UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Technology and Engineering

DEVELOPMENT OF THE SOLAR CHARGING MONITORING SYSTEM USING ARDUINO UNO FOR LIGHTING APPLICATION

MOHAMAD FAZLI BIN ABDUL RANI

Bachelor of Electrical Engineering Technology with Honours

2023

DEVELOPMENT OF THE SOLAR CHARGING MONITORING SYSTEM USING ARDUINO UNO FOR LIGHTING APPLICATION

MOHAMAD FAZLI BIN ABDUL RANI

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

Faculty of Electrical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJUTERAAN ELEKTRIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Development of the Solar Charging Monitoring System using Arduino Uno For Lighting Application.

Sesi Pengajian : 2 – 2023/2024

Saya Mohamad Fazli Bin Abdul Rani mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: No 462 Kampung Padang Kunyit Mukim Telaga Mas 06400 Pokok Sena Kedah.

TS. DR. SUZIANA BINTI AHMAD
KETUA PROGRAM TEKNOLOGI KEJURUTERAAN ELEKTRIK (AUTOMASI, INDUSTRI DAN ROBOTIK)
Fakulti Teknologi dan Kejuruteraan Elektrik
Universiti Teknikal Malaysia Melaka

Tarikh: 30/12/2023

Tarikh: 5/2/2024

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled Development of the Solar Charging Monitoring System using Arduino Uno For Lighting Application 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	:	Mohamad Fazli Bin Abdul Rani
Date	:	30/12/2023

APPROVAL

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

Signature :

Supervisor Name : Ts. Dr. Suziana Binti Ahmad

Date : 5/2/2024

DEDICATION

To my beloved and supportive parents,

ABDUL RANI BIN SHAHIDAN and **JAMILAH BINTI MOHD ZAIN**

Thank you for your endless support in taking care of me physically and mentally, loving me whole heartedly and providing everything I needed without any hesitations.

My project supervisor,

TS DR SUZIANA BINTI AHMAD

Thousands of gratitude for the lesson and guidance throughout the process of completing this project.

To all my friends,

Thank you for the unlimited support and guidance which contributes in completing this project. Wish you all happiness in your life.

ABSTRACT

Due to modern technology, solar energy has lately expanded in scope and is one of the most promising renewable energy sources. This project is intended to implement the Solar Charging Monitoring System using Arduino Uno for lighting applications. Furthermore, to fabricate Charging Monitoring Systems using Solar Panel, Arduino Uno and Solar Charge Controller. The final purpose is to evaluate the performance of Solar Charging Monitoring System using experimental setup and data measurements. Additionally, the microcontroller in this system is an Arduino UNO, which is interfaced with an ESP8266 to display and monitor voltage and current data from a solar panel in real time on an LCD and through the Blynk application. Moreover, this system uses a solar charge controller to manage the voltage and current from the solar panel to the battery, preventing overcharging. The LDR sensor module enhances the system's capacity to adapt to change environmental factors, which allows it to regulate the LED light's on/off status. From the results, the solar panel specs are precise and acceptable, and the system's lifespan may be extended, according to parameter values obtained from data measurements.Other than that, having a solar charge controller increases the battery’s lifetime and safety by ensuring effective voltage and current regulation to avoid overcharging the battery. In conclusion, the proposed system successfully maximises solar charging for lighting applications, providing a long-term, remotely monitored option for increased dependability and energy efficiency.

ABSTRAK

Disebabkan teknologi moden, tenaga suria baru-baru ini berkembang dalam skop dan merupakan salah satu sumber tenaga boleh diperbaharui yang paling menjanjikan. Projek ini bertujuan untuk melaksanakan Sistem Pemantauan Pengecasan Suria menggunakan Arduino Uno untuk aplikasi pencahayaan. Tambahan pula, untuk mengarang Sistem Pemantauan Pengecasan menggunakan Panel Suria, Arduino Uno dan Pengawal Caj Suria. Tujuan akhir adalah untuk menilai prestasi Sistem Pemantauan Pengecasan Suria menggunakan persediaan eksperimen dan pengukuran data. Selain itu, mikropengawal dalam sistem ini ialah Arduino UNO, yang disambungkan dengan ESP8266 untuk memaparkan dan memantau voltan dan data semasa daripada panel solar dalam masa nyata pada LCD dan melalui aplikasi Blynk. Selain itu, sistem ini menggunakan pengawal cas suria untuk menguruskan voltan dan arus dari panel solar ke bateri, mengelakkan pengecasan berlebihan. Modul sensor LDR meningkatkan kapasiti sistem untuk menyesuaikan diri dengan faktor persekitaran yang berubah-ubah, yang membolehkannya mengawal status hidup/mati lampu LED. Daripada keputusan, spesifikasi panel solar adalah tepat dan boleh diterima, dan jangka hayat sistem boleh dilanjutkan, mengikut nilai parameter yang diperoleh daripada pengukuran data. Selain itu, mempunyai pengawal cas suria meningkatkan jangka hayat dan keselamatan bateri dengan memastikan voltan dan peraturan arus yang berkesan untuk mengelakkan pengecasan berlebihan bateri. Kesimpulannya, sistem yang dicadangkan berjaya memaksimumkan pengecasan solar untuk aplikasi pencahayaan, menyediakan pilihan jangka panjang yang dipantau dari jauh untuk meningkatkan kebolehpercayaan dan kecekapan tenaga.

