

# Faculty of Electrical and Electronic Engineering Technology



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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**Bachelor of Electrical Engineering Technology with Honours** 

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# DEVELOPMENT OF A SMART TRAFFIC LIGHT SYSTEM USING A SOLAR-POWERED STANDALONE PV SYSTEM

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering Technology with Honours



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

## **DECLARATION**

I declare that this project report entitled "Development of a Smart Traffic Light System Using a Solar-Powered Standalone PV System" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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# APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

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# DEDICATION

To my beloved mother, Azuraizam Binti Omar, my late father, Ariff Bin Salleh, and my dearest sister, Alya Azrissya Binti Ariff, who have meant and continue to mean so much to me.



#### ABSTRACT

Nowadays, electricity generation from standalone solar energy is increasing and gaining a lot of demand, especially in developing smart technology such as intelligent traffic light systems. A standalone solar PV system can generate, store and supply power to the traffic light without depending on the grid supply. Moreover, the conventional traffic light system is inefficient. The conventional system uses a fixed timing system for each lane and depends on the grid supply to operate, which can sometimes malfunction due to power failure and cause road accidents. A smart traffic light system using a solar-powered standalone PV system has been developed to overcome this problem. This project aims to analyze the existing traffic light system by studying related articles, journals and previous works, to design and develop a smart traffic light system integrated with standalone PV solar power, and to evaluate the suitability of solar panels, charge controller, batteries and sensors in a smart traffic light system. The smart traffic light system uses infrared (IR) sensors to detect traffic density. The Arduino Nano is used as the microcontroller to control the timer of the traffic light system and change the signal appropriately based on the vehicle density. LED traffic light modules have been used to represent the traffic light signal. Thus, with the integration of a standalone PV solar system, the PV solar can provide enough electricity to power the smart traffic light system and overcome many mishaps on the road due to traffic light malfunction.

#### ABSTRAK

Pada masa kini, penjanaan elektrik daripada tenaga suria kendiri semakin meningkat dan mendapat banyak permintaan, terutamanya dalam pembangunan teknologi pintar seperti sistem lampu isyarat pintar. Sistem PV solar kendiri boleh menjana, menyimpan dan membekalkan kuasa kepada lampu isyarat tanpa bergantung pada bekalan grid. Selain itu, sistem lampu isyarat konvensional adalah tidak cekap. Sistem konvensional menggunakan sistem pemasaan tetap dan bergantung pada bekalan grid untuk beroperasi, yang kadangkala boleh rosak akibat kegagalan kuasa dan menyebabkan kemalangan jalan raya. Sistem lampu isyarat pintar menggunakan sistem PV kendiri berkuasa solar telah dibangunkan untuk mengatasi masalah ini. Projek ini bertujuan untuk menganalisis sistem lampu isyarat sedia ada dengan mengkaji artikel, jurnal dan karya berkaitan, untuk membentuk dan membangunkan sistem lampu isyarat pintar yang disepadukan dengan kuasa solar PV kendiri, dan menilai kesesuaian panel solar, pengawal cas, bateri dan penderia. dalam sistem lampu isyarat pintar. Penderia inframerah (IR) digunakan dalam sistem lampu isyarat pintar untuk mengesan kesibukan lalu lintas. Arduino Nano digunakan sebagai pengawal mikro untuk mengawal pemasa sistem lampu isyarat dan menukar isyarat dengan sewajarnya berdasarkan kepadatan kenderaan. Modul lampu isyarat LED telah digunakan untuk mewakili isyarat lampu trafik. Oleh itu, dengan penyepaduan sistem suria PV kendiri, solar PV boleh membekalkan tenaga elektrik yang mencukupi untuk menghidupkan sistem lampu isyarat pintar dan mengatasi banyak kemalangan di jalan raya akibat kerosakan lampu isyarat.

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# LIST OF SYMBOLS

V	-	Voltage
А	-	Ampere
W	-	Watt
μm	-	Micrometre
KB	-	Kilobyte
MB	-	Megabyte
Wh	-	Watt-hour
Ah	-	Ampere-hour
MHz	-	MegaHertz
MA	-	MegaAmpere



# LIST OF ABBREVIATIONS

PV	-	Photovoltaic
IR	-	Infrared
NiMH	-	Nickel-Metal Hydride
Li-ion	-	Lithium-ion
LED	-	Light-Emitting Diode
PIR	-	Passive Infrared
GSM	-	Global System for Mobile Communications
ADC	-	Aalog Digital Converter
AC	-	Alternate Current
DC	-	Direct Current
RAM	-	Random Access Memory
EEPROM	-	Electrically Erasable Programmable Read-Only Memory
ROM	-	Read-only Memory
OTP	- 10	One Time Programmable
USB	3×	Universal Serial Bus
IC	<b>S</b> -	Integrated Circuit
AVR	- E	Automatic Voltage Regulator
GPIO	- 1	General-Purpose Input/Output
UART	En-	Universal Asynchronous Receiver Transmitter
SD	Sea and	Secure Digital
PC		Personal Computer
SOC	state	System On Chip
PWM	270	Pulse Width Modulation
HDMI	-	High-Definition Multimedia Interface
DEV	UNIVI	Developer EKNIKAL MALAYSIA MELAKA
IDE	-	Integrated Development Environment
RCA	-	Radio Corporation of America
PCB	-	Printed Circuit Board
MPPT	-	Maximum Power Point Tracking
ICSP	-	In-Circuit Serial Programming
DOD	-	Depth of Discharge
DOA	-	Days of Autonomy
BBTM	-	Battery Bank Temperature Multiplier
PSH	-	Peak Sun Hour
PDRM	-	Polis Di-Raja Malaysia
MIROS	-	Malaysian Institute of Road Safety Research
JKR	-	Jabatan Kerja Raya

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#### **CHAPTER 1**

#### **INTRODUCTION**

## 1.1 Background

Electricity is the most crucial component of a traffic signal system's operation, as the traffic control systems can function continuously in the presence of energy. Electricity failure or interruption may impair the system's operation and affect road users' safety. Moreover, conventional traffic light systems usually use underground and overhead cables to supply electric power, which can sometimes malfunction due to power outages and cause road accidents. Nowadays, standalone PV solar traffic light systems have been deployed in developed countries. By utilising solar energy, the traffic light system can reduce or eliminate its reliance on the electrical grid, enhancing its dependability and decreasing its operating expenses. Integrating solar power into the traffic light system can also reduce energy consumption and installation costs, particularly in grid-isolated or remote areas.

Solar energy is a type of energy obtained directly from the sun and converted to electrical energy, the most environmentally friendly form of energy that does not contribute to climate change or energy crises. The two most significant advantages of solar energy are that it has no fuel costs and produces no greenhouse gases throughout the solar energy generation process [1]. Furthermore, a standalone PV solar model integrates all components necessary for electricity generation and supply, including the solar photovoltaic panel, battery, charge controller, and load [2]. A battery is added to store the excess energy generated by the solar panel, which can be utilized at night or on overcast days. A charge

controller is connected to the battery to protect it against overcharging and regulates the system's general performance.

This project focuses on developing a standalone PV solar system to power the smart traffic light system. The infrared (IR) sensors are used in the smart traffic light system to detect the traffic density and transmit the data to the Arduino Nano. This microcontroller will vary the timer of the traffic light system based on the vehicle density and change the signal appropriately. Therefore, with the integration of a standalone PV solar system, the generator can provide enough electricity to power the traffic light system and overcome many mishaps on the road due to traffic light malfunction.

# **1.2 Problem Statement**

When an area experiences power outages, it affects the conventional traffic light system to malfunction since it uses underground and overhead cables to supply the electric power. This matter causes the smoothness of the traffic to be disrupted and causes road accidents. Moreover, the number of vehicles on the road has proportionally increased to the global population growth, resulting in road congestion, especially in urban cities. This road congestion happens due to the configuration of conventional traffic light systems that use a fixed timer program to give signals to road users. As a result, the drivers need to wait longer for the signals to turn green even though there are no vehicles at other intersections. The long traffic light timer not only stresses the drivers but also results in significant fuel waste and increases the carbon dioxide emissions from the queued vehicles. Thus, using a standalone PV solar system to power the smart traffic light system can solve the problems mentioned above.

## **1.3 Project Objective**

The main objective of this project is to propose a systematic and effective methodology to power a smart traffic light system by using electricity produced by the PV solar panel integrated with a backup battery. Specifically, the objectives are as follows:

- i. To analyze the existing traffic light system by studying related articles, journals and previous works.
- ii. To design and develop a smart traffic light system integrated with standalone PV solar power.
- iii. To evaluate the suitability of the solar panel, charge controller, battery and sensor in a smart traffic light system.
- 1.4 Scope of Project

The scope of the project is defined as follows:

- a) This project is targeted to be used at road intersections.
- b) The infrared (IR) sensor is used to detect the traffic density and control the program of the traffic light system. MALAYSIA MELAKA
- c) The type of solar panel used in this project is polycrystalline solar panels.
- d) The battery used to store the excess energy generated by the solar panel is the rechargeable Lithium-ion (Li-ion) battery.
- e) The system in this project uses Arduino Nano as the main microcontroller.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

This chapter summarises the theories and system design for a standalone PV solar generator and smart traffic light system. Moreover, this chapter also explains the overview of the conventional traffic light system and the statistic of accidents occurring at traffic light intersections. The existing projects from related articles, journals and works also have been discussed and compared so that the outcome of this project will be better.

## 2.2 Overview of Existing Project System

This section will review some previous project designs and implementations that have been conducted in connection with this project system. Several outstanding researchers have spent years finding the best way to optimize smart traffic signal systems and standalone PV solar systems. VERSITI TEKNIKAL MALAYSIA MELAKA

#### 2.2.1 Adaptive Traffic Lights through Traffic Density Calculation on Road Pattern

This project was developed to control the traffic light signal timing based on the traffic density calculation on the road pattern. The traffic density was calculated by processing the image on various road patterns. Then, a server collected data and managed traffic signal operations at a crossroads. The camera, mini pc (Raspberry Pi) and Wi-Fi router adapter were used. The battery Lithium Polymer (LiPo) 12.6V was utilized as a power supply, and its voltage was regulated to 5V before being linked to the Raspberry Pi through a UBEC voltage regulator. A Wi-Fi adapter was used to connect the Raspberry Pi to the

server through Wi-Fi, allowing the server to operate each traffic light via the Raspberry Pi. Then, the Raspberry Pi will send the server the current traffic density for monitoring purposes. However, the image processing method was unsuitable for this system because several noises interpreted as objects remain in the image frame even though several filtrations had been done [3].

#### 2.2.2 Density Based Traffic Signal System Using Arduino UNO

The density-based traffic light system was designed to control traffic based on density at the road intersection with the four-ways lane. The infrared (IR) sensor was used in this project to measure the traffic density by counting the number of vehicles passing through the IR sensors. Then, the IR sensor detected the vehicle density and transmits the data to the microcontroller to process and control the delay time of the traffic signal. This project used Arduino UNO ATMega 328P as its microcontroller.

