is the supply voltage of the microcontroller. Any voltage greater than 5 volt will burn the microcontroller which means any input voltages to the microcontroller must be pulled down to just below 5 for safety measures before these are fed to the input pins.

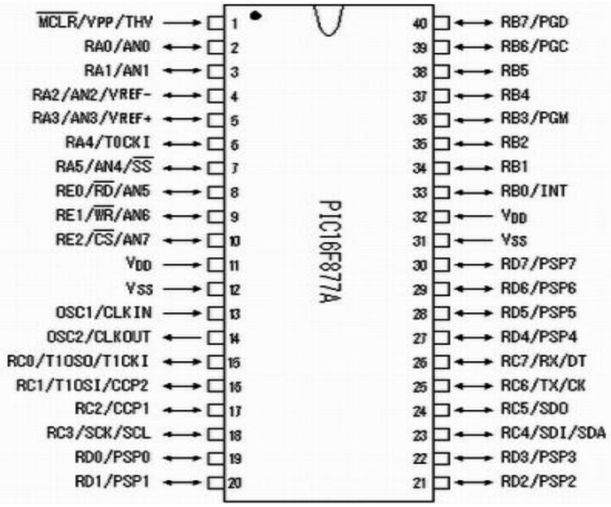


Figure 5.6: PIC16F877a pin configuration

5.2.6 Software used for Simulation and Programming

The software that have been used in this project are Matlab for Matlab coding, MicroC Pro for PIC for MicroC coding, ISIS Professional more commonly known as Proteus for circuit construction and simulation, and Microsoft Office Visual Basic for diagrams and figures.

