Design and Simulation of Solar-Powered Smart Street Lighting System for Rural Areas

By

Sohana Salim Oyshi
16161001

A project report submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of
Master of Engineering in Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering
BRAC University
December 2022

Declaration

It is hereby declared that

1. The project submitted is my own original work while completing degree at BRAC University.
2. The project does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The project does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

Student's Full Name & Signature:

Sohana Salim Oyshi
16161001

Approval

The project titled "Design and Simulation of Solar-Powered Smart Street Lighting System for Rural Areas" submitted by

1. Sohana Salim Oyshi (16161001)

of Fall, 2022 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Electrical and Electronic Engineering on 27 December 2022.

Examining Committee:

Supervisor:
(Member)

____

Dr. Md. Mosaddequr Rahman
Professor and Chairperson, EEE Department
BRAC University

Internal Expert Examiner 1:
(Member)

____

Dr. Shahidul Islam Khan
Professor, EEE Department
BRAC University

Internal Expert Examiner 2:
(Member)

____

Dr. A.S. Nazmul Huda
Associate Professor, EEE Department
BRAC University

Departmental Head:
(Chair)

____

Dr. Md. Mosaddequr Rahman
Professor and Chairperson, EEE Department
BRAC University

Abstract

This study proposes the design of a standalone Photovoltaic (PV) street lighting system on a village road in the Haripur Upazilla of Thakurgaon, Bangladesh. To optimize the system, simulation software has been utilized. Through software simulations, the optimal 15W LED light and 28.50m pole-to-pole distance have been determined. The system's monthly electrical output, taking into account all relevant efficiency parameters and the environmental impact. A 90W PV module-powered street light system generates 0.147 MWh of energy per year from a single pole, while the LED consumes only 0.073 MWh at its peak, which is 50.34% less than the amount of energy the system is designed to generate. A cost benefit analysis shows that the proposed system costs 18.33% less than the conventional local grid-connected system.

Keywords: Photovoltaic, Street Light, cost benefit

Acknowledgement

I would like to thank my supervisor Professor Dr. Md. Mosaddequr Rahman whose excellence and perfection helped us a lot throughout the work. Also, I want to thank Mr. Mohaimenul Islam for helping me in difficult situations and polishing my work.

Table of Contents

List of Tables

List of Figures

.

This page left blank intentionally.

List of Acronyms

PV	Photovoltaic
LED	Light Emitting Diode
LDR	Light Dependent Resistor
IR	Infrared

Chapter 1

1. Introduction

In the past two decades, renewable energy sources have obtained a lot of attention as an alternative to fossil fuels for the electricity generation. With its boundless energy supply, the sun is a free and abundant resource. Natural gas, which is used to generate 65% of Bangladesh's electricity, is rapidly depleting and can no longer be used reliably. However, solar energy has the capacity to supply future electricity demands in a sustainable and cost-effective manner [1]. Solar street lighting systems are a beneficial option as they not require the extensive cabling

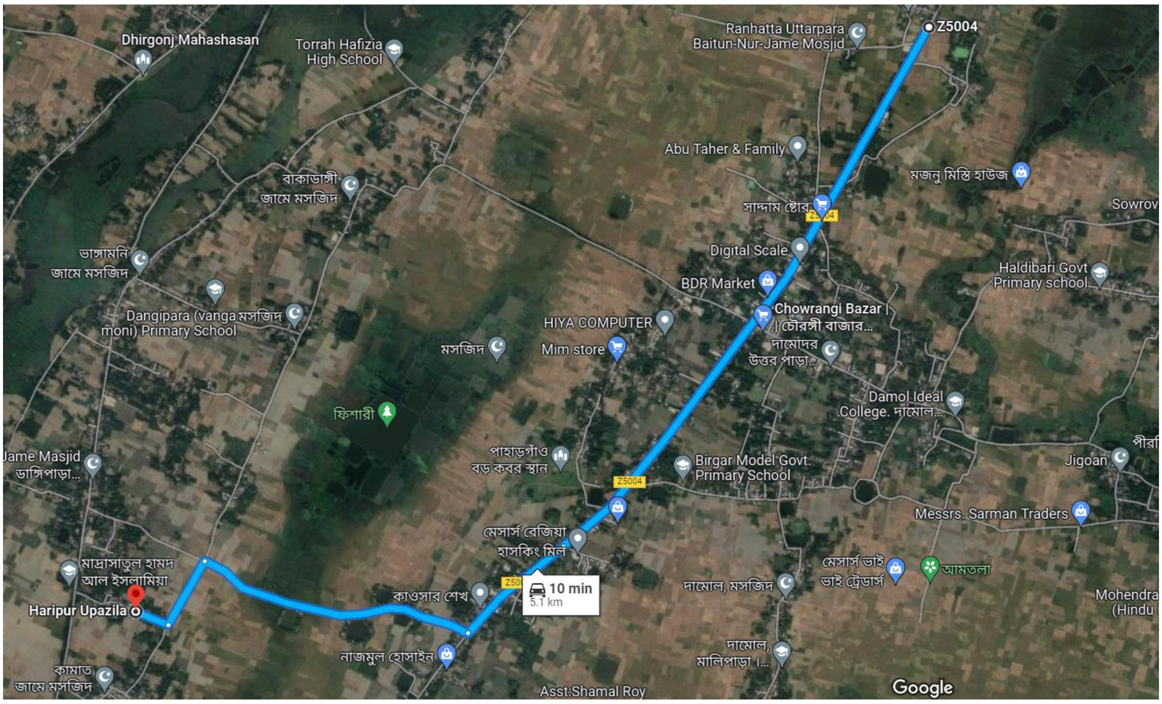


Figure 1.1: Google Map of Haripur Upazila, Thakurgaon, Bangladesh (Latitude: 25.83°)

required by conventional AC-powered lighting systems. Moreover, solar lights based on light emitting diodes (LED) are more efficient than the conventional high-pressure sodium vapor (HPS) lights used in AC lighting systems. This study proposes an optimal design for a solar-powered, standalone street lighting system for a road in Haripur Upazilla, Thakurgaon District, Bangladesh(Fig 1.1). Solar streetlights can provide cost-effective light sources in remote areas where a grid connection is unfeasible [2]. Lighting is essential in rural villages to improve safety, security, and mobility [3], and solar streetlights can provide environmental benefits in comparison to grid-connected lights [4]. Excess energy use can be prevented successfully if traffic lights can be controlled on roadways so that they only illuminate when there is traffic. However, without the presence of light, it is nearly impossible to detect the approach of a vehicle manually. In this case, a system has been considered where the luminance of the street light can be regulated based on the daylight and the presence of vehicles in that particular area. This concept resulted in the solar panel-based method of regulating street lights.

1.1. Background

There has been little research on the effectiveness of solar streetlights in remote locations; nonetheless, multiple researchers have recognized important issues that deserve more study. Ahmed, Sanjana, et al. proposed a design on the optimum mounting angle of solar street lights and the traffic sensing design approach in 2013 [5]. Avotins, Ansis, et al. (2014) provide an overview of numerous studies dealing with smart or intelligent street lighting systems [6]. In 2017, Bhairi, Maheshkumar Narsayya, et al. proposed a smart design of an energy efficient smart streetlight system for energy saving in conventional rural, urban, and smart city streetlights [7].

In this study, the optimal powered led has been evaluated, as well as the panel and storage capacity. Furthermore, automated led light intensity control based on day-light density and vehicle presence has been assessed in this system.

1.2. Objectives

The purpose of this study is

- To evaluate the performance of a solar module-based street lighting system while taking environmental impacts into account.
- To evaluate how effectively solar energy can be used electrically in the street lighting system.
- This technology will consume less energy and cost less than before when used in rural regions.
- To simulate the luminance whether the designed street light is optimized
- To design the light control circuit for efficient performance

1.3. Motivation

Solar energy has the most prospects compared to other types of renewable energy. Moreover, solar energy is not only widely available, but also entirely free. Also, it is much easier to get power to rural areas with solar panels than with a grid power plant. Green energy is also important in rural areas, and photovoltaic energy can be used to keep it going.

1.4. Report Organization

The remainder of the report is organized in a way that makes it simple for the reader to comprehend. The structure of the report is as follows: Chapter 2 covers the theoretical background of this work; Chapter 3 discusses the proposed system operation/methodology. The results and analysis of the study are described in Chapter 4. The conclusion and future plans are presented in Chapter 5.

Chapter 2

2. Theoretical Background

2.1. Photovoltaic Energy

Photovoltaic energy is generated by transforming solar incident energy into electrical energy using a photoelectric effect-based technology. A renewable, eternal, and non-polluting source of energy, which can be generated in a variety of ways, from smaller units for subjective use to large photovoltaic facilities. The PV cell is the fundamental component of a PV system. Individual cells can range in dimension from approximately 0.5 to 4 inches. However, a single cell only produces 1 or 2 Watts, which is not capable to power up the small devices. PV cells are connected to each other electrically in a package called a PV module or panel that is weatherproof. PV modules come in different sizes and can make different amounts of electricity. The amount of electricity a PV module can make depends on how many cells it has and how big its surface area is.

2.2. Solar Radiation

2.2.1. Definition

Extraterrestrial radiation: Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation.

Solar constant (G_{sc}): solar constant is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere.

Beam Radiation (I_B)*:* The solar radiation received from the sun without having been scattered by the atmosphere [8].

Air mass (M): The ratio of the mass of atmosphere through which beam radiation passes to the mass it would pass through if the sun were at the zenith.

Diffuse Radiation (I_{DC}): The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

Irradiance (W/m^2): The rate at which radiant energy is incident on a surface per unit area of surface.

Latitude (L): The angular location north or south of the equator, north positive.

Slope/Tilt angle (β): The angle between the plane of the surface in question and the horizontal.

Surface azimuth angle (γ): the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive.

Angle of incidence (θ): The angle between the beam radiation on a surface and the normal to that surface. Zenith angle (θ_Z) and the azimuth angle (γ) is necessary to calculate the total angle of incidence.

Zenith angle (θ_z): The angle between the vertical and the line to the sun, that is, the angle. of incidence of beam radiation on a horizontal surface.

Solar altitude angle (α_s): The angle between the horizontal and the line to the sun that is, the complement of the zenith angle.

Solar azimuth angle (γ_s): The angular displacement from south of the projection of beam.

Declination angle (δ): The angular position of the sun at solar noon. The angular position of the sun at solar noon , δ can be calculated by the derived equation given below,

$$\delta = 23.45° \sin\left[\frac{n + 284}{365} * 360°\right] \tag{2.1}$$

This particular declination angle is calculated on the nth day of the year.

Hour angle (H): The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour; morning negative, afternoon positive [8].