Furthermore, the system integrated three light-emitting diode (LEDs) colours: red, yellow, and green, which were applied following traffic conditions. The road with the most vehicles was given a green signal, while the remaining routes received a red signal. Additionally, they developed the technology in this project with a 1000 millisecond delay. The microprocessor monitored traffic based on the sensors' output and adjusted the signals; hence, traffic was regulated by the delay [4].

## 2.2.3 Smart Traffic Light Control System

The smart traffic light control system was designed and implemented as an automated traffic light system with traffic-based timing to increase the traffic flow efficiency on urban roads. This system worked by adjusting the duration of present traffic lights to durations that varied according to the density of vehicles on the roads. Besides, this smart traffic light used an IoT system based on their system, including Raspberry Pi 2 Model B and Wi-Fi modules. In this project, they also included a bar of red light-emitting diodes (LEDs) in this trial to signify the countdown to the vehicles' completion of the waiting stage, signalled by a red traffic light. Additionally, this project utilized a passive infrared (PIR) sensor aimed at the vehicles that passed the roadway controlled by that traffic light. Furthermore, this project replaced the PIR sensor with video cameras. It processed the images using the open-source OpenCV package in Python to identify vehicles' numbers, speed, the distance between vehicles, and other important data [5].

#### 2.2.4 Smart Density Based Traffic Light System

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The development of this system was to manage traffic by automatically changing its timing in response to traffic density using an Arduino UNO ATMega 328. The system sensed traffic density by using digital infrared (IR) sensors, where the sensor detected the vehicles based on the signal reflected from them. Sensors installed alongside the road help manage traffic density by appropriately adjusting traffic signals. All infrared (IR) sensors were connected to an Arduino UNO, which reads data from them. The system's traffic signals were generated using (Light-Emitting Diodes (LEDs), with each signal consisting of two LEDs for each lane. Moreover, this project also used renewable energy sources which as solar PV panels, to power their system. Using renewable energy sources was relevant as the Arduino UNO consumed less power and had an inbuilt ADC [6].

#### 2.2.5 Design of Intelligent Traffic Light Controler Using Embedded System

This project was developed to create a safe and efficient traffic flow, assign the correct route, and reduce delays or waiting times on the road. The traffic jam was alleviated by increasing the duration of the green signal on busy roads and decreasing the duration of the red signal on non-busy roads. Car drivers were alerted about road congestion or alternative routes via their GSM cell phones. The traffic flow was determined using an Infrared–Light Emitting Diode (IRLED) transmitter and receiver. Furthermore, the 'Intelligent Traffic Light Controller' project employed the AT89C51 microcontroller, which offers advantages such as efficient control, GSM connectivity to mobile phones, and a fast response time. This project also included an emergency mode. The signals for vehicles such as an ambulance, firefighters, or police cars are changed to allow for the vehicle's rapid and easy movement [7].

#### 2.3 Comparison of Literature Review

Table 2.1 compares the components used in the previous related work mentioned above. Based on the overview of the literature reviews, most related projects used infrared (IR) sensors to detect the density of the vehicle on the road. Besides, light-emitting diodes (LEDs) have also been used to show the signals that change according to traffic conditions.

As for the microcontroller, the Design of Intelligent Traffic Light Controller project Using Embedded System used AT59C51. Moreover, the Adaptive Traffic Lights through Traffic Density Calculation on Road Pattern and the Smart Traffic Light Control System project used Raspberry Pi as their microcontroller since they are IoT-based systems and image processing methods. The Density Based Traffic Signal System Using Arduino UNO, and Smart Density Based Traffic Light System use Arduino UNO as that microcontroller consumes less power and has inbuilt ADC.

Components Existing Project	Raspberry Pi	Arduino UNO	AT59C51	IR Sensor	PIR Sensor	GSM	LED	IR-LED	Webcam	Wi-Fi Adapter	Wi-Fi Module
Adaptive Traffic Lights through Traffic Density Calculation on Road Pattern											
Density Based Traffic Signal System Using Arduino UNO	1400										
Smart Traffic Light Control System	AKA				E		V				
Smart Density Based Traffic Light System	ئل م TEK	NIK	کنيد AL N	IAL	ي ب AYSI	,سب A M	بۇ مر ELA	اود KA			
Design of Intelligent Traffic Light Controller Using Embedded System											

# Table 2.1 Comparison between the components used in the related existing project systems

## 2.4 Conventional Traffic Light system

The conventional traffic light units consumed approximately 400 W continuously, with short power transients reaching up to 1800 W [8]. These light units consisted of sensors, controllers and lamps that operate on 120 V utility power supplies [9]. On the approach to a traffic signal, sensors are mounted either beneath the road's surface or on top of the light. These count the cars that pass down the road and determine which ones must be the most environmentally friendly. If a regular stream of cars was approaching from one direction, but none were approaching from the other, the signals chose to maintain the busy area green. However, if many automobiles accumulated in the opposite direction, the light would turn red, and the opposite direction will remain green.

This procedure is called Vehicle Actuation and is the most frequently utilized. However, some intersections employ a Fixed Time operation, which maintains one set of lights green for a certain period regardless of traffic volume. The lights are controlled by a fixed circuit, with high-powered LEDs concealed behind each glass circle. Once the green light has been switched off, power would be passed to the yellow and then to the red light.

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#### 2.5 Statistics of Road Accidents at Traffic Lights

Violations of red traffic lights at traffic-lighted junctions should be stressed as a road safety hazard. According to PDRM road accident data from 2009, Malaysia experienced 397,330 accidents, with 1,038 occurring at signal light crossings. The accident claimed 80 lives and resulted in 908 significant injuries to road users [10].

The Malaysian Institute of Road Safety Research (MIROS) conducted a study to determine the effect of improved traffic light design on road users' compliance with red traffic lights and the risk of intersection disputes. Six crossroads in Selangor with distinct characteristics were chosen for this study. Additionally, this research will collaborate with the Jabatan Kerja Raya (JKR) of the Hulu Langat, Sepang, and Sabak Bernam districts to aid in the effort to replace the present traffic light design with the MIROS-proposed new design. The design suggestion is based on the most recent traffic volume analysis of other industrialized countries utilizing the 'SIDRA Intersection software.

According to preliminary survey findings, an average of 6.29% of vehicles ran red lights at each selected intersection [10]. Moreover, the analysis reveals that the travel time (peak or normal time), the type of vehicle, the type of intersection, the level of operation of the intersection, and the direction of the vehicle route all contribute to the commission of this offence (turning right or left). However, additional research is necessary on the effectiveness of the new traffic light interval design, which is believed to lessen congestion and red-light infraction behaviour.

## 2.6 Solar Radiation in Malaysia

Malaysia is one of the countries located in the tropical zone, which experiences yearround sunshine [11] and abundant rainfall. Furthermore, the country's climate can be described as having a constant temperature, moderate winds, high humidity, and two types of monsoons. A monsoon is a seasonal change in the wind accompanied by a change in precipitation. Malaysia has two monsoons: the Southwest Monsoon and the Northeast Monsoon. The Southwest Monsoon is the country's driest and hot season, usually from late May to September. Meanwhile, Northeast Monsoon is the country's wet or significant rainy season, usually from November to March [12]. Malaysia's tropical climate provides an advantage with a lot of solar radiation as it receives an average of 4.21 kWh/m<sup>2</sup> to 5.56 kWh/m<sup>2</sup> of solar radiation per day [13]. Malaysia's yearly solar radiation ranges between 1400 and 1900 kWh/m<sup>2</sup>, with an annual average of 1643 kWh/m<sup>2</sup> [14]. Figure 2.1 illustrates Malaysia's annual average of solar radiation (MJ/m2 per day).



Figure 2.1 Annual average of solar radiation in Malaysia (MJ/m<sup>2</sup> per day)

Besides, Malaysia's monthly solar radiation increases during the Northeast monsoon, whereas it falls during the Southwest monsoon [15]. In addition, the temperatures and humidity levels in Malaysia are relatively high. Except for the highlands, humidity ranges from 80% to 90%. The Temperature ranges between 22 and 33 degrees Celsius throughout the year, with an average daily temperature of 26.5 degrees Celsius [15]. The global solar radiation on any surface is influenced by the location's sunlight hours, ambient air temperature, and relative humidity [16]. As a result, sun radiation decreases as the average humidity rises, and vice versa [16]

## 2.7 Background of PV Solar Power System

In recent years, solar energy has gained enormous popularity as a clean and alternative renewable energy source. Natural resource utilization has been a priority, particularly in developed cities, due to its efficiency and ease of maintenance. This initiative addresses the energy issue due to climate changes, rising fuel prices, and depletion of fossil fuel resources. People have to rely on alternative energy sources when fossil fuels run out entirely. Renewable energy systems will be utilized to generate electricity in the future.

## 2.7.1 Types of Photovoltaic (PV) Solar System

Solar energy is one of the renewable energy sources employed in various applications such as rural electrification, water pumping, lighting system, and remote home power. As illustrated in Figure 2.2, there are two types of solar photovoltaic (PV) systems: grid-connected and standalone PV systems.



Figure 2.2 PV system types

The grid-connected PV system is the most typical configuration for applications where consumers wish to save money on utility bills. At the same time, the utility grid remains available for usage when the PV array is not producing any energy. The PV array directly connected to the grid without using a storage system is called the Utility-Interactive or Grid-Tied PV System, as shown in Figure 2.3. Alternatively, excess energy can be stored in battery banks for later use, which is referred to as a Bimodal PV System or Battery Backup PV System, as shown in Figure 2.4.



Figure 2.3 The connection of the Utility Interactive PV System



Figure 2.4 The Connection of Bimodal PV System

All standalone (off-grid) systems operate independently of the utility grid, as shown in Figure 2.5. The perfect match between supply and demand must be anticipated to calculate the size of the photovoltaic system and the load required. If the calculation is suitable for a single load, the PV system is referred to as a Direct-Coupled PV System, as it has few components and does not require storage.



Figure 2.5 The connection of the standalone AC PV system

Next, another standalone requires a storage system to store excess energy when it is **UNIVERSITITEKNIKAL MALAYSIA MELAKA** not needed for the load and can be pulled later during the overcast day or at night. This system can be directly linked to DC loads, an additional power conditioning component, or an inverter to AC loads. The other common standalone system is the hybrid photovoltaic system, which supplies loads parallel to the photovoltaic array, as shown in Figure 2.6. In this system, wind turbines, hydro turbines, diesel generators, or fuel cells can be used as energy sources, and batteries can be used to store the energy.



Figure 2.6 The Connection of Hybrid PV System

A standalone (off-grid) solar energy system can generate enough energy to meet consumers' needs. A standalone system is not connected to any utilities. Solar energy systems are utilized to electrify rural areas and distant homes when grid power is unavailable. Solar standalone systems are more cost-effective than main electricity for powering rural houses or towns where just a small amount of energy is required.