5.2.7 Complete System Circuit

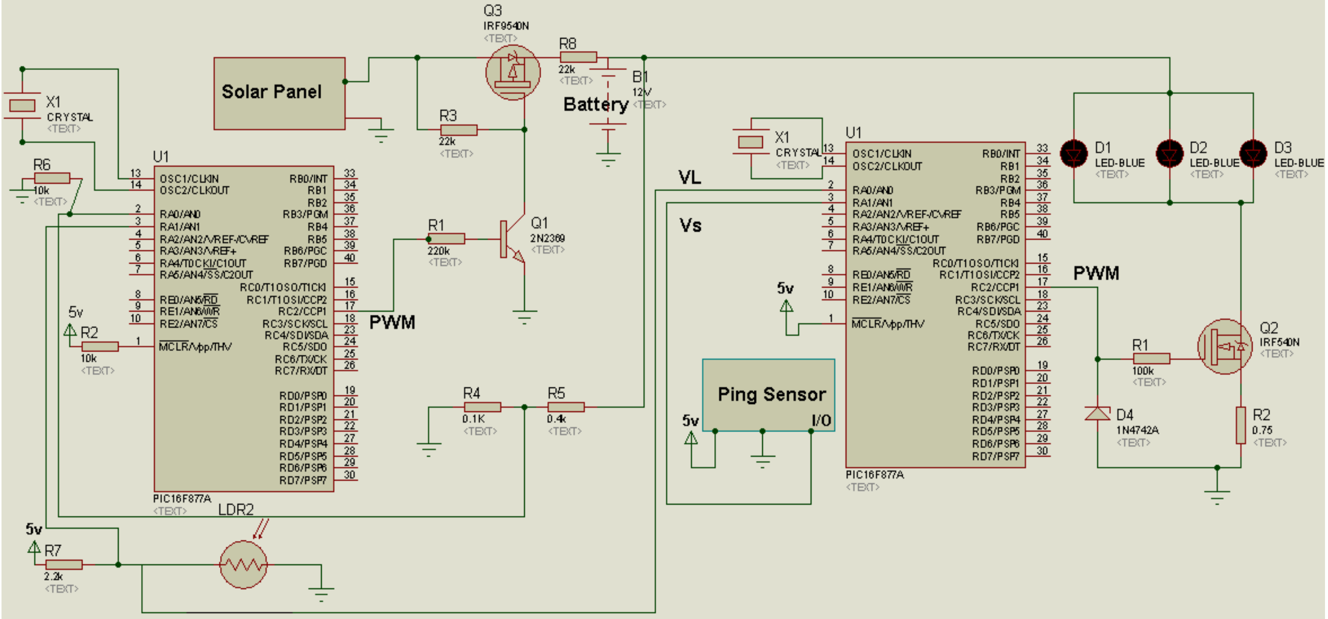
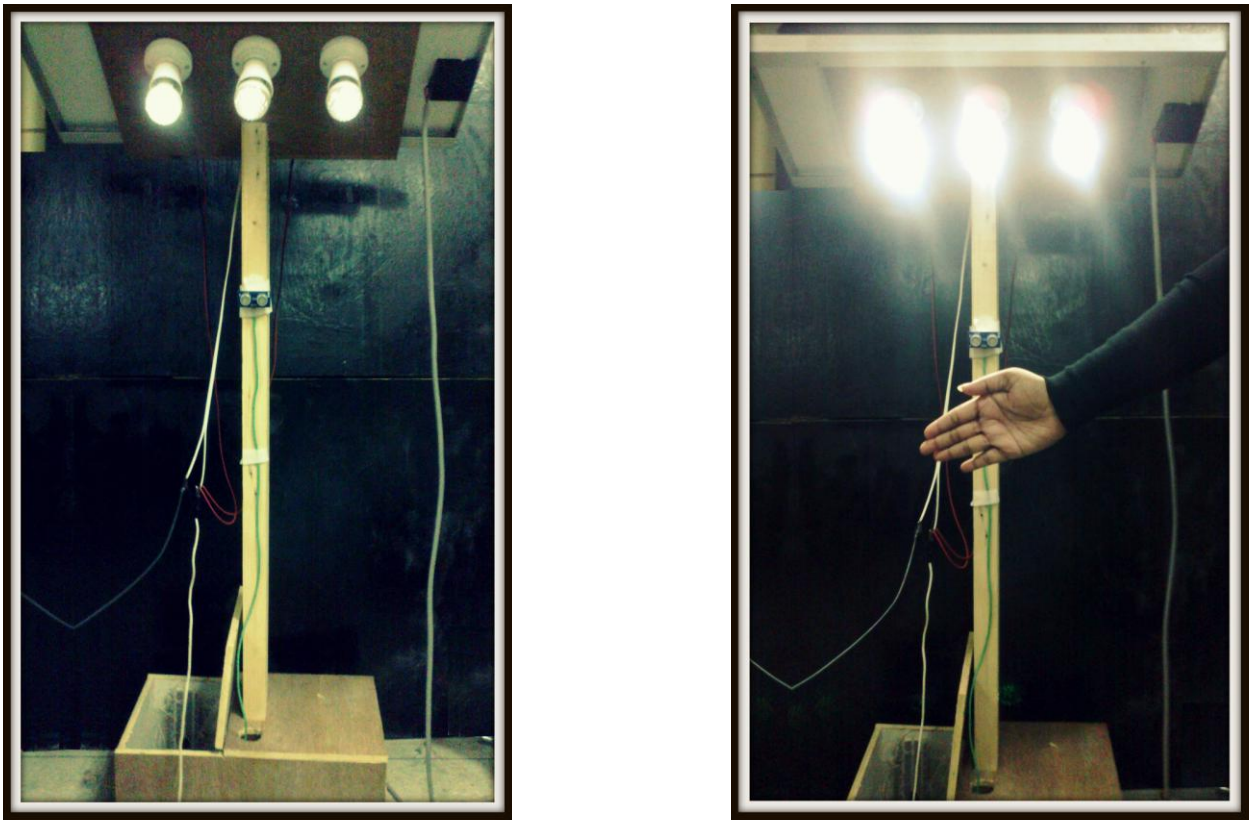


Figure 2.7: Solar Powered Traffic Sensitive Automated Outdoor LED Lighting System Circuit