From the perspective of northern hemisphere, hour angle is negative from the sunrise time S_r, H_s is the sunrise angle and t are the time of a day in 24-hour format clock.

$$H = -H_s + 2\frac{H_s}{T}(t - S_r) \tag{2.2}$$

$$H_s = cos^{-1}(-tan\delta . tan\gamma) \tag{2.3}$$

Altitude angle (α_S): Altitude angle is the angle between the sun and the local horizon directly beneath the sun. The formula of solar altitude angle(α_S) combines with latitude(L), declination angle(δ) and hour angle (H)[9]. The equation is known as,

$$\text{Cos}\ (\theta_z) = Sin(\alpha_S) = Cos(L)Cos(\delta)Cos(H) + Sin(L)Sin(\delta) \tag{2.4}$$

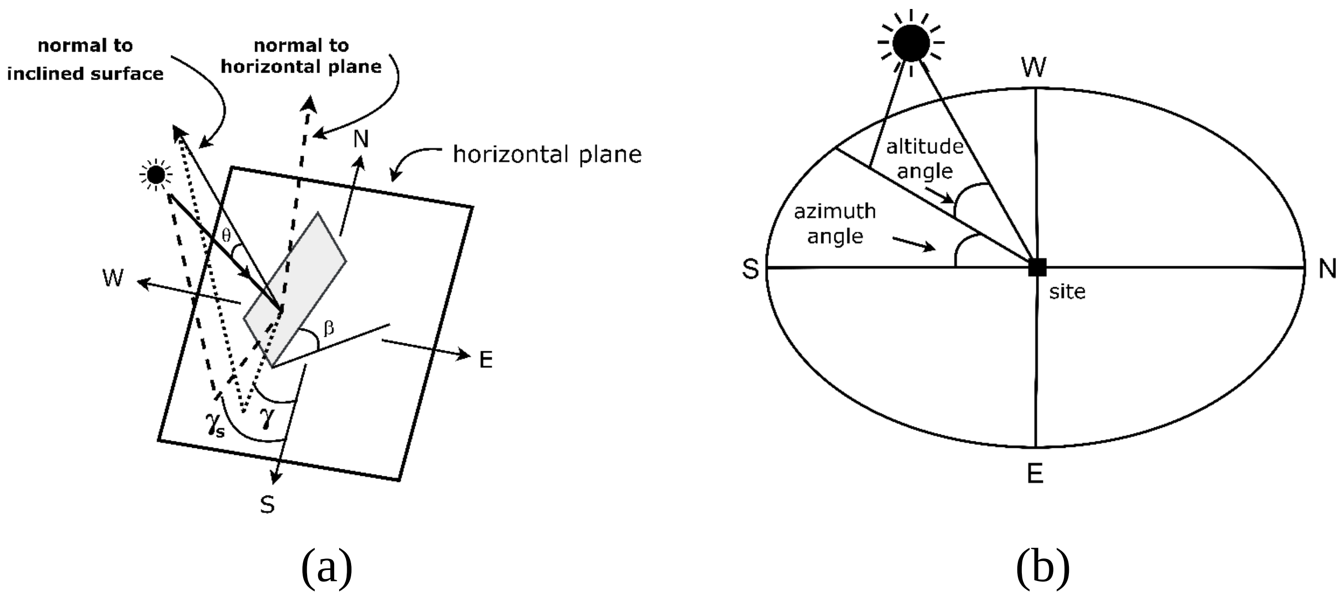


Figure 2.1: Illustrating the collector azimuth angle γ_S Incident angle θ and tilt angle β (a) along with the solar azimuth angle γ and altitude angle α_S (b).

2.2.2. Irradiation Model

Initially, a study was initiated to simulate a system compatible enough to collect all the irradiation on a collector panel. The sun's irradiation is divided into three types direct irradiation, diffuse irradiation and reflection. Estimating the diffusion energy that is diffused by the atmosphere is harder due to the impact of weather conditions and geographic location on the diffusion rate. The final component of the isotropic model is the ground reflected irradiation generated by the subsurface and any other nearby objects.

Liu and Jordan came up with an isotropic model. Later, THRELKELD and JORDAN developed a modified model that was utilized in the ASHRAE solar day clear flux model.[10]

2.2.3. ASHRAE Modifications

This specific modified model was developed by Threlkeld and Jordan (1958) titled as American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Clear Day Solar Flux Model, suitable for the dusty atmosphere. This isotropic diffuse model has introduced and declared the value of 3 factor named as apparent extraterrestrial flux (A) generated due to irradiance of sun, Dimensionless factor (K) also knows as the optical depth and the sky diffuse factor (C) [10].

The electricity power generated by PV systems is directly related to the solar energy received by the PV module, while the PV module can be placed at any orientations and any tilt angles, but most local observatories only provide solar irradiance data on a horizontal surface. Thus, an estimation of the Solar radiation striking a Collector (I_C), is calculated by adding the direct or beam radiation (I_{BC}), Diffuse radiation (I_{DC}), and reflected irradiance (I_{RC}).

$$I_C = I_{BC} + I_{DC} + I_{RC} \tag{2.5}$$

Collector solar radiation (I_C) is expressed by W/m^2, so does the beam radiance, reflected radiance and diffuse radiance [10].

.

2.2.4. Solar Calculations

2.2.4.1. Beam Irradiation

Beam solar irradiance can be expressed as the amount of energy that has to travel through the atmosphere which is easy to be calculated though the other factor of the atmosphere as dust, cloud, pollution level and the humidity of the weather varies from place to place. To calculate the value of beam solar irradiance, a set of equation is well established,

$$I_B = Ae^{-kM} \tag{2.6}$$

Equations stated above, I_B is the normal rays reaching to the earth surface, (A) is the apparent extraterrestrial flux lost in space.

$$A = 1160 + 75\sin\left[\frac{360}{365}(n - 275)\right] \tag{2.7}$$

Optical depth termed as the dimensionless factor (*K*)

$$K = 0.174 + 0.035\sin\left[\frac{360}{365}(n - 100)\right] \tag{2.8}$$

and the air mass ratio (*M*)

$$M = \frac{1}{sin\alpha_s} \tag{2.9}$$

Total solar beam irradiance I_{BC}, can be calculated from the value of normal ray irradiation I_B.

$$I_{BC} = I_B cos\theta \tag{2.10}$$

Now, the solar azimuth angle (γ) is illustrated as the product of the declination angle (δ) and the Hour angle divided by the surface tilt (β)

$$sin\gamma = \frac{cos\delta cosH}{cos\alpha_s} \tag{2.11}$$

Moreover, altitude angle, surface azimuth, solar azimuth and the angle of the surface tilt associated within this system is calculated to determine the incident angle (θ) of the sun [12] To be precise, incident angle is the normal ray angle on the photovoltaic panel face and the solar beam irradiance (I_{BC}).

$$cos\theta = cos\alpha_s \cos(\gamma - \gamma_s)\, sin\beta + \sin\alpha_s \cos\beta \tag{2.12}$$

2.2.4.2. Diffuse Irradiation

The diffuse irradiation is to be calculated as the sky is considered as isotropic and the amount of cloud, dust or brighter day with a clear sky and factors like a cloudy day with rain is expressed as the factor C while calculating the diffuse irradiation of any side of the collector [12].

$$I_{DF} = CI_B \frac{1 + cos\beta}{2} \tag{2.13}$$

$$C = 0.095 + 0.04\sin\left[\frac{360}{365}(n - 100)\right] \tag{2.14}$$

2.2.4.3. Reflected solar irradiance

I_{RC}, is the available solar irradiation on the collector panel after the reflection from any albedo (ρ) surface expressed as reflectance.

$$IR_C = \rho I_B(sin\beta + C)\left(\frac{1 - cos\beta}{2}\right) \tag{2.15}$$

2.2.5. Environmental Impact

Cloud impact is one of the major drawbacks for PV cells. Diffuse irradiation is isotropic, which means that the intensity of diffuse irradiation is uniform throughout the sky dome, according to the isotropic diffuse module. The presence of clouds has a negative impact on the efficiency of solar energy conversion. Because of the existence of clouds, a substantial part of the sun's rays may be unable to reach the earth's surface. The amount of radiation energy emitted by the sun and gathered on a surface may be quantified as solar insulation, which can be adjusted to account for cloud density, height angle of the sun's position, and other factors depending on a particular time period [13].

Mathematical equations related to cloud impacts are;

$$E_{sunny} = \int_{T_{SR}}^{T^{SS}} (Isin\alpha + 0.1I)\, dx \tag{2.16}$$

$$E_{Cloudy} = \int_{T_{SR}}^{T^{SS}} 0.2I\, dy \tag{2.17}$$

T_{SS} = Time of sunset

T_{SR} = Time of sunrise

Proposed solar panels total energy given as,

$$E_{Total} = x * E_{sunny} + y * E_{Cloudy} \tag{2.18}$$

x = Number of sunny days

y = Number of cloudy days

$x + y$ = total days for a particular month

2.2.6. Electrical Energy Calculations

The total required solar incident energy (E) for the proposed system can be calculated using the following equation [14]:

$$E = A_p \int_{TR}^{TS} I \, dt \tag{2.19}$$

Where A_p is the area of the panel, TR and TS are the sunrise and sunset times respectively, and E is the incident solar energy.

First, the optimized required led load (L_{load}) needs to be set in order to figure out what size solar panel is needed for a certain street led pole.

Later, corrected load ($L_{load\_corrected}$) has been calculated to evaluates the Battery utilization efficiency, η_B and Wiring efficiency, η_W [15].

$$L_{load\_corrected} = L_{load} * \eta_W * \eta_B \tag{2.20}$$

Furthermore, required battery capacity ($Batt_{cap}$) for this system can be estimated utilizing the battery temperature correction factor ($Batt_{temp}$) and the depth of discharge ($Batt_{soc}$) of the battery [15].

$$Batt_{capacity} = \frac{L_{load\_corrected}}{Batt_{voltage}} * Batt_{temp} * Batt_{soc} \tag{2.21}$$

2.3. Street Light Design Parameters

2.3.1. Street Classifications

The purpose of roadway and highway lighting is to provide uniform horizontal and vertical illumination on the road and a safe and comfortable ambiance for evening drivers. The fundamental concept of lighting design is the selection and placement of lighting equipment to

Table 2.1: Type of Road [16]

TYPE OF ROAD	DENSITY OF TRAFFIC	TYPE	EXAMPLE
A	Heavy and high speed motorized traffic	Road with fixed separators, No crossings for very long distance	National highways or state highways or called interstate highways, express ways or motor ways
B	Slightly lower density and lower speed traffic termed	Road which is made for vehicular traffic with adjoining streets for slow traffic and pedestrians as we find in metros	Trunk road or major road in a city
C	Heavy and moderate speed traffic	Important urban roads or rural roads. they do not interfere with the local traffic within the town	Ring roads
D	Slow traffic, pedestrians	Linking to shopping areas and invariably the pedestrians, approach road	Shopping street, trunk road
E	Limited speed. Slow or mixed traffic predominantly pedestrians,		Local streets, collectors road

enhance visibility and safety. The luminosity levels at the light source and on the road should not vary significantly. It is best to avoid abrupt changes in illumination levels, which can lead to eye fatigue and headaches. The illumination of roads allows for the safe, swift, and comfortable movement of road users. This research has considered the "E" road type (Table 2.1) since its quality and structural aspects are comparable to most village roads [16].

2.3.2. Street Light Design Parameters

Main Factors in the Street Lighting Design Scheme

Luminance Uniformity (Uo): Luminance always influences the contrast sensitivity of the obstructions with respect to the back ground [17]. If the street is brighter, then darker surroundings make the car driver adapted, unless the driver will be unable to perceive the objects in the surroundings. To provide visual comfort to the viewer's eyes, enough luminous uniformity is needed. Luminous uniformity means the ratio between minimum luminance level to average luminance level, i.e.

$$U_o = \frac{L_{min}}{L_{avg}} \tag{2.22}$$

It is termed as longitudinal uniformity ratio as it is measured along the line passing through the viewers position in the middle of the traffic facing the traffic flow.

Glare (Ti): The Ti index measures the debilitating glare, caused from the presence of light sources in the sight of an observer [17]. The percent value measures the increment of luminance that should be applied to the road to compensate the presence of the said light source, keeping the same visibility of obstacles. Glare parameter, applies only for street and tunnel lighting.

Disability glare makes human eyes disable to see any object for a little while. For an example, when we look at any bright source for a few seconds and then we look at any object with low brightness, we become unable to see this object properly, rather we see black spot for some times. This is one type of momentarily blindness.

It is defined as [18],

$$T_i = 65 * \frac{L_v}{{L_{avg}}^{0.8}} \tag{2.23}$$

Where, L_v is veiling luminance and L_{avg} is the average luminance of the object or road surface.

Longitudinal Uniformity (Ui): Longitudinal uniformity is calculated from the ratio between minimum luminance, L_{min} and maximum luminance, L_{max}, measured on the axis of the lane. The measurement is repeated for every lane. This parameter is much important in street and tunnel lighting design. A uniformity level below the minimum requirement is clearly visible when dark and bright stripes are evident on the pavement.