# 2.7.2 Solar Cell Structure and Working Principle

Solar cells are composed of a class of semiconductors, including silicon. The term "solar cell" is also used to refer to a photovoltaic (PV) cell. As the name implies, photovoltaic relates to light, and voltaic refers to energy. A solar cell is a solid-state electrical device with a P-N junction that utilizes the PV effect to convert light energy directly into electricity (DC). The conversion process begins with a substance that absorbs solar energy photons and then raises an electron to a higher energy state, which flows to an external circuit. These extra charges can be used to generate electricity by passing them through an external circuit. The basic structure of the solar cell is shown in Figure 2.7.



Figure 2.7 Basic structure of solar cell

The solar cell is the fundamental component of a solar energy system, and solar cells are the basic components of solar panels. A solar module is a series of solar cells connected to generate a larger output. Solar modules produce a small amount of energy to generate energy through several solar panels connected in a string.

## 2.7.3 Major Element of Standalone Solar Power System

Solar energy systems are composed of many components to generate electricity UNIVERSITI TEKNIKAL MALAYSIA MELAKA from sunlight. The standalone solar power system's major elements include solar panels, a solar charge controller, a battery bank, and a DC-DC converter. Solar energy system components are chosen based on climate, geographical location, system type, and application.

#### 2.7.3.1 Solar Panel

Solar panels or solar modules are vital elements of a solar energy system. Solar panels collect solar energy from the sun and convert it to direct current electricity. Besides, the strings of solar modules can be connected in series or parallel, as illustrated in Figure 2.8. The solar panel gives higher voltage in a series connection, and the current value remains

the same. The solar panel provides more current in a parallel connection, and the voltage remains constant.



Figure 2.8 Types of solar panel connection

Solar panels comprise several Si-based photovoltaic cells connected in series or parallel depending on the desired voltage and current. Polycrystalline silicon, monocrystalline silicon, copper-indium selenide, and amorphous silicon are today's most frequently utilized forms of photovoltaic cells. Amorphous has the lowest power efficiency (about 6%), whereas monocrystalline has the highest (approximately 15%) and, therefore, the highest cost [17]. Polycrystalline is used because it is less expensive than monocrystalline and more efficient (approximately 10%) than amorphous [17]. A monocrystalline silicon photovoltaic cell has a higher conversion efficiency (about 22%) but is also more expensive [18]. In addition, the solar coverage area influences the generated power. The coverage area is the square meters of solar area. PV Panel electrical characteristics (values at STC (AM1.5, 1000W/m2, 25°C)) [18].

- Max Power Pmax: 50Wp +/-3%
- Panel Voltage: 12 V
- Nominal Current Imp: 2.77A
- Nominal Voltage Vmp: 17.20V
- Cell Efficiency: 17%
- Open–Circuit Voltage Voc: 21.6 V
- Module Efficiency: 14.6%
- Short-Circuit Current Isc: 3.23 A

Figure 2.9 illustrates the I-V characteristic of a solar cell under changing levels of sunshine. The knee point indicates the optimal power available where decreasing voltage



Figure 2.9 Standard I-V characteristics of PV cell
## 2.7.3.2 Charge Controller

The solar charge controller is the most vital part of a standalone PV solar power system. A solar charge controller is an electrical component that manages the amount of charge entering and exiting the battery and the battery's optimal and most efficient performance. Alternatively referred to as solar regulators, solar charge controllers are also the primary component of any standalone system. Almost always, a charge controller is connected with a battery. The controller protects the batteries against various problems, such as overcharging, current leaking back to the solar panel during the night, under voltage, and monitors the battery's status.

With MPPT (maximum power point tracking) technology, solar charge controllers are advantageous for off-grid solar power systems. By ensuring that solar modules operate at their highest efficient voltage, MPPT charge controllers extract the maximum available power from them. The MPPT charge controller compares the solar panel's output voltage to the battery voltage and determines the optimal voltage to deliver the maximum current to the battery. When the battery is fully charged, the MPPT can extract additional current and charge the battery if the battery's state of charge is low. MPPT charger controllers perform well in inclement weather and low-temperature conditions. PV modules perform better in cold temperatures, and MPPT is used to extract the module's maximum power output [19].

# 2.7.3.3 Battery Bank

A battery bank is a bunch of batteries that have been connected series or parallelly. It is an integral part of a standalone PV solar system. The battery bank can store the electrical energy converted from PV solar panels and distribute it to electric devices. The battery should be large enough to store enough power to run the device at night and on overcast days. A solar battery cycle occurs when it is discharged and recharged to its full capacity; the amount by which a solar battery is discharged is referred to as the depth of discharge. Several rechargeable batteries are usually used to store the excess energy generated from the solar panel, including lead-acid, lithium-ion (Li-ion) and nickel-metal hydride (NiMH) batteries. Table 2.2 compares the specification of lead-acid, lithium-ion and nickel-metal hydride batteries.

Specification	Lead-Acid	Lithium-Ion (Phosphate)	Nickel-Metal Hydride	
Specific energy (Wh/kg)	30-50	90-120	60-120	
Internal resistance	Very low	Very low	Low	
Life cycle (80% Depth of Discharge)	200-300	1000-2000	300-500	
Charge time	8-16 hours	1-2 hours	2-4 hours	
Overcharge tolerance	High	Low	Low	
Self-discharge/month (room temperature)	5%	<5%	30%	
Cell voltage NIVER (nominal)	SITI TEKNIKAL 2V	MALAYSIA ME 3.7 V	LAKA 1.2V	
Charge temperature	-20 to 50°C	0 to 45°C	0 to 45°C	
Discharge temperature	-20 to 50°C	-20 to 60°C	-20 to 65°C	
Maintenance requirement	3-6 month	Maintenance-free	Full discharge every 90 days when in full use	
Cost	Low	High	Moderate	
Safety requirement	Thermally stable	Protection circuit mandatory	Thermally stable, fuse protection	
Environmental	Not eco-friendly	Eco-friendly	Eco-friendly	

Table 2.2 Comparison between lead-acid, lithium-ion and nickel-metal hydride batteries

Based on the table, the lead-acid batteries have the lowest range of specific energy, making them the greatest weight of the other batteries. Besides, it has the shortest life cycle and charging time. Lead-acid batteries also have the lowest percentage of self-discharge per month, low maintenance, and are thermally stable. Even though the cost of lead-acid batteries is low, it is not eco-friendly due to their electrolyte toxicity.

In addition, Li-ion batteries have the highest range of specific energy, which makes Li-ion batteries lighter than lead-acid and NiMH batteries. It also has very low internal resistance, the same as lead-acid batteries. Moreover, Li-ion batteries have the greatest life cycle because of the lowest self-discharge per month. It also has the highest nominal voltage compared to the two battery types. Li-ion batteries are environmentally friendly and maintenance-free, but the cost is expensive. Li-ion is not safer than other batteries as it may explode if overheated or mishandled. Therefore, a protection circuit is needed to charge this battery.

Furthermore, NiMH batteries have a higher energy density range than lead-acid batteries. It also has a higher internal resistance and greater life cycle than lead-acid batteries. Compared to lead-acid batteries, it has a faster charging time but is still slower than Li-ion batteries. NiMH batteries have the highest self-discharge per month, making them have a lower life cycle than Li-ion batteries. NiMH batteries. NiMH batteries need to be fully discharged every 90 days if they are fully used. Even though NiMH batteries are more expensive than lead-acid batteries, they are still cheaper than Li-ion batteries. It is also eco-friendly and thermally stable.

#### 2.7.3.4 DC to DC Converter

The DC-to-DC converter, also known as a power optimizer, is developed to optimize the energy harvesting potential of photovoltaic and wind turbines. Increasing or

decreasing the input panel voltage to the required battery level is necessary. The inductor, capacitor, and MOSFET are the primary elements of the DC-to-DC converter circuit.

## 2.8 Microcontroller

A microcontroller is a small computer contained within a single metal-oxidesemiconductor (MOS) integrated circuit (IC) chip. A microcontroller comprises one or more CPUs (processor cores), memory, and programmable I/O peripherals. Moreover, on-chip program memory in ferroelectric RAM, EEPROM, NOR flash, or OTP ROM is frequently included, as is a tiny amount of RAM. Microcontrollers are developed for embedded applications instead of microprocessors, which are utilized in personal computers and other general-purpose applications and consist of multiple discrete chips.

## 2.8.1 Arduino Nano

There is a wide range of microcontrollers available nowadays, and Arduino is one of the most famous and simple development boards. There are many versions and types of Arduinos, and each of them has different capabilities in computing characteristics and interface functionalities. Figure 2.10 shows the structure of Arduino Nano.



Figure 2.10 Structure of Arduino Nano

Arduino Nano is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (6 can be used as PWM outputs) and 8 analog inputs. Besides, this microcontroller also has a 16 MHz quartz crystal, a mini USB connection, an ICSP header, 3 reset pins, and a reset button. It includes everything necessary to support the microcontroller; connect it to a computer through USB or power it with an AC-to-DC adapter or battery to be operated. Table 2.3 shows the technical specification of Arduino Nano.

Properties	Specification		
Microcontroller	ATmega328P – 8-bit AVR family microcontroller		
Operating Voltage	5 V		
Recommended Input Voltage	7 V – 12 V		
Input Voltage Limits	6 V – 20 V		
Analog Input Pins	8 (A0 – A7)		
Digital I/O Pins	14 (6 can be used as PWM output)		
DC Current on I/O Pins	اويو سيني بيد 40 mA		
DC Current on 3.3V Pin EKN	50 mAMALAYSIA MELAKA		
Flash Memory	32 KB (2 KB is used for the Bootloader)		
SRAM	2 KB		
EEPROM	1 KB		
Frequency (Clock Speed)	16 MHz		

Table 2.3 The technical specification of Arduino Nano

# 2.8.2 Raspberry Pi

The raspberry pi is a small, low-cost computer the size of a credit card that connects to a computer monitor or television through a conventional keyboard and mouse. It is a competent tiny device that enables individuals of all ages to investigate computing and learn to program in Scratch and Python. It can perform all the expected functions of a desktop computer, from internet browsing and high-definition video viewing to spreadsheet creation, word editing, and gaming.

The raspberry pi is available in Model-A and Model-B. The primary distinction between models A and B is in the presence of a USB port. The Model-A board consumes less power and lacks an Ethernet port, while the Model-B board is equipped with an Ethernet port and was designed in China.

The raspberry pi board comprises random access memory (RAM), a processor, and a graphics chip. It also includes an Ethernet port, GPIO pins, an Xbee socket, a UART, and a power supply connector. Besides, there are a variety of interfaces for different external devices. It requires mass storage, which we accomplish using an SD flash memory card. Thus, the Rasberry Pi board will boot from the SD card like a PC when it boots into Windows from its hard disc.