ACKNOWLEDGEMENTS

My commendations and appreciation, first and foremost, go to the Almighty Allah S.W.T whom I put my trust and faith in. The process of completing this project was not an easy task, however I managed to endure the obstacles of ups and downs with the help of the Almighty.

I would like to grab this chance to express my countless gratitude towards my excellent supervisor Ts. Dr. Suziana Binti Ahmad for the immeasurable guidance and valuable advice throughout the journey of completing this project. Her patience, enthusiasm, helpful information, insightful comments, practical advice and unlimited ideas have helped me tremendously at all times in my project and writing of this thesis. Without her help and direction, this venture could never have been conceivable. I could never have envisioned having a great supervisor in my review.

My sincere appreciation goes to all my friends especially my course mate and housemate who have assisted me in various ways possible. Their opinions and views matter the most and are very useful indeed.

Finally, I would like to thank my family members for the encouragement, endless support, and prayers from them that keep me motivated to finish this project. Without their help, I would not be able to complete this project.

TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATIONS		
ABSTRACT		**i**
ABSTRAK		**ii**
ACKNOWLEDGEMENTS		**iii**
TABLE OF CONTENTS		**iv**
LIST OF TABLES		**vii**
LIST OF FIGURES		**viii**
LIST OF SYMBOLS		**xii**
LIST OF ABBREVIATIONS		**xiii**
LIST OF APPENDICES		**xiv**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Background	1
1.2	Societal and global issue on solar charging monitoring system using Arduino Uno for lighting application.	2
1.3	Problem Statement	3
1.4	Project Objective	4
1.5	Scope of Project	4
CHAPTER 2	**LITERATURE REVIEW**	**5**
2.1	Introduction	5
	2.1.1 Societal and global issue on solar charging monitoring system using Arduino Uno for lighting application	6
2.2	Renewable Energy	6
2.3	Typical of Solar Energy	8
2.4	Typical of Wind Energy	10
2.5	Typical of Geothermal Energy	13
2.6	Typical of Biomass Energy	15
2.7	Typical of Hydropower Energy	17
2.8	Typical of Tidal Energy	19
2.9	Microcontroller	21
2.10	Typical of Raspberry Pi	22
2.11	Typical of Arduino Uno	24

2.12 Typical of ESP 8266 27
2.13 Solar Charging System 30
2.14 Typical of Grid-Tied System 31
2.15 Typical of Off-Grid System 33
2.16 Typical of Hybrid Solar PV System 35
2.17 Comparison of Charging Monitoring System 38

CHAPTER 3 METHODOLOGY 39
3.1 Introduction 39
3.2 Justification for sustainable development on the project 39
3.3 Workflow of Project 40
3.4 Implement Solar Charging Monitoring System 46
3.4.1 Polycrystalline Solar Panel 46
3.4.2 Solar Charge Controller PWM 48
3.4.3 Sealed Lead Acid Battery 50
3.4.4 Voltage and Current Sensor 51
3.4.5 Arduino Uno R3 52
3.4.6 LED Light 54
3.4.7 Relay Module 55
3.4.8 LDR Sensor Module 56
3.5 Fabricate Charging Monitoring System 57
3.5.1 ESP 8266 57
3.5.2 Micro SD Card Module 58
3.5.3 Donut Board 59
3.5.4 Voltage and Current Sensor 60
3.5.5 Sealed Lead Acid Battery 61
3.5.6 Solar Charge Controller PWM 63
3.5.7 Arduino Uno R3 64
3.6 Experimental setup and Data Measurement 66
3.6.1 Open Circuit Voltage (VOC) and Short Circuit Current (ISC) values 66
3.6.2 Full System Data Collection 67
3.7 Software 68
3.7.1 Arduino IDE 69
3.7.2 Blynk Application 70

CHAPTER 4 RESULTS AND DISCUSSIONS 72
4.1 Introduction 72
4.2 Results and Analysis 72
4.2.1 The Open Circuit Voltage (VOC) and Short Current Circuit (ISC) results and graph 73
4.2.2 Collecting data over three days across the entire system 77
4.2.3 Comparison between the result of data collection 87
4.2.4 The data presentation of the Blynk application 88
4.2.5 Data on a battery's State of Charge (SOC) 98
4.2.6 Functionality test results 100

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 101
5.1 Conclusion 101
5.2 Potential for Commercialization 102

5.3 Future Works 102

REFERENCES **104**

APPENDICES **112**

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Comparison of Charging Monitoring System	38
Table 3.1	Technical Specification	47
Table 3.2	Technical Specification	49
Table 3.3	Technical Specification	51
Table 3.5	Technical Specification	53
Table 3.6	Technical Specification	62
Table 3.7	Technical Specification	63
Table 3.8	Technical Specification	65
Table 4.1	Data collected for VOC and ISC value	73
Table 4.2	Data Collection for Day 1	77
Table 4.3	Data Collection for Day 2	80
Table 4.4	Data Collection for Day 3	83
Table 4.5	Comparison between data collection	87
Table 4.6	Data Collection for Day 1	88
Table 4.7	Data Collection for Day 2	91
Table 4.8	Data Collection for Day 3	94
Table 4.9	State of Charge at no load	99
Table 4.10	Functionality test	100
Table 5.1	Gantt Chart PSM 1	112
Table 5.2	Gantt Chart PSM 2	112

LIST OF FIGURES

FIGURE **TITLE**
PAGE

Figure 1.1 Solar charge controller structure [3] 2

Figure 2.1 Measurement of electrical parameter of small off-grid PV system [10] 5

