Faculty of Electrical Technology and Engineering

THE DEVELOPMENT OF PORTABLE HYBRID SOLAR WIND CHARGER

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Bachelor of Electrical Engineering Technology with Honours

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THE DEVELOPMENT OF PORTABLE HYBRID SOLAR WIND CHARGER

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A project report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "Portable Hybrid Solar Wind Charger" 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.

Signature	:	
Student Name	:	AHMAD SODIQ BIN LOKMAN
Date	:	28/12/2024

DEDICATION

This report is dedicated to my cherished family, whose steadfast support, encouragement, and sacrifices have been my foundation of strength during my academic pursuits.

I extend my gratitude to my lecturers and mentors for their invaluable expertise, guidance, and inspiration, which have significantly influenced my development.

In conclusion, I extend my gratitude to my friends and colleagues for accompanying me on this journey, imparting your expertise, and rendering this experience both unforgettable and rewarding.

This work embodies your faith in me, and I dedicate it to everybody who have contributed to my success.

ABSTRACT

The Portable Hybrid Solar Wind Charger (PHSWC) is a project that harnesses two renewable energy sources: solar and wind energy. Solar and wind are among the most plentiful natural energy supplies globally and are regarded as favored renewable energy alternatives. Nonetheless, these energy sources encounter challenges, including irregular energy production stemming from climatic fluctuations and geographical constraints. These issues underscore the necessity for a hybrid system to enhance energy capture. The initiative seeks to integrate these two energy sources into a unified system to provide more reliable and sustainable electricity. The primary objective of the project is to offer a systematic and efficient methodology for delivering clean energy to rural areas with restricted grid connectivity. Conventional techniques, such as fossil fuel-powered generators, generate pollution and are less sustainable. The project objectives encompass the design of the hybrid system, the evaluation of the appropriateness of components including solar panels, batteries, and charge controllers, and the verification of the components' dimensions for portability. This project aims to serve outdoor enthusiasts in need of a dependable power source in off-grid locations. The system operates by capturing energy from solar panels and wind turbines, managing electricity using a charge controller, storing it in a battery, and converting it to AC with an inverter. The substantial findings indicate that the PHSWC system effectively delivers a portable, environmentally sustainable, and efficient power source. It can consistently provide electricity for small devices and diminish reliance on conventional fossil fuel-powered generators. In conclusion, the PHSWC project exemplifies a feasible method for clean energy production, providing tangible advantages for outdoor and rural applications while mitigating environmental issues.

ABSTRAK

Pengecas Hibrid Solar Angin Mudah Alih (PHSWC) ialah projek yang menggunakan dua sumber tenaga boleh diperbaharui: tenaga solar dan angin. Solar dan angin merupakan antara sumber tenaga semula jadi yang paling banyak terdapat di dunia dan dianggap sebagai pilihan tenaga boleh diperbaharui yang digemari. Walau bagaimanapun, sumber tenaga ini menghadapi cabaran seperti pengeluaran tenaga yang tidak menentu akibat perubahan iklim dan kekangan geografi. Isu-isu ini menekankan keperluan untuk sistem hibrid bagi meningkatkan keupayaan penjanaan tenaga. Inisiatif ini bertujuan untuk mengintegrasikan dua sumber tenaga ini ke dalam satu sistem yang mampu menyediakan elektrik yang lebih dipercayai dan mampan. Objektif utama projek ini adalah untuk menawarkan kaedah yang sistematik dan cekap dalam menyampaikan tenaga bersih ke kawasan luar bandar yang mempunyai akses grid terhad. Kaedah konvensional, seperti generator berasaskan bahan api fosil, menghasilkan pencemaran dan kurang mampan. Objektif projek ini meliputi reka bentuk sistem hibrid, penilaian kesesuaian komponen termasuk panel solar, bateri, dan pengawal cas, serta pengesahan dimensi komponen untuk memastikan ia mudah alih. Projek ini mensasarkan golongan peminat aktiviti luar yang memerlukan sumber kuasa yang boleh dipercayai di kawasan tanpa grid. Sistem ini berfungsi dengan menangkap tenaga daripada panel solar dan turbin angin, menguruskan elektrik menggunakan pengawal cas, menyimpannya dalam bateri, dan menukarkannya kepada AC menggunakan penyongsang. Penemuan penting menunjukkan bahawa sistem PHSWC berjaya menyediakan sumber kuasa yang mudah alih, mesra alam, dan cekap. Sistem ini dapat membekalkan elektrik secara konsisten untuk peranti kecil serta mengurangkan kebergantungan kepada generator berasaskan bahan api fosil. Kesimpulannya, projek PHSWC membuktikan kaedah yang praktikal untuk penjanaan tenaga bersih, memberikan manfaat nyata untuk aplikasi luar dan kawasan luar bandar sambil mengurangkan isu alam sekitar.

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LIST OF SYMBOLS

δ	-	Voltage angle
$\approx$	-	Approximately equal
%	-	Percentage
η	-	Efficiency factor
π	-	Pi (3.14159)
P	-	Power
A	-	Area
I	-	Current
R	-	Resistance

LIST OF ABBREVIATIONS

V	-	Voltage
PV	-	Photovoltaic
SOC	-	State of Charge
MPPT	-	Maximum Power Tracking Point
AC	-	Alternating Current
DC	-	Direct Current
VAWT	-	Vetical Axis Wind Turbine
HAWT	-	Horizontal Axis Wind Turbine

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CHAPTER 1

INTRODUCTION

1.1 Background

The hybrid portable solar-wind charger is an advanced device that seamlessly combines solar photovoltaic (PV) panels and small wind turbines, utilising their synergistic properties to generate electricity across diverse weather situations. Solar photovoltaic panels harness sunlight and transform it into electrical energy via the photovoltaic effect, exhibiting excellent efficiency on bright days. Nonetheless, their efficacy substantially declines in overcast or inclement weather, constraining their usefulness. Conversely, wind turbines harness the kinetic energy of wind to produce rotational motion, which is subsequently transformed into electricity via a generator. This characteristic enables wind turbines to generate electricity even when solar energy is inaccessible, such as at night or on cloudy days. The hybrid system guarantees continuous power generation by integrating these two renewable energy sources, ensuring reliability throughout the day and throughout seasons. In times of intense sunlight, the solar panel predominates in electricity generation, whilst the wind turbine can augment this energy during breezy circumstances. This dual-resource strategy diminishes reliance on a singular energy source and optimises energy capture efficiency. The system's portable design improves its utility, rendering it appropriate for isolated locations, disaster response situations, and outdoor activities where traditional power sources are inaccessible. It fulfils an essential requirement for dependable, sustainable, and environmentally friendly energy solutions across various contexts. Furthermore, hybrid systems of this nature provide substantial benefits in energy storage and application. The electricity produced by solar panels and wind turbines is stored in batteries, enabling customers to obtain power even when neither resource is readily available. Advanced charge controllers optimise the charging and discharging processes of these batteries, thereby prolonging their lifespan and preserving efficiency. The contemporary hybrid portable solar-wind charger may include inverters for AC power supply, USB outputs for device charging, and intelligent controllers for real-time monitoring of energy production and consumption. These attributes render the system both ecologically sustainable and exceptionally functional and user-friendly.

1.2 Addressing Human or Community Needs of the Project (Sustainable Development Goal (SDG))

In many remote, off-grid communities, the absence of reliable energy sources presents a significant challenge. Traditional energy solutions, such as diesel generators, not only prove unsustainable but also emit harmful air pollutants. Conversely, the adoption of clean energy technologies, such as solar and wind power, exemplifies a sustainable alternative, aligning directly with SDG 7's imperative for affordable and clean energy access. Moreover, the transition to clean energy sources brings about additional benefits, notably in promoting improved air quality within surrounding environments, thus addressing SDG 3's mandate for enhancing health and well-being. The implementation of Hybrid Portable Solar Wind Chargers (HPSWC) further advances sustainable development goals. By harnessing renewable energy sources, these devices effectively mitigate greenhouse gas emissions, consequently reducing dependence on fossil fuels and contributing significantly to SDG 13's call to action against climate change. Additionally, HPSWC exemplifies responsible consumption and production practices, a cornerstone of SDG 12. By utilizing renewable energy sources efficiently, these chargers minimize resource depletion and environmental impact, contrasting favourably with traditional energy generation methods. In essence, the integration of clean energy technologies, exemplified by the HPSWC, not only addresses energy poverty but also promotes environmental sustainability, health improvement, and climate resilience, thereby fostering a more mature and inclusive approach to sustainable development.

1.3 Problem Statement

The absence of power sources for outdoor activities in areas without grid power poses significant challenges as modern electronic devices increasingly rely on electricity. Resorting to traditional methods such as fossil fuels in generators to generate electricity becomes not only expensive but also detrimental to the environment, subsequently impacting the health of living organisms in the vicinity. Moreover, alternative power solutions like power banks prove inadequate for long-duration off-grid power needs, as there is no available power source to recharge the power banks. This situation underscores the urgent need for a reliable and sustainable power solution tailored for outdoor activities in off-grid areas, addressing both energy demands and environmental concerns effectively.

1.4 Project Objective

The main aim of this project is to propose a systematic and effective methodology for providing clean energy and to devise a well-structured approach that can be implemented seamlessly to achieve the targeted goals. Specifically, the objectives are as follows:

a) To design the hybrid portable solar wind charger.

b) To evaluate the performance of the hybrid portable solar wind charger.

c) To analyze the suitability of solar panels, batteries, charger controller and inverter using Arduino Uno microcontroller.

1.5 Scope of Project

The scope of this project are as follows:

a) This project is primarily designed for outdoor enthusiasts who require reliable power supply.

b) The sensors used for collecting data input and output of the solar panels and wind turbine.

c) The type of solar panels used in this project is monocrystalline.

d) The DC motor used in this project as generator for wind turbine.

e) The type of battery uses to store the power is polymer lithium-ion battery

f) The type of microcontroller used in this project is Arduino Uno.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The need to guarantee energy independence and reduce climate change has fueled a global search for sustainable energy solutions in recent years. The quantity and accessibility of solar and wind energy make them stand out among the variety of renewable energy sources. The merging of these two renewable energy sources in hybrid systems offers a convincing solution to the variability and erratic nature of standalone solar and wind systems. Hybrid solar-wind chargers are a cutting-edge technology at the vanguard of sustainable energy development. This literature review examines their history, present condition, and potential future applications.

2.2 Solar Power

Semiconductor cells, which generate electrical current when photons from sunlight dislodge electrons on the cell's surface, can be used to convert solar energy into electrical energy. There are several ways to use the sun's radiant light and heat, including solar hot water heating with thermal collectors or photovoltaic cells [1]. Photovoltaic (PV) cells have a modular design that makes it simple to add or remove cells as needed, which gives them an edge over other electricity generation methods. Furthermore, PV cells are lighter and more durable because they don't have any moving parts. A PV cell's power output is contingent upon its orientation and level of exposure to solar radiation. Power generation is improved by orienting PV panels towards the sun on a regular basis. Solar path data can be gathered using sensors tracking the sun continually or by applying calculations. Storage is required to make up for periods of low or no generation, such as at night or on overcast days. Batteries act as a buffer, giving loads consistent power. To find the ideal PV array size and battery capacity combination, optimal sizing and computations are required. The solar panel's operating schematic is displayed in Figure 2.1.

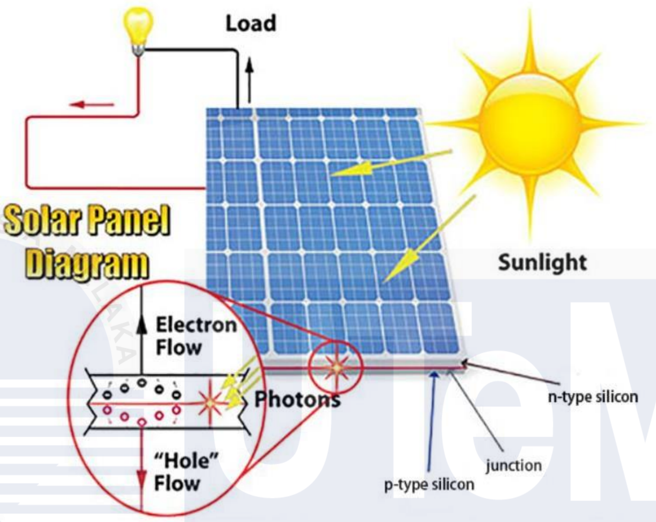


Figure 2.1: Solar Panel's Operating Schematic

2.2.1 Comparative Analysis of Solar Cell Efficiency

The comparison of efficiency between polycrystalline and monocrystalline systems will be discussed in this section. The form made up of several silicon crystal rods is called polycrystalline. Nowadays, polycrystalline is the most often utilised form, with an efficiency of roughly 13% to 16%. Conversely, monocrystalline is composed of bars of pure silicon crystal that have been slightly cut. It will produce efficiency that is 15% to 20% greater than polycrystalline because to this advanced technology. This solar panel will cost a lot because technology and pure silicon are expensive [2]. The specifications for monocrystalline and polycrystalline solar panels are displayed in Table 2.1.

Table 2.1: Solar Cell Specification

Parameter	PV Panel Monokristalin 50 Wp	PV Panel Polykristalin 50 Wp
Ratec Max Power	50 Watt	50 Watt
Power Telorance	0 -+ 5 W	0 -+ 5 W
Max Power Voltage (Wmp)	17.40 V	17.40 V
Max Power Current (Imp)	2.85 A	2.284 A
Open Circuit Voltage (Voc)	22.40 V	22.40 V
Short Circuit Current (Isc)	3.04 A	3.04 A
Cell Effiency	17.60%	17.20%
Junction box	IP 65	IP 65
Max System Voltage	1000 V	1000 V
Max Series Fuse Rating	10A	10A
Application Class	Grace A	Grace A

2.2.2 The Effects of Irradiance in the Solar Cell Output

The energy that the sun emits onto a flat surface per unit area is known as irradiance, and it is one of the key factors affecting how well solar cells work [3]. The amount of irradiance that a solar panel absorbs and converts into electrical energy through solar cells determines how effective and efficient the panel is. This element has been the subject of numerous research, which have shown that higher irradiance levels cause solar cells to produce more energy. Because diodes can adequately describe the properties of solar cells, this work uses them . It indicates that irradiance is being used to test the diode rather than solar cells. Figure 2.2 illustrates how irradiance affects solar output, and equation 2.1 shows the daily extraterrestrial radiation formula.

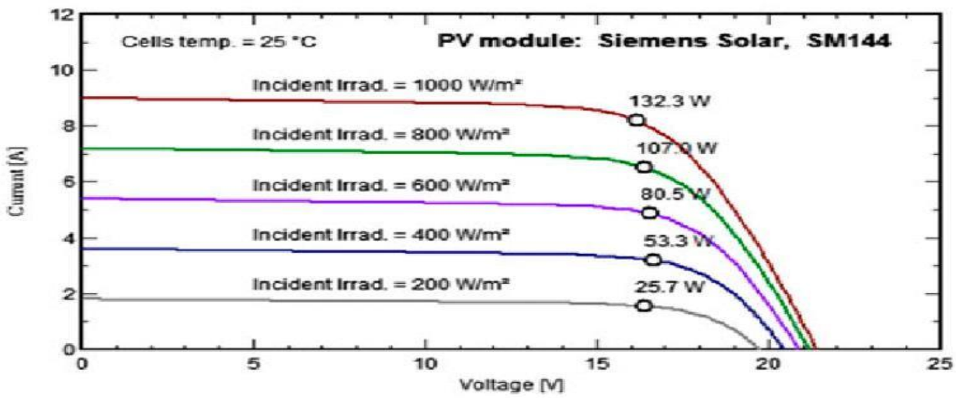


Figure 2.2: Effect of Radiance on Ouput Solar Panel

Daily Extraterrestrial Radiation (H0)

$$= \frac{86{,}400 G_{sc}}{\pi}\left[\left(1 + 0.33\cos\left(2\pi \frac{n}{365}\right)\right)\right] \times \left(\cos \emptyset \cos\delta \sin_{\omega s} + \omega s \, Sin\emptyset \sin\delta\right) \qquad (2.1)$$

2.2.3 Relationship Between the Direction of Sunlight and Output of Solar Power

Optimising the direction of sunlight and solar power output is essential for maximising the efficiency of solar energy systems. When solar panels are looking straight into the sun, they maximise their efficiency in capturing sunlight and produce more electricity [4]. The amount of sunlight that reaches the solar panel's surface depends on the angle of incidence, or the angle at which it strikes the panel. A higher percentage of sunlight can be converted into electricity by the solar cells when it hits the panel at an ideal angle. This angle fluctuates based on the latitude of the place, the season, and the time of day. Ultimately, the direction of the sun has a direct impact on the amount of electricity produced by solar panels, and optimising energy production and system efficiency requires careful orientation and tracking. According to a place's position, Figure 2.3 illustrates the inclination that must be applied in order for it to be perpendicular to the sunlight.