# 2.8.2.1 Raspberry Pi Model-A Board

The Raspberry Pi board is Broadcom's SOC (system on chip) (BCM2835). It features an ARM1176JZF-S core CPU, 256 MB of SDRAM, with a clock speed of 700 MHz. The raspberry pi's USB 2.0 ports are exclusively for external data communication. The board is powered by a micro USB adapter with a minimum output of 2.0 Watts (500 mA). The graphics-specific processor is intended to accelerate picture calculating operations. Figure 2.11 shows the Raspberry Pi Model A board.



Figure 2.11 Raspberry Pi Model-A board

Features of Raspberry Pi Model-A:

- 256 MB SDRAM memory
- Single 2.0 USB connector
- Dual-Core Video Core IV Multimedia coprocessor
- HDMI (rev 1.3 & 1.4) Composite RCA (PAL and NTSC) Video Out
- 3.5 mm Jack, HDMI, Audio Out
- SD, MMC, SDIO card slot onboard storage
- Linux Operating system
- Broadcom BCM2835 SoC full HD multimedia processor
- Dimensions are 8.6 cm  $\times$  5.4 cm  $\times$  1.5 cm

# 2.8.2.2 Raspberry Pi Model-B Board

The Raspberry Pi is based on the Broadcom BCM2835 system-on-a-chip (system on chipboard). It features a 700 MHz processor, 512 MB of SDRAM, and an ARM1176JZF-S core CPU. The raspberry pi boars' USB 2.0 connector supports solely external data communication. In Model B, the raspberry pi's Ethernet interface serves as the primary connection point to other devices and the internet. This board is powered by a micro USB adaptor with a minimum power output of 2.5 Watts (500 mA). The graphics-specific processor is intended to accelerate picture modification calculations. Table 2.12 shows the Raspberry Pi Model B board.



Figure 2.12 Raspberry Pi Model-B board

Features of Raspberry Pi Model-B:

- 512 MB SDRAM memory
- Broadcom BCM2835 SoC full high-definition multimedia processor
- Dual-Core Video Core IV Multimedia coprocessor
- Single 2.0 USB connector
- HDMI (rev 1.3 and 1.4) Composite RCA (PAL & NTSC) Video Out
- 3.5 mm Jack, HDMI Audio Out
- MMC, SD, SDIO Card slot onboard storage
- Linux Operating system
- Dimensions are 8.6 cm  $\times$  5.4 cm  $\times$  1.7 cm
- Onboard 10/100 Ethernet RJ45 jack

# 2.8.3 Comparison of Arduino Nano and Raspberry Pi

Arduino Nano is based on the ATmega family and has a reasonably basic architecture and software framework. Raspberry Pi is fundamentally a single-board computer. They both have a CPU that executes the instructions, timers, memory, and I/O pins. The fundamental distinction between the two is that Arduino tends to have a powerful I/O capability that drives external devices directly. In contrast, Raspberry Pi has a poor I/O, which requires transistors to drive the device. The comparison between Arduino Nano and Raspberry Pi Model-A and Model-B is illustrated in Table 2.4.

Feature/ Specification	Arduino Nano	Raspberry Pi Model-A	Raspberry Pi Model-B		
Dimension (cm)	4.5  imes 1.8	8.6  imes 5.4	8.6  imes 5.4		
Chip	-	Broadcom	BCM2835		
Processor	Atmega328P	ARMv6 single core			
Operating System	LAYSIA 4	Linux			
Clock Speed	16 MHz	700	MHz		
RAM -	2 KB	256 MB	512 MB		
ROM	32 KB	Micro SD Card			
EEPROM	EEPROM 1 KB -				
Input Voltage	7 V – 12 V	اوىيۇ×ىسىتى ئىكنىچ			
GPIO					
Analog Input	8	AL WALATSIA WELAKA			
PWM	6	-			
Dev IDE	Arduino	Scratch, IDLE, Linux			
USB	1 Mini-B USB	1 USB 2.0	2 USB 2.0		
Ethernet	-	Onboard 10/100 Ethernet RJ45 jac			
Audio	- Jack, HDMI		HDMI		
Video	-	RCA, HDMI			

Table 2.4 Comparison between Arduino Nano, Raspberry Pi Model-A, and Model-B

## 2.9 Summary

The main elements of a standalone PV solar panel are a solar PV panel, charge controller, battery bank, and electrical power converter. The polycrystalline silicon PV solar panel is the most suitable PV solar panel as the solar cell is more efficient in converting sunlight to electricity and less expensive than other PV solar panels. The charge controller is important in a standalone PV solar system as it protects the battery bank from overcharging or over-discharging. Besides, Lithium-Ion (Li-ion) batteries are the most suitable batteries to store the excess electricity generated by the PV solar panel. In addition, Arduino Nano is the most suitable microcontroller to operate the entire smart traffic light system as it is simple and consumes less power than other microcontrollers. The infrared (IR) sensor has been chosen as the main sensor to detect the density of the vehicles on the road, and the light-emitting-diode (LED) is used to represent the traffic light signal.

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## **CHAPTER 3**

#### METHODOLOGY

## 3.1 Introduction

This chapter focuses on a planned technique for systematically completing this project. This project development is divided into two parts which are hardware and software development. The methodology is essential to the project's success and achievement of the desired outcome. This chapter describes the project's development process using flowcharts and block diagrams to understand the process better.

# 3.2 Methodology

In order to achieve the objectives, several methods will be implemented in this project, including reading materials and the development of a standalone solar PV generator and smart traffic light system. The system is developed in stages, beginning with a project title search, identifying the problem statement, objectives, project scope, literature search, hardware and software development, and concluding with data collection. This section explains all the applied methods, equipment, and software used for this project. Figure 3.1 shows the flowchart of the overall project development.



Figure 3.1 The flowchart of the overall project

# 3.3 Block Diagram of Overall System



Figure 3.2 Block diagram of a smart traffic light system

As illustrated in Figure 3.2, the standalone PV solar system supplies the power to the Arduino Nano to operate it. When the IR sensor detects a high vehicle density in any lane, it will transmit the signal to the Arduino Nano microcontroller. The Arduino Nano will process the signal and send the output signal to the LED on the high-density lane to appropriately change the signal of the LED traffic light module to clear the road.

## 3.4 Block Diagram of Standalone PV Solar System



As illustrated in Figure 3.3, when a photovoltaic (PV) solar panel gets sunlight from the sun, it converts the solar energy into DC power. During the day, the solar panel will directly deliver power to the DC load, while the charge controller will charge the batteries to provide power to the load at night or on cloudy days. The dc-dc converter has been used to step up the voltage to power the microcontroller.

## 3.5 Flowchart of Smart Traffic Light System



The smart traffic light system has been designed to function under three conditions. Figure 3.4 shows the flow of the smart traffic light system of this project. When the traffic status is normal, or the sensor detects no vehicle density, the relevant traffic lights for lane A, lane B, lane C, and lane D will be activated and run in the normal sequence B, D, A and C. The second condition is met when the vehicle density on a particular lane increases. The traffic light system will change the signal based on the vehicle density to prioritize that highdensity lane. Thirdly, when the vehicle density is equal in all lanes, the traffic light system will run in the normal sequence, lanes B, D, A and C. These three conditions are required to prevent traffic congestion by prioritizing the lane with a high-density of vehicles.

## **3.6** Overall System Sizing Design

Calculating the solar panel, charge controller, and battery bank specifications is very important. The system sizing calculation is essential since the PV solar system must produce sufficient output to power the smart traffic light system. As no sunlight is accessible on cloudy days or at night, the battery bank must have enough power to provide electricity to the load system. Assuming the project is conducted on a small scale, the calculation for the PV solar system design is as follows:

## 3.6.1 Size of Solar Panel

Load details by assuming power usage for 1 hour/day:

8 no's of 0.225 W IR sensor 4 no's of 0.255 W LED Traffic Light Module 1 no's of 0.48 W Arduino Nano Total loads usage for 1 hour/day =  $(8 \ge 0.225 \text{ W}) + (4 \ge 0.255 \text{ W}) + 0.48 \text{ W} = 3.3 \text{ W}$ System-specific requirement: Energy usage (per hour) =  $3.3 \text{ W} \ge 1$  hour = 3.3 WhEnergy usage (per day) =  $3.3 \text{ W} \ge 1$  hour = 3.3 WhBattery voltage = 3.7 VDepth of Discharge = 50%Days of Autonomy = 2 day Battery Bank Temperature Multiplier (BBTM) = 1 Peak Sun Hour = 4 hours Solar panel size:

The output power of solar panel

= Energy usage (per day)  $\div$  Peak Sun Hour  $\div$  system efficiency

 $= 3.3 \text{ Wh} \div 4 \text{ hours} \div 0.85$ 

= 0.971 W

Suggested solar panel size = 2 W, 5 V (Polycrystalline Silicon PV Solar Panel)

Therefore, 0.971 W  $\div$  2 W  $\approx$  1 solar panel needed

Hence, 1 polycrystalline silicon PV solar panel is needed for the whole system to operate. The suggested solar panel size produces 2 W of maximum output power, which should be enough to supply power to the load. Table 3.1 shows the specification of the PV solar panel used in this project.

Properties	اويور سيني Specification
Types of panel RSITI TEKNIK	Polycrystalline Silicon PV Solar Panel
Peak voltage	5 V
Peak current	400 mA
Short circuit current	480 mA
Open circuit voltage	6.8 V
Power rating	2W
Weight	0.2 Kg
Dimension	152 mm × 127 mm

Table 3.1 Specification of PV solar panel

## 3.6.2 Size of Battery Bank

Average daily:

Energy usage (per day) =  $3.3 \text{ W} \times 1 \text{ hours} = 3.3 \text{ Wh}$ 

Battery bank capacity (Wh):

= (Daily average usage × Days of Autonomy × BBTM) ÷ Depth of Discharge

$$= (3.3 \text{ Wh} \times 2 \text{ days} \times 1) \div 0.5$$

= 13.2 Wh

Suggested battery size = 1.2 Ah, 3.7 V (18560 rechargeable Lithium-Ion battery) Battery bank capacity (Ah): = Battery bank capacity (Wh) ÷ system voltage = 13.2 Wh ÷ 3.7 V = 3.566 Ah, 3.7 V

Total batteries needed =  $3.566 \text{ Ah} \div 1.2 \text{ Ah} \approx 3 \text{ pieces of batteries}$ 

Hence, this project requires 3 batteries of 3.7V 18650 Lithium-ion (Li-ion) connected in parallel with the capacity sum of 3.6 Ah. Table 3.2 shows the specification of the 18650 rechargeable Li-Ion battery.