Figure 2.2 Schematic diagram of multi energy system [17] 7

Figure 2.3 Overall energy flow of PV generation [18] 9

Figure 2.4 Power system grid with wind integration [26] 11

Figure 2.5 Flash steam geothermal power plant [33] 14

Figure 2.6 Schematic diagram of the FBG [38] 16

Figure 2.7 Typical hydropower plant with reservoir [43] 18

Figure 2.8 Tidal barrage (Flood generation) [49] 20

Figure 2.9 The overview of an IoT system [55] 22

Figure 2.10 Raspberry Pi 4B pinout [57] 23

Figure 2.11 Arduino UNO [63] 25

Figure 2.12 Pin Definitions or layout of 1st generation ESP8266 NodeMCU development board [67] 28

Figure 2.13 Solar Power System [73] 31

Figure 2.14 Grid-Interfaced Solar Photovoltaic System [75] 32

Figure 2.15 Hardware configuration of SCADA system [80] 34

Figure 2.16 Solar PV-diesel with battery backup [85] 36

Figure 3.1 Sustainable development goals 40

Figure 3.2 Block diagram 1 41

Figure 3.3 Block diagram 2 41

Figure 3.4 Block diagram 3 41

Figure 3.5 Block diagram 1 42

Figure 3.6 Block diagram 2 42
Figure 3.7 Block diagram 3 43
Figure 3.8 Flowchart of the system 46
Figure 3.9 Solar Panel 47
Figure 3.10 Solar Charge Controller 49
Figure 3.11 SLA Battery 12V 4.5AH 50
Figure 3.12 Voltage and Current Sensor 52
Figure 3.13 Arduino Uno R3 53
Figure 3.14 LED Light 12V 55
Figure 3.15 Relay Module 56
Figure 3.16 LDR Sensor Module 57
Figure 3.17 ESP 8266 58
Figure 3.18 Micro SD Card Module 59
Figure 3.19 Donut Board 60
Figure 3.20 Voltage and Current Sensor 61
Figure 3.21 SLA Battery 12V 4.5AH 62
Figure 3.22 Solar Charge Controller 63
Figure 3.23 Arduino Uno R3 65
Figure 3.24 Hardware Setup 67
Figure 3.25 Experimental Setup 68
Figure 3.26 Arduino IDE 70
Figure 3.27 Blynk Application 71
Figure 4.1 Voltage vs Time 74
Figure 4.2 Current vs Time 74
Figure 4.3 Power vs Time 75
Figure 4.4 Time vs Voltage and Current 75

Figure 4.5 Solar panel specification 76

Figure 4.6 Data measured setup 77

Figure 4.7 Voltage vs Time 78

Figure 4.8 Current vs Time 78

Figure 4.9 Power vs Time 79

Figure 4.10 Time vs Voltage and Current 80

Figure 4.11 Voltage vs Time 81

Figure 4.12 Current vs Time 81

Figure 4.13 Power vs Time 82

Figure 4.14 Time vs Voltage and Current 82

Figure 4.15 Voltage vs Time 83

Figure 4.16 Current vs Time 84

Figure 4.17 Power vs Time 85

Figure 4.18 Time vs Voltage and Current 85

Figure 4.19 Experimental Setup 86

Figure 4.20 Voltage vs Time 88

Figure 4.21 Current vs Time 89

Figure 4.22 Power vs Time 89

Figure 4.23 Time vs Voltage and Current 90

Figure 4.24 Voltage vs Time 91

Figure 4.25 Current vs Time 92

Figure 4.26 Power vs Time 93

Figure 4.27 Time vs Voltage and Current 93

Figure 4.28 Voltage vs Time 95

Figure 4.29 Current vs Time 96

Figure 4.30 Power vs Time 97

Figure 4.31 Time vs Voltage and Current 98

Figure 4.32 Data obtained for the OCV value 99

LIST OF SYMBOLS

%	-	Percentage
<	-	Less than

LIST OF ABBREVIATIONS

V	-	Voltage
A	-	Current
Hz	-	Frequency
W	-	Power

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Gantt Chart	112

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, Nowadays, electricity is a crucial aspect of daily lives and people heavily rely on it [1]. Solar energy, which is primarily derived from the sun's electromagnetic emissions is the most abundant and eco-friendly form of energy. The popularity of utilizing solar power systems as an alternative source of energy has increased globally due to their effortless installation and minimal maintenance requirements. Solar energy can be used to generate electricity using photovoltaic (PV). As people continue to explore and advance with the research and development of sustainable energy, the advantages and merits of photovoltaic power generation are becoming more prominent and obvious. Electricity is an essential element that encompasses every aspect of daily life, from lighting homes to powering refrigerators, heating, cooling systems and even means vehicles. As time goes on, the demand for electricity has increased along with the necessity of producing more of it. However, the amount of electricity currently produced is insufficient to meet this demand, both in our country and in other developing nations, the rising cost of electricity has made it unaffordable for the majority of people. As a sustainable and workable solution, the use of solar power has become more and more popular [2]. Figure 1.1 below shows the system of solar charging.