Figure 5.7 shows the integration of all the individual circuits and gives an overall understanding of the internal circuitry of the complete system. The solar panel supplies energy extracted from the sun to the battery through the charge controlling circuit which helps to charge the battery from 0 volt to 14.6 volt. When the battery is fully charged or when the LDR output indicates night time, it is disconnected from the charge controlling unit and is connected to the load that is the driver circuit. Now, the battery discharges through the load i.e. the LED lamp but as soon as the battery reaches below a threshold voltage level or as soon as the LDR voltage indicates day time, it is disconnected from the driver circuit and reconnected to the charging circuit. The LED lamp on the other hand switches off and on and varies in brightness according to the battery voltage level, the LDR and the ping sensor. As microcontroller 2 receives input from either the sensor or LDR, the LED bulbs responds to them accordingly.



(a) **(b)**

Figure 5.8: A prototype of the practical implementation, showing ping sensor. (a) Without Traffic Sensor, (b)With Traffic Sensor

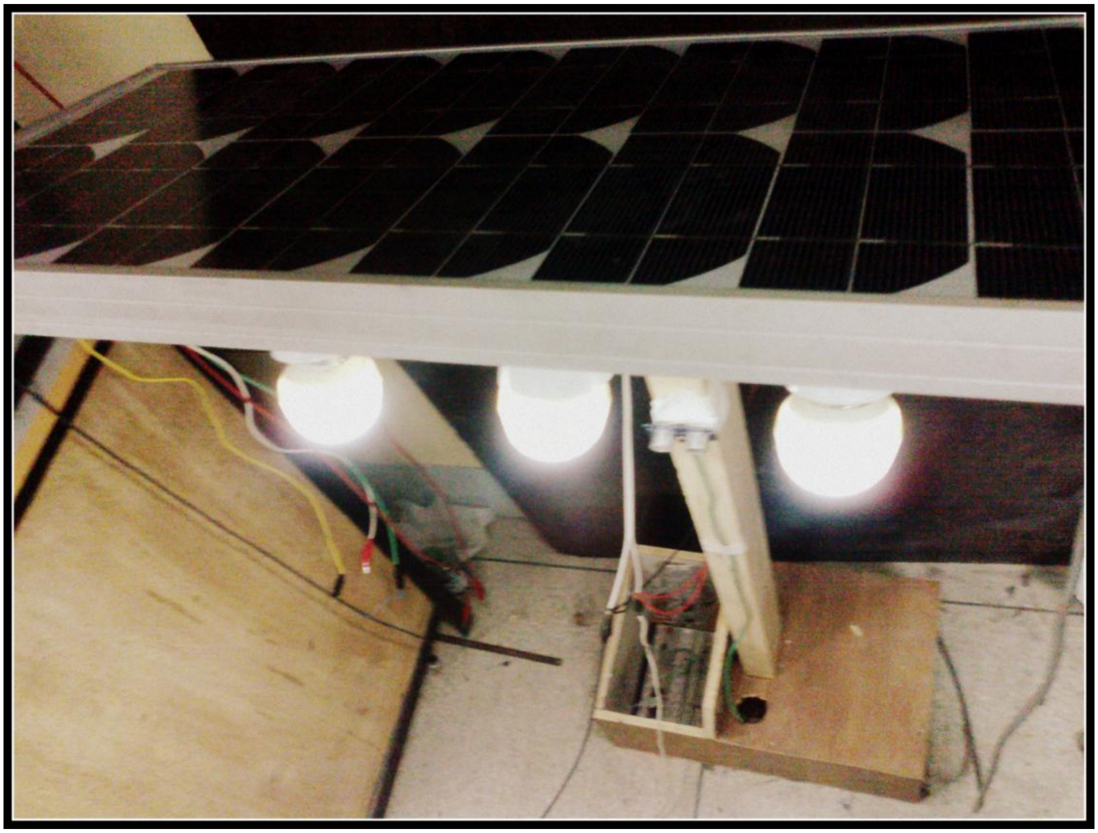


Figure 3.9: Top view of Prototype, showing solar panel, and installed circuitry

5.3 Results and Discussion

The project is an output of 1 year of research and implementation. The circuits when implemented separately works as per the desired output however during integrating all, output fluctuates and shows different response every time. This could be a problem of loose connections of the wires or internal wiring of the bread board used. However the desired PWM for both the charge controller and driver circuit is achieved successfully. On the other hand both the light and sonar sensor works perfectly as desired and the ping sensor when connected to the driver circuit yields corresponding PWM and the LED glows accordingly. Since ping is very sensitive to objects around it and it can detect object even within a very short range covering a beam width angle, keeping its range till its maximum of 3m tends to be less practical inside laboratories. Therefore for convenience and for testing purpose, the maximum range of the ping sensor is programmed to be less 1.5 m. Also this goes well with the prototype having the 3W LED bulbs and just a few centimeter in height. The results also showed after calculating the system size that the panel size was reduced by approximately 33.3% due to the use of traffic sensor in all seasons, and by 9% as a result of mounting at an angle of 46.5^o instead of at 23.1^o, even without traffic sensing mechanism.

5.5 Conclusion

With two sensors, LDR and Ping, in the complete system, the LED lamp is driven by the lead acid deep cycle battery. The battery in turn is charged efficiently through a PWM type charge controlling system. The source of this charge or energy is the $3m^2$ mono-crystalline panel that extracts solar energy mounted at an angle of 46.5^o.The battery responds to both the LDR and its charge status while the LED responds to the LDR and the ping sensor. Depending on the LDR value indicating night or day time, the batter will be discharging or charging and the LED will be on or off respectively. The battery will also start recharging when its voltage drops below a threshold level. The ping sensor on the hand will help the LED to save energy and operate efficiently via the traffic sensing mechanism. When there will be no traffic, LED will be dimly lit and when there will be traffic LED will be brightly lit.