Properties	Specification	
Battery type	Lithium-Ion (Li-Ion)	
Model no.	18650	
Dimension	18 mm × 65 mm	
Nominal voltage	3.7 V	
Capacity per cell	1200 – 3600 mAh	
Operating voltage	2.5 V – 4.2 V	
Cut-off voltage	2 V – 2.5 V	
Charge density (Energy per cell)	1.5 Wh – 11.5 Wh	
Charge/discharge cycle	250 – 2000 cycle	
Charging voltage	4.2 V – 5 V	
Self-discharge per month	6 % - 10 %	

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# Table 3.2 Specification of 18650 rechargeable Li-Ion battery

# 3.6.3 Size of Battery Charge Controller L MALAYSIA MELAKA

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The output power of the solar panels = 2 W

Battery voltage = 3.7 V

Suitable size of the charge controller =  $2 \text{ W} \div 3.7 \text{ V} = 0.5405 \text{ A}$ 

Suggested charge controller size = 1 A (TP4056 module)

TP4056 module has been selected as it is the most suitable charge controller for the 18650 Li-Ion battery type. As shown in Table 3.3, the maximum charging current of a single charge controller module (TP4056) is 1 A. Hence, 3 modules are needed to be connected to charge 3 cells of 18650 Li-ion batteries.

Properties	Specification
Module	TP4056
Protection IC	DW01A or DW01P
Charge method	Constant-Current/Constant-Voltage (CC/CV)
Charge/discharge control MOSFET	FS8205A
Input voltage via micro-USB or mini-USB	5 V
Input voltage via solder pads on the left-hand side of the module	4.5 V ~ 5.5 V
Charging current	1 A by default
Charge complete (float) voltage	اوىيۇم,سىتى ت%4.2×4.2×4.2
Overcharge detection voltage	4.3 V ± 50 mV/SIA MELAKA
Overcharge release voltage	$4.1~V\pm50~mV$
Over-discharge detection voltage	$2.4 \text{ V} \pm 100 \text{ mV}$
Over-discharge release voltage	$3.0 \text{ V} \pm 100 \text{ mV}$
Overcurrent protection threshold	3 A
Trickle charge threshold voltage	$2.9~V\pm0.1~V$
Trickle charge current	130 mA ± 10 mA
Charging indicator	Red LED, green or blue LED

Table 3.3 Specification of the TP4056 charge controller with protection

#### 3.6.4 Summary of Standalone PV Solar System Sizing

Since the prototype is designed for a small-scale project, it is assumed that the smart traffic light system will work for 1 hour per day. Based on the above calculation, the size of this PV solar panel selected to power the 3.3 Wh load per day is 2 W with a maximum output voltage of 5 V and a maximum output current of 0.4 A. The selected PV solar panel type is the Polycrystalline Silicon PV panel.

In addition, assuming that the load consumed power for 1 hour per day and that the autonomy (days when the sun is unavailable) is 2 days, the battery bank should be able to provide power to the load for 1 hour/day for 3 days. The selected battery bank type is the 18650 lithium-ion rechargeable battery with 1.2 Ah and 3.7 V per cell. As the load required a minimum of 3.566 Ah of battery capacity to operate for 1 hour/day for 3 days, 3 cells of Li-Ion batteries connected in parallel with a total capacity of 3.6 Ah are needed.

In addition, a charge controller is required to charge the battery bank safely. The recommended charge controller for lithium-Ion batteries is the TP4056 module, which is the most suited charge controller for this purpose. Since this single module's maximum charging current is just 1 A by default, three modules are required to charge the 3 cells of Li-Ion batteries faster.

As the total voltage of the proposed battery bank is only 3.7 V, a boost DC-DC converter module is required to increase the voltage from 3.7 V to 5 V, as the Arduino Nano requires 5 V to operate. Table 3.4 summarize the sizing of the standalone PV solar system required for this project.

Total load usage of 1 hour/day	3.3 Wh
Total load usage of 1 hour/day for 3 days (assuming days without sunlight is 2 days)	13.2 Wh
Solar panel output (considering 4 hours of peak sun hour)	2 W, 5 V, 0.4 A
Charge Controller output	3 A
Battery bank capacity	3.7 V, 3.6 Ah
DC-DC converter output	5 V

#### Table 3.4 Summary of standalone PV solar system sizing

#### 3.7 Hardware Development

The solar PV system is the most crucial part of the project as it produces electricity that will power the smart traffic light system. Several elements are essential in developing the PV solar generator, such as solar panels, charge controller, battery bank, and DC-to-DC converter. This section will also explain the hardware used to develop the smart traffic light system. The main components used are Arduino Nano, IR sensors, resistors, and LEDs.

# 3.7.1 Polycrystalline Silicon PV Solar Panel

Polycrystalline or Multicrystalline PV solar panels, as illustrated in Figure 3.5, consist of several silicon crystals in a single PV cell. Multiple silicon shards are fused to generate the wafers of polycrystalline solar panels. The vat of molten silicon used to make polycrystalline solar cells is allowed to cool directly on the panel. These photovoltaic panels have a mosaic-like surface. As a result of their polycrystalline silicon composition, they have a square form and a brilliant blue tint. As numerous silicon crystals exist in each cell, polycrystalline panels restrict the movement of electrons within the cells. These solar panels absorb solar energy and transform it into electricity.



Figure 3.5 Polycrystalline silicon solar panel

# 3.7.2 18650 Rechargeable Lithium-Ion Battery

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The 18650 battery, as illustrated in Figure 3.6, is a cylindrical Li-ion battery with a diameter and height of 18 mm and 65 mm, respectively. The 18650 battery has between 1200 mAh and 3600 mAh capacity with a nominal voltage of 3.7 V. The 18650 batteries are used in rechargeable and high-current-draining devices because of their high-level capabilities, such as over 250 charging cycles and greater energy density.



Figure 3.6 18650 rechargeable Lithium-Ion (Li-Ion) battery

## 3.7.3 TP4056 Charge Controller Module

The charge controller connects the solar panel to the storage batteries through the battery. It regulates the power from the solar panel to protect the battery bank. Without a charge controller, overcharging might cause damage to the battery.

The TP4056 module is a single-cell lithium-ion battery charger that prevents overcharging and over-discharge. The suggested operating voltage for the TP4056 module circuit is 4.5 V - 5.5 V, with a charging current rating of 1A. This module can be powered by any mobile charger and its associated connection. It features two status outputs that indicate charging is in progress and complete. When the charger is activated, the RED indicator light will illuminate, signifying that the battery is being charged. Once the module has fully charged the battery, it will automatically cease charging, and the Red LED will turn OFF while the Blue LED will turn ON. Table 3.5 shows the summaries of LED conditions during the charging state of TP4056.

		and the second	
Charge State VERSITI TEKNIKAL	Red LED ME	Blue LED	
Charging	ON	OFF	
Charge Termination	OFF	ON	
Vin too low / Temperature of battery too low or too high / No battery	OFF	OFF	
BAT Pin Connect 10µ Capacitance / No battery	Blue LED ON, Red LED coruscate T = 1-4 s		

Table 3.5 LED conditions during the charging state of TP4056

Lithium batteries can be dangerous if improperly charged. Thus, the TP4056 is useful for preventing overvoltage and overcurrent charging by detecting specified voltage conditions. Figure 3.7 shows the solar charge controller for the solar PV system.



Figure 3.7 Lithium-Ion charge controller module

# 3.7.4 DC-DC Boost Converter Module

Figure 3.8 illustrates the module for the DC-DC boost converter. With a DC voltage range of 0.9 V to 5 V, the boost converter can provide a 5 V DC voltage that is stable. It can provide 500 – 600 mA output current with a single Li-Ion battery. This ultra-miniature USB module is suitable for USB charger applications and onboard USB device supply solutions, such as microcontrollers which require a 5 V DC voltage to operate. Table 3.6 shows the specifications of the DC-DC boost converter module.



Figure 3.8 DC-DC boost converter module

Properties	Specification	
Module	Boost converter	
Input voltage	0.9 V – 5 V	
Output voltage	5.1 V – 5.2 V	
Output current	600 mA	
Switching frequency	500 kHz	
Voltage indication	LED lights with a load	
Operating Temperature	-40° Celsius to +85° Celsius	
Full load temperature rise	30° Celsius	
Efficiency	Up to 96%	
Input terminal LAYS/4	IN + input is level, IN-type negative	
Output terminal	Standard USB	
Dimension	2.9 mm × 1.8 mm × 0.8 mm	

Table 3.6 The specification of the DC-DC boost converter module

# 3.7.5 Arduino Nano

As illustrated in Figure 3.9, Arduino Nano is an open-source microcontroller board designed by the technology company Arduino and based on the Microchip ATmega328P microcontroller. The board has digital and analog input/output (I/O) pins connecting to several expansion boards (shields) and other circuits. It includes 14 digital I/O pins, 6 of which can be used as PWM outputs, 8 analog inputs, a 16 MHz quartz crystal, a mini USB port, an ICSP header, 3 reset pins, and a reset button. It can be powered by connecting it to a computer through a USB, an AC-to-DC adapter, or a battery. It has all of the necessary components for microcontroller operation.



Figure 3.9 Arduino Nano microcontroller

## 3.7.6 Infrared Sensor

An infrared (IR) sensor is a simple electronic device that produces and detects infrared radiation to locate objects or obstacles within its range. Its characteristics include temperature and motion detection. IR sensors utilize infrared radiation with a wavelength ranging from 0.75  $\mu$ m to 1000  $\mu$ m, which lies between the visible and microwave sections of the electromagnetic spectrum. Depending on its wavelength, the infrared spectrum is divided into three areas which are Near Infrared (0.75  $\mu$ m to 3  $\mu$ m), Mid Infrared (3  $\mu$ m to 6  $\mu$ m), and Far Infrared (more than 6  $\mu$ m).

The IR sensor has two main parts: the IR Transmitter and the IR Receiver. IR transmitter serves as a source of infrared radiation. Radiation that hits an object and is then reflected. Then, the IR receiver detects the reflected radiation. The radiation detected by the IR receiver is then analyzed based on its intensity.

In most cases, the output of an IR receiver is low, requiring amplifiers to boost the detected signal. The working operation of the IR sensor is shown in Figure 3.10. In this project, the IR sensor module is used for the smart traffic light system by detecting the density of the vehicle on the road. Figure 3.11 shows the IR sensor module.



Figure 3.10 Working operation of infrared (IR) sensor



3.7.7

LED traffic light module has high luminance and is ideally suited for developing prototype traffic light systems. It is characterized by its small size, simple wiring, targeted installation, and great design. It can be connected to PWM to adjust the LED's brightness. Figure 3.12 shows the LED traffic light module. The LED traffic light module consists of huge red, yellow, and green LEDs grouped in a typical traffic light pattern with currentlimiting resistors. The red, yellow, and green LEDs indicate the respective stop, ready to stop, and go signs.



Figure 3.12 LED traffic light module

## 3.8 Software Development

In this section, the software utilized to construct this project, such as Arduino IDE and Proteus 8 Professional, will be described. These applications are used for coding, circuit design, and simulation.

# 3.8.1 Proteus 8 Professional

Proteus 8 Professional or Proteus is a software mainly used to create schematics diagrams, PCB layouts, and run schematic simulations. This software is also suitable for designing and testing programming codes as it has various libraries of microcontrollers. The Proteus software has been used in this project to design and simulate the circuit of the Smart Traffic Light system before applying it to the hardware. The circuit of the smart traffic light system is shown in Figure 3.13.