The Edge Illuminance Ratio (R_{ei}): The function of the edge illuminance ratio is to ensure that light directed on the surrounding is sufficient for objects to be revealed. The edge illuminance ratio is considered only for roads with adjacent footway/cycle path for which no specific requirements are given. According to the European Standard EN 13201-2 the edge illuminance ratio is defined as the ratio of the average horizontal illuminance on a strip just outside the edge of a carriageway to the average horizontal illuminance on a strip inside the edge of the same width and equal to the width of one driving lane of the carriageway. Separate values apply for each of the two sides of a (dual) carriageway; the minimum of both values shall meet the requirements [19].

2.4. Cost Benefit Analysis

This study intends to examine the cost benefit analysis of implementing solar energy in Haripur, Thakurgaon to meet part of the growing demand for electricity. Cost benefit analysis provides the methodological framework which allows for an overall evaluation of projects by taking into account the economic profit (benefit) of producing electricity using PV solar system [21]. Each unit of electricity produced using PV system will replace a unit of electricity produced from local grid.

The costs of a PV system include of procurement and control system operation expenses. A system's decommissioning cost or salvage value can be determined at the end of the system's lifespan. The method of life cycle costing, takes into account the time value of money and all costs connected with a system over its lifetime.

Two phenomena affect the value of money over time. The inflation rate, i, is a measure of the decline in value of money. The discount rate, d, relates to the amount of interest that can be earned on principal that is saved. If money is invested in an account that has a positive interest rate, the principal will increase from year to year [15].

The present worth factor, PR is a factor which is used to indicate the present value of cash to be received in the future and is based on the time value of money [15]. This factor is a number which is always less than one, i.e., the number of periods over which payments are to be made.

$$PR = (\frac{1+i}{1+d})^n \tag{2.24}$$

For the item to be purchased *n*th number of years later, the present worth value, PW is given by,

$$PW = C_o(PR) \tag{2.25}$$

Here, C_o is the initial cost of the particular equipment.

In order to estimate the economic value of PV energy, electricity tariff, E_T and annual PV electricity generation, E_G need to be utilized [22].

$$C_{in} = E_T \ x \ E_G \tag{2.26}$$

Where C_{in} is gained money from source energy.

Furthermore, annual PV electricity generation, E_G need to be evaluated for generated energy source in each year.

$$E_G = E_{g1} \ x \ (1 - P_{DR})^n \tag{2.27}$$

Here, E_{g1} is the initial generated energy by the PV module and P_{DR} stands for the degradation rate of the PV module.

Chapter 3

3. Proposed System Methodology

In order to design the whole solar powered street light system for the rural area, solar irradiance and energy were calculated theoretically for the road side of Haripur Upazilla, Thakurgaon, Bangladesh, depending on the latitude (25.83^{o}) of the site [34]. In addition, the optimal required power of the street light for the system has been analyzed base on the global standard parameter of the road [16]. Moreover, required wattage of PV panel along with the storage battery has been estimated to supply power to the street light which has evolved to the assessment of the electrical power output, accounting in panel loss factors. Energy return on investment in this system has also been analyzed. Finally, an optimized power control system was designed and simulated while taking into account the priority of the object visible under the street light. Fig. 1 represents in sequential order the entire systematic procedure.

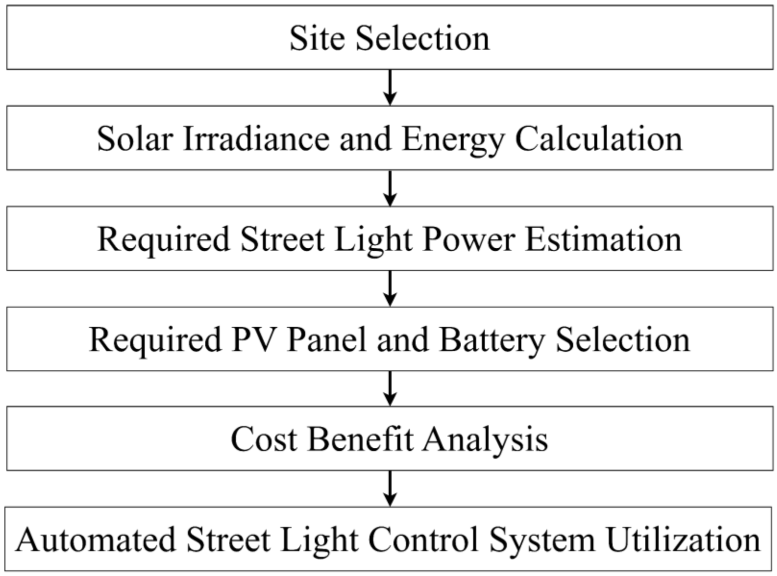


Figure 3.1: Proposed System Design Methodology

3.1. Software System Operation

The village's street lighting system is one of the most essential infrastructure aspects. This approach can enhance the safety of road traffic users and provide pedestrians with a sense of security. However, this constant lighting system has a great correlation with energy consumption, as energy consumption is a major issue for the village due to its association with the cost that must be paid. Thus, recent discussions [23, 24-25] have focused on emphasis on the development methods for rural street lighting systems. Street lighting accounts for around 2.30 percent of global electricity usage [26]. Reduced street lighting is the simplest approach to reduce electricity use. However, the lowering of street lighting at night without studies and calculations will have an effect on traffic accidents and crime [27]. Therefore, attention must be taken when considering energy-efficiency planning. Typically, road lighting systems are planned and operated to meet lighting regulations, save energy usage, and enhance convenience and beauty. [23, 26] Typically, conventional street lighting using mercury lamps uses a great deal of electricity [28]. Halogen spotlights, Light-Emitting Diode (LED), and compact fluorescent light are examples of new light sources [23, 26]. According to studies by Nandiyanto et al. [29], Sastry et al. [30], and Pattison et al. [31], among numerous type of available light bulbs, LED is believed to be the best option because, in addition to its relatively low required wattage, its energy is highly efficient, and it has a long operational life of 50,000 h or more [29-31].

The DIALux software is a software for illumination analysis, which is utilized in this study for the process of street lighting redesign analysis. Indoor, outdoor, and street lighting are typical applications for DIALux. Indoor, outdoor, and street lighting lamps can be utilized by designers. There are various sorts of bulbs accessible on the marketplace that can be utilized by designers. This is possible by obtaining catalogs of lighting from various manufacturers. The software also enables designers to store their planning outcomes as 2- or 3-dimensional designs in a variety of file formats (e.g., AutoCAD, pdf, dxf, and jpg).

The recommended EN 13201 road lighting should be provided with methods for measuring lighting performance and applied to luminaires utilizing LED technology as a source of light, which are intended to provide better views for villagers of public areas during the hours of darkness, thereby enhancing personal safety [16].

3.1.1. Material and Parameter values

The study started with a survey on the existing condition of roads whose lighting systems would be evaluated. The study was conducted on one of the most populous roads in Haripur Village, Thakurgaon, Bangladesh (25°49'55.4"N 88°07'32.5"E; shown in Fig. 1.1. The research was carried out on one of the busiest streets in Haripur Village, Thakurgaon, Bangladesh (25°49'55.4"N 88°07'32.5"E; see Fig. 1.1). The road block diagram illustrated in Fig. 3.2. depicts the information on the research site.

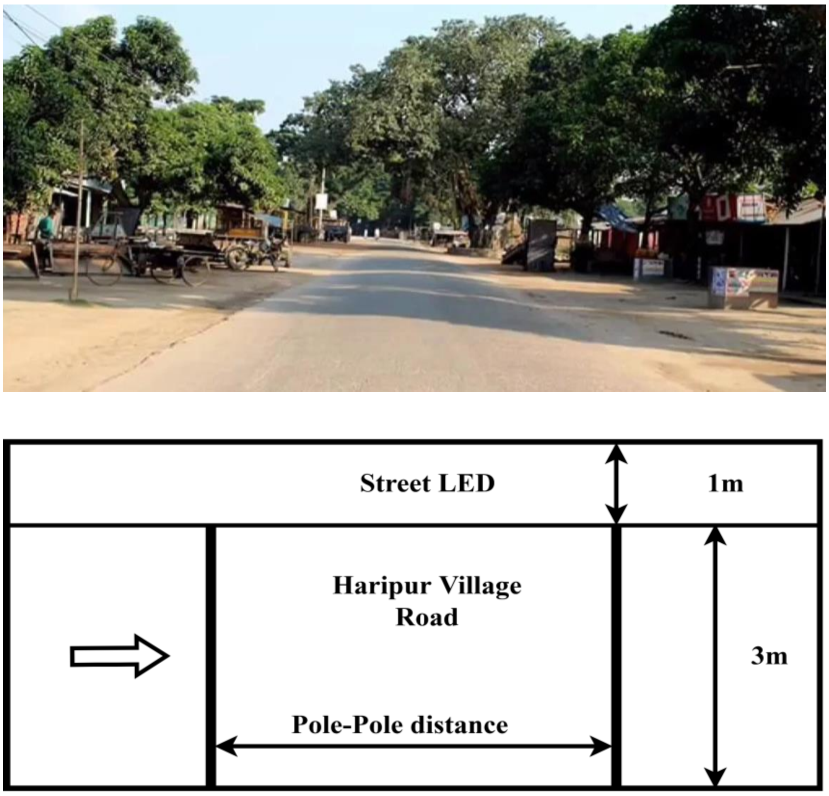


Figure.3.2: Road block diagram

The complete data of the road is in the following:

- Name of the village of street: Haripur.
- Rules of illumination method lighting: EN 13201[16].
- Type of Road: E [16][20]
- Length/width: 5.05 km/3 m.
- Width of the left/right side: 1 m/1m.
- Traffic system: Two ways.
- Number of lanes: 1 lane.

3.1.2. Software Assessment Method

A street light's pole to pole distance is determined by the luminance level and other street-light system components, based on the system's illumination parameters. Therefore, Dialux software analysis has been utilised to identify the optimal LED that can provide the maximum distance between poles while maintaining the global luminosity standard. If the road lane, width, preferred pole height, boom inclination, and length are given into the Dialux software, the software will generate a report with the street light luminance associated parameter values (U_O, T_i, L_{avg}, R_{ei}) and the optimal minimal pole to pole distance. The street lighting pole mounting system is depicted in Fig 3.3 where the parameter value has been enlisted in Table 3.1. The pole-to-pole distance has been regulated from 10m to 30m. On the other hand, the number of luminaires as well as the source of light has been estimated one for each pole. Besides, the pole distance from the main road path has been decided at least 0.626m based on the rules of illumination method lighting: EN 13201 so that the light can be hanged just over the edge of the main road [16].