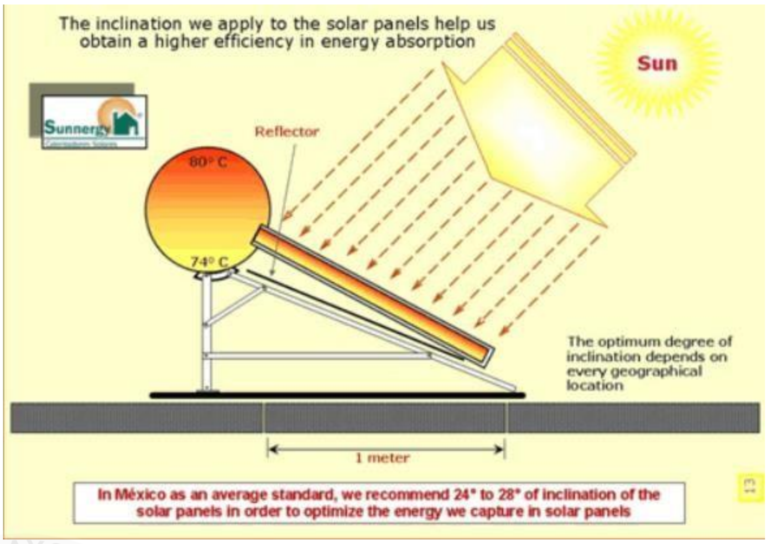


Figure 2.3: Solar Panel Perpendicular to Sunlight

2.2.4 Effects of Dust Accumulation on Solar Power Output

According to this study, dust and debris raise the temperature of solar panels and diminish solar irradiance, which has the most effect on solar panel output [5]. The collection of dust on solar panels can dramatically reduce their output of power and efficiency. Dust creates a barrier on the surface of solar panels, blocking sunlight from getting to the photovoltaic cells underneath. The amount of power generated decreases as a result of this decrease in light absorption. Dust can also cause hotspots and shadowing on the panels, which reduces performance even more and may harm the solar cells over time. To lessen these impacts, regular cleaning and maintenance are crucial, especially in dry areas like deserts where dust accumulation is more common. Numerous elements, such as wind speed, electrostatic charges, gravitational forces, and surface moisture, are thought to affect dust deposition. If dust accumulation is not addressed, maintenance costs may rise and energy production may eventually decrease . The impact of dust on solar panel output is depicted in Figure 2.4.

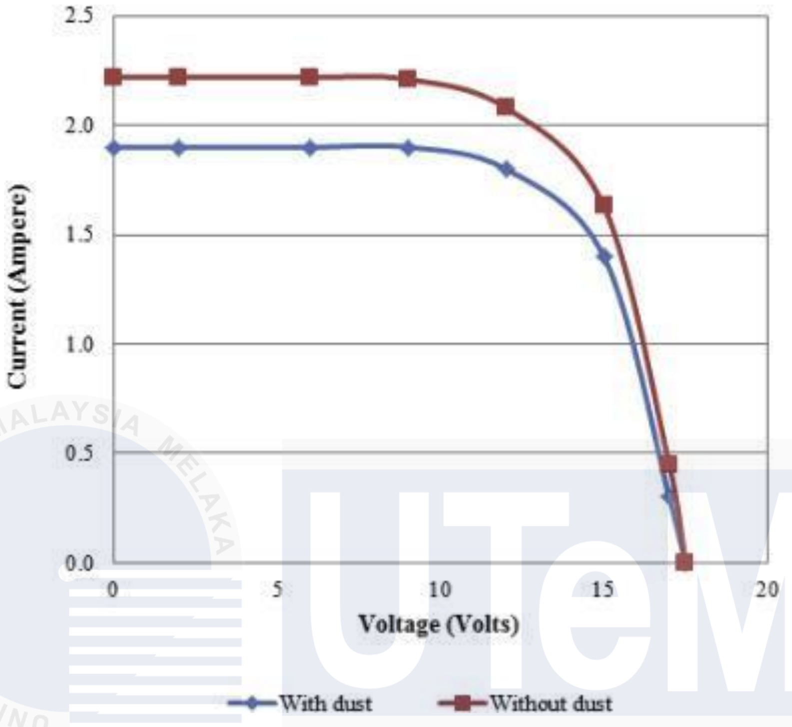


Figure 2.4: Effects of Dust on Solar Output

2.2.5 Effects of Operating Temperature on Solar Power Output

The operating temperature of a photovoltaic panel has a considerable impact on its efficiency and performance. This is a crucial piece of information for project design and analysis, especially for hybrid power plants. The yield value of solar panels drops as surface temperature rises because open circuit voltage, maximum power output, and fill factor all decrease. In addition, as the temperature of the solar panel rises, there is a slight increase in the short current circuit [6]. Mathematical equations can be used to express the link between a solar cell's efficiency and the ambient temperature, which helps to explain how temperature impacts performance. These formulas provide insightful information that can be used to optimise project designs for optimal performance under a range of environmental circumstances. The relationships between a solar cell's efficiency and its surrounding temperature are displayed in equation 2.2.

$$\eta_p = \eta_r[1-\beta_p\,(T_c - T_r)]$$

$$T_c - T_a = (219 + 832\,K_t)\,\frac{NOCT-20}{800} \qquad (2.2)$$

- n_p = Average efficiency
- n_r = Solar cell efficiency
- β_p = Temperature coefficient for module efficiency
- NOCT= Nominal operating for module efficiency
- $\bar{K}_T$ = Monthly clearness index
- Tc = Average module temperature
- Tr = Reference temperature 25 degrees Celsius
- Ta = Mean monthly ambient temperature

2.2.6 Effect of Humidity on Output Solar Panel

This study examines how several photovoltaic (PV) cell types—specifically, monocrystalline, polycrystalline, and amorphous silicon cells—perform when exposed to elevated humidity levels. Clouds and land masses absorb or reflect about 30% of the sun's total solar energy in cities with high humidity levels (40–78%). This results in energy losses in solar cells through absorption and reflection, which make up 15–30% of the energy. Only 70% of the total energy is used when there is a 5% reduction in solar light reaching the cells due to humidity. This energy loss causes notable fluctuations in the short circuit current (ISC) and nonlinear changes in the open circuit voltage (VOC), both of which lower the PV cells' performance efficiency. According to the study, reduced relative humidity raises the energy, voltage, and current produced, which improves the solar cells' power efficiency. These results emphasise the negative correlation between solar energy system efficiency and relative humidity, underscoring the significance of taking environmental conditions into account while deploying and optimising photovoltaic technology [7]. The output power decreases as humidity rises, as seen in Figure 2.5.

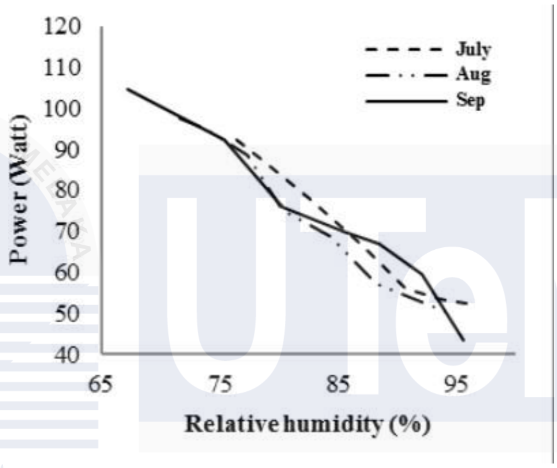


Figure 2.5: Output Power vs Relative Humidity

2.3 Wind Power

Wind power, an essential component of renewable energy, utilizes wind turbines to harness the kinetic energy of moving air and convert it into electricity. These turbines feature large blades mounted on towers, which rotate as wind blows, generating mechanical energy that is then converted into electrical power. The use of wind power is very environmentally friendly and plays a critical role in economic growth, creating more employment opportunities and promoting the development of science and technology [8]. Wind resource assessment is crucial for identifying suitable locations for wind farms, considering factors like wind speed and direction. However, challenges such as intermittency and grid integration must be addressed. Ongoing technological advancements aim to enhance wind turbine efficiency and reduce environmental impacts. Despite challenges, wind power remains a key solution in the global transition to sustainable energy. Figure 2.6 shows the working principle of wind turbine. When the wind impacts the blades, causing them to rotate, the gearbox modulates the rotational speed, transforming the larger, slower rotations into smaller, quicker ones to power the generator. The generator subsequently generates energy, which is transmitted to a transformer to increase the voltage prior to distribution to consumers.

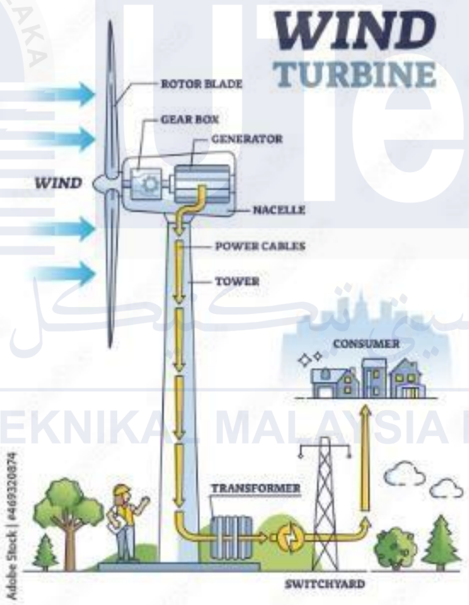


Figure 2.6: Wind Turbine Working Diagram

2.3.1 Types of Wind Turbine

HAWTs and VAWTs are the two types of wind turbines that use wind energy to generate electricity. The blades and efficiency of these two varieties differ. It's crucial to select the right kind of wind turbine for the job; VAWTs work well for small-scale applications, while HAWTs are typically utilised for huge wind farms. The most common type of wind turbine these days, HAWTs have blades that are perpendicular to the direction of the wind and have an efficiency of about 45%. The turbine shaft in a VAWT is vertical and perpendicular to the direction of the wind. This implies that the wind VAWTs can flow in any direction. Because of their roughly 35% efficiency, VAWTs are not very popular [9]. The two types of wind turbines are depicted in Figure 2.7.

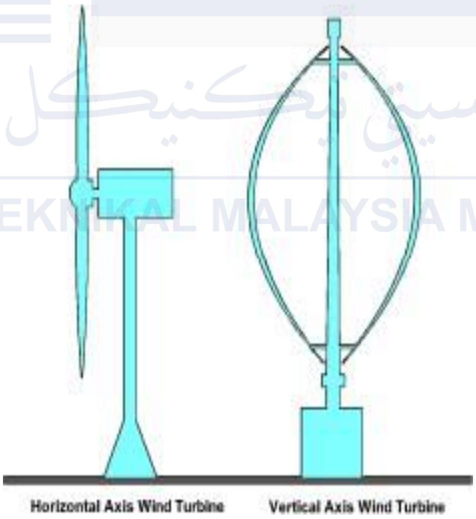


Figure 2.7: Two Types of Wind Turbines [9]

2.3.2 Effect of The Number Blade on The Efficiency of a Wind Turbine

A renewable energy system's wind turbine blade is a crucial part since it can harness wind energy. The swept area of the blades of a wind turbine directly relates to the amount of electricity it can generate from the wind. This indicates a direct relationship between the blades and power generation. A wind turbine's torque output and rotational speed decrease with the number of blades it possesses. Turbines that produce energy normally need to run at high speeds, which means they don't need much torque. Horizontal axis wind turbines typically consist of three blades because of this compromise. Designing wind turbines with a single blade would result in imbalance, making it impractical; yet, designing with two blades gives an uneven torsional force at the core of the blade, which causes vibration and eventually mechanical failure. In contrast to wind turbines with three blades, wind turbines with more blades would create more wind resistance, poorer power generation, and overall inferior efficiency. Three-blade wind turbines offer the best balance of cost-effectiveness, high power, stability, small weight, and turbine durability [10]. The power coefficient of a two- and three-bladed wind turbine is plotted against tip speed in Figure 2.8.

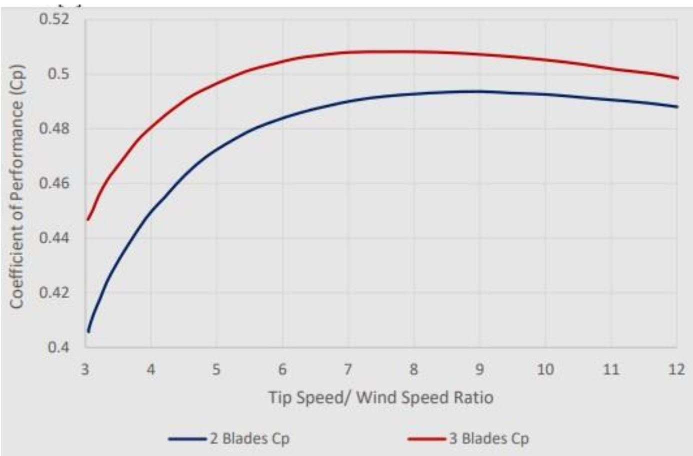


Figure 2.8: The Power Coefficient of Versus Tip Speed of a Two Bladed and Three Bladed Wind Turbine [10].

2.3.3 Effect of the Incident Angle of Wind to the Output of Wind Turbine

The performance characteristics of a multi-blade drag-type vertical-axis wind turbine (VAWT) with stationary vanes acting as wind direction plates are examined in this work. In comparison to lift-type turbines, drag-type VAWTs are known for their strong beginning torque, superior self-starting capabilities, and non-directionality with respect to wind direction. These attributes enable them to function efficiently at lower speeds. They often generate less output per sectional area, though. In order to overcome this, the research created and approved a technique for estimating the output power of these turbines using only the features of a single rotor blade. Measurements made in a wind tunnel verified the precision of the approach. The findings showed that turbine production is greatly increased by stationary vanes. Additionally, it was found that the ideal wind incidence angle for highest output was from 44 to 48 degrees and varied with wind speed between 6 and 12 m/s. The results showed that the incidence angle's effect on output power varies significantly above and below this optimal range, emphasising the significance of accurate angle adjustment for efficiency maximisation [11]. When approaching a specific incidence angle, the turbine's power production and rotational speed are displayed in Figure 2.9.

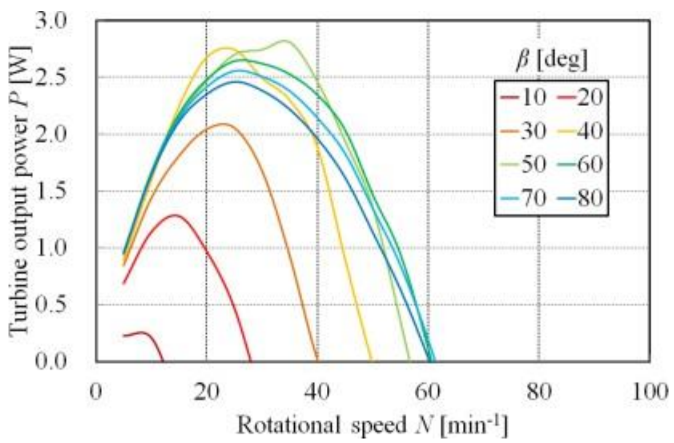


Figure 2.9: Characteristics of Incident Angle [11]

2.3.4 Wind Speed in Malaysia

Due to rising energy demands and the depletion of conventional energy sources, wind energy has attracted significant interest recently on a global scale. Wind energy is widely acknowledged as an economical and sustainable substitute that may make a substantial impact on lowering carbon emissions. Wind energy has grown rapidly; by the end of 2018, its global generation capacity had reached 564 GW. In Malaysia, the wind energy sector and academia have developed a strong interest in wind energy. The present paper offers a thorough overview of wind energy research conducted in Malaysia, with particular emphasis on wind potential assessments, wind direction and speed modelling, wind forecast, spatial mapping, and the ideal sizing of wind farms. A lack of standardised wind data has led researchers to investigate hybrid power systems that combine solar and hydropower. The assessment found that typical wind speeds in Malaysia varied from 2 to 8 m/s, depending on monsoon conditions. Many techniques have been used to convert wind energy, including power law, computer programmes like HOMER, wind turbine power curves, and wind speed density distributions. For wind speed data, the Weibull distribution is frequently advised. Vertical-axis wind turbines, which function well in varying wind directions, and hybrid renewable energy systems have been suggested as workable solutions despite difficulties in commercial wind power generation caused by low average wind speeds. In addition to highlighting the potential advantages of hybrid systems that combine several renewable energy sources, the study underscores the necessity of designing wind turbines specifically matched to Malaysia's wind profile [12]. Data on Malaysia's power density, wind speed, and energy density are displayed in Table 2.2.