Figure 3.13 Proteus 8 Professional software

## 3.8.2 Arduino IDE

Arduino IDE is an open-source program of Arduino.cc, which is used for writing, compiling, and uploading code to most Arduino modules. Many Arduino module libraries are available in software, including Arduino UNO, Arduino Nano, Arduino Mega, Arduino Leonardo, Arduino Micro, etc. Furthermore, the main code, also known as a sketch, written on the IDE platform will generate a Hex File which can be uploaded to the board's controller.

Moreover, the Editor and Compiler are the two primary components of the IDE environment. The Editor is used to write the necessary code; meanwhile, the Compiler compiles and uploads the code to the Arduino Module. This software is compatible with both C and C++ languages. Figure 3.14 shows the Arduino IDE software.



Figure 3.14 Arduino IDE software

## 3.9 Tools

In this section, the tools used in the development of this project are listed. The tools are necessary to improve the project testing and troubleshooting effectiveness.

# 3.9.1 Multimeter

A multimeter is a measurement device capable of measuring several electrical properties. A standard multimeter can measure voltage, resistance, and current; in this case, it is sometimes referred to as a volt-ohm-milliammeter (VOM) because it includes a voltmeter, ammeter, and ohmmeter capabilities. Figure 3.15 shows the multimeter with probes.



Figure 3.15 Multimeter with probes

# 3.9.2 AC-DC Switching Power Supply Adapter

ALAYS/A

AC-DC converter is often used as an external power supply unit for electrical equipment that cannot draw power directly from the mains. The power supply adapter typically consists of a rectangular central unit with power-switching electronics. This adapter converts AC electricity from the wall outlet to the DC voltage required by the device. A USB cable is connected to transfer the power from the adapter to the device to charge its battery or enable it to function. This adapter is used as a backup supply adapter during the development and troubleshooting of the project's system. Figure 3.16 show the AC-DC Switching Power Supply Adapter.



Figure 3.16 Wall power supply adapter

# 3.10 Cost and Bill of Materials

The total expected to purchase all the hardware components for this project is about RM127.90. Table 3.7 shows the cost and bill of materials used in this project.

No.	Material	Description	Quantity	Price (RM)
1.	5 V, 2 W Polycrystalline Silicon Solar Panel	1 unit = RM17.30	1	17.30
2.	3.7 V, 1200 mAh 18650 Lithium- ion (Li-ion) battery	1 unit = RM3.90	3	11.70
3.	1A TP4056 Charge Controller	1 unit = RM1.15	3	3.45
4.	DC-DC Converter (Step-Up Boost Module)	1 unit = RM3.50	1	3.50
5.	Arduino Nano	1 unit = RM21.95	1	21.95
6.	Infrared Sensor Module	1 unit = RM2.90	8	23.20
7.	LED Traffic Light Signal Module	1 unit = RM1.95	4	7.80
8.	Jumper Wire Female-to-Male	1 set = RM3.70	1.	3.70
9.	Jumper Wire Male-to-Male	1 set = RM3.70	اويور	3.70
10.	Battery Holder	1 unit = RM1.25	IELĄKA	3.75
11.	Donut Soldering Board	1 unit = RM2.50	1	2.50
12.	Multimeter	1 unit = RM16.90	1	16.90
13.	Crocodile Clips	1 unit = RM1.95	1	1.95
14.	Polyplast Board	1 unit = RM3.70	1	3.70
15.	Car Toys	1 unit = RM0.35	8	2.80
Total (RM)				127.90

Table 3.7 Cost and bill of materials for the overall project

# 3.11 Summary

This chapter describes the proposed method for initiating a new system development project. To achieve the overall objective of this project, each of the chapter's suggested enhancements must be implemented effectively. This chapter details all hardware and software elements of the system. In addition, the operation of the processing system has been demonstrated using a flowchart and a block diagram to describe step-by-step procedures. This chapter elaborated on the hardware and software selected for this project and the logic behind its implementation.



## **CHAPTER 4**

#### **RESULTS AND DISCUSSIONS**

## 4.1 Introduction

This chapter highlights the troubleshooting process and results obtained based on the data of the output of this project. The analysis is focused on two parts which are the electric power produced by the standalone PV solar system and the effectiveness of the smart traffic light system. The tabulated project result will be analyzed and explained in this chapter.

The project prototype has been developed with all the chosen components and tools based on the study conducted in Chapter 2. The selection of the components used has been made based on the calculations done in Chapter 3. Besides, the chosen hardware for the standalone PV solar system and smart traffic light system has been partly assembled according to the circuit design simulated in Chapter 3. All the software and tools stated in Chapter 3 are used during the project's design, simulation, assembly and troubleshooting process. The system coding is tested and adjusted several times to meet the desired output.

#### 4.2 **Prototype Development**

There are two systems connected in this project: a standalone PV solar system and a smart traffic light system. Figure 4.1 illustrates the drawing of the hardware installation plan.



Figure 4.1 Illustration of the hardware installation plan

Firstly, the components used for the standalone PV solar systems are a polycrystalline PV solar panel, TP4056 charge controllers, 3.7 V 18650 Li-ion batteries, and a DC-DC boost converter module. The system has been developed by connecting the solar panel to the charge controller input port. The TP4056 charge controller is used to charge a single cell of a Li-ion battery and protect the battery from overcharging or undercharging. Next, the charging port of TP4056 is attached to the battery terminal. The 18650 Li-ion batteries are used as the battery bank for standalone solar systems. The output port of the charge controllers is connected to the DC-DC boost converter module, which is used to step up the voltage to power the microcontrollers. Figure 4.2 shows the standalone PV solar system proposed in this project.


Figure 4.2 Standalone PV solar system

Furthermore, a few components are used to develop the smart traffic light system, including Arduino Nano, infrared (IR) sensors, and LED traffic light modules. Based on the circuit design, the IR sensors and traffic light modules are attached to the Arduino Nano ports. The program of the density-based traffic light systems is uploaded into the Arduino Nano microcontroller. Then, the standalone PV solar system is assembled with the smart traffic light system by connecting the DC-DC converter module's USB port to the Arduino Nano's input port. As illustrated in Figure 4.3, the prototype base has been built using a black polyplast board representing a road with four intersections controlled by a traffic light system.

Precaution steps are taken to ensure that the connections, especially the components' terminal, are correctly connected to prevent the circuit from blowing up and harming the hardware. Figure 4.4 shows the completed project prototype.



Figure 4.3 The prototype of the smart traffic light system with IR sensors



Figure 4.4 The completed project prototype

#### 4.3 **Project Testing Result**

The data collection procedure has been carried out by conducting experiments for seven consecutive days from 27/11/2022 until 3/12/2022 to test the system's performance and obtain more accurate data. In addition, the data collection process is also carried out every hour for 12 hours a day, starting from 7 am until 7 pm. This procedure has been done to ensure that the solar panel can receive maximum sunlight and function properly. Furthermore, the battery bank has been tested by connecting the load on the output side to ensure its efficiency based on the calculation.

During the data collection, the electrical power formula is used to obtain the value of power generated by the solar panel. The relationship between the solar panel power, voltage and current is shown in Equation 4.1. Meanwhile, the battery charging time data has been obtained by referring to Equation 4.2.

(4.1)

Where P = Solar panel power (mW) V = Solar panel voltage (V)I = Solar panel current (mA)

P = VI

$$T = \frac{C}{R} \tag{4.2}$$

Where T = Battery bank charging time (Hours)

C = Battery bank capacity (mAh)

R =Charging current (mA)

#### 4.3.1 PV Solar System Data on Day 1

Table 4.1 shows the data obtained from the standalone PV solar system on 27/11/2022. The weather recorded on that day was hot in the morning and rainy in the afternoon.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)
7 am	3.55	5.68	20.16	3.7	633.80
8 am	3.77	35.63	134.33	3.7	101.04
9 am	3.98	133.54	531.49	3.7	26.96
10 am	4.02	254.00	1021.08	3.7	14.17
11am	4.06	320.00	1299.20	3.7	11.25
12 pm	4.10	10.00	41.00	3.7	360.00
1 pm	3.87	310.00	1199.70	3.7	11.61
2 pm	4.17	240.00	1000.80	3.7	15.00
3 pm	3.93	20.00	78.60	ويبوجرج سيب	180.00
4 pm	3.91	40.00	156.40	3.7	90.00
5 pm	2.64	0.23	0.61	1A MELAKA 3.7	15652.17
6 pm	2.00	0.15	0.30	3.7	24000.00
7 pm	0.25	0.09	0.02	3.7	40000.00

Table 4.1 The result of data collection for day 1

Based on Table 4.1, the solar panel generated the lowest power at 7 pm with a value of 0.02 mW as the sun was getting set. In comparison, the power generated by the solar panel at 11 am is the highest recorded, with a value of 1299.20 mW. The power dropped at noon as the weather started to rain and cloudy in the evening.

#### 4.3.2 PV Solar System Data on Day 2

Table 4.2 shows the data obtained from the standalone PV solar system on 28/11/2022. The weather recorded that day was cloudy and rainy during the data taken.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)
7 am	3.45	0.33	1.14	3.70	10909.09
8 am	4.10	29.96	122.84	3.70	120.16
9 am	4.18	9.75	40.76	3.70	369.23
10 am	4.15	12.37	51.34	3.70	291.03
11am	4.12 LAYS	14.28	58.83 3.70		252.10
12 pm	4.09	18.91	77.34 3.70		190.38
1 pm	4.24	16.53	70.09	3.70	217.79
2 pm	4.32	13.92	60.13	3.70	258.62
3 pm	4.55	11.86	53.96	3.70	303.54
4 pm	4.26	14.67	62.49	3.70	245.40
5 pm	4.10	15.53	63.67	و بىو3.70 سىپ	231.81
6 pm	3.72	10.65	39.62	3.70	338.03
7 pm	0.10	0.16	0.02	1A ME AKA	22500.00

Table 4.2 The result of data collection for day 2

Based on Table 4.2, the lowest power generated by the solar panel was at 7 pm with a value of 0.02 mW. The power generated by the solar panel at 8 am is the highest recorded, with a value of 122.84 mW. The power dropped at 9 am as the weather started to rain for the rest of the day.