Table.3.1: Lighting Pole Parameter

1	Light Spot Height	4.572 m
2	Light Point Overhang	0 m
3	Boom Inclination	25.8º
4	Boom Length	0.5 m

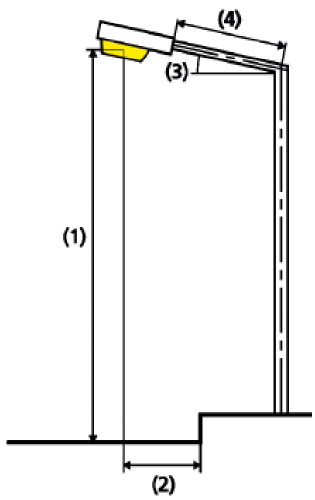


Figure.3.3: Lighting Pole

3.2. Control System Operation

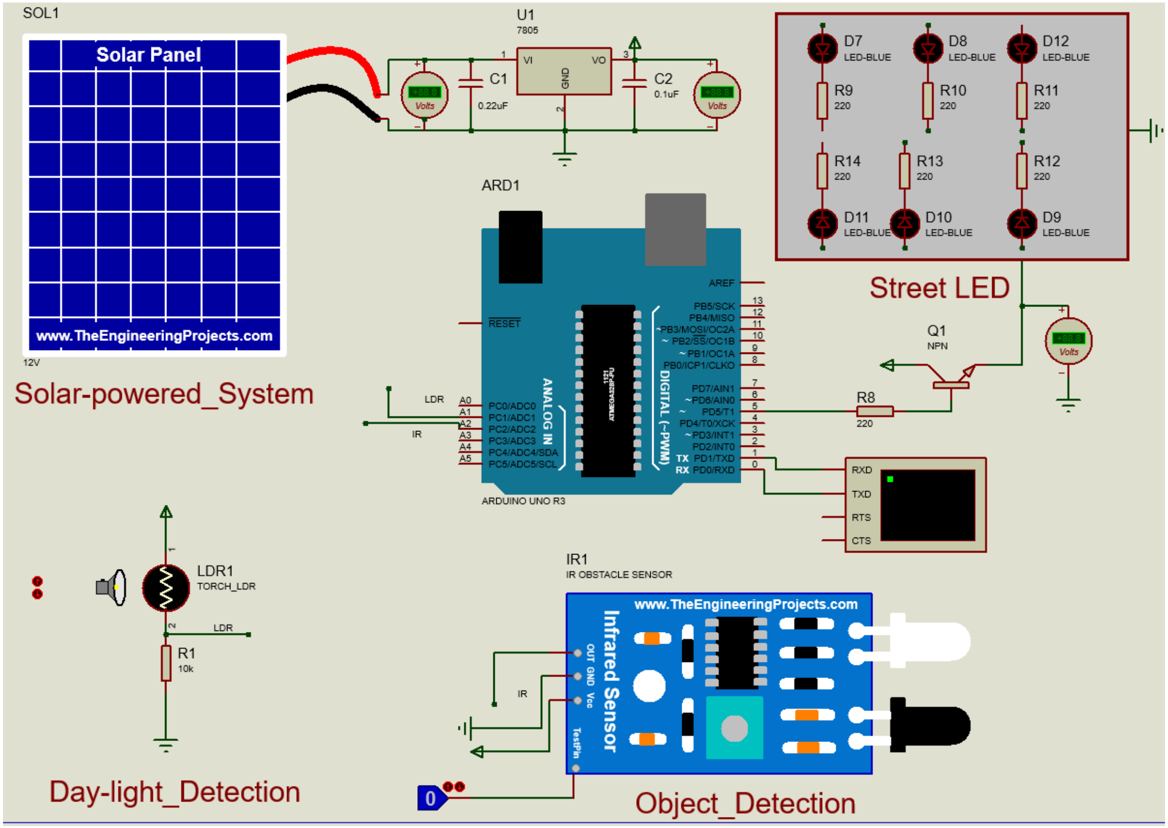


Figure 3.4: Control System of Street LED (single pole)

Due to maintaining the optimized lighting energy, automated lighting controlling system need to be applied [32]. Therefore, several digital logic electronics applications have been applied and simulated through a circuit simulation software (Proteus). The whole controlling system illustrated in Fig. 3.4. will be powered from the main solar panel which is coupled with the street led. Initially, light dependent resistor will assist to observe the day-light situation. Based on a particular threshold parameter value of the LDR, it can be determined the sunrise and evening period of time. During a significant day light, the street led will remain off and will turned on when the LDR value will be below its threshold level. Besides, on account to maintain the optimized power consume, an Infrared sensor module has also been integrated into the system device in order to determine the passing object under the street pole. The street led will glow brightly if any object come towards the particular pole otherwise it will be luminated with lower power. All of these control operations along with logical calculation has been solved through a 328p micro-controller.

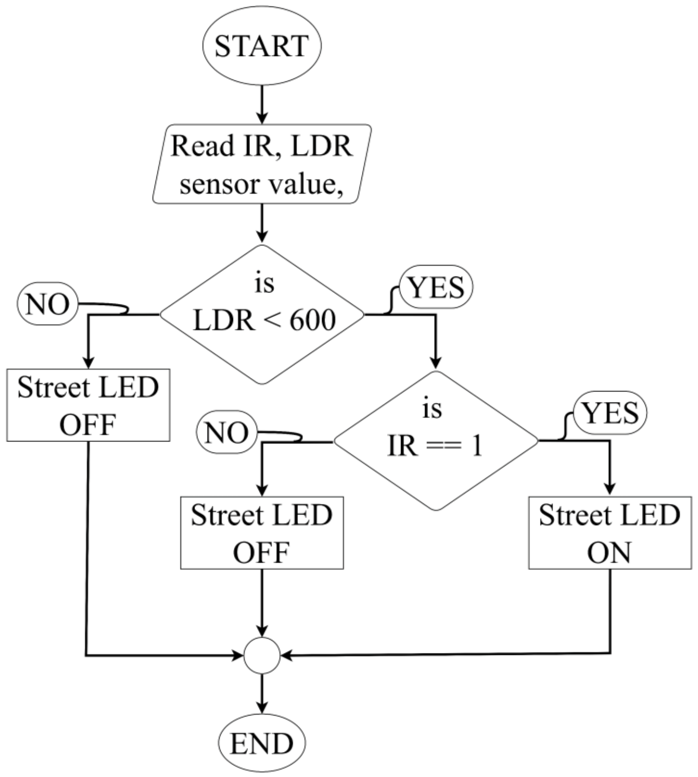


Figure 3.5: Control System flowchart

The controlling system methodology through a microcontroller is illustrated in Fig. 3.5. The infrared sensor's receiving value and a light-dependent resistor are the key factors in determining whether a street light is on. Considering environmental nominal brightness, the LDR threshold analog value is 600. If LDR's receiving value is less than 600, the light will be turned off; otherwise, the process will continue. The second conditional decision is made based on the IR receiving value; if the value is 1, indicating that an object is moving under the pole, the street light will be turned on brightly; otherwise, it will be turned off.

3.2.1. Control System Operation Feedback (Day)

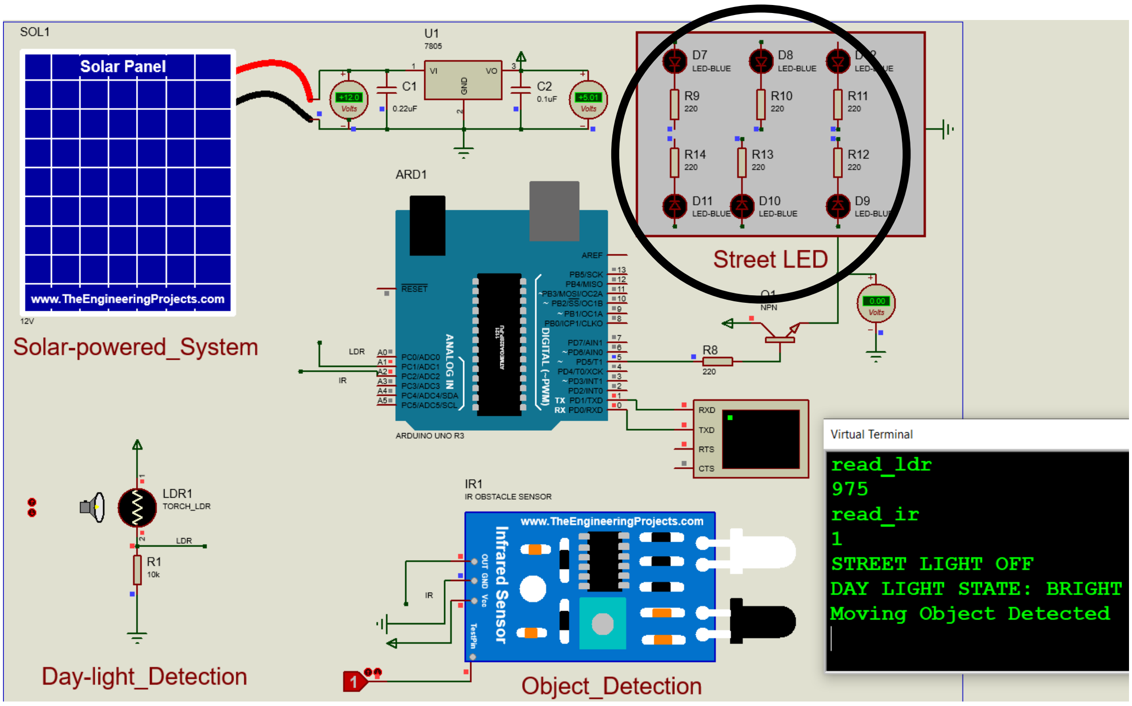


Figure 3.6: System operating during daylight and object moving under the street light

The microcontroller's reading of 975 for the analog value of the light dependent resistor (LDR) module indicates that there is a period of clear, sunny weather at that moment, as shown in Fig. 3.6. In addition, the digital value 01 of the IR module indicates that something or someone is passing beneath the poles. Nevertheless, the street light will remain in the off position. It can be assumed that during daylight hours, even if a person or vehicle passes under the street light, the street light will remain off.

3.2.2. Control System Operation Feedback (Day)

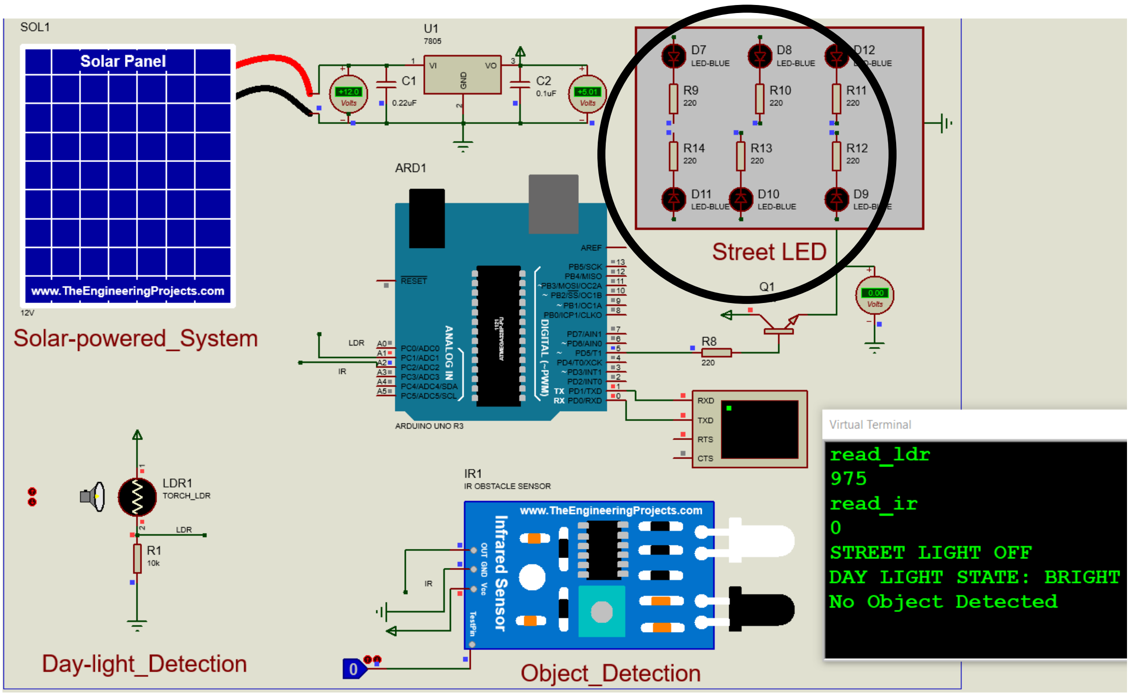


Figure.3.7: System operating during daylight and nothing moving under the street light

As shown in Fig. 3.7. when the microcontroller reads 975 for the analog value of the light dependent resistor (LDR) module, it means that the weather is clear and sunny. Also, the IR module's digital value of 0 means that nothing or no one is moving under the poles. Because of this, the street lights will stay turned off. During the day, when no one or nothing goes under the street light, it's possible to say that the street light will be off.