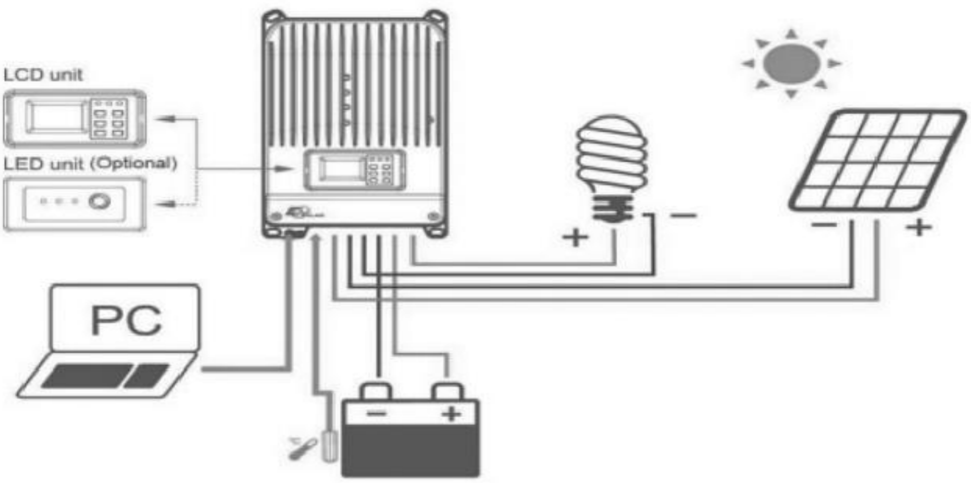


Figure 1.1 Solar charge controller structure [3]

1.2 Societal and global issue on solar charging monitoring system using Arduino Uno for lighting application.

The problem with this system is that not everyone has access to clean energy and traditional energy sources have an adverse effect on the environment[4] [5]. Although this method encourages the use of solar energy which is sustainable and lowers carbon emissions, obstacles like pricing, maintenance and technical know-how prevent its broad use. Additionally, maximising the system's effectiveness and impact requires guaranteeing stable battery performance and storage capacity [6], scalability for future energy demands and efficient data monitoring and administration. To promote fair and sustainable access to clean energy and reduce the negative impacts of conventional energy sources on both the environment and local populations, it is imperative to address these challenges.

1.3 Problem Statement

Coal is a plentiful fossil fuel that can be turned into usable energy [7]. Unfortunately, the extraction and application of fossil fuels have a negative impact on both the environment and human health. However, when solar panels are used to generate electricity, the resulting emissions of greenhouse gases are not released into the atmosphere which is a crucial and compelling reason why solar energy has emerged as a pivotal component of the ongoing transition towards a more sustainable and eco-friendly energy landscape.

When charging devices are not properly managed, there is a danger of experiencing overcharging or undercharging which can result in decreased performance, a shorter lifespan, and safety risks. These risks can impede on the proficiency of the system and can cause more cost to be put into maintenance. Thus, a good monitoring system can be a great solution to overcoming this problem as it provides sufficient data so that users can observe the device's data and avoid incoming damages [8].

The presence of Arduino Uno is crucial to monitor the data of voltage and current values that is generated by the solar charging system [9]. As stated previously, the danger of experiencing overcharging can occur but with a simple monitoring system, the charging system can operate smoothly without the risk and dangers of over or undercharging. Therefore, Arduino uno can play a critical role in ensuring the efficient and reliable operation of the system by communicate with other devices and measure physical quantities such as voltage and current.

1.4 Project Objective

1. To implement the Solar Charging Monitoring System using Arduino Uno for Lighting application.
2. To fabricate Charging Monitoring System using Solar Panel, Arduino Uno and Solar Charge Controller.
3. To evaluate the performance of Solar Charging Monitoring System using experimental setup and data measurements.

1.5 Scope of Project

This work consists of the following items:

a) This project uses a solar power as a main supply to the system.

b) The monitoring system for the charging detects amount of voltage and current supply from the solar panel.

c) Arduino Uno acts as receiving and sending data.

d) Voltage and current sensors are used to measure and control the system's electrical properties.

e) The ESP8266 transmits data for the Blynk application to display.

f) LED lights are the project's output.

g) The system stores the recorded data acquired on an SD card.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A solar charging monitoring system as in figure 2.1 below using an Arduino Uno is a system that keeps track of how solar panels are being used to charge a battery or group of batteries. The voltage and current levels of the batteries and solar panels are measured and watched by this system using an Arduino Uno. The microprocessor then modifies the charging rate to enhance efficiency and guard against battery deterioration.

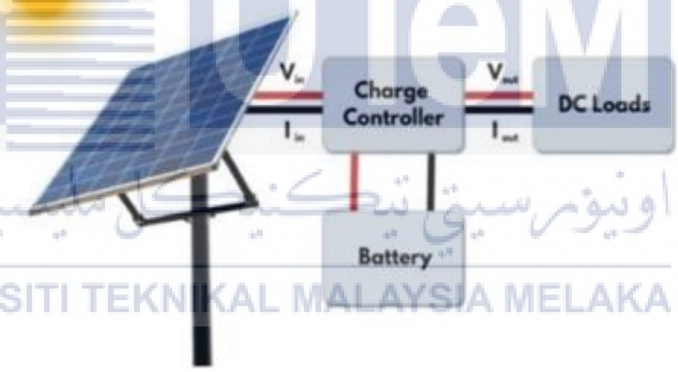


Figure 2.1 Measurement of electrical parameter of small off-grid PV system [10]

The microprocessor in this device keeps track of how well the solar panels are working and modifies the charging rate as necessary to achieve optimal energy effectiveness. Overall, Arduino Uno based on solar charging monitoring system is a useful tool for streamlining the charging procedure and enhancing the performance of solar-powered devices. This technology can help to increase the dependability of solar-powered systems and help to increase battery life by offering real-time monitoring and management of the charging process. This can contribute to the wider adoption of solar energy systems and help to reduce people's reliance on non-renewable energy sources.