Table 2.2: Power Density, Wind Speed and Energy Density in Malaysia [12]

Location	Power Density (W/m^2)	Wind Speed (m/s)	Energy Density
Kuala Terengganu	Average in 2017 was 43.42 W/m^2	2.01	N/A
Mersing	18.2 – 25 W/m^2	Average between 2 and 6	N/A
Kudat and Labuan	Highest power density was 67.40 W/m^2 in Kudat and 50.81 W/m^2 in Labuan	Kudat: 3.37, 3.36, 3.00 (2006–2008), Labuan: 3.50, 3.81, 2.67	Maximum: 590.40 kWh/m^2/year (Kudat), 445.12 kWh/m^2/year (Labuan)
Langkawi	N/A	Mean speeds: 2.00 and 2.50 at 10 and 30 m	Range: 68.6–286.7 kWh/m^2/year
Perlis (Chuping and Kangar)	Chuping: 2.13 W/m^2, Kangar: 19.69 W/m^2 at hub heights above 50 m	Average: 1.2 & 2.5	N/A
Butterworth	32.61 and 35.65 W/m^2 for 2008 and 2009 respectively	Average: 2.86	288.23 and 315.10 kWh/m^2/year at hub height of 100 m

Sarawak	Highest/lowest power density: 34.39–18.67 W/m² (Marudi), 32.66–15.82 kWh/m²/year (Kula Baram)	Average annual: 2.0	N/A
Kuala Terengganu	Kuala Terengganu	2.9201 (highest)	N/A
Peninsular Malaysia	Monthly range: 84.60 and 15.20 W/m²	2.00–5.20	N/A

2.4 Microcontroller

A microcontroller is a tiny integrated circuit that is used in embedded systems to control particular functions. A microcontroller is a single chip that consists of a CPU, memory, and input/output (I/O) peripherals. Microcontrollers, sometimes known as embedded controllers or microcontroller units (MCUs), are found in a variety of products, including cars, robotics, office equipment, medical equipment, mobile radio transceivers, vending machines, and home appliances. They are essentially tiny, straightforward personal computers (PCs) without complicated front-end operating systems (OS) that are intended to control specific functions of a bigger component [13].

2.4.1 Arduino Uno

The Arduino Uno is an open-source electrical device that employs an ATmega328P processor with a dual in-line package (DIP) or surface-mount device (SMD) to act as the system's controller. It also features an ICSP header, a USB port, a reset button, six analogue input pins, fourteen digital input and output pins, and a 32 Kb flash memory capacity to store embedded code or sketches. It operates at a frequency of 16 MHz. While 1 Kb and 2 Kb EEPROM are available for SRAM [14]. An easy-to-use integrated development environment (IDE) is offered by the open-source Arduino platform, which includes the Arduino Uno, for authoring, compiling, and uploading code to the board. It is simple to locate resources, lessons, and project ideas on the platform thanks to its large library support and vibrant community. The Uno's price, versatility, and ease of use make it a popular choice for DIY electronics, educational environments, and prototyping. A dependable and easy-to-use starting point for exploring the realm of microcontroller programming, the Arduino Uno is ideal for managing LEDs, perceiving sensors, or constructing intricate robotic structures. The Arduino Uno board used in this project is shown in Figure 2.10.

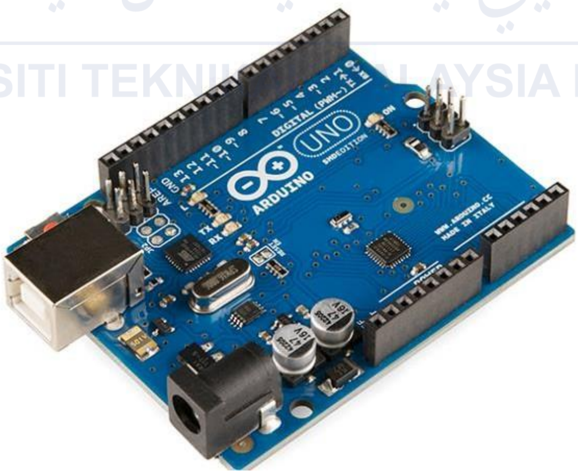


Figure 2.10: Arduino Uno Board

2.5 An Overview of Previous Studies Related to Hybrid Portable Wind Solar Charger

Portable Hybrid Solar Wind Chargers represent an innovative solution for sustainable energy generation, combining wind and solar power to create a versatile and efficient charging system. These chargers are particularly useful in remote or off-grid locations where traditional power sources are unavailable. This overview synthesizes the findings from various studies on hybrid portable wind-solar chargers, highlighting their design, performance, and potential applications.

2.5.1 Portable Hybrid Power Storage System

In order to solve the absence of electrical power for electronic devices in remote locations without utility electricity, this research introduces a portable hybrid power storage system. Because of their large weight and inflexible installation, traditional solutions like uninterruptible power supply (UPS) with generators are frequently impracticable. In contrast, the suggested system is small, lightweight, and portable. It can supply power continuously in both AC and DC versions. It includes a battery with improved charging current regulation, a rectifier, a power switch, a buck-boost converter, an inverter, and a unique AC/DC converter circuit. This eco-friendly system uses solar, generators, or utility power to power up to 500W of devices, including fans, lamps, and mobile chargers, for six hours. By keeping the battery's state of charge (SOC) between 20 and 90 percent and restricting charging and discharging currents to less than 20 amps, optimal battery sizing guarantees efficient operation, prolonging battery life and lowering replacement costs in the future. The system is a workable answer for remote power requirements because it shows suitability for both AC and DC loads with lower capital costs and better performance [15].

2.5.2 A study on Combined Batteries with a Solar/Wind Hybrid Renewable Energy System

The use and benefits of solar-wind hybrid energy systems (SWHES) as a sustainable option for future energy production are examined in this study. Investigating alternate, environmentally friendly energy sources is becoming more and more important as a result of the depletion of coal and rising expenses related to conventional power generation. With its abundance and environmental friendliness, solar energy has enormous potential to supply the energy needs of the future. SWHES, which combines solar and wind power generation, can provide a dependable and consistent power source that is especially advantageous for low-power applications. The study suggests a hybrid structure and the optimal battery energy storage system (BESS) capacity for renewable energy facilities in an effort to balance resource allocation and load needs at a reasonable cost. The study uses degradation models for batteries and supercapacitors in addition to mathematical modelling methodologies for photovoltaic (PV) and wind turbine (WT) systems. In order to satisfy energy demands and optimise resource utilisation, the research shows how successful hybrid RE resources may be through a case study based on real electricity demand data from several Australian states. The review also adds significantly to the body of knowledge on renewable energy integration and system optimisation by shedding light on several power converter topologies and methods of system optimisation for wind-solar hybrid energy systems [16].

2.5.3 Design of Wind and Solar Hybrid Power Plant to Support Electricity Needs for Shrimp Farms in Binangun, Cilacap

In order to meet the electricity needs of prawn ponds, this study leverages Indonesia's rich aquaculture potential to construct a wind and solar hybrid power plant (HPP), addressing the country's commitment to minimise reliance on fossil-based fuels and migrate towards renewable energy sources. The study shows that the suggested solar-wind HPP design is both feasible and advantageous, using HOMER modelling software. In comparison to dependency on the PLN network, the findings show a large reduction in CO2 emissions of 63.8%, with an impressive renewable energy share of 87.2% and significant annual electricity output of 1,998,584 kWh. With 2685 PV modules and 18 wind turbines, the proposed HPP system—which has 1074 kW of solar and 360 kW of wind power capacities—is optimised. In order to guarantee effective power generation, the research also takes peak load needs, oversupply coefficients, and converter capacity into consideration. Overall, the study supports Indonesia's aims for renewable energy by highlighting the potential of solar-wind hybrid systems to provide ecologically pleasant and sustainable energy solutions for particular applications [17].

2.5.4 Investigation of Hybrid Power Performance with Solar Module and Wind Turbine in MATLAB

This study uses MATLAB Simulink to examine the performance of a hybrid power system that combines solar and wind energy with a battery storage technology. The goal of the study is to improve the model's architecture in order to increase efficiency and optimise power output in a range of weather scenarios. The model aims to maximise energy generation by applying maximum power point tracking (MPPT) algorithms for wind turbines and solar photovoltaic (PV) modules. The MATLAB prototype shows that hybrid power generation is feasible in various locations, with only slight variations in power generation noted when solar irradiation levels and wind turbine pitch angles are changed. According to the study's findings, hybrid power generation systems of this kind are feasible and have the potential to be put into practice, especially in Bangladesh and other nations where encouraging green energy is essential for lowering greenhouse gas emissions and reducing dependency on fossil fuels. In addition to adding to the expanding body of information on renewable energy systems, this study emphasises how critical it is to switch to sustainable energy sources in order to address issues with energy security and the environment [18]. Figure 2.11 shows the simulink diagram of hybrid power generation process.

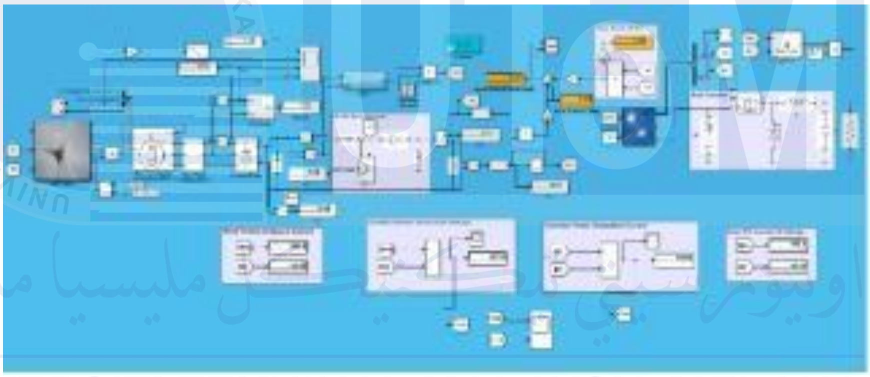


Figure 2.11: Simulink Diagram of The Hybrid Power Generation Process [18]

2.5.5 Self -Sufficient Power Generation Using Solar and Wind Hybrid System

This study proposes an integrated standalone system of solar modules and wind turbines as a solution to the problem of efficiently and economically supplying electricity to rural areas. Power output is derived from a virtual model that was created in Solidworks and verified by Matlab Simulink simulations. The hybrid system uses low-cost wind turbines with HDPE tarpaulin blades and solar tracking technologies to produce electricity. The project is to conceptualize a small integrated system that conserves space in comparison to conventional separate installations by utilizing model-based design thinking technique. The principal aim is to render electricity affordable to all, therefore augmenting energy security in rural areas and advancing sustainability, economic growth, and social justice. The hybrid solar-wind small power plant's efficacy in mitigating electrification issues, decreasing dependence on grid electricity, and conserving conventional resources is emphasized in the conclusion. The technology exhibits potential to supply free energy and facilitate a smooth transition to sustainable power generation in rural areas, with a comparatively short payback period of two years [19].

2.5.6 Experimental Design and Fabrication of Portable Hybrid Wind and Solar Energy System

The goal of this project is to create and test a 5 kW independent hybrid power system that combines solar and wind energy to deliver electricity in off-grid locations like highways. The transportable unit incorporates four 120-watt solar panels, a 1.5 kW wind turbine, a solar charge controller, remote power storage, and battery control. Its dimensions are 8 feet 5 inches wide, 8 feet 4 inches deep, and 38 feet high. To optimize energy generation, the system makes use of low-cost wind turbine using HDPE tarpaulin blades and sun tracking technologies. The gadget is positioned between road dividers and cars, capturing sun energy and wind from passing cars to guide airflow into the turbine for increased power output. Due to its novel design, the hybrid system seeks to balance social equality, economic viability, and sustainability while offering affordable and efficient energy solutions for remote and rural areas. According to preliminary testing, the technology can drastically lower CO2 emissions and dependency on traditional power sources, offering a practical substitute for the deployment of renewable energy. The combination of solar and wind energy also lessens the expensive and short-lived nature of battery storage, which makes the hybrid system a more viable and sustainable choice for stand-alone uses [20]. The hybrid solar wind energy tower's assembled view is displayed in Figure 2.12.

Figure 2.12: Assembled View Of Hybrid Energy Tower [20]

2.6 Comparison of Existing Previous Studies Related to Hybrid Portable Solar Wind Charger

Table 2.3: Comparison of Previous Studies Related to Portable Hybrid Solar Wind charger

No	Authors	Title	Main finding	Application
1	Muhammad Anwer Nazir1 , W. Z. Wan Hasan2 , M. Z. A. Ab. Kadir3 and N. Sulaiman.	Portable Hybrid Power Storage System	The research proposes a portable hybrid power storage that provides continuous power in both AC and DC forms.	In remotes area and off-grid locations.
2	Kuldep Narwat, Megha Gupta.	A Study on Combined Batteries With A Solar / Wind Hybrid	Operating solar and wind power plants as a combined unit enhances the overall	Residential power supply, rural and remote areas.

		Renewable Energy System	system effectiveness and ensuring a stable power supply.	
3	Faizal Basith, Rachmawan Budiarto, M.Kholid Ridwan, Wangi P. Sari.	Design of Wind and Solar Hybrid Power Plant to Support Electricity Needs for Shrimp Farms in Binangun, Cilacap	The study explores the potential of using a hybrid solar and wind power plant to meet the electricity needs of shrimp	Aquaculture: Shrimp pond
4	Md. Shajedul Islam, Sharifur Rahman, Suman Chowdhury.	Investigation of Hybrid Power Performance with Solar Module & Wind Turbine in MATLAB	Perfomance of a hybrid power system combining solar and wind energy with a battery storage system	Hybrid power system can be integrated into national grid to provide a stable and efficient power supply.
5	Nabil Mahadik, Namita Sawant, Khushbu Shirsat, Neha Barai, Dr. Amol Khatkhate	Self-sufficient Power Generation using Solar and Wind Hybrid System	The study proposes a standalone integrated system combining a wind turbine and solar .	Rural area where grid access is limited.
6	Abdul Razak Kaladgi, I.M. Navaneeth, Maughal Ahmed Ali Baig, Avala Raji Reddy, Abdulrajak Buradi.	Experimental Design and Fabrication of Portable Hybrid Wind and Solar Energy System	Standalone hybrid power system combining wind and solar energy. Designed to be portable, device can be used without the need for a grid.	Highway and roadway power supply or remote and off grid locations.
7	AS. Lokman	Development of hybrid solar wind charger	Portable device that can supply power using natural energy like sun and wind. This device can be	Rural area and off grid locations

			useful especially in emergency case.	

2.7 Summary

The current project that closed with this project is summarized in this chapter. To determine which component to employ for their project and which target area to use it for, preceding projects are observed. Solar and wind power are also covered in this chapter. For instance, the efficiency of solar panels is correlated with temperature and irradiance, while the efficiency of wind turbines is correlated with wind speed, turbine type, and blade size. Consequently, every detail in this overview will be closely scrutinized and given due consideration to proceeding this project to the next step, ensure its smooth operation, high degree of efficiency, and, most importantly, its success.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methods and processes used in the project's development are examined in this chapter. This section, which lists the hardware and software tools used to accomplish the project's goals, is very important. The primary focus of this chapter will be on the efficiency of using portable hybrid solar wind chargers. To ensure the project is successful, we will be utilizing a microcontroller based on Arduino Uno in addition to the required software.