3.2.3. Control System Operation Feedback (Night)

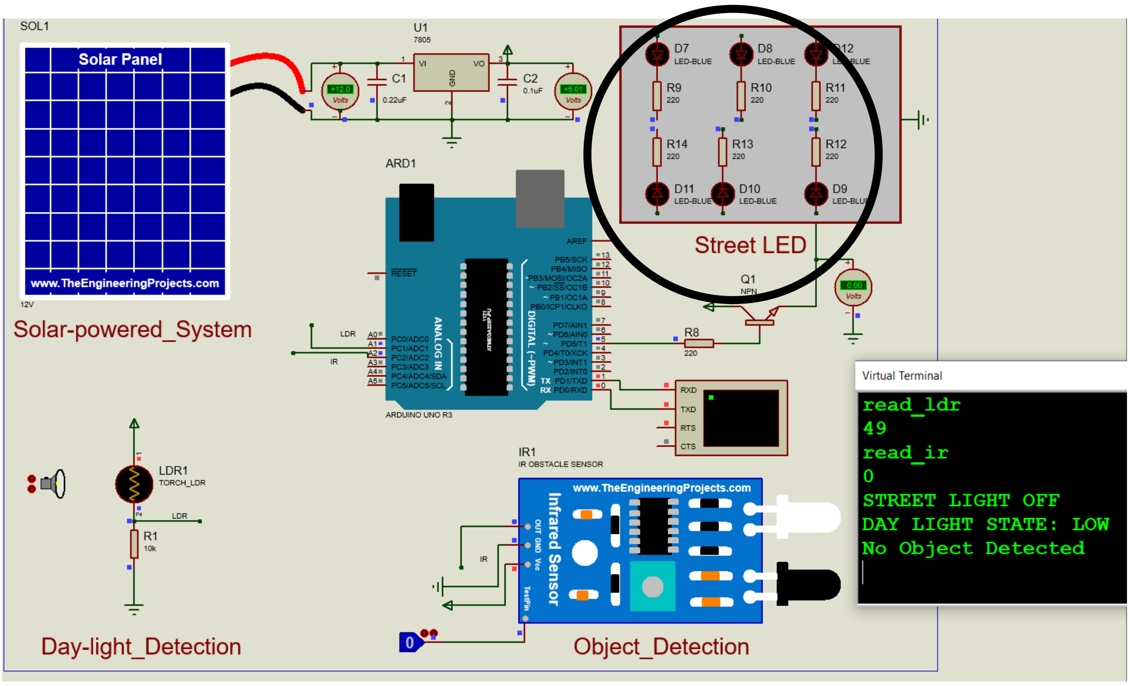


Figure 3.8: System operating during night and nothing moving under the street light

The microcontroller's reading of 49 for the analog value of the light dependent resistor (LDR) module indicates that it is either evening or cloudy, as represented in Fig. 3.8. In addition, an IR module with a digital value of 0 indicates that nothing or no one is moving beneath the poles. On account of this, the street lights will remain off. In the evening, when no one or nothing passes beneath the street light, it is conceivable to state that the street light will be off.

3.2.4. Control System Operation Feedback (Night)

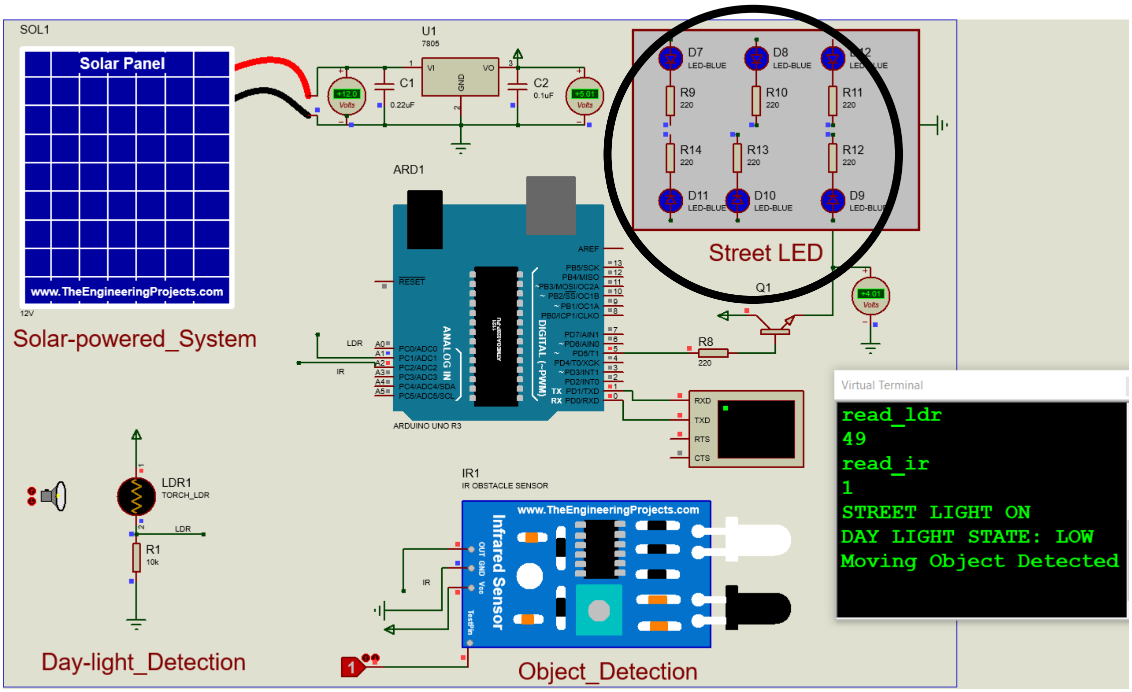


Figure 3.9: System operating during night and object moving under the street light

As depicted in Fig. 3.9. the microcontroller's reading of 49 for the analog value of the light dependent resistor (LDR) module denotes that it is either nighttime or cloudy. In addition, the digital value 01 of the IR module indicates motion beneath the poles. At this point, the street light will remain illuminated. When a person or vehicle passes beneath the street light in the evening, it can be anticipated that the light will remain on.

Chapter 4

4. Result Analysis

This chapter forecast on a discrete observation of Photovoltaic Module powered street light system considering energy accumulation on a daily and monthly basis. The yearly output system type is compared considering the effect of cloud and without cloud is compared to get the percentage of difference. Later on, luminance curve analysis has been made along with the luminaire filed valuation parameters data. At the end of the discussion, yearly electrical output is observed from the proposed system and cost benefit analysis is compared to get the percentage of difference.

4.1. Daily Solar Irradiance

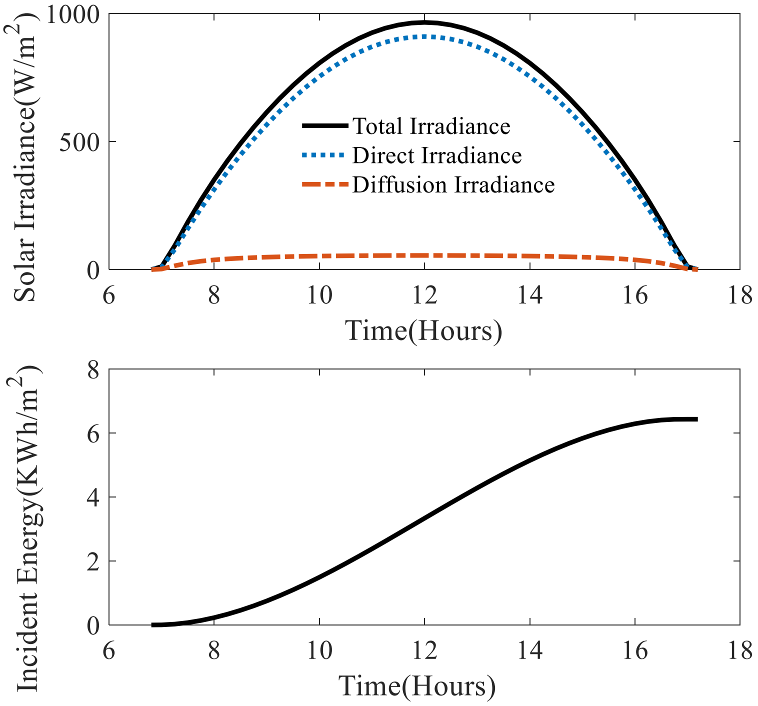


Figure.4.1: Daily Solar Irradiance and Incident Energy for December 15

Solar intensity on a regular basis figured in Fig. 4.1. considering December 15^{th} in Haripur Upazilla. Peak Direct irradiance during noon in this system is 882W/m^2 and diffused irradiance contributes with a significant amount of energy which is 14W/m^2. Calculations show that the incident energy on that particular day, received by the module is 6.42 KWh/m^2.

4.2. Monthly Solar Incident Energy

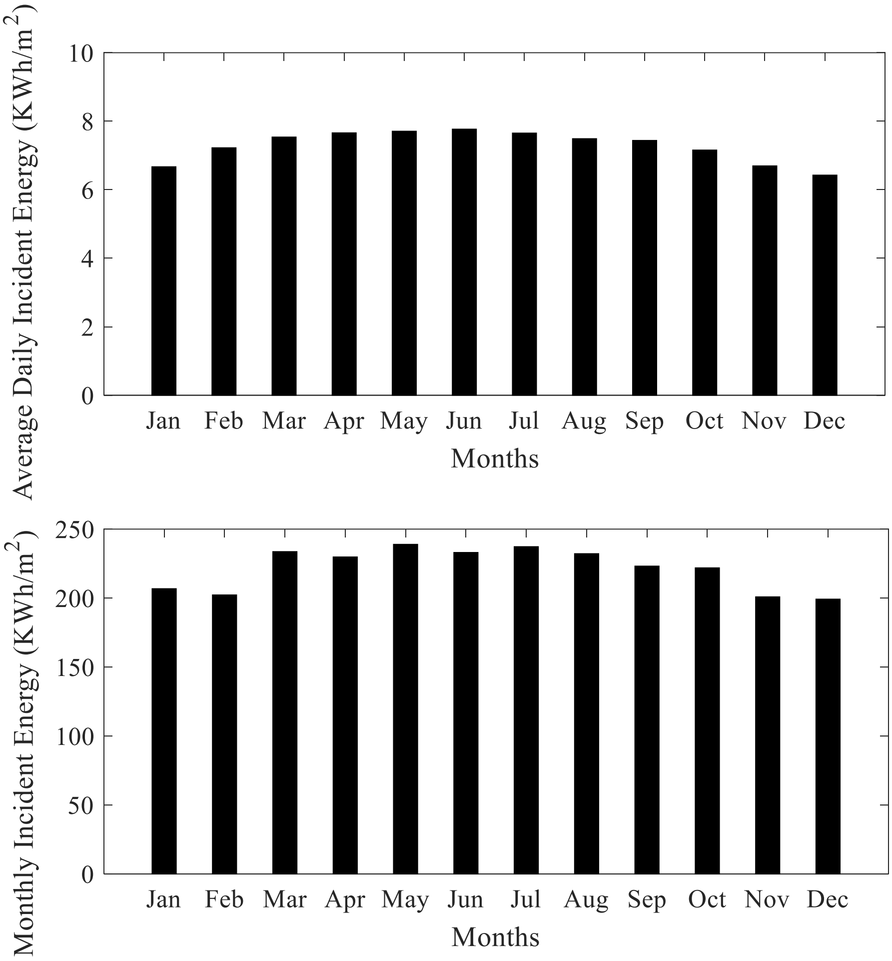


Figure 4.2: Average Daily and Overall Monthly incident energy

Fig. 4.2. shows the average monthly solar energy and the total monthly energy. From this, it can be figured that the average monthly solar energy accumulated by the module in December is 6.43 KWh/m^2, and the monthly energy is 199.23 KWh/m^2, which is less than any other month of every year. At the bottom, the total energy for each month is shown so that the total monthly energy can be observed in a clear sky environment. In May, the system can harness 238.95 KWh/m^2, which is more energy than in any other month of every year.