2.1.1 Societal and global issue on solar charging monitoring system using Arduino Uno for lighting application

The societal and global challenges surrounding the system are emphasised in the literature review. These concerns centre on the difficulties in putting such systems into practise and adopting, particularly in the context of clean energy availability and sustainable development [11]. The assessment talks on the affordability issues that prevent solar charging devices from being widely used, particularly in low-income areas[12]. It also emphasises how crucial technical know-how and upkeep are to the system's long-term efficiency. The literature analysis highlights the importance of battery performance and storage capacity in delivering a dependable power source as well as the requirement for scalable and adaptive solutions to meet changing energy demands [13]. The assessment also emphasises the need of efficient data administration and monitoring for optimising energy production and consumption. The goal of the literature study is to shed light on these problems and the social and international difficulties that must be resolved in order to successfully use this system.

2.2 Renewable Energy

Natural resources that are renewed over time and never run out are the source of renewable energy [14]. Renewable energy is a rapidly evolving and expanding field that encompasses a variety of sustainable and eco-friendly sources of power including solar, wind, hydroelectric, geothermal, biomass and others. These forms of energy are derived from naturally replenished resources that are continually available and do not deplete over time, as opposed to non-renewable sources such as fossil fuels which are finite and have significant environmental consequences. In 2020, 27 000 TWh of electricity from all sources were utilised globally, making up almost 17% of all energy consumption [15].

It is now more important than ever to embrace and use renewable energy technologies widely as the demand for a more robust and sustainable energy system rises as a result of issues including climate change, energy security, economic and social growth [16]. Reduced greenhouse gas emissions, better air, water quality, greater energy independence and more economic prospects are just a few of the many benefits of renewable energy. With multiple government policies, rules, and incentives targeted at accelerating renewable energy development and acceptance, the deployment and integration of renewable energy systems are growing on a worldwide scale as a result. The figure 2.2 shows the multi energy system.

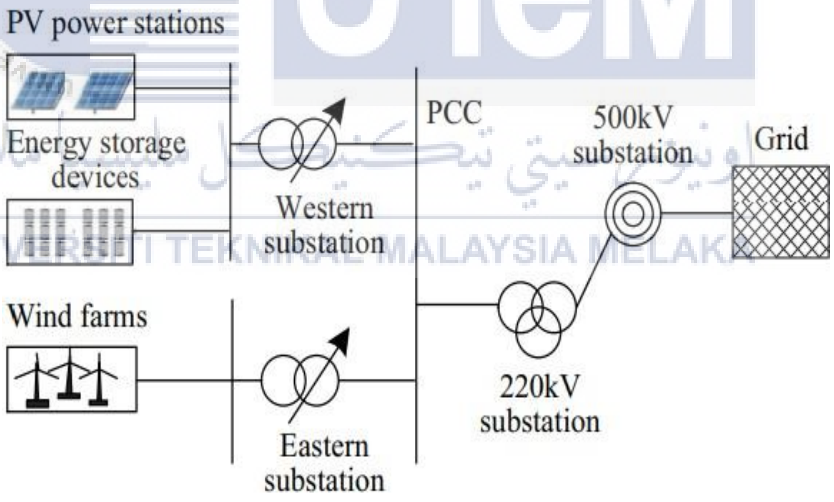


Figure 2.2 Schematic diagram of multi energy system [17]

2.3 Typical of Solar Energy

Solar energy is a rapidly growing and increasingly popular form of renewable energy that offers a clean, abundant, and sustainable source of electricity [11]. Solar energy systems are a sustainable and renewable source of energy since solar use the sun's energy to produce electricity. Solar energy systems employ photovoltaic panels to convert sunlight into electrical energy that may be used to power buildings such as houses and businesses. The surface of water bodies, the ground or even rooftops may all be used to put solar panels.

Because of this, solar energy systems may be used in a variety of contexts from little homes to massive businesses and industrial complexes. Additionally, solar energy systems may be modified to satisfy the unique energy requirements of various customers. A small residential solar panel system might be built to meet the energy requirements of a single-family home for example, or a larger system could be built to power an entire neighbourhood or a commercial building [15]. When it comes to reducing greenhouse gas emissions and minimising the effects of global warming, the incorporation of solar energy plays a vital part in the transition to a sustainable and environmentally conscious economy. The energy flow of PV system is shown in figure 2.3 below.

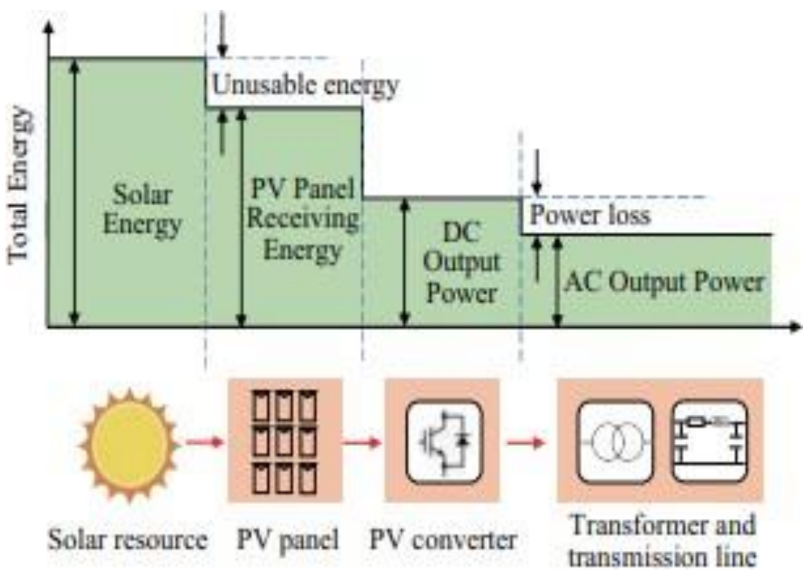


Figure 2.3 Overall energy flow of PV generation [18]