#### 4.3.3 PV Solar System Data on Day 3

Table 4.3 shows the data obtained from the standalone PV solar system on 29/11/2022. The weather condition recorded on that day was cloudy for the whole day.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)
7 am	3.64	2.54	9.25	3.70	1417.32
8 am	3.92	19.41	76.09	3.70	185.47
9 am	4.00	38.60	154.40	3.70	93.26
10 am	3.98	130.80	520.58	3.70	27.52
11 am	3.98 LAYS	146.30	582.27	582.27 3.70	
12 pm	3.99	164.20	655.16 3.70		21.92
1 pm	3.97	143.50	569.70	3.70	25.09
2 pm	3.96	69.58	275.54 3.70		51.74
3 pm	3.95	55.69	219.98	3.70	64.64
4 pm	3.95	51.24	202.40	3.70	70.26
5 pm	3.93	34.33	134.92	و بىو 3.70	104.86
6 pm	3.84	19.30	74.11	3.70	186.53
7 pm	0.27	0.08	0.02 AYS	3.70 AKA	45000.00

Table 4.3 The result of data collection for day 3

Based on Table 4.3, the solar panel generates the lowest power at 7 pm with a value of 0.02 mW. The power generated by the solar panel at 12 pm is the highest recorded, with a value of 655.16 mW. Then, the power dropped at 1 pm and forward due to the cloudy weather.

#### 4.3.4 PV Solar System Data on Day 4

Table 4.4 shows the data obtained from the standalone PV solar system on 30/11/2022. The weather condition recorded on that day was cloudy for the whole day.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)	
7 am	3.65	2.89	10.55	3.70	1245.67	
8 am	3.82	25.61	97.83	3.70	140.57	
9 am	3.88	38.97	151.20	3.70	92.38	
10 am	3.98	110.80	440.98	3.70	32.49	
11 am	3.95 LAYS	159.50	630.03 3.70		22.57	
12 pm	3.92	159.70	626.02 3.70		22.54	
1 pm	3.97	240.00	952.80	3.70	15.00	
2 pm	3.97	185.70	737.23	3.70	19.39	
3 pm	3.98	154.30	614.11	3.70	23.33	
4 pm	3.98	81.30	323.57 3.70		44.28	
5 pm	3.99	61.50	245.39	و بىو 3.70-	58.54	
6 pm	3.85	4.35	16.75	3.70	827.59	
7 pm	0.29 <sup>RSI</sup>	0.50	0.15 AYSIA MEAA		7200.00	

Table 4.4 The result of data collection for day 4

Based on Table 4.4, the solar panel generates the lowest power at 7 pm with a value of 0.15 mW. The power generated by the solar panel at 1 pm is the highest recorded, with a value of 952.80 mW. Then, the power dropped at 2 pm and forward due to the cloudy weather.

#### 4.3.5 PV Solar System Data on Day 5

Table 4.5 shows the data obtained from the standalone PV solar system on 1/12/2022. The weather condition recorded on that day was cloudy during the experiment data was taken.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)				
7 am	3.78	9.24	34.93	3.70	389.61				
8 am	3.85	53.65	206.55	3.70	67.10				
9 am	3.93	101.70	399.68	3.70	35.40				
10 am	4.14	143.30	593.26	593.26 3.70					
11 am	4.15	154.50	641.18	3.70	23.30				
12 pm	3.97	167.30	664.18	3.70	21.52				
1 pm	3.97	136.80	543.10	3.70	26.32				
2 pm	3.98	145.40	578.69	3.70	24.76				
3 pm	3.97	128.90	511.73	3.70	27.93				
4 pm	3.95	113.60	448.72 3.70		31.69				
5 pm	3.92 <sub>RSI</sub>	- 79.82	312.89	1A N3.70 AKA	45.10				
6 pm	3.89	8.68	33.77	3.70	414.75				
7 pm	0.31	0.90	0.28	3.70	4000.00				

Table 4.5 The result of data collection for day 5

Based on Table 4.5, the lowest power generated by the solar panel was at 7 pm with a value of 0.28 mW. The power generated by the solar panel at 12 pm is the highest recorded, with a value of 664.18 mW. Then, the power dropped at 1 pm and forward due to the cloudy weather.

#### 4.3.6 PV Solar System Data on Day 6

Table 4.6 shows the data obtained from the standalone PV solar system on 2/12/2022. The weather condition recorded on that day was rainy for the whole day.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Current (mA) Solar Panel Power (mW)		Charging Time (Hours)
7 am	3.02	0.13	0.39	3.70	27692.31
8 am	3.85	7.46	28.72	3.70	482.57
9 am	3.99	10.37	41.38	3.70	347.16
10 am	3.99	11.02	43.97	3.70	326.68
11 am	4.01 LAYS	12.35	49.52	3.70	291.50
12 pm	4.09	15.21	62.21	3.70	236.69
1 pm	4.15	16.52	68.56	3.70	217.92
2 pm	4.15	17.15	71.17	3.70	209.91
3 pm	4.11	10.66	43.81	3.70	337.71
4 pm	4.19	10.13	42.44	3.70	355.38
5 pm	3.65	9.53	34.78	و بىو3.70 سىپ	377.75
6 pm	2.51	5.34	13.40	3.70	674.16
7 pm	UNIVERSI	0.10	0.01 0.01	1A ME AKA 3.70	36000.00

Table 4.6 The result of data collection for day 6

Based on Table 4.6, the solar panel generates the lowest power at 7 pm with a value of 0.01 mW. The highest power generated by the solar panel recorded at 2 pm was 71.17 mW. Then, the power dropped at 3 pm due to the rainy condition.

#### 4.3.7 PV Solar System Data on Day 7

Table 4.7 shows the data obtained from the standalone PV solar system on 3/12/2022. The weather condition recorded on that day was cloudy for the whole day.

Time	Solar Panel Voltage (V)	Solar Panel Current (mA)	Solar Panel Power (mW)	Battery Bank Voltage (V)	Charging Time (Hours)
7 am	3.51	3.02	10.60	3.70	1192.05
8 am	3.65	32.87	119.98	3.70	109.52
9 am	3.94	41.26	162.56	3.70	87.25
10 am	4.10	109.30	448.13	3.70	32.94
11 am	4.10 LAYS	135.90	557.19 3.70		26.49
12 pm	4.11	149.90	616.09 3.70		24.02
1 pm	4.12	250.00	1030.00	3.70	14.40
2 pm	4.12	196.80	810.82 3.70		18.29
3 pm	3.98	154.30	614.11	3.70	23.33
4 pm	3.96	93.30	369.47	3.70	38.59
5 pm	3.89	55.10	214.34	و بىو3.70 سىپ	65.34
6 pm	3.86	3.67	14.17	3.70	980.93
7 pm	0.25	0.94	0.24	3.70 AK	3829.79

Table 4.7 The result of data collection for day 7

Based on Table 4.7, the lowest power generated by the solar panel is at 7 pm with a value of 0.24 mW. The power generated by the solar panel at 1 pm is the highest recorded, with a value of 1030.00 mW. Then, the power dropped at 2 pm due to the cloudy condition.

#### 4.4 Standalone PV Solar System Average Data Analysis

The result obtained from the experiment has been analyzed and calculated to get the average data value. The average output of solar panel voltage, current, power, battery voltage and charging time data for the 7 days are shown in Table 4.8 below.

	Average											
Day	Day Solar Panel Output Voltage (V) Solar		Solar Panel Output Power (mW)	Battery Bank Voltage (V)	Battery Charging Time (Hours)							
1	3.40 LAYS	105.33	421.82	3.70	6238.15							
2	3.80	12.99	54.02	3.70	2786.71							
3	3.64	67.35	267.26	3.70	3636.40							
4	3.63	94.24	372.82	3.70	749.57							
5	3.68	95.68	382.23		394.81							
6	3.52	9.69	38.49 MALAYS	3.70	5196.13							
7	3.66	94.34	382.13	3.70	495.61							

Table 4.8 The average data obtained from the standalone solar system

Figure 4.3 illustrates the graph of the relationship between the average solar panel power and average solar panel current. According to the graph in Figure 4.5, average solar panel power increases as average solar panel current increases.



Figure 4.5 Graph of the relationship between average solar panel current and average solar panel power.

Due to the fact that the prototype testing is conducted near the end of the year, that is during the rainy season in Malaysia, the 7-day average intensity of solar radiation is relatively low. As the weather over the past month has been predominantly gloomy and rainy, there is a major difference between the data taken each day.

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Besides, the suggested size of this project's solar panel is another element that contributes to the low output current of the solar panel. Based on the solar panel PV sizing calculation in Chapter 3, the peak sun hour specified in the calculation is 4 hours, as the experiment is expected to be conducted on a bright sunny day. Nonetheless, on the day of testing, the weather is mostly cloudy for the entire week, which affects the PV solar panel output. On a sunny day, the proposed 2 W, 5 V PV solar panel is supposedly able to produce a maximum current output of 400 mA. However, this PV solar panel cannot reach its maximum output current in overcast weather and only produce a small current as due to the incompatibility of PV solar panel specifications. As a result, the solar panel's ability to

convert more sunlight into electricity is diminished. Based on the experimental data obtained, the highest average output power produced by the solar panel is only 421.82 mW, with an average output current of 105.33 mA.

Next, the charge controller is the most important element when charging a lithiumion battery. It regulates the charging current to protect the battery bank from overcharging and over-discharging. Based on the experimental data in Table 4.8, the battery bank took a long time to fully charge, which is more than 24 hours. Since the output current from the panel is low, the charge controller module does not work correctly. This issue happened because the three parallel TP4056 modules need at least 4 A of input current to quickly and safely charge the 3.6 A battery bank.

Figure 4.6 shows the relationship between the average solar panel current and battery bank charging time. According to the graph in Figure 4.6, the average charging time of a battery bank decreases as the average solar panel output current increases. This relationship indicates that the higher the output current produced by the solar panel, the shortest time it takes for the battery bank to charge fully.



Figure 4.6 Graph of the relationship between the average battery bank charging time and average solar panel current.

Due to the PV solar panel's inability to convert sunlight into electricity at its optimum capacity, it takes a long time to charge the battery bank during the experiment. However, this issue is resolved by connecting the charge controller's micro-USB input port directly to the 4 A current source. Consequently, the time required to fully charge the battery bank is shortened.

In addition, the battery's endurance has been considered and analyzed to ensure that the battery bank can power the load at its maximum capacity. The battery endurance of the battery bank is the maximum amount of time it can support the load by itself. The battery bank endurance is obtained using the formula (4.3) shown below.

Battery Bank Endurance = 
$$\frac{V_{dc} \times Ah}{load}$$
 (4.3)

The battery endurance can be determined by using the battery's specifications in this project. Assuming the capacity of the battery is at its optimal capacity,

Battery Bank Endurance = 
$$\frac{3.7 V \times 3.6 Ah}{3.3 W}$$
 (4.4)  
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Battery Bank Endurance = 4.04 Hours

Referring to (4.4), theoretically, the battery bank can power the system for up to 4.0364 hours. Usually, the efficiency of any battery bank is only around 85% of its claimed specification. Therefore, the actual battery endurance is considered as below.

Battery Bank Endurance = 
$$\frac{3.7 V \times 3.6 Ah}{3.3 W} \times 85\%$$
 (4.5)

Battery Bank Endurance = 3.43 Hours

Based on (4.5), the actual battery bank endurance is 3.43 hours with a capacity loss of around 0.54 Ah. However, during testing, the battery bank could only power the smart traffic light system for 45 minutes or 0.75 hours. The battery bank is supposed to be able to power the load for up to 3 hours, as targeted. However, according to the 18650 Lithium-Ion battery specification, the battery has a cutoff voltage range of approximately 2 V to 2.5 V. The battery bank will stop discharging when the battery bank voltage reaches its cut-off voltage. Thus, the 18650 Lithium-Ion battery type was unsuitable to be used as a battery bank in this project due to its limited specification.