4.3. Incident Energy Comparison with Environmental Impact

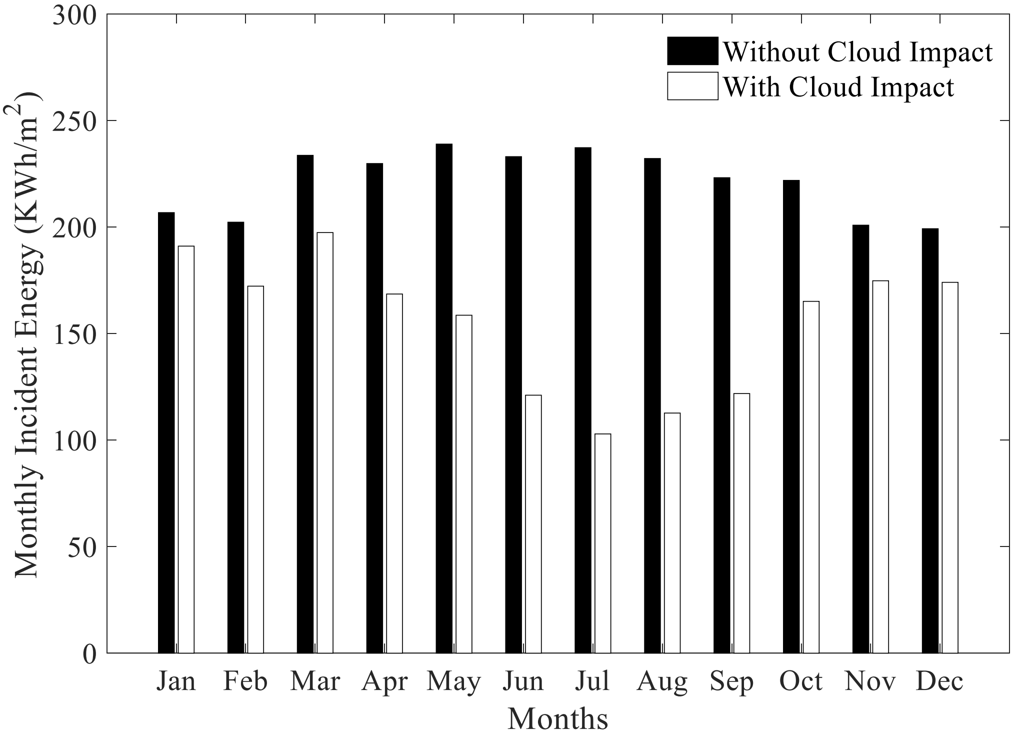


Figure 4.3: Monthly Incident Energy comparison between cloud impact and without cloud impact

Fig. 4.3. depicts a comparison between the monthly energy on days with sunny weather and the monthly energy considering cloud impact. The annual solar energy accumulated by the module is estimated to be 2.66 MWh/m^2 under clear skies and 1.86 MWh/m^2 when overcast days are considered. It is observable that in July and August, due to the rainy season, PV modules can accumulate less energy than in any other month of the year, despite the fact that December PV modules can harness less energy on clear days.

4.4. Luminance Curve Analysis

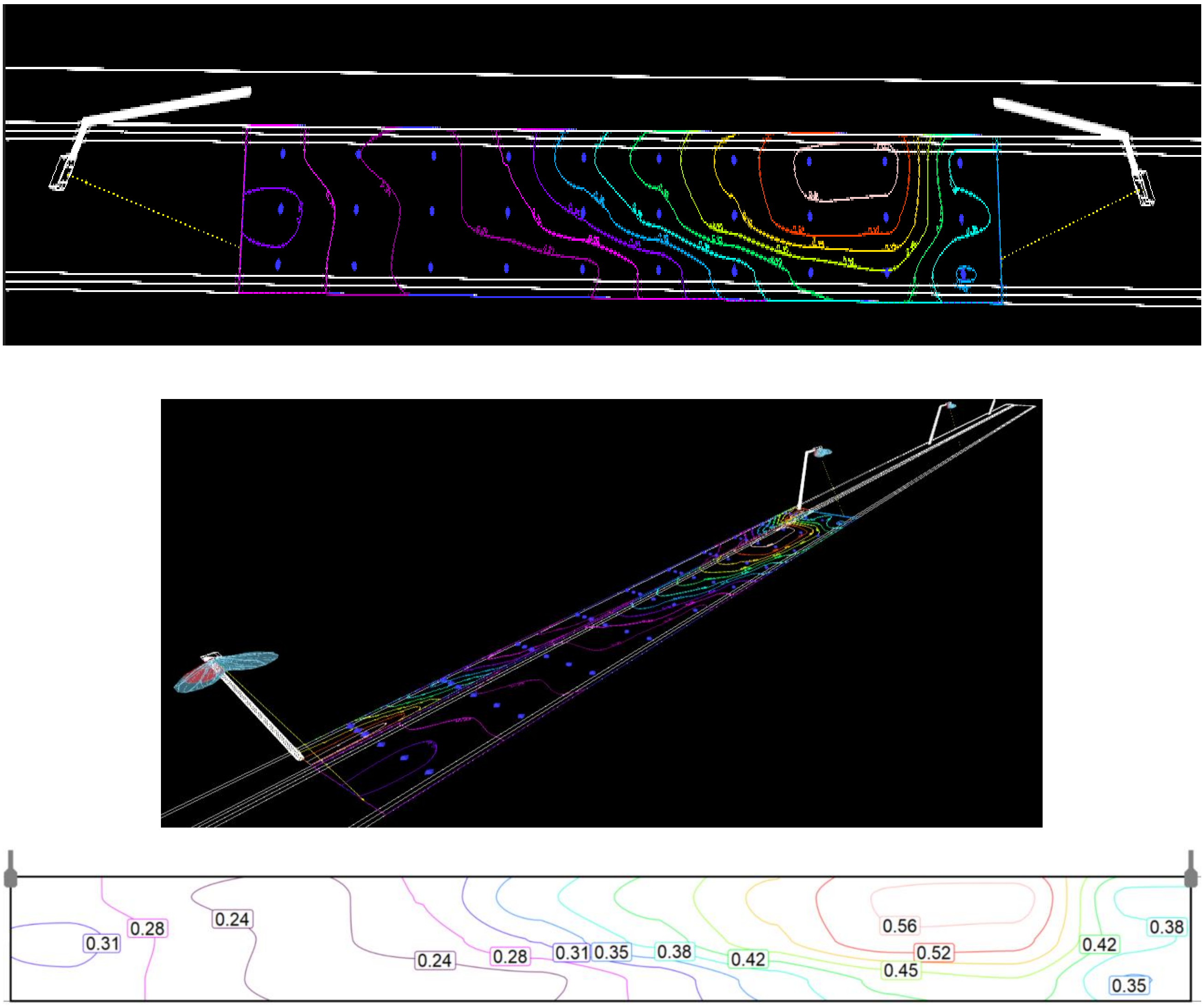


Figure 4.4: Luminance Curves analysis [cd/m^2]

Fig. 4.4. illustrates the luminance curve measured in candela per square meter between the two street lamp posts in a dry roadway of Haripur village area. Using the 15W LED street lights, the depicted values have been simulated. The simulation software found that the maximum luminance level is 0.56 and the minimum luminance level is 0.24. This shows that the average luminance level is 0.36, which is higher than the required minimum level for that site.

4.5. Optimized Powered LED estimation

Table 4.1: Luminance Result for various wattage

LED	Pole-Pole distance(m)	Parameters	Lav	Uo	Ui	Ti	Rei
		Required Values	>0.30	>0.35	>0.40	<20%	>0.30
11W	18.288	Simulated Values	0.35	0.80	0.81	14	0.33
15W	28.500		0.36	0.63	0.43	20	0.33
20W	26.900		0.48	0.66	0.78	20	0.33
28W	24.500		0.70	0.69	0.59	20	0.33
38W	21.900		1.16	0.73	0.71	20	0.33

In the software input section, 11W, 15W, 20W, 28W, 38W powered Street LED Light has been applied simultaneously in order to figure out the optimum powered led light. The decision has been made by approaching the highest possible pole to pole distance after meet up the all luminance associated parameters. Based on the LED power, the Average Luminance, Luminance Uniformity, Longitudinal Uniformity, Glare, and The Edge Illuminance Ratio can be determined from the Table 4.1. The feedback from the Dialux software came from by maintaining the targeted range of Average Luminance, L_{avg} which is at least 0.30, Luminance Uniformity, U_O which is at least 0.35, The Edge Illuminance Ratio, R_{ei} is at least 0.30 and Glare, T_i is in between 10% to 20%. However, it would be optimum commercially if the distance between poles remained longer. At this point, it can be determined that 15W led is suitable and optimized for the particular street where the pole-to-pole distance is 28.50m which is representing visually in Fig. 4.5.

4.6. Optimized Street Lighting System Design

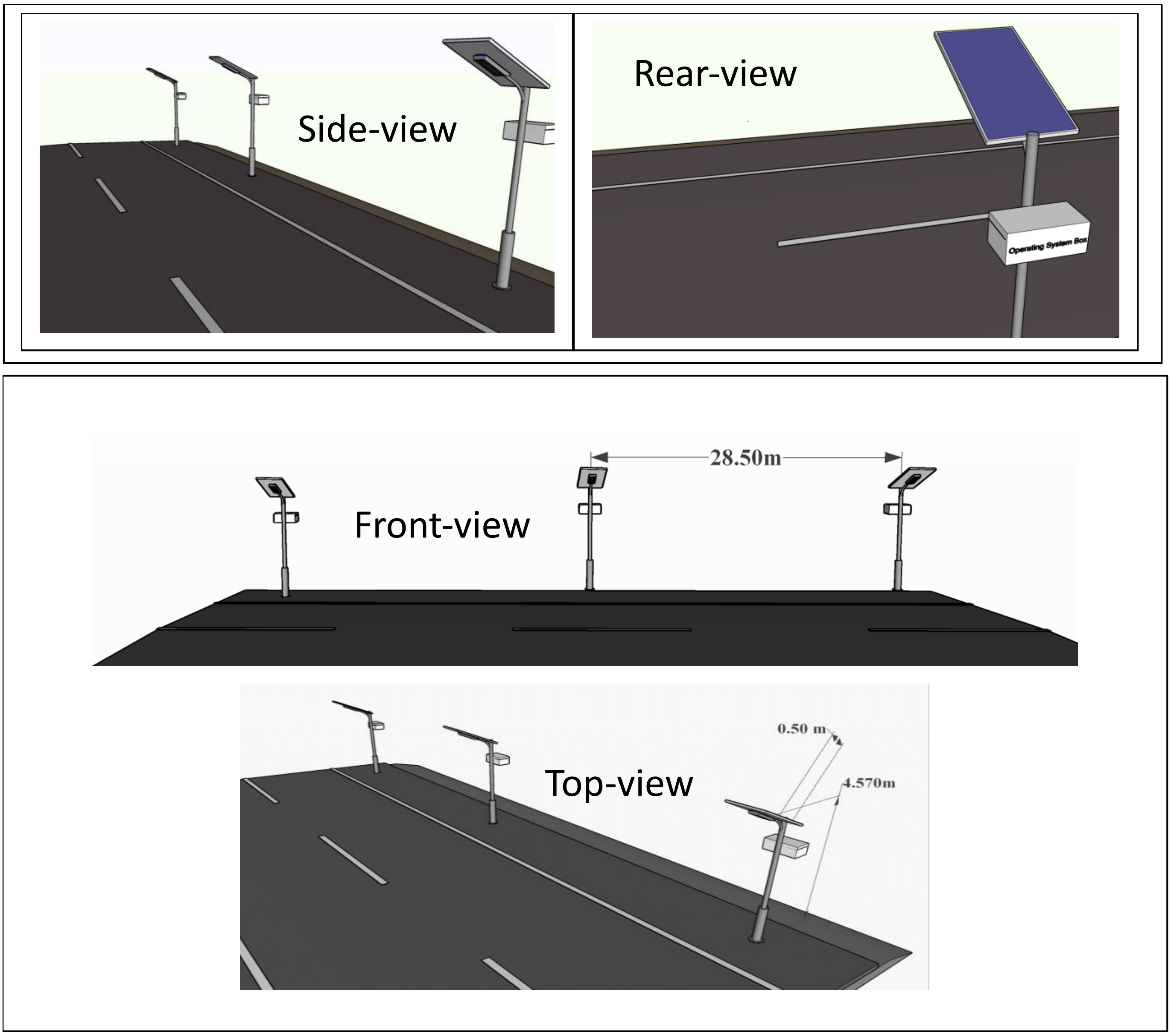


Figure 4.5: Final optimized design of the street lighting system

Fig. 4.5. displays the final scenario that was simulated to verify this is the optimum system design for that area. The distance between the poles has been set at 28.50 m, which is adequate for the 15W LED bulb to provide the sufficient lighting. The required mechanism and energy storage batteries have been mounted to a pole with a control system box.