This energy has several benefits including minimal maintenance costs [19]. Solar energy systems have no moving components and are made to function consistently for many years with minimum maintenance, therefore it requires very little maintenance. Solar panel installation has a hefty up-front expense, but the long-term advantages much exceed it. Solar energy may result in large electricity bill savings and once the solar panels are deployed, there is no further expenditure for fuel or maintenance.

Finally, the usage of solar energy can reduce reliance on fossil fuels [20]. As a limited resource that is quickly running out, fossil fuels have a huge detrimental influence on the environment. It causes water pollution, air pollution and greenhouse gas emissions that cause climate change. On the other hand, solar energy is a plentiful, sustainable and renewable energy source that has less of a negative environmental impact than fossil fuels [11]. People may lower the amount of fossil fuels that are harvested and burned, lessening the detrimental effects on the environment caused by these activities by moving our energy usage towards solar energy.

The drawback is that installation of this energy requires a suitable location [21]. One of the critical factors is the amount of direct sunlight that the location receives. To generate electricity, solar panels need to be exposed to sunlight and the more direct sunlight it receives, the more energy it can produce. This includes a location with high levels of direct sunlight and low levels of cloud cover as well as the correct orientation and tilt angle of the solar panels [19]. As a result, choosing a site with lots of direct sunshine is essential for a solar energy system to operate at its best.

Shading from nearby structures or trees can also reduce the system's energy output, making it crucial to select a location with little to no shading [22]. In general, choosing the ideal site for a solar energy system is essential for maximising performance and energy output. For maximising the system's energy output and reaping the full benefits of solar energy, the location must have high levels of direct sunshine and low levels of cloud cover, the solar panels must be oriented correctly and tilted and there must be little to no shade [18].

2.4 Typical of Wind Energy

Wind energy is a rapidly growing source of renewable energy that is clean, cost-effective and widely available around the world [23]. Due to global population expansion, economic expansion and technological advancements, energy consumption is increasing quickly. Traditional fossil fuel sources such coal, oil and gas are under a lot of strain as a result of this rise in energy demand. These non-renewable resources are rapidly running out and the extraction and consumption have a severe impact on the environment in the form of air and water pollution, greenhouse gas emissions and climate change [24].

Wind turbines harness the power of the wind to generate electricity without producing any harmful emissions, making it one of the most environmentally friendly forms of energy available. Wind energy is rising in popularity as a way to satisfy rising energy demands and reduce greenhouse gas emissions as nations all over the world work to minimise the carbon footprints and switch to more sustainable energy sources [25]. In this sense, wind energy stands for an essential part of the worldwide fight against climate change and the transition to a cleaner, more sustainable future. Power system grid with wind integration is mentioned in figure 2.4 below.

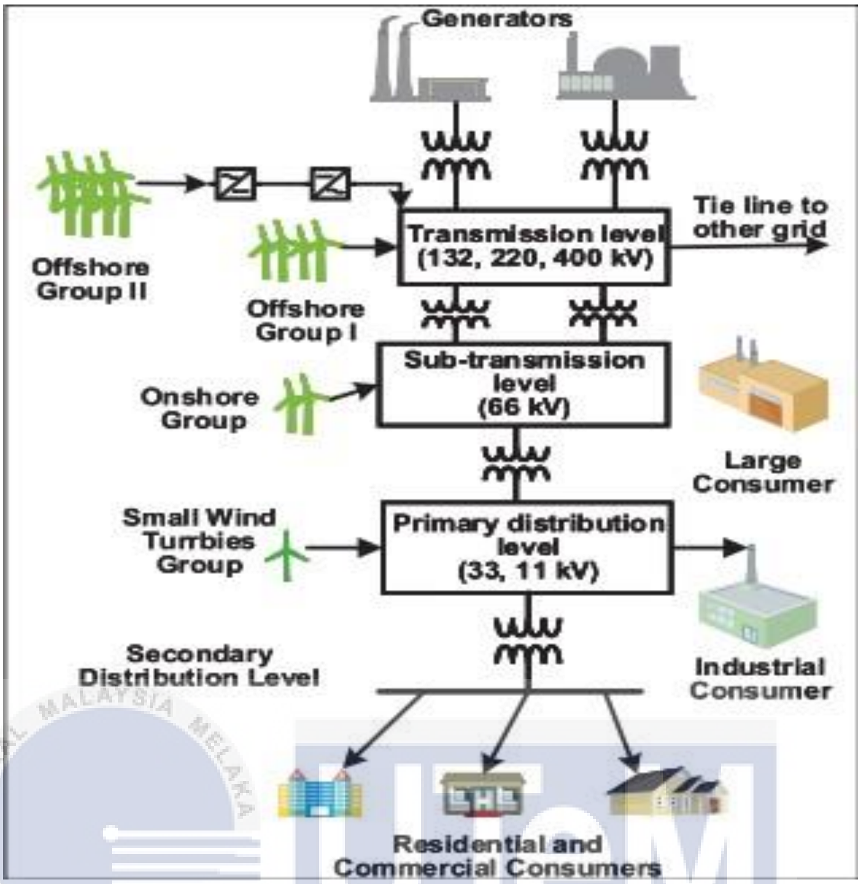


Figure 2.4 Power system grid with wind integration [26]