3.2 Selecting and Evaluating Tools for a Sustainable Development

The selection and assessment of tools to gather and analyze the data for the creation of a portable hybrid wind-solar charger are described in this section. A portable charging device that incorporates renewable energy sources, such solar and wind power, improves sustainability and helps meet sustainable development objectives. Careful selection of tools and technologies is required. For example, since the device is meant to be "portable," it needs to be small, light, and, most importantly, convenient to take around. The ideal sizes for the solar panels and the DC motor for the wind turbines must be chosen in order to accomplish this. It's also critical to assess the hardware and software compatibility and the project's possible environmental impact. To make sure the project satisfies the intended criteria and goals, the tools are chosen based on a number of aspects. Since solar and wind energy are the main ways to harvest energy from natural resources, their efficiency needs to be carefully studied. In order to reduce energy loss during the conversion process, the charge controller is crucial. Furthermore, because the components must resist a variety of climatic conditions, their endurance is essential. The integration and compatibility of the solar panels, wind turbine, charge controller, inverter, and batteries are necessary for seamless operation. These elements need to work together without problems or conflicts. Thus, in order to avoid mistakes or malfunctions, these components' specs must match. In conclusion, efficiency and sustainability are the main goals of the instruments that are chosen and assessed for the creation of a portable hybrid solar wind charger. This project attempts to produce an environmentally friendly charging gadget by selecting appropriate hardware and dependable software.

3.3 Methodology

The methodology outlines the systematic approach undertaken to design, develop, and evaluate a hybrid portable solar wind charger. The goal is to create a reliable, efficient, and sustainable device that can harness energy from both solar and wind sources to provide portable power.

3.4 Project Architecture

A flowchart is a visual representation of a process, system, or algorithm, typically using standardized symbols to denote different types of actions or steps, and arrows to indicate the flow or sequence in which these actions are performed. Flowchart helps document how a process works, which is useful for training, communication, identifying and analyzing. Figure 3.1 shows the flowchart of the project development.

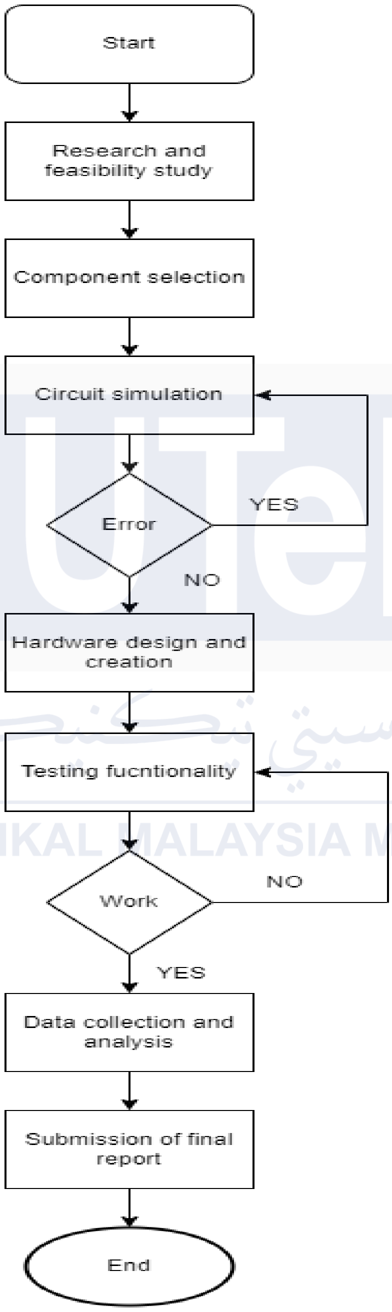


Figure 3.1: Flowchart of the project development

3.4.1 Experimental Setup

This section visualizes how the system operates. Firstly, the solar panels or wind turbine harness energy and convert it to electricity. If there is no wind, only the solar panels will function to absorb energy, and vice versa. The charge controller then regulates the electricity harnessed from these natural sources and stores it in the battery. The stored electricity is then converted to AC using an inverter. The charge controller plays a significant role in determining whether to continue or stop charging the battery. Figure 3.2 shows the flow chart of system operation.

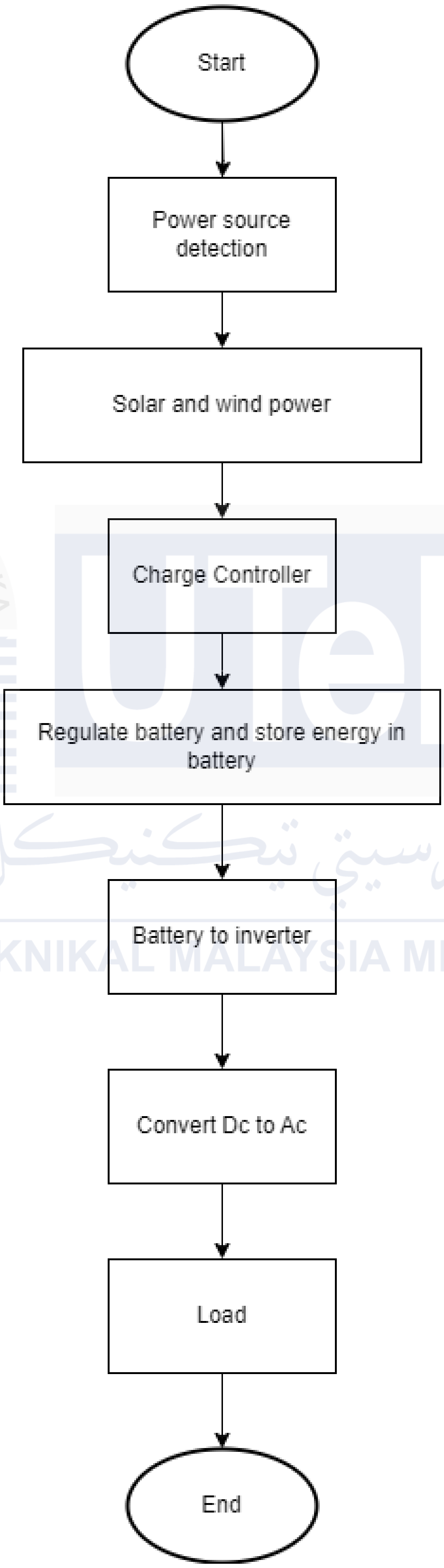


Figure 3.2 : Flowchart of the system operation

3.4.2 Block Diagram

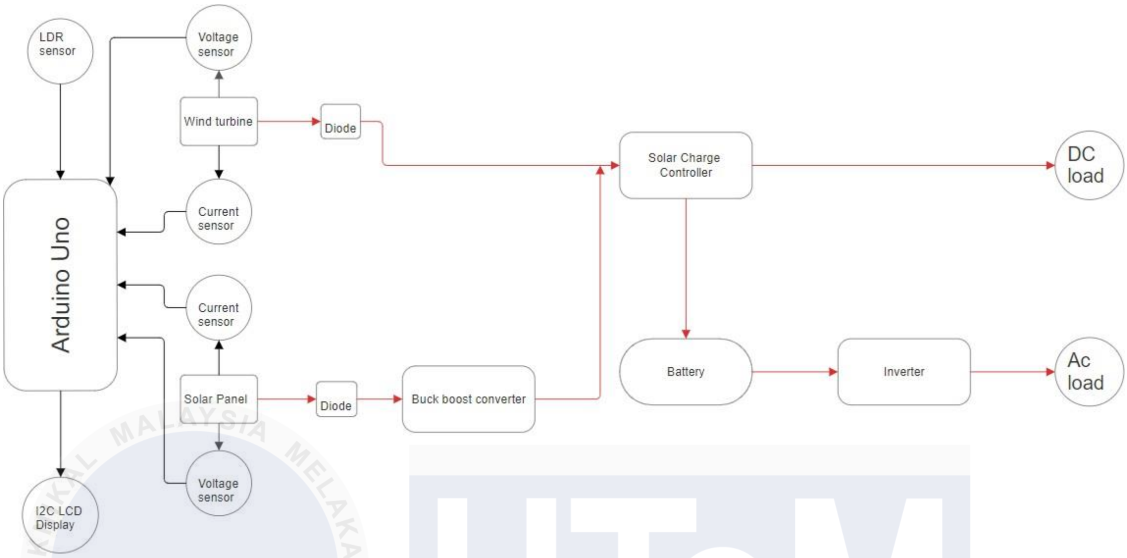


Figure 3.3 : Project Block Diagran

a) The hybridization of solar energy with wind turbine, which operates on direct current (DC), is achieved by connecting two sources in parallel via a diode to prevent current from re-entering between them.

b) When the current and voltage produced by the two sources, they are delivered to the charge controller which then control the amount of current and voltage that goes into the battery and serves as a storage device for extra energy.

c) The buck boost converter can regulate the voltage from the solar panel if the voltage of solar panel drop

d) The inverter will then convert the output from Dc to Ac for Ac load (small watt usage).

e) The reading from the current and voltage sensor will be read to Arduino microcontroller and will be displayed both of solar output and wind turbine output on the LCD display.

f) The LDR sensor will be read to Arduino microcontroller and will be displayed on the LCD display as light intensity.

3.5 Hardware Components

Hardware constitutes the physical elements within a system or device, encompassing electronic and mechanical components, distinct from software, which consists of programs and instructions executed by the hardware. In the absence of hardware, a project remains merely a conceptual framework. Within the domain of a hybrid portable solar wind charger, hardware components are the tangible constituents that form the system's infrastructure and enable its functionality. These components include solar panels, wind turbines, charge controllers, batteries and inverter with each hardware element plays a crucial role in harnessing renewable energy, regulating power flow and storing electricity. Together, these hardware components realize the project's objectives of sustainable energy generation and portability, making it a viable solution for off-grid power needs.

3.5.1 Solar Panel

In this project, monocrystalline solar panels are chosen for their superior efficiency compared to polycrystalline panels. The monocrystalline type excels in converting sunlight into electricity due to its uniform crystal structure, resulting in higher energy yields. Additionally, monocrystalline panels are renowned for their durability and long lifespan, making them a reliable choice for sustainable energy generation in the project. 10-Watt solar panel chosen in this project as its promoted the suitable size portable designing. Figure 3.4 shows the solar panel type for monocrystalline type.

Figure 3.4 : Solar Panel

Specifications of Solar Panel:

- Peak power: 10 W
- Max Power Current, Imp: 0.55 A
- Max Power Voltage, Vmp: 18.00 V
- Short Circuit Current, Isc: 0.60 A
- Open Circuit Voltage, Voc: 22.28 V
- Max System Voltage: 600 V
- Dimensions: 340 x 231 x 18 mm

3.5.2 Charge Controller

The primary role of a charge controller is to oversee and regulate the transmission of electricity between the solar panels or wind turbine and the battery within a renewable energy framework. It actively monitors the voltage output originating from the solar panels or wind turbine to ascertain alignment with the battery's voltage specifications. Furthermore, it safeguards against overcharging by discontinuing the charging current when the battery attains its maximum voltage threshold. Additionally, it governs the charging current provided to the battery, ensuring it remains within the confines of the battery's maximal charging capacity. Figure 3.5 shows the solar charge controller.

Figure 3.5: Solar Charge Controller

Specifications of Solar Charge Controller:

- Model: 10 A
- Max Solar Input: 25V (for 12V battery)
- Discharge stop 10.7V (default, adjustable)
- Discharge reconnect: 12.6V(default, adjustable)

- USB Output: 5V3A
- Operating Temperature: -35ºC ~ +60ºC
- Nett Weight: 130G+-
- Gross Weight: 155G+-

3.5.3 DC Motor

In this project, a DC motor is employed as a generator for the wind turbine. Its primary function is to convert the mechanical energy derived from the wind into electrical energy, which can then be harnessed for various applications. While the electricity generated by the DC motor may not match the output of solar panels in terms of current and voltage, it will demonstrate how the combination of energy sources can lead to the generation of free energy. Additionally, it will illustrate how this mini project can be upgraded to maximize its potential. Figure 3.6 shows the DC motor used in this project.

Figure 3.6: DC Motor

Specifications of DC Motor:

- Model: RS-385 Rated power: 3.6 (W)
- Product Type: Brush DC Motor
- Rated voltage: 12 (V)

- Rated current: 0.15-0.75 (A)
- Rated speed: 9800 (rpm)
- Rated Torque: 70 (g. cm)
- Shape size: 27.7 x 60 mm

3.5.4 Polymer Lithium-Ion Battery

The Polymer lithium-ion battery shown in Figure 3.6 are cutting-edge rechargeable power sources utilized in various modern devices due to their compact design and enhanced safety features. Unlike conventional lithium-ion batteries, they employ a solid or gel-like polymer electrolyte, reducing the risk of leakage and thermal runaway. This innovation not only enhances safety but also allows for greater design flexibility, as these batteries can be manufactured in thinner, lighter forms. Next, with their high energy density, polymer lithium-ion batteries pack more power into a smaller space, making them ideal for portable electronics and electric vehicles. Additionally, they boast a good cycle life, ensuring longevity and reliability in countless applications.

Figure 3.7: Polymer Lithium-Ion Battery

Specifications of Polymer Lithium- Ion Battery:

- Capacity: 9800 mAh
- Input voltage: 12.6 V
- Output voltage: 10.8~12.6 VDC
- Dimensions: 13 x 7 x 2.5 cm
- Weight: ~ 0.35 kg

3.5.5 Module Power Inverter

A power inverter is an electronic device that converts direct current (DC) electricity from a battery or solar panels into alternating current (AC) electricity, which is what most household appliances and devices use. In Asia, most of the country include Malaysia use 220 V Ac for their device. Power inverters achieve this conversion by using electronic components such as transistors, capacitors and transformers. In this project, the type of power inverter is stand- alone inverters which is used in off-grid solar power systems or in applications where grid power is unavailable. Figure 3.8 shows the power inverter for 500-watt appliances.

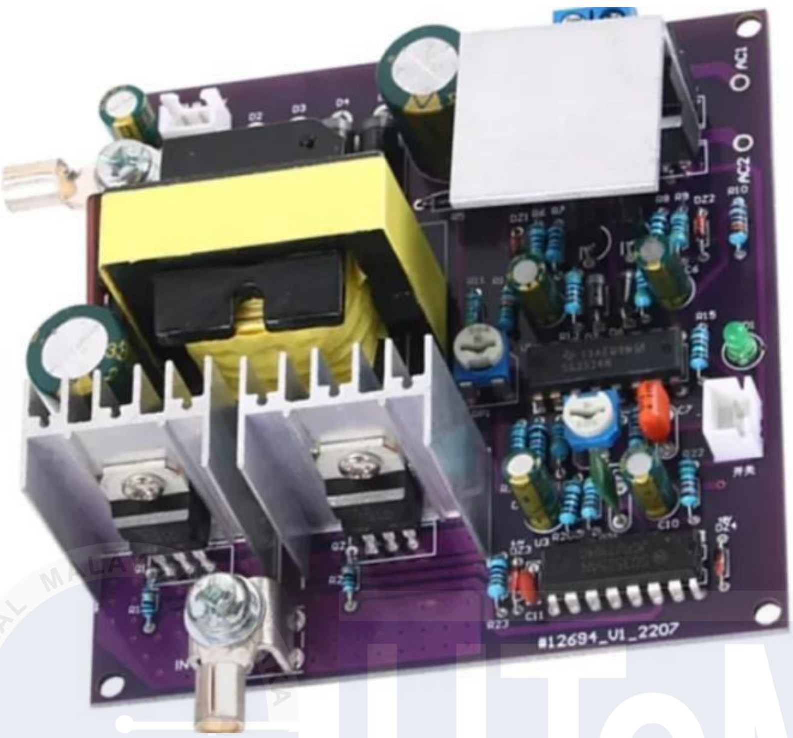


Figure 3.8 : Module Power Inverter

Specifications of Power Inverter:

- Input: 12V DC
- Output Voltage: Modified Sine Wave
- Power: 500 W
- USB Interface: 5V DC, 2.1 A

3.5.6 Arduino Uno

The Arduino Uno is a popular microcontroller board renowned for its simplicity, versatility, and accessibility in the realm of electronics and programming. Developed by Arduino LLC, it's based on the ATmega328P microcontroller and features digital and analog input/output pins that can be easily programmed to interact with various sensors, actuators, and other electronic components. The Uno board also includes onboard voltage regulation, USB connectivity for easy programming and communication with a computer, and a diverse community providing extensive libraries and resources. Its open-source nature encourages experimentation and innovation, making it an ideal choice for hobbyists, educators, and professionals alike seeking to create interactive projects, prototypes, and even commercial products. Figure 3.9 shows the Arduino Uno board.