4.7. Required Solar Panel Calculation

Based on the optimized lamination result, it can be determined that, 15W LED bulb is quite enough for provide luminosity to the village where pole to pole distance will be 28.5m. From the daylight duration time log map [27] it can be estimated that the highest night time duration will be 13.30 hours. Moreover, based on solar irradiance calculation, the lowest daily solar incident energy might be accumulated on that particular place is 6.4268 Wh/m^2.

There are few calculations (Table 4.2) need to be considered in order to determine the solar power capacity which has been shown below on the table:

Table.4.2: Solar Power Capacity Calculation

Required Content	Parameter	Calculated Result	Comments
Street LED Load Calculation	LED Power: 15W Night Time Duration: 13.30hrs/day[33]	~200Wh/day	Highest night duration of a particular day on the entire year
Solar Incident Energy	Lowest average daily incident energy on clear-sky: 6.4268Wh/m^2 Lowest monthly energy considering cloud impact: 112.7013Wh/m^2	3.63Wh/m^2	Lowest daily solar energy considering cloud impact in the month of August
Solar Insolation Hour	Daily solar energy: 3.6355Wh/m^2	3.63hr	Considering cloud impact
Corrected Load	Battery Utilization Efficiency: 90% Wiring Efficiency: 98%	226.757Wh/day	
Estimated Battery Capacity	Battery Voltage: 12V	18.896Ah	
Required Battery Charge Capacity	Temperature Correction Factor: 90% Depth of Discharge: 80%	26.244Ah	
Estimated Battery Energy Storage Capacity		314.928Wh	

Estimated PV Panel Current Supply Capacity	Battery Capacity: 26.244Ah Insolation Hour: 3.63hr	7.22A	
Required Power of PV Panel	Estimated PV Panel Voltage: 12V	86.64W(~90W)	Estimated PV Panel Area: 0.648m^2
Estimated Electrical Output from the System	PV Panel power: 90W Insolation Hour: 3.63hr	207Wh	Considering all the efficiency factors

** Extra 7 Wh from the output system might be useful in order to power up the control system.

4.8. Electrical Output (considering cloud cover)

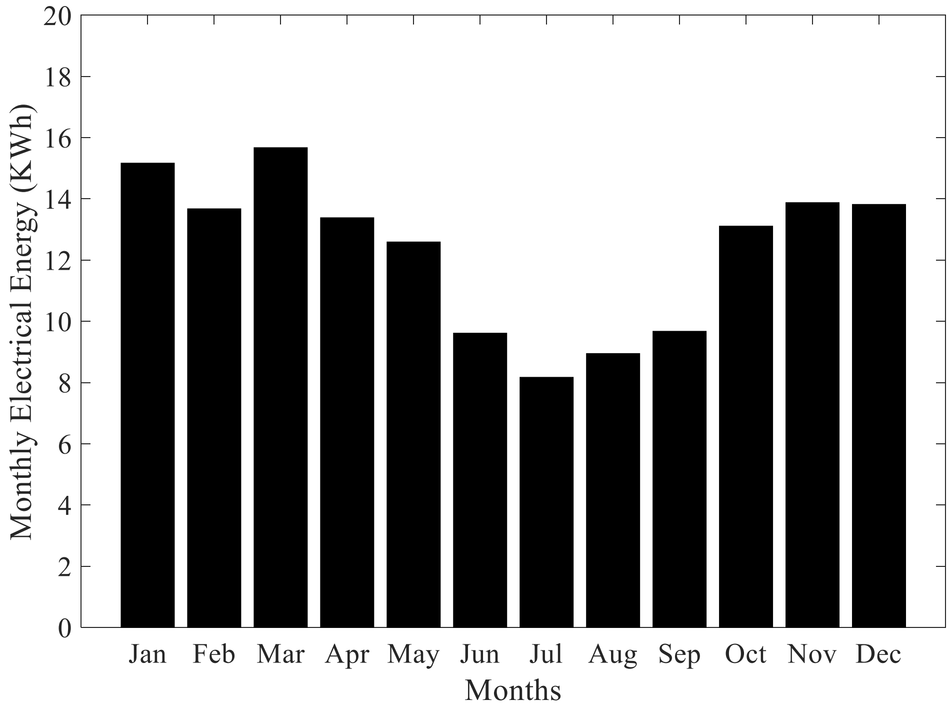


Figure 4.6: Monthly electrical output from PV (considering cloud impact)

Fig. 4.6. depicts the system's electrical output on a monthly basis, taking into account all relevant efficiency factors and the cloud's environmental impact. A 90 W PV module-powered street light system acquires 0.147 MWh of energy per year from a single pole, while the LED will only use 0.073 MWh of energy at its peak, which is 50.34 % less than the amount of energy the system is designed to generate.

4.9. Cost Benefit Analysis

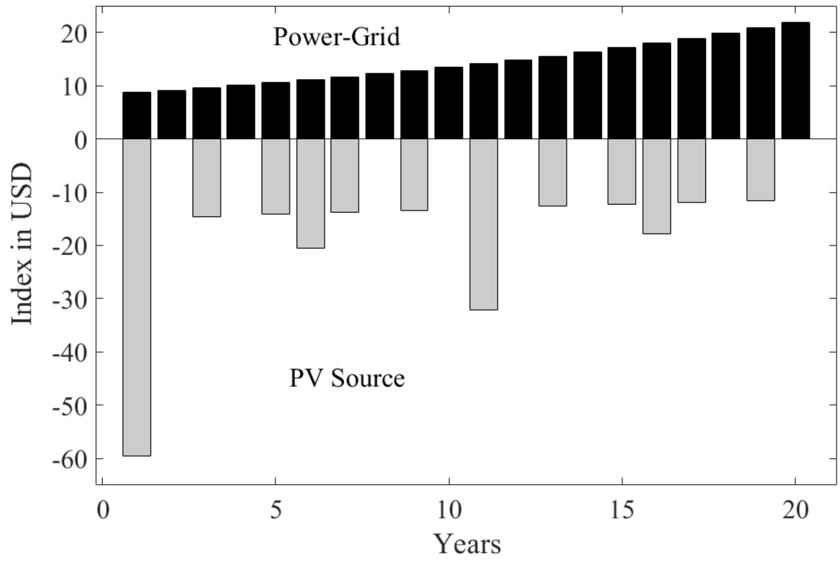


Figure 4.7: Cost Benefit Analysis

Table 4.3: Estimated Cost of The Proposed System

Utilizing Parameter	Estimated Cost (USD)	Estimated Life-Span (Year)
90W Solar Panel	22.5	20
27Ah 12V Lead Acid Battery	22	5
Control System	15	2
Grid Power Unit	0.11	

The total cost of the proposed system for 20 years is 234.12 USD with an initial installing cost of 59.5 USD, whereas the local grid unit cost is 286.64 USD. The estimated price is enlisted in table 4.3. From Fig. 4.7. it can be observed that the grid unit charge is 19.53% less than the proposed system in the first 10 years, but it is 80.45% more in the second 10 years with considering 5.48% inflation rate [35] and 7% discount rate[36]. Besides, the module degradation rate 0.50% has been considered. Total cost analysis has been listed in Table 4.4. The proposed system costs 18.33% less than the conventional local grid-connected system.

Consequently, it is possible to claim that the government is capable of conducting this type of system project.

In this study, for the 5.05km road length of the assessment area, 178 poles are required for this proposed system. At this case, a total of US$41673.68 need to be deposited in a PV-based system, whereas US$51021.95 is anticipated to be consumed on grid electricity costs.

Table 4.4: Estimated present worth value of The Proposed System

Number of Year	Present Worth Factor	Present Worth Cost of PV System	Present Value of Local Grid Unit Tariff
0	1	59.5	8.712256833
1	0.9813084112	0	9.143740064
2	0.9629661979	14.5769	9.596592935
3	0.9449668297	0	10.0718738
4	0.9273038983	14.1657	10.57069342
5	0.9099711152	20.4812	11.09421758
6	0.8929623093	13.766	11.6436698
7	0.876271425	0	12.22033419
8	0.8598925199	13.3777	12.82555846
9	0.8438197625	0	13.46075707
10	0.8280474305	32.0675	14.12741453
11	0.8125699084	0	14.82708886
12	0.7973816858	12.6336	15.56141526
13	0.7824773553	0	16.33210991
14	0.7678516103	12.2772	17.14097399
15	0.7534992437	17.7508	17.98989786
16	0.7394151457	11.9309	18.88086555
17	0.7255943019	0	19.81595929
18	0.7120317916	11.5943	20.79736449
19	0.6987227861	0	21.82737477

Chapter 5

5. Conclusions

In this study, a solar powered performance analysis has been assessed in the village area of Haripur Upazilla, Thakurgaon. Based on Dialux software simulation, 15W led is suitable and optimized for the particular village street where the pole-to-pole distance is 28.50m for this system. The most accumulated lowest average daily incident energy on clear-sky is 6.43Wh/m^2 whereas the lowest monthly energy considering cloud impact is 112.70Wh/m^2. The system has been designed for the longest night time duration (around 13.30 hours). Overall, the proposed system costs 18.33% less than the conventional local grid-connected system.

References

[1] Uddin, M. N., Rahman, M. A., Mofijur, M., Taweekun, J., Techato, K., & Rasul, M. G. (2019). Renewable energy in Bangladesh: Status and prospects. *Energy Procedia*, *160*, 655–661. doi:10.1016/j.egypro.2019.02.218

[2] R. Ciriminna, F. Meneguzzo, L. Albanese, and M. Pagliaro, “Solar street lighting: a key technology en route to sustainability: Solar street lighting technology for sustainability,” Wiley Interdiscip. Rev. Energy Environ., vol. 6, no. 2, p. e218, 2017.

[3] “Sustainable urban infrastructure for all: Lessons on solar-powered street lights from Kampala and Jinja, Uganda,” Working Papers. [Online]. Available: http://newclimateeconomy.report/workingpapers/workingpaper/sustainable-urban-infrastructure-for-all-lessons-on-solar-powered-street-lights-from-kampala-and-jinja-uganda/. [Accessed 31st March 2021]

[4] S. Tannous, R. Manneh, H. Harajli, and H. El Zakhem, “Comparative cradle-to-grave life cycle assessment of traditional grid-connected and solar stand-alone street light systems: A case study for rural areas in Lebanon,” J. Clean. Prod., vol. 186, pp. 963–977, 2018.

[5] S. Ahmed, A. H. Zenan, N. Tasneem and M. Rahman, "Design of a solar powered LED street light: Effect of panel's mounting angle and traffic sensing," 2013 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (CSUDET), Selangor, Malaysia, 2013, pp. 74-79, doi: 10.1109/CSUDET.2013.6670990.

[6] A. Avotins, P. Apse-Apsitis, M. Kunickis and L. Ribickis, "Towards smart street LED lighting systems and preliminary energy saving results," 2014 55th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 2014, pp. 130-135, doi: 10.1109/RTUCON.2014.6998219.

[7] M. N. Bhairi, S. S. Kangle, M. S. Edake, B. S. Madgundi, and V. B. Bhosale, “Design and implementation of smart solar LED street light,” in 2017 International Conference on Trends in Electronics and Informatics (ICEI), 2017.