CHAPTER 6

CONCLUSION

The solar powered traffic sensitive automated outdoor LED lighting system is an energy efficient system in three major ways. Firstly, the use of solar energy as the power source instead of using electrical power saves huge amount of energy, since the former source is free, infinite and non-renewable. Secondly, with the traffic sensing system by the ultrasonic sensor ping, it is possible to cut down half of the energy when not required unlike traditional street lamps in Dhaka city, which use power lamps and remain on from sunset till sunrise. This causes energy loss and undoubtedly appears to be inefficient. The third factor that contributes to energy saving is the lamp itself. Choosing the LED lamp over other lighting source, not only makes the system further energy efficient but also makes it cost effective and be easy to maintain in the long run. Compared to other lamps LED consumes much less power and has a very high life. Although the initial cost is slightly more than the other lamps, considering no maintenance and replacement cost for at least 6 consecutive years, makes it the best choice for this project. The combination of these three factors makes the whole system sustainable. Although due to time restraint, much could not be achieved and the whole system could not be tested together but the prototype will be hopefully able to deliver the essence of the real system. In Bangladesh, such detailed practical implementation is a first and further improvement can certainly enhance its efficiency and performance in the future.

There are mainly two key limitations that serve as a drawback to the whole system. To begin with, both the charge controller circuit and the driver circuit ought to be current sensitive. However no current sensing mechanism has been established so far and a little change in the coding and the addition of a basic current sensor or a more advance Hall sensor could increase system performance. Overheating and burning due to unexpected high current flow could therefore be easily prevented. The second limitation happens to be the range of the sonar sensor. However in future, more complex sensors based on the mechanism of MEMS (Microelectromechanical System) could be implemented which will have a high range, a direct beam pulse and have the ability to penetrate through any air condition for example during rain, fog, wind etc. Using Maximum Power Point Tracking (MPPT) charge controllers instead of 3 stage charging types will ensure more efficient charging process. For the simplicity of the system, 2 intensity levels were implemented in the system, but in the future, all three levels of brightness can be added. Nevertheless, since this is just a prototype and is not built in bulk like commercial products, the use of cost effective yet suitable devices is logical while ensuring sustainability and energy efficiency.

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