Since fossil fuels are not used to power turbines, wind energy has developed into one of the cleanest sources of energy and does not cause climate change by emitting greenhouse gases during energy production [25]. Wind turbines operate by harnessing the natural power of the wind and converting it into usable electricity without emitting harmful pollutants or greenhouse gases into the atmosphere. Thus, wind energy not only benefits the environment but also aids in lowering human reliance on fossil fuels and other non-renewable energy sources [27]. By continuing to develop and invest in wind energy technologies, people can significantly reduce this energy's carbon footprint and move towards a cleaner, more sustainable future for generations to come.

Furthermore, the generation of jobs is one of the most important economic benefits of wind power [28]. The wind energy sector employs many people and provides a variety of job possibilities in a variety of industries including production, building, maintenance and operation. Specialised parts and infrastructure are needed for wind turbines, which supports the creation of jobs in the manufacturing industry. This covers the manufacture of parts like towers, generators and blades. In addition to creating economic opportunities, the construction of wind farms also necessitates the installation and building of wind turbines and other supporting infrastructure [19]. The wind energy sector provides employment possibilities across a range of education and skill levels, ranging from skilled crafts to managerial roles. The sector is anticipated to provide more jobs as wind power continues to gain recognition and significance, which will be good for the economy and nearby towns.

Wind turbines are generally located in remote, rural areas where there are fewer people living nearby. This is because wind turbines can generate a significant amount of noise [29], which can be disruptive to people living in close proximity. While modern wind turbines are much quieter than turbine's predecessors, these technologies still produce some level of noise, particularly when operating at full capacity. Typically, wind turbines are located in areas with minimal human activity and few residents to mitigate any potential noise pollution. Furthermore, wind turbines are strategically positioned to leverage natural terrain features such as hills or ridges, which can help to reduce the impact of noise on nearby communities.

Besides, in order to maintain efficiency, wind turbines require routine maintenance [30]. Depending on the particular parts and systems of the turbine, this maintenance may take many different forms. To preserve the durability of the turbine's parts, avoid malfunctions and maximise energy output, routine maintenance is essential. Regular blade inspection and cleaning, replacement of worn-out parts, lubrication of mechanical elements, troubleshooting and repairs of any difficulties are a few examples of routine maintenance duties. The frequency of maintenance required may depend on several factors such as the age of the turbine, its location and environmental conditions. For instance, turbines located in hostile areas or exposed to severe weather can need maintenance more frequently than those in more temperate settings.

2.5 Typical of Geothermal Energy

Geothermal energy is a renewable energy source that harnesses the natural heat of the Earth to generate electricity and provide heating and cooling for buildings [31]. This energy is obtained by drilling deep into the Earth's surface and accessing the hot water and steam trapped below the ground. Unlike other sources of energy, geothermal energy is renewable and emits little to no greenhouse gases, making it one of the cleanest and most sustainable forms of energy available. Geothermal power plants can be found all over the world, tapping into the heat energy of underground reservoirs of hot water and steam [32]. The use of geothermal energy has been steadily growing in recent years as countries around the world seek to reduce its dependence on fossil fuels and transition towards cleaner, more sustainable energy sources. Figure 2.5 below show the system of geothermal power plant.

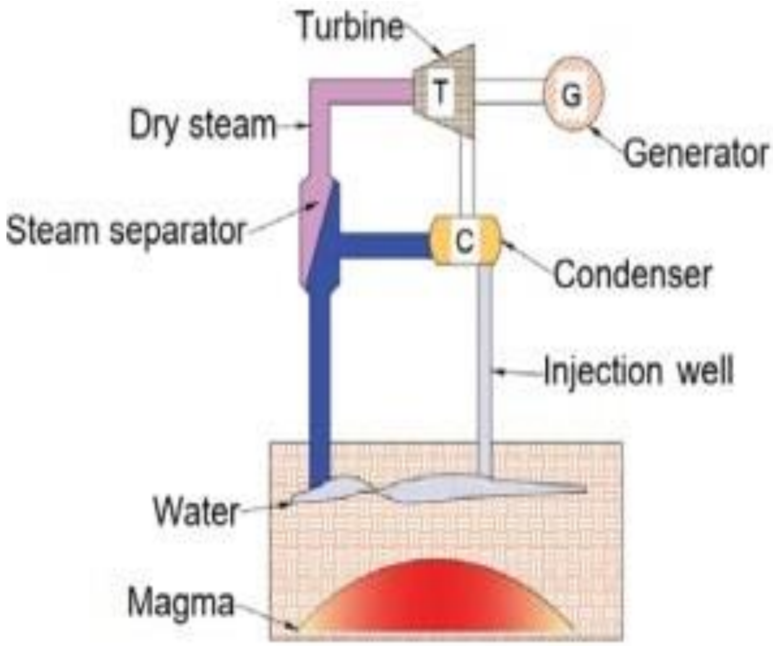


Figure 2.5 Flash steam geothermal power plant [33]

In comparison to other renewable energy sources like solar, wind or biomass, geothermal energy also has several benefits. Because it is not reliant on the wind or the sun and is accessible all year round, it is an exceptionally consistent source of energy[34]. This consistency is due to the fact that the Earth's heat is a virtually limitless source of energy. The temperature of the Earth's core is estimated to be around 6,000 degrees Celsius, and this heat energy is constantly being replenished through natural processes such as radioactive decay [35]. Geothermal energy is an important source of baseload power because of its dependability which is the minimal amount of electricity needed to consistently supply a community or region's demands.