[8] Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes (4th ed.). Hoboken, N.J.: John Wiley & Sons

[9] Liu, B Y.H., & Jordan, R C. Interrelationship and characteristic distribution of direct, diffuse, and total solar radiation. United States. https://doi.org/10.1016/0038-092X(60)90062-1

[10] G.M. Masters, “Renewable and efficient electric power systems”, 2004, New jersey: John Wiley & Sons, Inc.

[11] Marion, W. F., & Dobos, A. P. Rotation angle for the optimum tracking of one-axis trackers.

[12] I. Daut, M. Irwanto, Y. M. Irwan, N. Gomesh and N. S. Ahmad, "Clear sky global solar irradiance on tilt angles of photovoltaic module in Perlis, Northern Malaysia," International Conference on Electrical, Control and Computer Engineering 2011 (InECCE), Kuantan, Malaysia, 2011, pp. 445-450, doi: 10.1109/INECCE.2011.5953923.

[13] H. M. Fahad, A. Islam, M. Islam, M. F. Hasan, W. F. Brishty, and M. M. Rahman, “Comparative analysis of dual and single axis solar tracking system considering cloud cover,” in 2019 International Conference on Energy and Power Engineering (ICEPE), 2019

[14] S. A. M. K. R. M. R. Ahmed Hosne zenan, "A new multilevel Solar panel System for Urban Areas," in Developments in Renewable Energy Technology (ICDRET) 2014 3rd International Conference, 2013.

[15] Ventre, M. R. (2005). Photovoltaic system engineering. Boca Raton, Florida: CRC P LLC.

[16] EN 13201-4:2003. Road lighting - Part 4: Methods of measuring lighting performance. ISBN 0 580 43081 2.

[17] Lighting glossary (no date) Dleds.com. Available at: https://en.dleds.com/area-tecnica/glossario-illuminotecnico (Accessed: July 2, 2022).

[18] *Electrical4u.com*. Available at: https://www.electrical4u.com/road-lighting-design/ (Accessed: July 2, 2022).

[19] “CHAPTER 2 ROAD PLANNING AND RECONNAISSANCE,” Fao.org. [Online]. Available: https://www.fao.org/3/T0099E/T0099e02.htm. (Accessed: July 2, 2022).

[20] (Street Lighting Guidebook) Com-dep.eu. Available at: https://com-dep.eu/wp-content/uploads/guidebook_sl_en.pdf (Accessed: July 2, 2022).

[21] M. Ramadhan and A. Naseeb, “The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait,” Renew. Energy, vol. 36, no. 4, pp. 1272–1276, 2011.

[22] H. Gholami, H. N. Røstvik, N. M. Kumar, S. S. and Chopra, Lifecycle cost analysis (LCCA) of tailor-made building integrated photovoltaics (BIPV) façade: Solsmaragden case study in Norway, vol. 211, Solar Energy, 2020, pp. 488-502.

[23] Kim, D.; and Park, S. (2017). Improving community street lighting using CPTED: A case study of three communities in Korea. Sustainable Cities and Society, 28, 233-241.

[24] T. Lawson, R. Rogerson, and M. Barnacle, “A comparison between the cost effectiveness of CCTV and improved street lighting as a means of crime reduction,” Comput. Environ. Urban Syst., vol. 68, pp. 17–25, 2018.

[25] A. T. Murray and X. Feng, “Public street lighting service standard assessment and achievement,” Socioecon. Plann. Sci., vol. 53, pp. 14–22, 2016.

[26] D. Herbert and N. Davidson, “Modifying the built environment: the impact of improved street lighting,” Geoforum, vol. 25, no. 3, pp. 339–350, 1994.

[27] D. Szakonyi; and J. Urpelainen, (2015). Energy poverty among urban street vendors in India: Evidence from Patna, Bihar. Energy for Sustainable Development, 24, 44-49.

[28] M.S. Wu; H.H. Huang; B.J. Huang; C.W. Tang; and C.W. Cheng, (2009). Economic feasibility of solar-powered led roadway lighting. Renewable Energy, 34(8), 1934-1938.

[29] A.B.D. Nandiyanto; R. Zaen; R. Oktiani; A.G. Abdullah; and L.S. Riza (2018). A simple, rapid analysis, portable, low-cost, and Arduino-based spectrophotometer with white LED as a light source for analyzing solution concentration. Telkomnika, 16(2), 580-585.

[30] Sastry, O.S.; Devi, V.K.; Pant, P.C.; Prasad, G.; Kumar, R.; and Bandyopadhyay, B. (2010). Development of white LED based PV lighting systems. Solar Energy Materials and Solar Cells, 94(9), 1430-1433.

[31] P.M. Pattison; M. Hansen; and J.Y. Tsao, (2018). LED lighting efficacy: Status and directions. Comptes Rendus Physique, 19(3), 134-145.

[32] S. Sarkar, K. Mohan and P. Vankhande, "Smart street-lighting using green energy designing a novel stand-alone solar powered lighting system," 2017 International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 2017, pp. 157-163, doi: 10.1109/ICCONS.2017.8250701.

[33] *Haripur, Bangladesh sunrise sunset times* (no date) *Maplogs.com*. Available at: https://sunrise.maplogs.com/haripur_bangladesh.419077.html (Accessed: June 25, 2022).

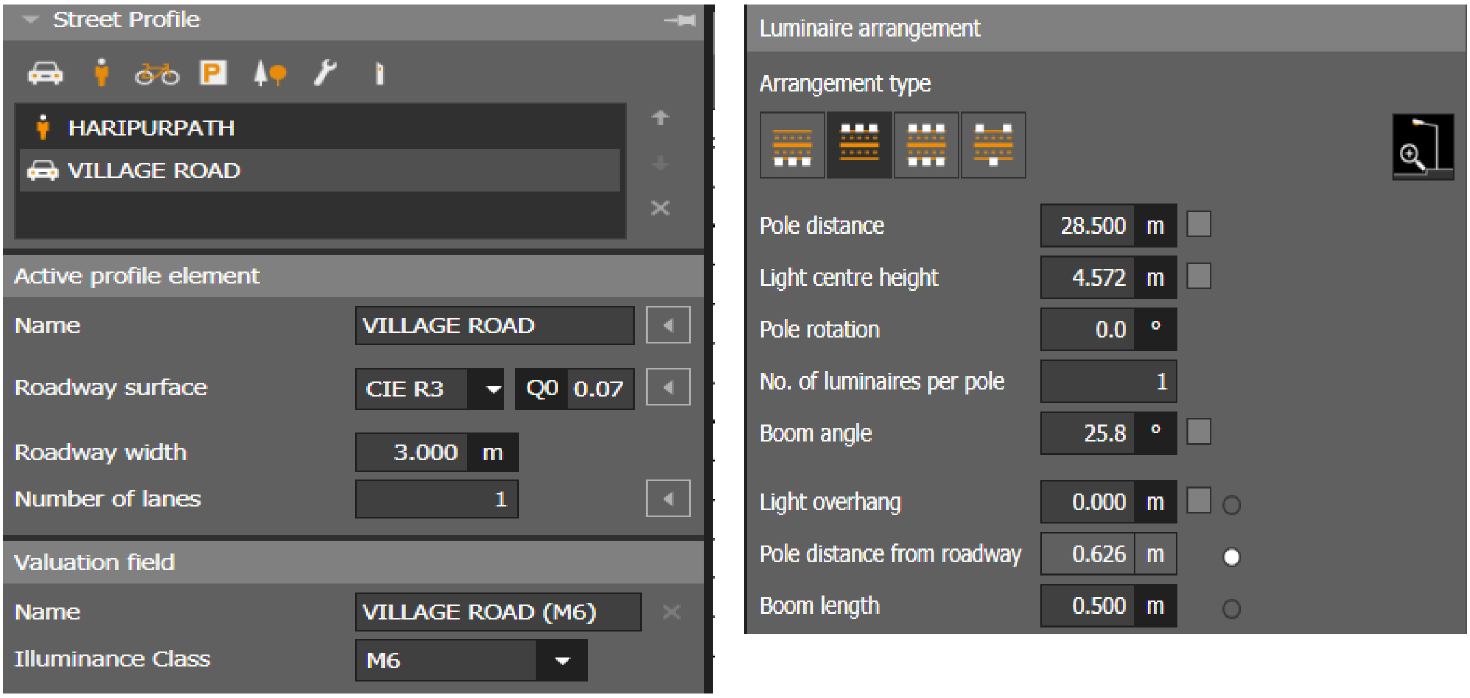
[34] H. Darhmaoui and D. Lahjouji, “Latitude based model for tilt angle optimization for solar collectors in the Mediterranean region,” *Energy Procedia*, vol. 42, pp. 426–435, 2013.

[35]“Bangladesh Bank,” Org.bd. [Online]. Available: https://www.bb.org.bd/en/index.php/econdata/inflation. [Accessed: Dec 20, 2022].

[36] “Bangladesh Bank Lending Rate,” Ceicdata.com, 01-Jun-2018. [Online]. Available: https://www.ceicdata.com/en/indicator/bangladesh/bank-lending-rate. [Accessed: Dec 20, 2022].

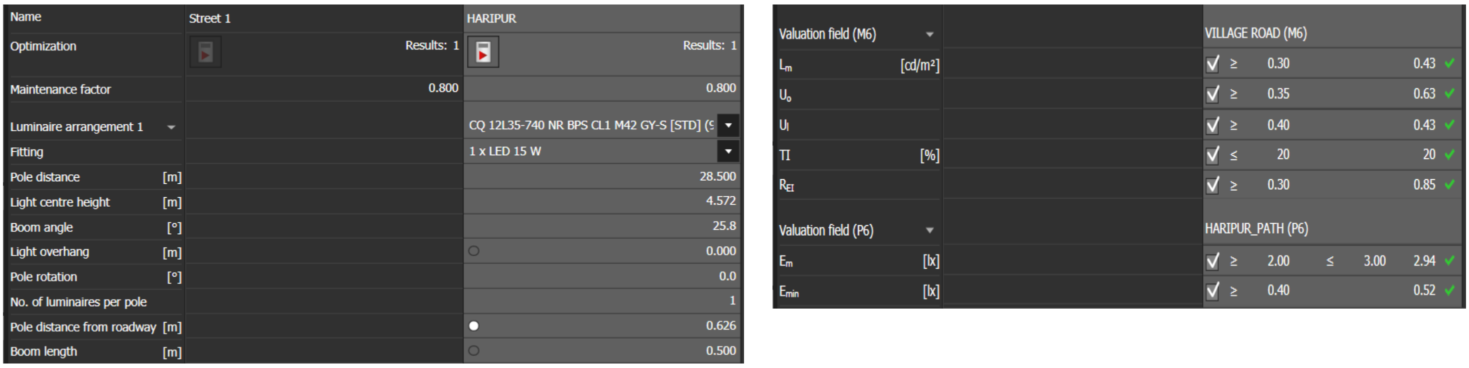
Appendix A1.

Screen shot of input values and feedback:
Dialux Software:



a b

Figure 5.1: Street Profile of Haripur village area (a) and Luminaire Arrangement (b) of street lamp poles



a b

Figure 5.2: Street Pole Input Parameters(a) and DiaLux Software Feedback(b)

Appendix A2.

Code for IR, LDR sensor implementation:

Code: Arduino IDE

```
int read_ldr = analogRead(ldr);
int read_ir = digitalRead(ir);
delay(200);
Serial.println(" ");
Serial.println("read_ldr");
Serial.println(read_ldr);
Serial.println("read_ir");
Serial.println(read_ir);
if (read_ldr < 600 && read_ir == 1)
{ digitalWrite(output, HIGH);
Serial.println("STREET LIGHT ON");
}
else
{ digitalWrite(output, LOW);
Serial.println("STREET LIGHT OFF");
}
if (read_ldr < 600)
{
Serial.println("DAY LIGHT STATE: LOW");
}
else
{
Serial.println("DAY LIGHT STATE: BRIGHT");
}
delay(700);
if (read_ir ==1)
{
Serial.println("Moving Object Detected");
}
else
{
Serial.println("No Object Detected");
}
delay(700);
```

Arduino IDE:

Figure 5.3: Control System Code Compiler