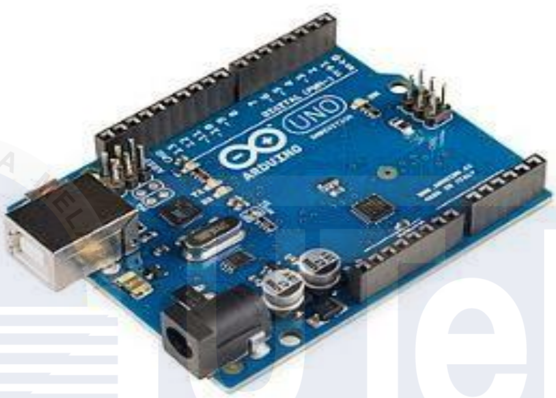


Figure 3.9 : Arduino Uno

3.5.7 Current Sensor

Figure 3.10 shows the current sensor that is used in this project to collect the data and analysis. A current sensor measures electric current in a circuit, crucial for monitoring and control in electronics. Arduino Uno, a popular microcontroller board, easily integrates with current sensors. By connecting the sensor to Uno's input pins, developers can read current data and implement various functions like monitoring loads, detecting faults, or regulating power. Arduino's versatility and community support offer libraries and resources for seamless integration, making it an ideal choice for projects requiring current sensing capabilities. From monitoring device consumption to controlling motors based on load conditions, the Arduino Uno paired with a current sensor provides a straightforward and cost-effective solution for diverse electronic applications.

Figure 3.10: Current Sensor

3.5.8 Voltage Sensor

In Figure 3.11, voltage sensor also used to collect data and make an analysis. A voltage sensor detects electrical potential difference in a circuit, essential for monitoring and control. When paired with an Arduino Uno, it becomes a versatile tool for real-time voltage measurement and analysis. By connecting the sensor to Uno's input pins, developers can accurately read voltage levels for tasks like monitoring battery health or detecting overvoltage conditions. Arduino's adaptability and community support simplify integration, providing access to libraries and resources for rapid implementation. From monitoring power sources to controlling voltage-dependent devices, the Arduino Uno combined with a voltage sensor offers a cost-effective solution for diverse electronics projects.

Figure 3.11 : Voltage Sensor

3.5.9 LCD Display I2C

In figure 3.12, I2C LCD (Inter-Integrated Circuit Liquid Crystal Display) communicates via the I2C protocol, enabling data transfer with devices like Arduino Uno using just two wires. When paired with the Uno, it offers a simple method to display information without needing many digital pins. By connecting the I2C LCD to the Uno's I2C pins and installing the relevant library, developers can easily control and display text or graphics. Arduino's robust community support and libraries streamline integration into various projects, such as temperature monitors or digital clocks. This combination provides a user-friendly interface for displaying crucial data, enhancing the functionality of Arduino-based applications.

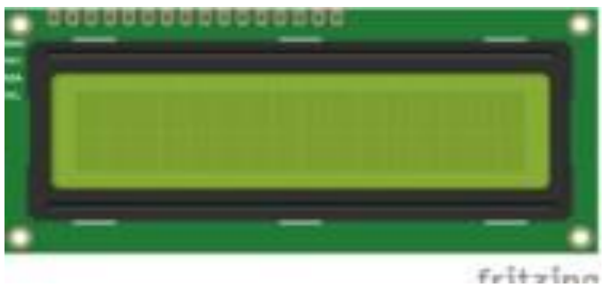


Figure 3.12: I2C LCD (Inter-Integrated Circuit Liquid Crystal Display)

3.6 Software Development

Software is essential to this project because it keeps the system running smoothly and makes it easier to compare hardware and software components. Software for circuit design, function testing, and sketching drawings is necessary. To get the best possible system performance and functioning, several actions are necessary. With the use of meticulous sketching and comprehensive testing of circuit designs, the program will make precise visualization possible. Its crucial function emphasizes how important software development is to accomplishing project goals and guaranteeing success in general.

3.6.1 Arduino IDE

The Arduino Integrated Development Environment (IDE) is crucial for the development of the hybrid solar-wind charger project. It offers a platform for writing, debugging, and uploading code to the microcontroller, facilitating smooth interaction among the hardware components. The Arduino IDE enables the microcontroller to process data from current and voltage sensors, essential for monitoring system performance. The current sensor (e.g., ACS712) quantifies the current, whereas the voltage sensor assesses the system's voltage. The Arduino microcontroller, programmed via the IDE, interprets these analogue signals, computes the corresponding values, and presents them on an LCD screen utilising the “LiquidCrystal” library. This real-time data visualisation enables users to oversee the system's state and guarantee safe functioning. Additionally, the IDE's Serial Monitor facilitates debugging by presenting sensor information for diagnostic purposes. The Arduino IDE, due to its simplicity and adaptability, is essential for developing an efficient and dependable hybrid energy system. Figure 3.13 shows the Arduino IDE used

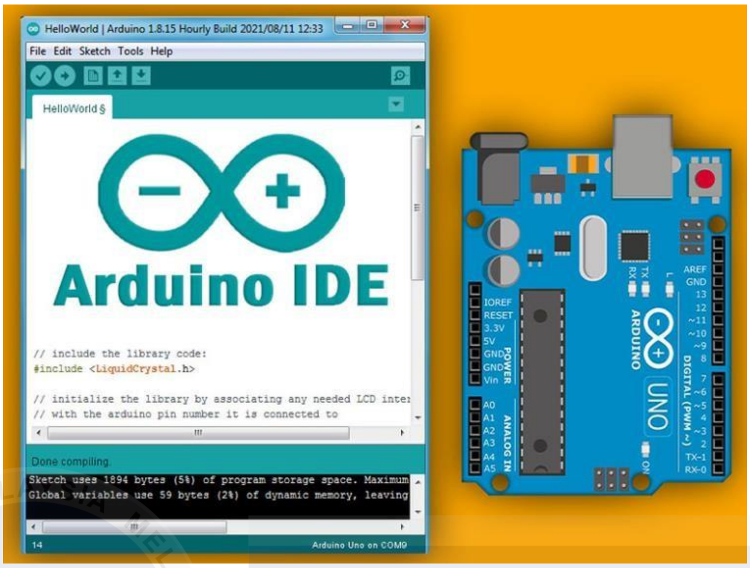


Figure 3.13: Arduino IDE Software

3.6.2 Proteus 8 Professional

Proteus 8 Professional is a robust software suite utilised for the design and simulation of electrical circuits. It provides an extensive platform for the creation, testing, and debugging of circuit designs prior to physical execution. You can employ Proteus to replicate the functionality of wind turbine and solar circuits, allowing you to observe their performance under diverse settings. It accommodates a diverse array of components, such as sensors, microcontrollers, and power electronics, rendering it suitable for renewable energy initiatives. Proteus enables the creation of control systems, monitoring of energy flows, and assurance of the predicted functionality of wind and solar systems. The software's user-friendly interface facilitates seamless integration of various components, while its simulation features offer an accurate depiction of circuit behaviour, aiding in the optimisation of designs prior to physical construction. Figure 3.14 shows the proteus 8 professional used in the making of the circuit design.

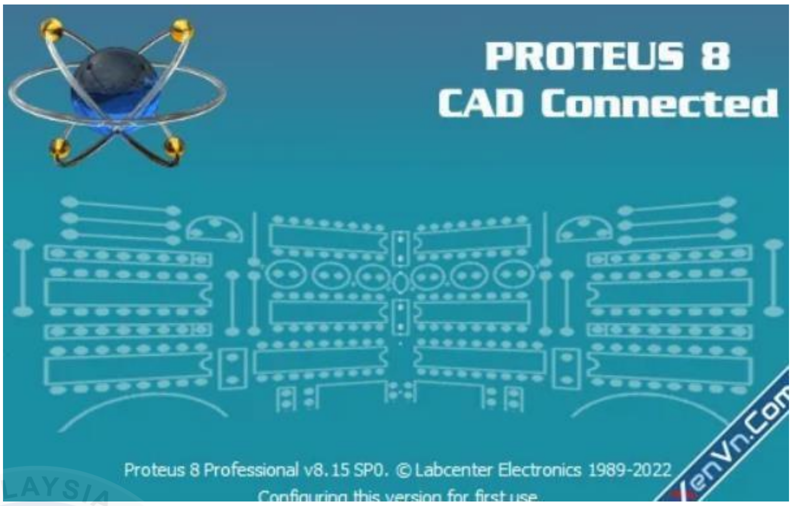


Figure 3.14: Proteus 8 Proffesional Software

3.7 Solar and Battery Configuration

a) Solar panel power output.

P_{solar} = Voc x Isc x Effiency factor

= 22.0 x 0.9 x 0.9

= 17.98 W

b) Energy generated

Assume peak-sun hour (PSH) = 5

Egenerated = Psolar x PSH

=17.98 x 5

= 89.91 Wh

c) Battery charging time

$E_{battery}$ = $V_{battery}$ X Capacity battery (Ah)

= 12 x 9.8

= 117.6 Wh

$T_{charge} = E_{battery} / P_{solar}$

$= 117.6 / 17.98$

$= 6.5 \text{ hour} \approx 7 \text{ hour}$

3.8 Wind Turbine (DC Motor) and Battery Configuration

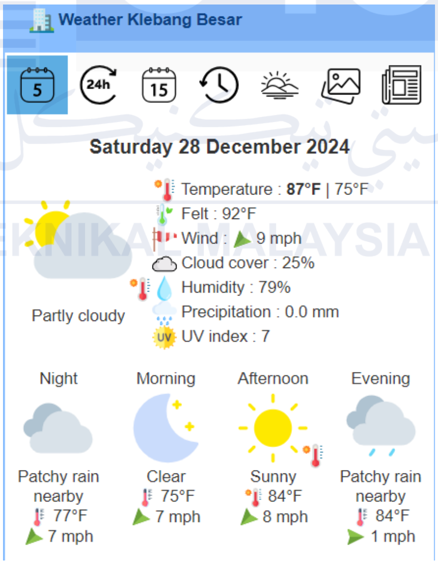


Figure 3.15: Weather Klebang Besar, Malacca

a) Wind turbine power output

$$P_{wind} = 0.5 \times P \times A \times V^3 \times \eta_{wind\ turbine}$$

$$A_{(vertical\ axis)} = D \times H$$

$$= 0.1524 \times 0.3048$$

$= 0.0464m^2$

Based on figure 3.15, it is shown that wind speed is 9 mph.

9 mph = 4.02336 m/s

$P_{wind} = 0.5 \times 1.223 \times 0.0464 \times 4.02336^3 \times 0.25$

$= 0.462\ W$

b) Energy generated by wind turbine

$E_{wind} = P_{wind} \times H$

$= 0.462 \times 2$

$= 0.924\ Wh$

c) Battery charging time

$E_{battery} = 12 \times 9.8A$

$= 117.6\ Wh$

$T_{charge} = 117.6 / 0.462$

$= 254.55\ H \approx 255\ H$

3.9 Combine System Solar and Wind Energy

a) Power output from the combination

$P_{total} = P_{solar} + P_{wind\ turbine}$

$= 17.98 + 0.462$

$= 18.422\ W$

b) Battery charging time

$T_{charge} = 117.6 / 18.422$

$= 6.38\ hour \approx 6.5\ Hour$

3.10 System setup for solar panel

The system setup and testing phase are to ensure that all components and sensors are working and functional well. A well prepared is necessary in order to reduce problems in the final assembly. Figure 3.16 illustrates the system setup for solar panels.

Figure 3.16: Solar Panel System Setup

3.10.1 System testing for solar panel

After the system setup, the system is tested directly under the sunlight. All components are checked to ensure the functionality of each component. Current, voltage and light intensity are display on LCD display showing the system functional. Figure 3.17 illustrates the experiment testing under the sunlight.

Figure 3.17: System testing of solar panel

3.10.2 Verifications of component functionality through LCD display

Figure 3.18, 3.19 and 3.20 show the voltage, current and light intensity reading for solar panel. The correct and stable value readings confirm that the sensors and the circuit are fucntioning properly. Multimeter is used to double check the reading from LCD display.

Figure 3.18: Voltage reading of the solar panel

Figure 3.19: Current reading of the solar panel

Figure 3.20: Light intensity of the solar panel

3.11 Design and Development of Wind Turbine

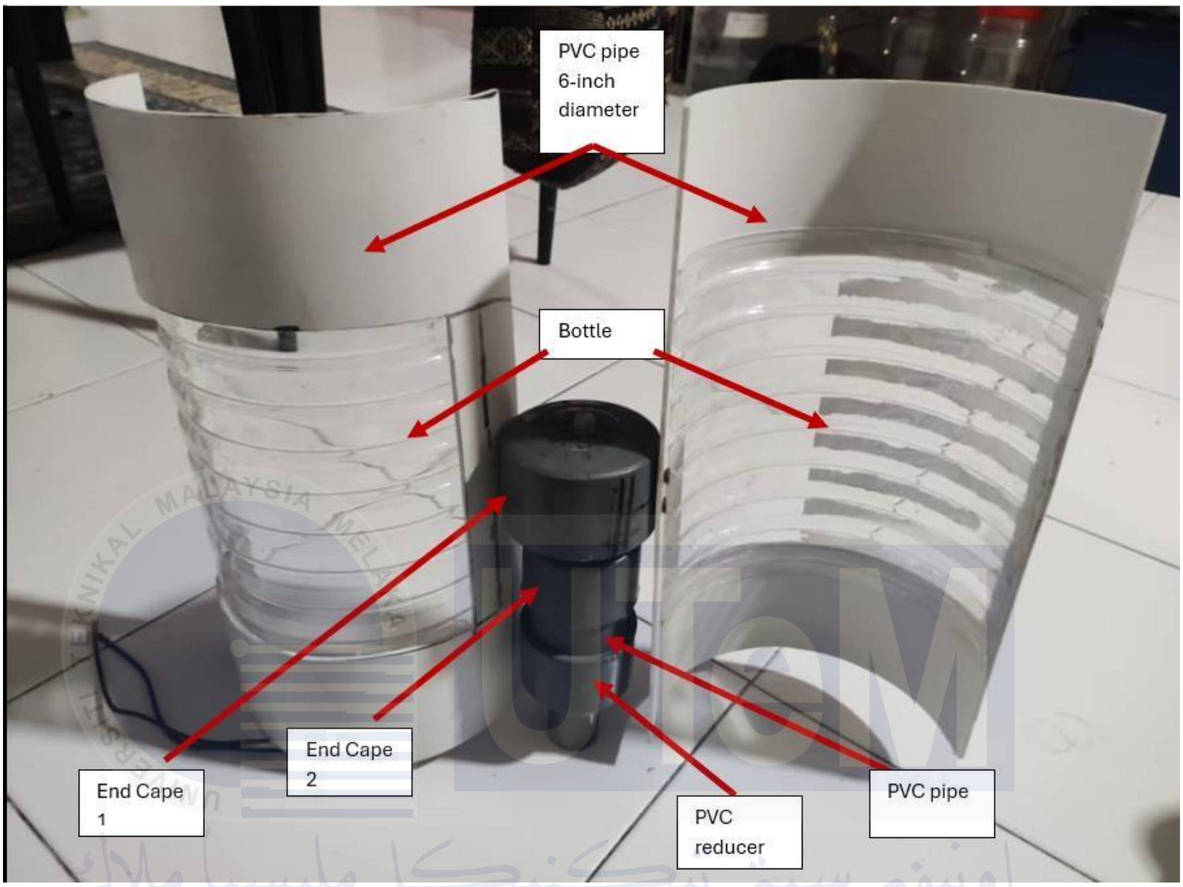


Figure 3.21: Wind Turbine Design

a) Concept and design

A vertical-axis wind turbine is a type of wind turbine that has vertical axis of rotation. This type of wind turbine can capture wind from any direction. The design is more compact as it generally requires less space and is closer to ground.

b) Material selection as shown in figure 3.21

- PVC end cap 1 – To hold the blade
- PVC end cap 2 – To attach at the motor to hold the motor
- PVC pipe – Housing of dc motor body

- PVC pipe reducer – To make the wind turbine stand using pvc pipe through the reducer
- PVC pipe 6 inch – Blade for wind turbine
- Bottle – Used to reduce the weight of the blade

3.12 Fabrication of Housing for Hybrid Solar-Wind Charger

The housing for hybrid solar wind charger is essentially needed to serve some purpose including protection, support and integration of components. Well-designed housing is essential to provide a stable base to hold the wind turbine and solar panel. It is also to protect from accidental touch of electrical components. Figure 3.22 illustrates the cutting process.