#### 4.5 Smart Traffic Light System Performance Analysis

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The smart traffic light system is an intelligent traffic management system that uses solar power as its primary energy source and advanced algorithms to optimise traffic flow and reduce congestion. This system consists of 3 significant elements: the Arduino Nano microcontroller, IR sensors and LED traffic light modules. All these elements consume about 3.3 W of power per hour. The IR sensors have been connected to the Arduino Nano to control the traffic light system based on the traffic density. After the traffic light system has been loaded, digital Infrared sensors detect the traffic density. The infrared sensors identify vehicles based on the light in their reflection. The sensors have been installed adjacent to the road and facing the lane to measure the traffic density. In addition, the IR sensor has been placed at a considerable distance from the lane to detect stopped traffic once a predetermined threshold has been achieved. Table 4.9 shows that the infrared (IR) sensor is programmed to detect obstacles representing traffic density.

Sensors Condition	Time for the sensor to respond
Starting (the sensor loading once the system startup)	1 second
Indicator ON (sensor detects obstacle)	1 second
Indicator OFF (no obstacle detected)	1 second

#### Table 4.9 Condition of IR sensors

The IR sensor required one second to load during the system's initialization. Once the sensor has been loaded, it is ready to work. Table 4.10 shows the green traffic light signal duration based on the traffic density. When an obstacle is detected, the IR sensors transmit the signal to the Arduino Nano to change the traffic light modules on the high-density lane to green for 5 seconds. However, if any vehicle density is still detected on the same road, the traffic light module on that road will keep showing green until the road is clear. When no density is detected, the IR sensor indicator will turn off and send a signal to Arduino Nano to change the traffic light module to red light and rotate the sequence until the lane with the high-density vehicle is detected again.

Table 4.10 Duration of green traffic light signal based on the traffic density

Traffic Density	Duration of green traffic light signal (s)
Low (1 sensor ON on a particular lane)	5 s
High (2 sensors ON on particular lane)	$\geq 10 \text{ s}$

Moreover, this smart traffic light system could reduce traffic congestion and improve traffic flow. The road users do not need to wait long even though no vehicle is in the other lane, as the traffic light automatically runs in a density-based system and prioritizes the lane with high density. A non-conventional energy source, the standalone PV solar system power, also supplies this smart traffic light system. Table 4.10 shows the comparison between the conventional traffic light system and the proposed smart traffic light system.

Criteria	Conventional Traffic Light System	Proposed Smart Traffic Light System
Time	Unnecessary time wastage	Save time
Power	High power consumption	Low power consumption
Energy source	Conventional	Non-conventional
Control system	Manual	Automatic

Table 4.11 Comparison of conventional and smart traffic light systems

#### 4.6 Summary

This chapter summarises the experimental data collection and analysis performed in this project to determine system performance. The proposed standalone PV solar system is targeted to be conducted on a bright sunny day so that the PV solar panels can produce maximum output power and charge the battery more quickly. The experiment demonstrates that the proposed system sizing is unsuitable to be tested during an overcast day. Throughout the rainy season, the sunlight during the day is inadequate to fully charge the battery bank to support the load when sunlight is unavailable. This project's main objective is to determine the suitability of the solar panel, charge controller, battery, and sensor for a smart traffic light system. Overall, the proposed standalone PV solar system is under-designed as the suggested specification of the PV solar panel, charge controller, and battery bank are insufficient to power the smart traffic light system as desired. Nevertheless, the traffic light system has been successfully operated based on the traffic density by using infrared sensors as obstacle detectors.

#### **CHAPTER 5**

#### CONCLUSION AND FUTURE IMPROVEMENTS

#### 5.1 Introduction

This chapter describes the development of a smart traffic light system using a solarpowered standalone PV system. This project is targeted to study and evaluate the suitability of elements in a standalone PV solar system to power the smart traffic light system independently. This system is separated into two parts which are the PV solar system and the smart traffic light system. The PV solar system converts electricity from solar energy to power the smart traffic light system and charges the battery bank when sunlight is available. When the sunlight is unavailable, the traffic light will operate using the power stored in the battery bank. The traffic light system works based on the vehicle density in each lane, where the system will prioritize the vehicle in the high-density lane to move first. As a result, this project will help to reduce traffic congestion, especially in urban cities.

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#### 5.2 **Project Objectives**

The three main objectives of this project are briefly revisited and discussed as follows:

### 5.2.1 To analyze the existing traffic light system by studying related articles, journals and works.

In chapter 2, a few existing traffic light systems have been analyzed by studying the related articles, journals, and other researchers' works. The study has been done to review other researchers' works, especially on how other project systems are designed and operated. Based on the literature review, several elements have been compared to find the most suitable components for designing the density-based traffic light system powered by the standalone PV solar system.

## 5.2.2 To design and develop a smart traffic light system integrated with standalone PV solar power.

The second objective has been achieved by designing a standalone PV solar generator and a basic density-based traffic light system. The standalone PV solar generator and smart traffic light system flow have been constructed to ensure both systems work as desired. Besides, the PV solar generator and traffic light system elements have been selected by comparing the components' specifications in Chapter 2. In Chapter 3, the sizing of the solar panel, charge controller and batteries also has calculated based on the system power usage. The project's design is essential to ensure the prototype's development goes as planned. The standalone PV solar system and smart traffic light system have been successfully developed based on the suggested design.

### 5.2.3 To evaluate the suitability of solar panels, charge controllers, batteries and sensors in a smart traffic light system.

In this project, the combination of hardware chosen to build the system must be compatible with one another in order to develop a standalone system. The study has been conducted in Chapter 2 to select the most appropriate equipment for the project by comparing several components. The suitable sizes of solar panels, batteries, and charge controllers have been determined through study and calculations. The solar panel must produce sufficient energy to meet the specifications of the smart traffic light system, and the battery bank must have adequate energy storage capacity for the system to operate when the sun is unavailable. In order to charge a battery bank without overcharging or over-discharging, a suitable solar charge controller is required. Moreover, a suitable sensor for detecting vehicle density has also been selected for the traffic light system. Chapter 4 elaborates on the analysis of the experimental data collected to evaluate the suitability of the components chosen to develop the standalone PV solar system and smart traffic light system. The sizing of the standalone PV solar system has been concluded to be under-designed as the sizing of the solar panel, charge controller, and battery bank proposed is insufficient to produce the desired output.

#### 5.3 **Project Limitation**

During the development of the project prototype and the collection of testing data, a number of limitations and challenges were encountered, which affected the experimental output data.

Since the project testing is done near the end of the year, during the rainy season in Malaysia, the average intensity of solar radiation is relatively low, and the peak sun hour in that season is also shorter. The proposed PV solar system sizing is targeted to be conducted during a sunny day as the peak sun hour, as stated in the sizing calculation, was 4 hours.

Therefore, implementing the proposed PV solar system during an overcast day is incompatible as the ability of the solar panel to convert more solar energy to electricity will diminish. The selection of 18650 batteries as battery banks has caused the charging system to be more complex because it requires many charge controller modules to charge the battery bank faster. Besides, the voltage of a single 18650 Lithium-Ion battery is also low, which makes the PV solar system require a DC-DC boost converter module to step up the voltage to operate the microcontroller.

#### 5.4 **Recommendations**

This project is focused on studying the suitability of the components used to build the standalone PV solar system and smart traffic light system. The sizing of the solar panel, charge controller and battery bank is the most important element in ensuring that the standalone PV solar system can sufficiently power the traffic light system during daylight and overcast days.

A few elements have been analyzed, including the solar panel's performance, charge controller and battery bank endurance. Therefore, a few improvements can be made to this project. The recommendation provided are as follows:

- i. Increase the PV solar panel's size to convert more solar energy into electricity even on cloudy days.
- ii. Use an intelligent charge controller to make the charging circuit simpler and charge the battery faster.
- iii. Increase the battery capacity to 12 V to extend the battery bank's capability to power the smart traffic signal system.
- iv. Use a DC–DC buck converter to step down the voltage if a big battery bank capacity is used to power the load.

#### 5.5 **Project Potential**

Every new invention must have its commercialization potential. Commercialization is the process of transforming anything into a product or service. This process would elevate the project to a level where any company or factory would be interested in the product or system developed from the invention products. Two systems from this project have great potential to be implemented commercially: standalone PV solar systems and smart traffic light systems. The potentials of the smart traffic light system using a solar-powered standalone PV system project are as follows:

- i. Equip at any busy traffic light junctions.
- ii. Implement together with a smart street lighting system.



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#### APPENDICES

### Appendix A Gantt Chart of BDP 1

WEEK	K ACADEMIC WEEK																
TASK	STATUS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Briefing of BDP 1	PLAN																
	ACTUAL																
Selection of BDP project title	PLAN																
	ACTUAL																
Study of project background	PLAN																
	ACTUAL																
Review of problem statement	PLAN																
	ACTUAL																
Literature review	PLAN																
	ACTUAL								SEN								
Identification of hardware and software	PLAN								E								
	ACTUAL								TE								
Project flow chart construction	PLAN								RB								
	ACTUAL								RE								
Design of basic project simulation	PLAN								AK								
	ACTUAL																
Conclusion drafting	PLAN																
	ACTUAL																
Review of BDP 1 report	PLAN																
A AV	ACTUAL																
BDP 1 presentation	PLAN																
~	ACTUAL																
BDP 1 report improvisation and submission	PLAN	ar.															
S	ACTUAL	7															

# Appendix B Gantt Chart of BDP 2

WEEK			ACADEMIC WEEK														
TASK	STATUS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Design and simulation of project system	PLAN																
	ACTUAL																
Purchase project hardware	PLAN	1.	de la caractería de la			e an											
يها فالإل	ACTUAL	1.5	-		1.1		-	J.	Buch	14	1	an	5.0				
Development of prototype	PLAN			_	-				5.		11	1	1				
	ACTUAL							1	10.00								
Hardware troubleshooting	PLAN																
LINIVERSI	ACTUAL	E M	MIL	CA		A B.	1 /	Nº C	21.4	N		A	(A)				
Collection of project data	PLAN	-12		5			i last"	21.2		1.18	l les la		1.00				
	ACTUAL								E								
Analysis and discussion of data obtained	PLAN								TE								
	ACTUAL								RE								
Conclusion drafting	PLAN								RE								
	ACTUAL								AK								
Review of BDP 2 report	PLAN																
	ACTUAL																
BDP 2 mock presentation	PLAN																
	ACTUAL																
BDP 2 presentation	PLAN																
	ACTUAL																
BDP 2 report improvisation and submission	PLAN																
	ACTUAL																