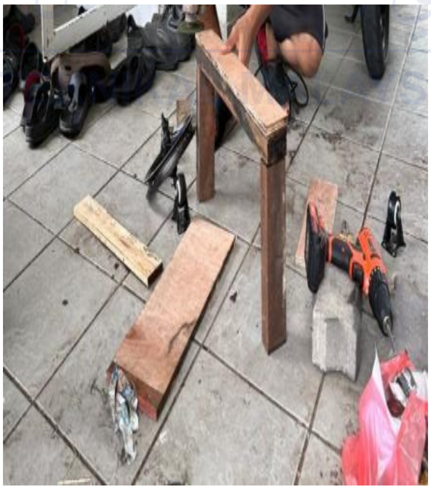


Figure 3.22: Cutting Process

After the cutting phase is done, the assembly is made with complete tools such as drill, elbow L, and other equipment to make it more precise, stable and durable, as shown in figure 3.22. Figure 3.23 illustrates the complete design of housing for solar wind chargers.

Figure 3.23: Final Shape of the Housing

3.13 Battery Charging Via Solar Setup

In this configuration, the two solar panels which each 12V 10W are connected in parallel to charge the battery. A solar charge controller is integrated with the solar system to prevent overcharging and certain circumstances. Figure 3.24 shows the experiment setup for charging battery via solar energy.

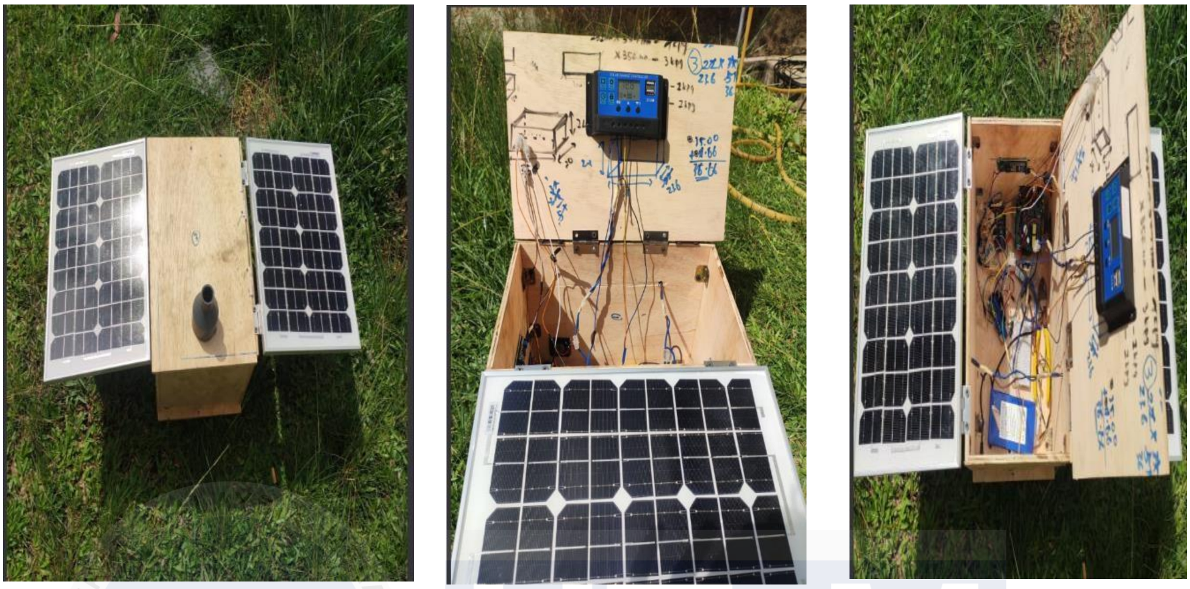


Figure 3.24: Experiment setup for charging battery via solar energy

3.14 Battery charging via solar and wind energy setup

Figure 3.25 shows the battery charging by using combination of solar and wind energy. The solar panels and wind turbine are connected in parallel. Solar charge controller is integrated with this system to protect from overcharging. A diode is positioned in each positive terminal of the solar and wind turbine to prevent the current and voltage reverse from battery to solar panel. As it is connected in parallel, diode also prevents the solar to power the wind turbine (dc motor).

Figure 3.25: Hybrid Solar Wind Setup Experiment

3.15 Data collection from circuit design

Figure 3.26 shows the solar panel circuit design in which data is collected regarding the generation of voltage and current for solar power and the process of charging and discharging battery. In figure 3.27, it shows the hybrid solar and wind turbine circuit design to collect data on energy consumption of the battery, voltage and current produced by the hybrid solar and wind turbine.

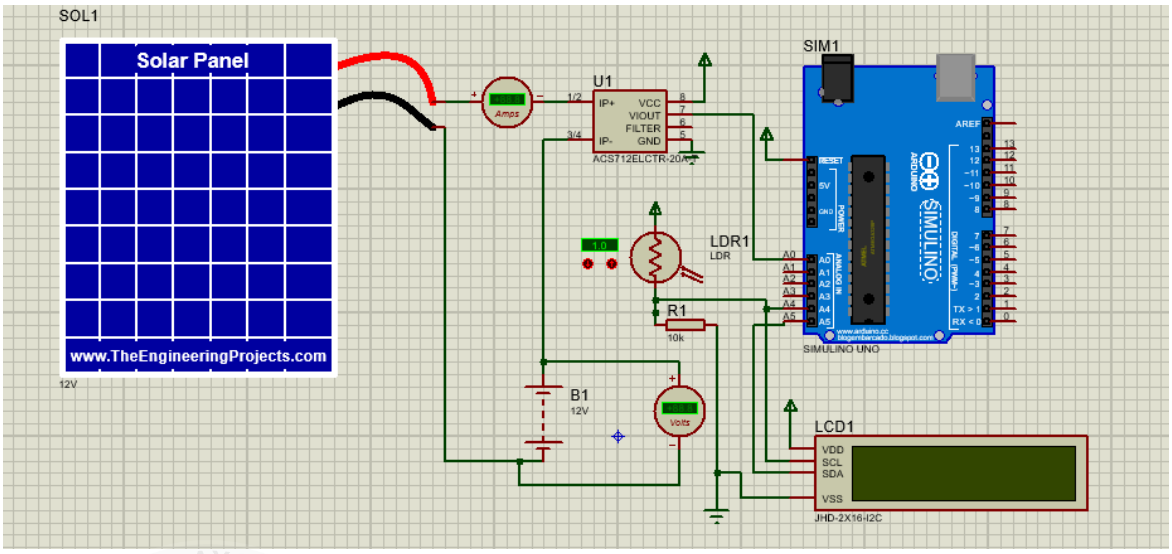


Figure 3.26: Solar Panel Circuit Design

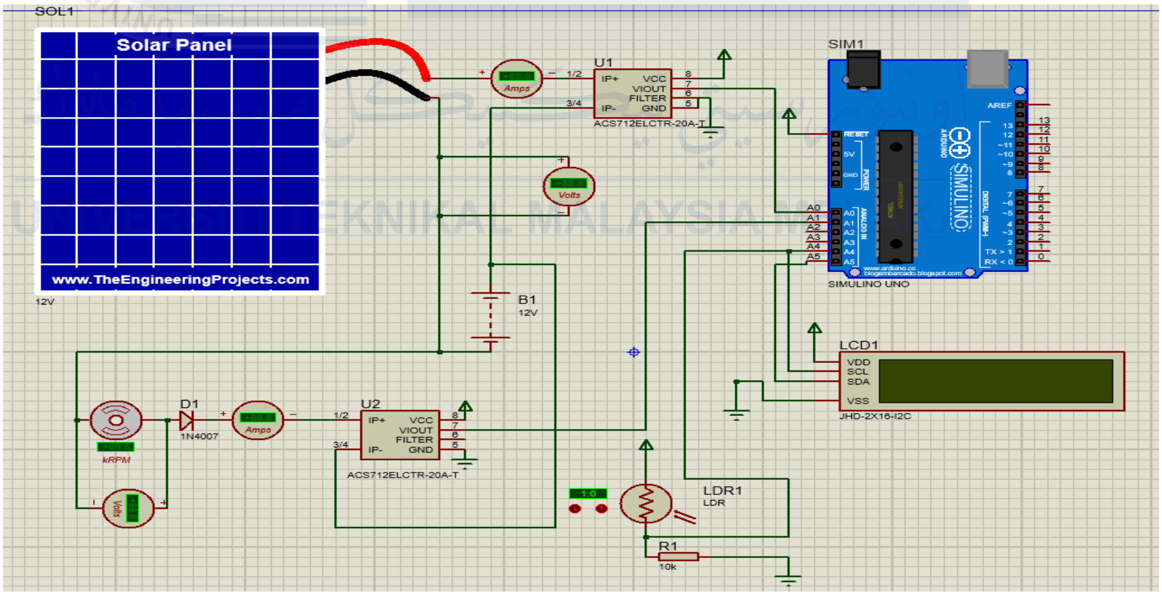


Figure 3.27: Integration of Hybrid Solar and Wind Turbine Circuit Design

3.16 Summary

The development process for the entire "The Development of Hybrid Portable Wind Solar Charger" project has been detailed in this chapter. Along with the hardware and software utilised for each task, the system's build and design are documented. In order to make sure the various features of the system are operating according to design, a variety of approaches and procedures are employed during development. The following chapter will provide a clear statement of the data analysis.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This section discusses the experimental findings and assesses their importance in relation to the project's aims. The acquired data, which includes voltage, current, and other pertinent characteristics, is analysed to ensure that the designed system functions and performs properly. This component interprets the findings to validate the system's efficiency, dependability, and alignment with the desired outcomes. Graphs, tables, and visual representations are employed as needed to improve comprehension and provide a clear comparison between theoretical predictions and real facts. Furthermore, any differences or restrictions discovered during the testing process are addressed in order to identify potential areas for improvement.

4.2 Data Collection

Data has been successfully acquired and analyzed as a result of the experiment that was actually carried out. To obtain voltage and current readings generated by solar panels and wind turbines, the data collected is based on real-time measurements and is obtained through the utilization of electrical measurement tools such as multimeters and anemometer. Voltage sensor, current sensor and LDR sensor are used to determine the output of solar panels and wind turbine with appropriate programming.

4.2.1 Input Data For Solar Panels Experiment Setup

The data was successfully gathered for input analysis, which was carried out on 28/12/2024 from 10.00 a.m. in the morning to 6.00 p.m. in the evening and the data is represented in Table 4.1. Table 4.2 represents the input data for solar panels on 29/12/2024.

Table 4.1: Input Data for Solar Panels on 28/12/2024

Time	Voltage (V)	Current (A)	Power (W)
10.00 a.m.	22.7	0.62	14.07
11.00 a.m.	21.8	0.42	9.156
12.00 a.m.	22.2	0.71	15.76
1.00 p.m.	21.9	0.51	11.2
2.00 p.m.	22.2	0.92	20.42
3.00 p.m.	22.2	0.95	21.09
4.00 p.m.	20.2	0.42	8.484
5.00 p.m.	20.2	0.1	2.02
6.00 p.m.	21.4	0.25	5.35

Figure 4.1,4.2 and 4.3 presents an illustration of the voltage, power and current over time powered by solar energy on 28/12/2024. The graph shows that the voltage appears to be relatively stable around 20 volts as time passes. In figure 4.2, current has higher value at 2.00 p.m. and 3.00 p.m. with 0.92A and 0.95A. A sharp drop- off happened at 5.00 p.m. resulting in 0.1A. In figure 4.3, power is the product of voltage and current. The higher the current and voltage or the lower the current and voltage will affect the resulting of power as shown in the 4.3. The graph power over time shows the power levels peaking at around 21.09 watts at 3.00 p.m. This may suggest that the solar power output was influenced by the sunlight intensity or cloud cover at the testing site.

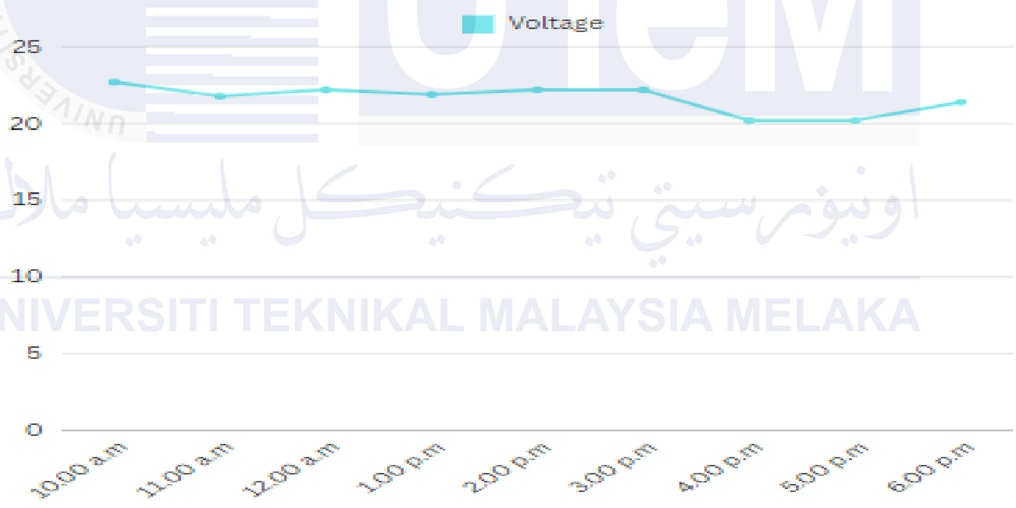


Figure 4.1: Graph of Input Voltage Over Time

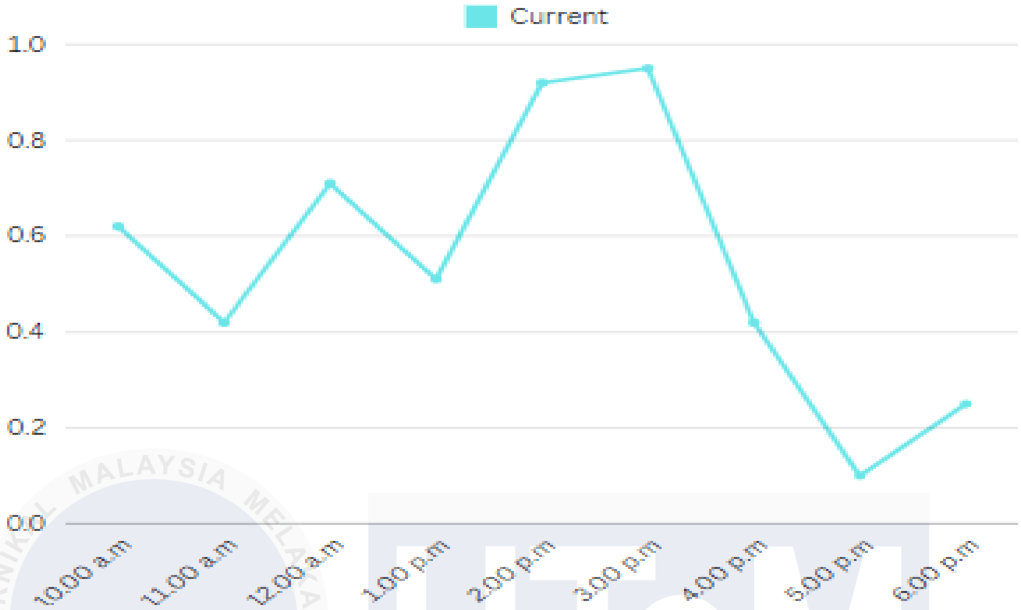


Figure 4.2: Graph of Input Current Over Time

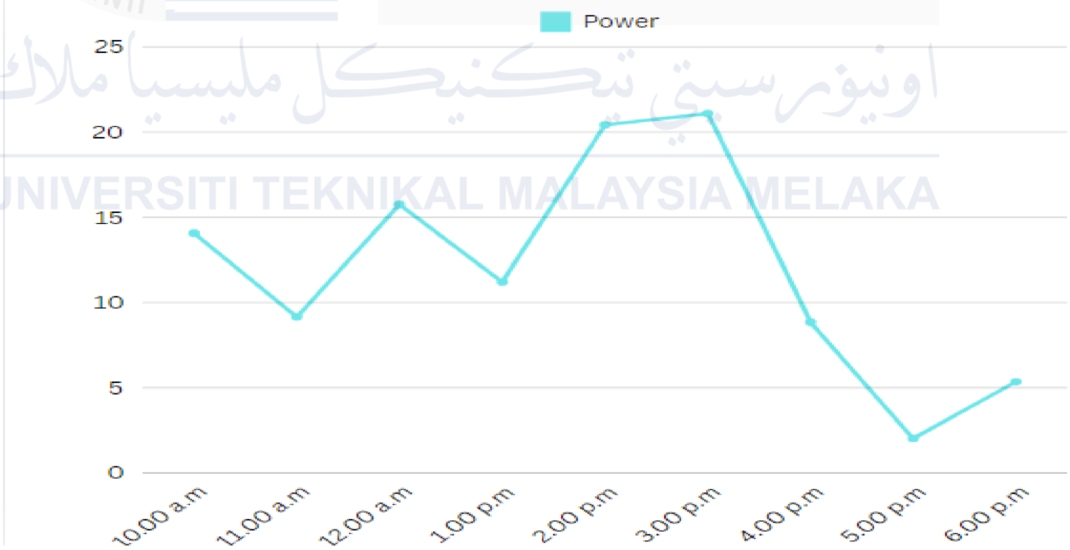


Figure 4.3: Graph of Input Power Over Time

Table 4.2: Input Data for Solar Panels on 29/12/2024

Time	Voltage (V)	Current (A)	Power (W)
11.00 a.m.	23.6	0.90	21.24
12.00 a.m.	23.3	1.20	27.96
1.00 p.m.	22.2	1.31	29.08
2.00 p.m.	22.2	1.30	28.86
3.00 p.m.	20.5	0.25	5.125
4.00 p.m.	21.2	0.22	4.664
5.00 p.m.	19.8	0.1	1.98
6.00 p.m.	19.7	0.05	0.985

Figures 4.4, 4.5 and 4.6 present an illustration of the voltage, power and current over time powered by solar energy on 29/12/2024. Based on the graph in figure 4.4, it shows the peak voltage is at 11.00 a.m. around 23.6V. In figure 4.5, it shows on that day, the peak value of current is 1.31 A at 1.00 p.m. The sky is very sunny and the light intensity very high. However, the current has sharp- drop off to 0.1 A at 5.00 p.m. and 0.05 A at 6.00 p.m. It is because the weather at that time is overcast. Figure 4.7 shows the weather condition on 29/12/2024 at around 5 p.m.

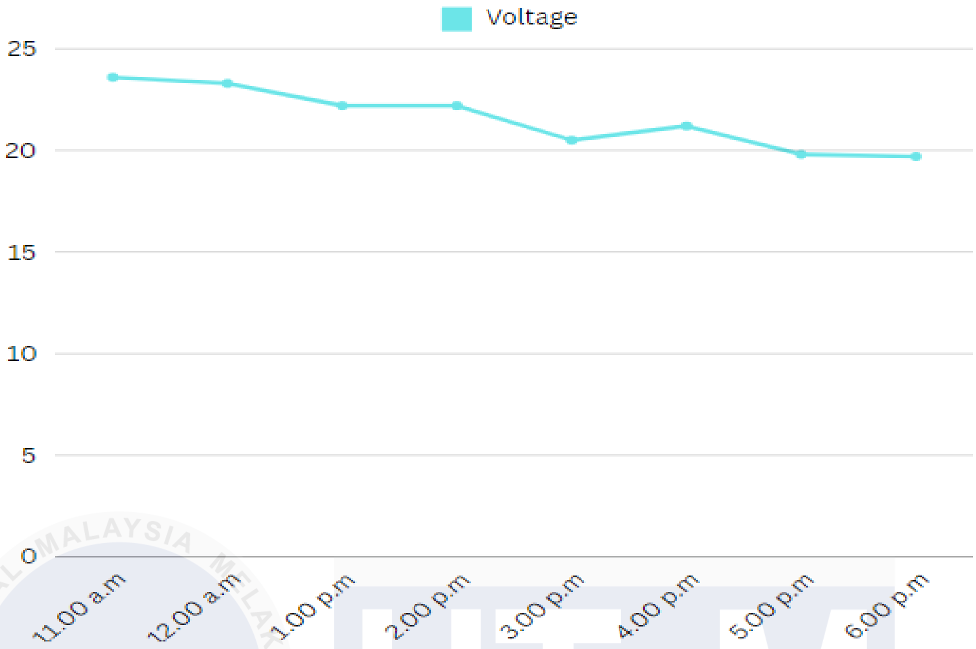


Figure 4.4: Graph of Input Voltage Over Time

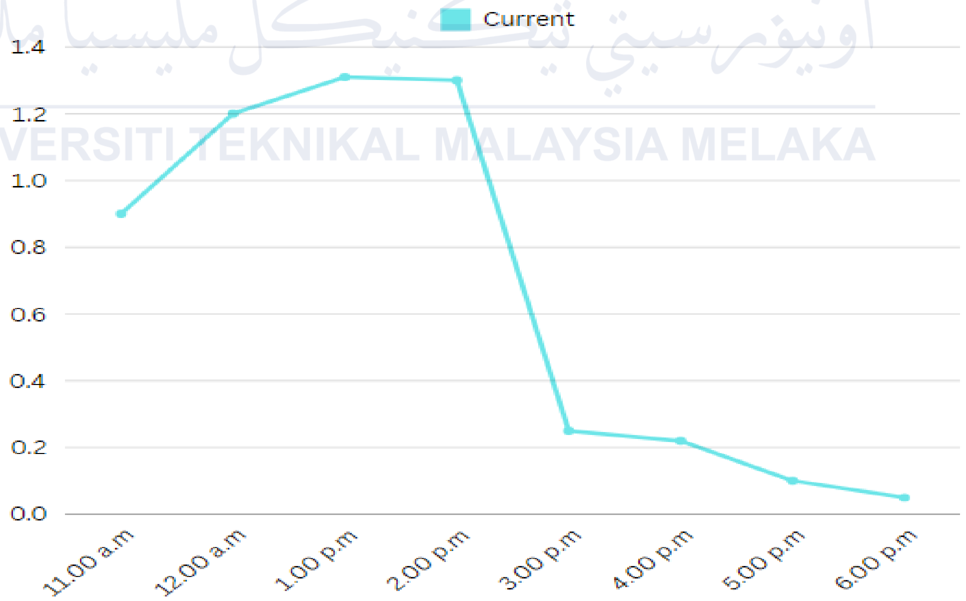


Figure 4.5: Graph of Input Current Over Time

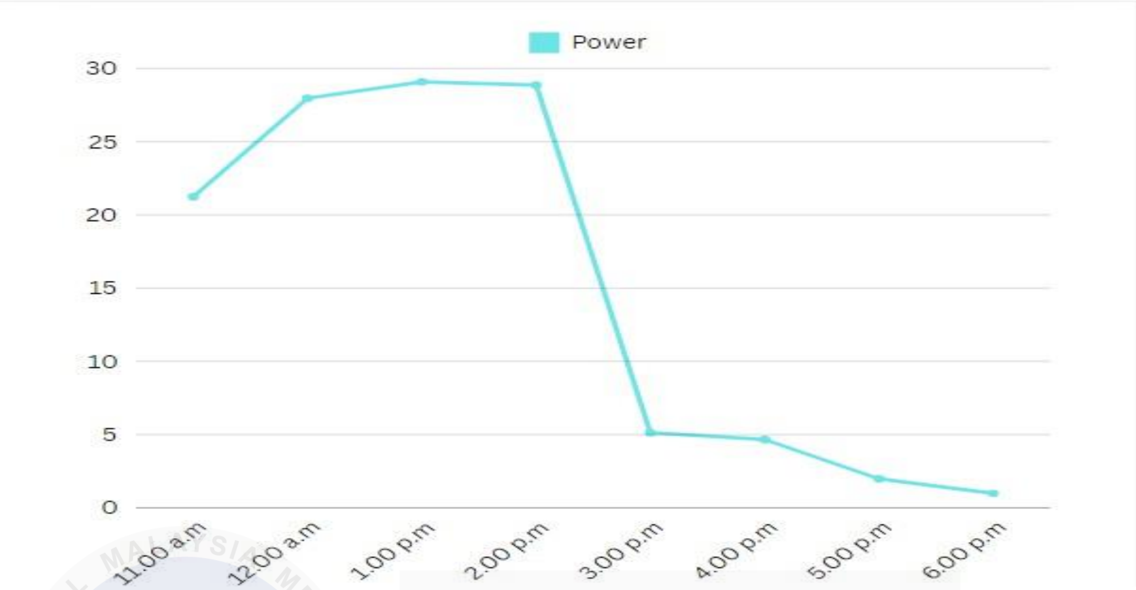


Figure 4.6: Graph of Input Power Over Time

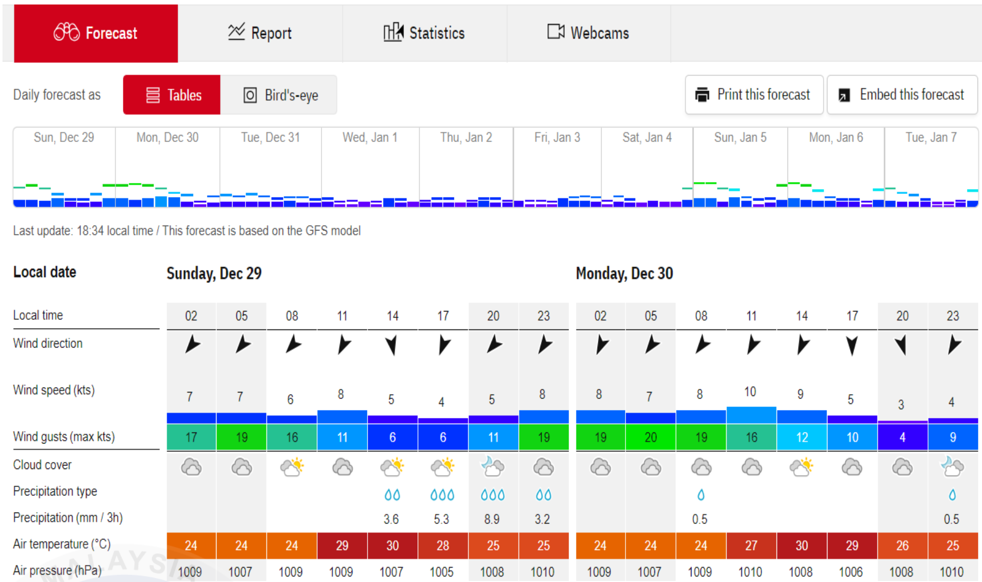
Figure 4.7: Overcast weather on 29/12/2024

4.2.2 Input Data for Wind Turbine Experiment Setup

The input data of wind turbine was gathered and presented in Table 4.4. The wind speed on 29/12/24 was referred to as the forecast table at Kampung Ayer Keroh, Malacca as shown in figure 4.8. The wind speed is then tested at home using a stand fan. The anemometer is placed in front of the fan and the wind speed is observed to be the same as the forecast table. The distance between turbine and stand fan needs to be adjusted after getting the reading wind speed from anemometer. The wind speed record is the same as shown in forecast table figure 4.8. Figures 4.9, 4.10 and 4.11 show the graph of voltage over wind speed, current over wind speed and power over wind speed. From the graph, it may suggest that output of wind turbine directly proportional to the wind speed.

Table 4.3: Input Data Wind Turbine

Time	Wind Speed (m/s)	Voltage, (V)	Current, (A)	Power (W)
8.00 a.m	3	0.16	0.07	0.0112
11.00 a.m	4.2	0.26	0.12	0.0312
2.00 p.m	2.6	0.13	0.05	0.0065
5.00 p.m	2.0	0.12	0.05	0.006
8.00 p.m	2.6	0.12	0.04	0.0048
11.00 p.m	4.2	0.26	0.13	0.034



Forecast | Report | Statistics | Webcams

Daily forecast as | Tables | Bird's-eye | Print this forecast | Embed this forecast

Sun, Dec 29 | Mon, Dec 30 | Tue, Dec 31 | Wed, Jan 1 | Thu, Jan 2 | Fri, Jan 3 | Sat, Jan 4 | Sun, Jan 5 | Mon, Jan 6 | Tue, Jan 7

Last update: 18:34 local time / This forecast is based on the GFS model

Local date	Sunday, Dec 29								Monday, Dec 30							
Local time	02	05	08	11	14	17	20	23	02	05	08	11	14	17	20	23
Wind direction																
Wind speed (kts)	7	7	6	8	5	4	5	8	8	7	8	10	9	5	3	4
Wind gusts (max kts)	17	19	16	11	6	6	11	19	19	20	19	16	12	10	4	9
Cloud cover																
Precipitation type																
Precipitation (mm / 3h)					3.6	5.3	8.9	3.2			0.5					0.5
Air temperature (°C)	24	24	24	29	30	28	25	25	24	24	24	27	30	29	26	25
Air pressure (hPa)	1009	1007	1009	1009	1007	1005	1008	1010	1009	1007	1009	1010	1008	1006	1008	1010

Figure 4.8: Forecast table for wind speed at Kampung Ayer Keroh

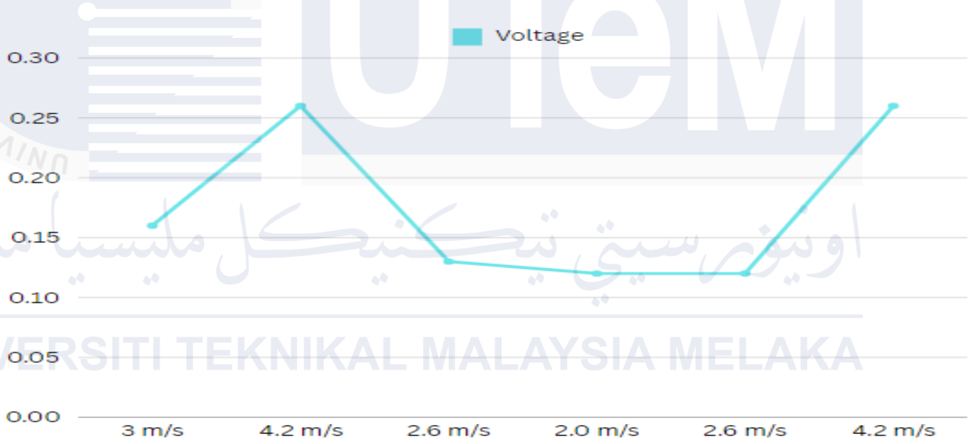


Figure 4.9: Graph of voltage over the wind speed (m/s) based on forecast table

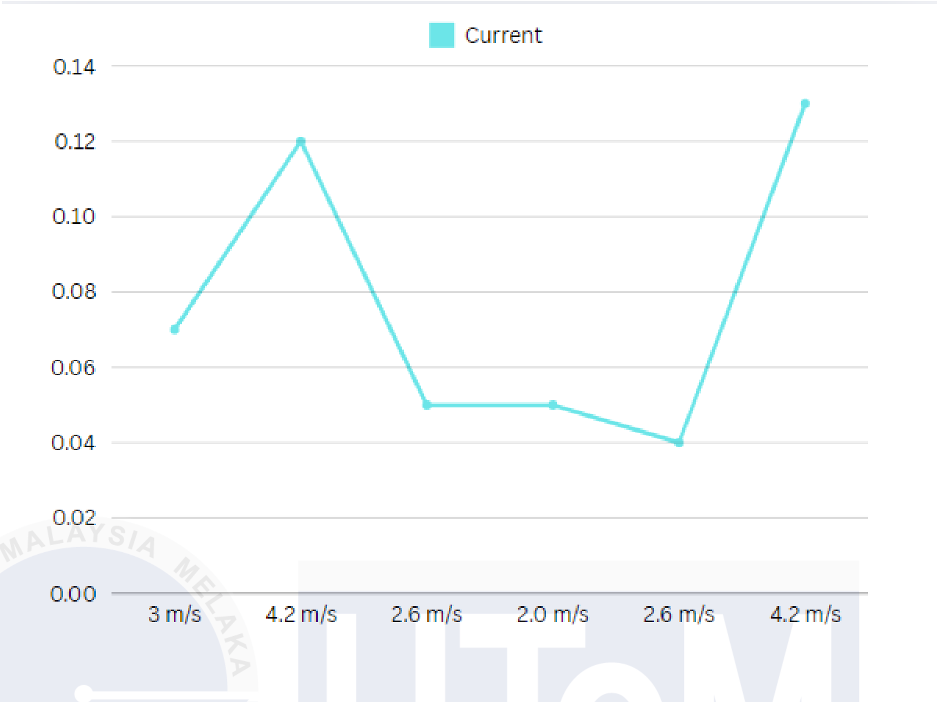


Figure 4.10: Graph of current over the wind speed (m/s) based on forecast table

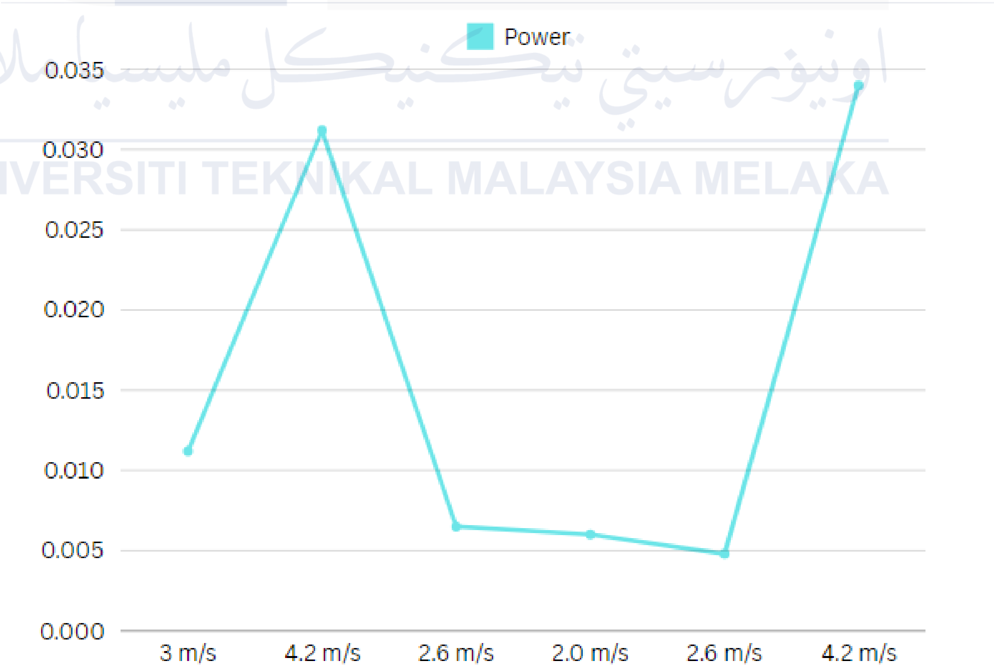


Figure 4.11: Graph of power over the wind speed (m/s) based on forecast table

4.2.3 Charging and Dischargin battery

In battery testing and performance monitoring, input data denotes the power and energy supplied to the battery while charging, whereas output data signifies the power and energy withdrawn when discharging. Monitoring input data facilitates the assessment of charging efficiency, identifies problems such as overcharging or energy losses, and enhances charging profiles to prolong the battery's lifespan. Output data, conversely, indicates the efficiency with which the battery delivers stored energy to loads, offering insights into factors such as capacity, state of charge (SOC), and depth of discharge (DOD). Analysing input and output data facilitates the computation of round-trip efficiency, which reveals energy losses throughout charging and discharging cycles, aiding in the identification of inefficiencies or ageing effects. A comprehensive review of this data is crucial for comprehending battery health.

4.2.3.1 Input Data of Battery (Charging)

Table 4.5 show the charging rate of battery used in this project. This concept utilizes a battery powered by renewable energy sources such as sun and wind, with charging speed influenced by weather conditions and time of day. The battery's voltage and state of charge (SOC) were recorded at multiple intervals from 11:00 a.m. to 5:00 p.m., as detailed in Table 4.5. The data indicates that the charging rate peaks during clear sky conditions, and the battery charges effectively even with partial cloud cover.

Table 4.4: Input Data of Battery on 29/12/2024

Time	Weather	Voltage (V)	Battery percentage	Charging rate (%/hour)
11.00 a.m	Passing cloud	11.96	36	-
12.00 a.m	Scattered cloud	12.15	55	19
1.00 p.m	Scattered cloud	12.28	68	13
2.00 p.m	Scattered cloud	12.44	84	16
3.00 p.m	Scattered cloud	12.5	90	6
4.00 p.m	Passing cloud cloud	12.56	96	6
5.00 p.m	Cloudy, overcast	12.56	96	0

Figure 4.12 show the graph of battery percentage and charging rate over the time. The charging rate of battery decrease as the time passes by. It may suggest that the charging rate directly proportional to the intensity of sunlight.

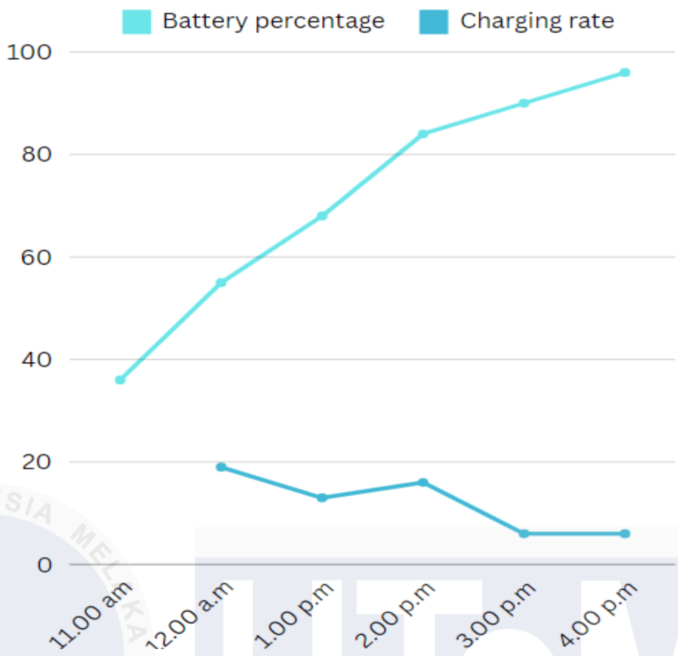


Figure 4.12: Graph of Battery Percentage and Charging Rate Over Time

4.2.3.2 Ouput data of battery (Discharging)

Table 4.6 presents the battery discharge statistics throughout various time intervals during which the battery provides power to a load. The table offers critical insights into the battery's performance under different load settings and the temporal variations in voltage. By monitoring the voltage drop, current draw, and energy discharge, we can evaluate the battery's performance and its response to varying load demands. This information is essential for assessing the battery's overall efficiency and the rate at which it depletes its charge during continuous use.

Table 4.5: Output Data of Battery (Discharging)

Time (minutes)	Initial voltage (V)	Final voltage (V)	Load (W)	Voltage drop (V)	Average voltage (V)	Current (A)	Energy discharged (Wh)
60	12.54	12.13	33	0.41	12.335	2.67	0.19
60	12.2	12.0	8	0.2	12.1	0.66	0.08
60	12.0	11.9	10	0.1	11.95	0.84	0.08
60	12.56	12.22	33	0.34	12.39	2.67	0.20
60	12.12	11.73	33	0.39	11.925	2.77	0.21
60	12.07	11.68	33	0.39	11.875	2.78	0.21
60	12.04	11.63	33	0.41	11.835	2.78	0.21

4.3 Summary

This section delineates the results of the performance evaluation of the hybrid solar-wind charging system. Data was gathered for solar panels and wind turbines to evaluate their contributions to charging a lithium-ion battery under different environmental circumstances. The solar panel data for two days demonstrates optimal system performance under clear skies, with maximum power generation recorded around midday. The solar panel reliably generated stable voltage levels, achieving a maximum power output of 21.09W on December 28, 2024, and 29.08W on December 29, 2024. The performance of the wind turbine was assessed utilizing recorded wind speeds and predictive data, demonstrating a direct correlation between wind speed and turbine output, with maximum power output noted at 0.034W under elevated wind speeds.

The battery's charging and discharging behavior was observed to assess its efficiency and energy storage capacity. The charging rate peaked under scattered cloud circumstances and diminished as the battery approached full capacity. Discharge testing indicated voltage reductions and energy losses across different loads, elucidating battery efficiency during operation. The data indicates that the system efficiently combines solar and wind energy for battery charging, with performance affected by meteorological variables, time of day, and load demand. Potential for enhanced optimization is identified for increased efficiency and energy management.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the creation of the hybrid portable solar-wind charger illustrates the viability and practicality of amalgamating renewable energy sources into a compact, sustainable, and efficient apparatus. The system utilizes energy from solar and wind sources to deliver a dependable off-grid charging option for many applications. The hardware components, comprising monocrystalline solar panels, a DC motor operating as a wind turbine, and a polymer lithium-ion battery, were chosen to guarantee durability, efficiency, and mobility. The software tools utilized, including Proteus, Arduino IDE and Tinker cad, enabled the design, analysis, and testing phases, guaranteeing strong system performance.

The effective execution of the project underscores the capacity of renewable energy technology to meet global energy requirements while mitigating environmental consequences. The gadget functions as a prototype that can be further refined for improved efficiency, augmented energy output, and expanded uses. This project ultimately enhances sustainable energy options and motivates future developments in hybrid renewable energy systems.

5.2 Potential for Commercialization

The hybrid portable solar-wind charger demonstrates significant promise for commercialisation, addressing the increasing demand for sustainable and portable energy solutions. This gadget caters to a specialised market demanding dependable off-grid power, especially for outdoor enthusiasts, emergency responders, and rural communities, amidst the growing global emphasis on renewable energy.

A principal advantage of the device is its hybrid energy generation, integrating solar and wind power to maintain performance throughout various weather situations. This attribute distinguishes it from conventional single-source systems, enhancing its versatility and reliability. Furthermore, its compact and portable design improves utility, while its eco-friendly operation corresponds with sustainability objectives.

Nonetheless, obstacles persist, especially the restricted output of wind energy during calm circumstances, which may impede performance in specific areas. Future development should concentrate on optimising wind turbine performance, strengthening the solar charge controller for optimum energy extraction, and upgrading the battery for superior storage and endurance.

The commercialisation strategy of the product should highlight its distinctive selling features, such as dual energy sources and portability. By focussing on niche markets like outdoor enthusiasts and off-grid communities, and utilising online platforms for promotion, the product can attain broad audience reach. Pricing strategies must reconcile affordability with perceived value to maintain competitive market positioning.

The hybrid portable solar-wind charger, via ongoing innovation to overcome its limits and strategic marketing, possesses considerable potential as a viable and sustainable energy source, aiding the global transition to renewable energy adoption.

5.3 Future Works

The hybrid portable solar-wind charger, although showcasing the potential for renewable energy integration, exhibited certain limitations in the wind turbine's capacity to provide adequate power. To tackle these difficulties and enhance system performance, the subsequent recommendations for future endeavors are proposed:

a) Enhancement of Wind Turbine Design

- Scaling up: Future efforts could focus on increasing the size of the blade to enhance the capability to catch more wind.
- Blade redesign: Enhancing the aerodynamic efficiency of the wind turbine blade to optimise power generation, particularly at low wind speeds.

b) Selection of High- Efficiency Generator

- Utilise a direct current motor with a low revolutions per minute (RPM) rating to ensure that minimal blade rotation generates increased power.

c) Optimization of Solar Charge Controller

- Dual-input controller: Enhance a solar charge controller capable of managing both solar and wind energy sources.
- Mamimum Power Point Tracking (MPPT): Substitute the existing controller with an MPPT-based controller for solar and wind energy systems. This would optimise power extraction by dynamically adapting to the ideal voltage and current for each energy source.

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APPENDICES

Appendix A : Project coding

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 16, 2); // Adjust 0x27 if necessary

// Pin definitions
const int analogPinCurrent1 = A0;  // Current sensor 1 pin
const int analogPinCurrent2 = A1;  // Current sensor 2 pin
const int analogPinVoltage1 = A2;  // Voltage sensor 1 pin
const int analogPinVoltage2 = A3;  // Voltage sensor 2 pin
const int ldrPin = A4;             // LDR connected to A4

// Current sensor parameters
const float currentSensitivity = 100.0; // Sensitivity in mV/A (adjust for your model)
float currentOffset = 2.49;             // Adjust based on measured zero-current offset (in
volts)

// Voltage factor to convert ADC reading to actual voltage
const float voltageFactor = 25.0 / 5.0; // Adjust based on your voltage divider

void setup() {
  lcd.init();           // Initialize LCD
  lcd.backlight();      // Turn on the backlight
  pinMode(ldrPin, INPUT);   // Set LDR pin as input
  Serial.begin(9600);
}

// Function to read the average value from the specified analog pin
float readAverage(int pin) {
  float sum = 0;            // Initialize sum
  int samples = 50;         // Number of samples to average
  for (int i = 0; i < samples; i++) {
    sum += analogRead(pin);  // Read analog value
    delay(5);                // Small delay between readings
  }
  return sum / samples;      // Return average value
}

void loop() {
  // **1. Read and calculate current for sensor 1**
  float sensorValueCurrent1 = readAverage(analogPinCurrent1);
  float voltageCurrent1 = (sensorValueCurrent1 / 1023.0) * 5.0; // Convert ADC to voltage
```

```
  float current1 = (voltageCurrent1 - currentOffset) / (currentSensitivity / 1000); // Convert
voltage to current
  if (abs(current1) < 0.1) current1 = 0; // Set current to zero if below threshold

  // **2. Read and calculate current for sensor 2**
  float sensorValueCurrent2 = readAverage(analogPinCurrent2);
  float voltageCurrent2 = (sensorValueCurrent2 / 1023.0) * 5.0; // Convert ADC to voltage
float current2 = (voltageCurrent2 - currentOffset) / (currentSensitivity / 1000); // Convert
voltage to current
  if (abs(current2) < 0.1) current2 = 0; // Set current to zero if below threshold

  // **3. Read and calculate voltage for sensor 1**
  float sensorValueVoltage1 = readAverage(analogPinVoltage1);
  float voltage1 = (sensorValueVoltage1 / 1023.0) * 5.0; // Convert ADC to voltage
  float actualVoltage1 = voltage1 * voltageFactor;       // Convert to actual voltage

  // **4. Read and calculate voltage for sensor 2**
  float sensorValueVoltage2 = readAverage(analogPinVoltage2);
  float voltage2 = (sensorValueVoltage2 / 1023.0) * 5.0; // Convert ADC to voltage
  float actualVoltage2 = voltage2 * voltageFactor;       // Convert to actual voltage

  // **5. Read LDR value for light intensity**
  int ldrValue = analogRead(ldrPin);

  // **Display current for sensor 1 on the LCD**
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("I1:");
  lcd.setCursor(5, 0);
  lcd.print(current1);
  lcd.print(" A");
  delay(2000); // Show for 2 seconds

  // **Display voltage for sensor 1 on the LCD**
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("V1:");
  lcd.setCursor(5, 0);
  lcd.print(actualVoltage1);
  lcd.print(" V");
  delay(2000); // Show for 2 seconds

  // **Display LDR value on the LCD**
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Light:");
  lcd.setCursor(7, 0);
  lcd.print(ldrValue);
  delay(2000); // Show for 2 seconds
```

```
  // **Display current for sensor 2 on the LCD**
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("I2:");
  lcd.setCursor(5, 0);
  lcd.print(current2);
  lcd.print(" A");
  delay(2000); // Show for 2 seconds

  // **Display voltage for sensor 2 on the LCD**
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("V2:");
  lcd.setCursor(5, 0);
  lcd.print(actualVoltage2);
  lcd.print(" V");
  delay(2000); // Show for 2 seconds
}
```