Other than that, the geological and geographical features of the location are just two of the many variables that determine whether geothermal energy is suitable for a certain region [35]. Due to the higher temperatures and greater availability of subterranean water or steam in locations with significant levels of volcanic and tectonic activity, geothermal energy is frequently most prevalent and accessible in these areas. The regional energy demand is a significant component in deciding if geothermal energy is appropriate for a certain area. In locations with significant energy needs, geothermal energy may be more appealing since it can help to reduce the high initial capital costs of constructing and operating geothermal power plants [35]. In general, a variety of geological, topographical, economic and policy elements interact in complicated ways to determine if geothermal energy is appropriate for a given area.

2.6 Typical of Biomass Energy

A renewable source of energy is biomass [36] as shown in figure 2.6 below. It entails turning organic materials such plant matter, agricultural waste and forestry leftovers into energy. The most common method for producing biomass energy is combustion, in which the organic material is burned to produce heat that may be utilised to create electricity or heat structures. When generated and handled appropriately, biomass energy has the potential to be a sustainable and eco-friendly source of energy [37]. It falls under the renewable category due to its ability to regenerate over the duration of an individual's lifespan.

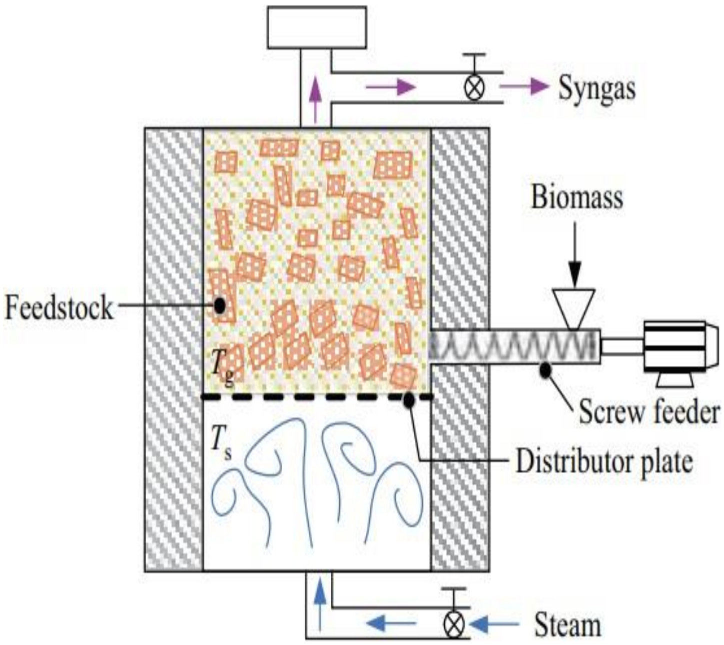


Figure 2.6 Schematic diagram of the FBG [38]

Biomass energy also a source that offers the advantage of reducing greenhouse gas emissions and promoting sustainable resource management practices [39]. Emissions of carbon dioxide are the primary cause of climate change. As opposed to conventional fossil fuels which do not fit into the natural carbon cycle, biomass is regarded as a carbon-neutral energy source. Carbon dioxide from the atmosphere is taken up by growing plants and stored in its biomass. The carbon that is released into the atmosphere when this biomass is burned for energy is instead taken up by new plant growth.

However, this is the same quantity of carbon dioxide that plants absorbed throughout its life cycle. As a result, a closed carbon cycle is created, in which the carbon emitted during the generation of biomass energy is balanced by the carbon absorbed during plant development. Therefore, burning biomass does not cause any new carbon emissions to enter the atmosphere [36]. The cycle is then restarted when new plants emerge and take carbon dioxide from the atmosphere.

While biomass energy has the potential to reduce reliance on fossil fuels and promote sustainable land use practices, it also has several disadvantages such as it requires a lot of area [40], mostly because it needs room for storage. Furthermore, because biomass energy systems are often employed on a smaller scale, storage might be difficult because the required amount of fuel might not always be readily available. This restricts the potential locations for biomass energy facilities.

Aside from reducing safety risks, proper storage management may also assist preserve the quality of biomass fuel by using the right handling and storage methods [41]. Additionally, some biomass plants produce its own organic material. To be able to cultivate crops or tiny forests, these plants may require a lot of room. For every kilowatt hour of power produced, biomass energy plants that grow its own fuel require more land.

2.7 Typical of Hydropower Energy

A sustainable energy source known as hydropower uses the force of moving water to create electricity [42]. It is one of the earliest kinds of renewable energy, going back to the days when mills and other machinery were powered by waterwheels. Large-scale hydroelectric power facilities that provide energy for millions of people make hydropower a significant source of electricity today. Hydropower facilities exist in a wide range of shapes and sizes, from large-scale dams that supply electricity to entire regions to small-scale run-of-river systems that supply electricity to specific residences or commercial establishments [43]. Figure 2.7 below shows the hydropower plant system.

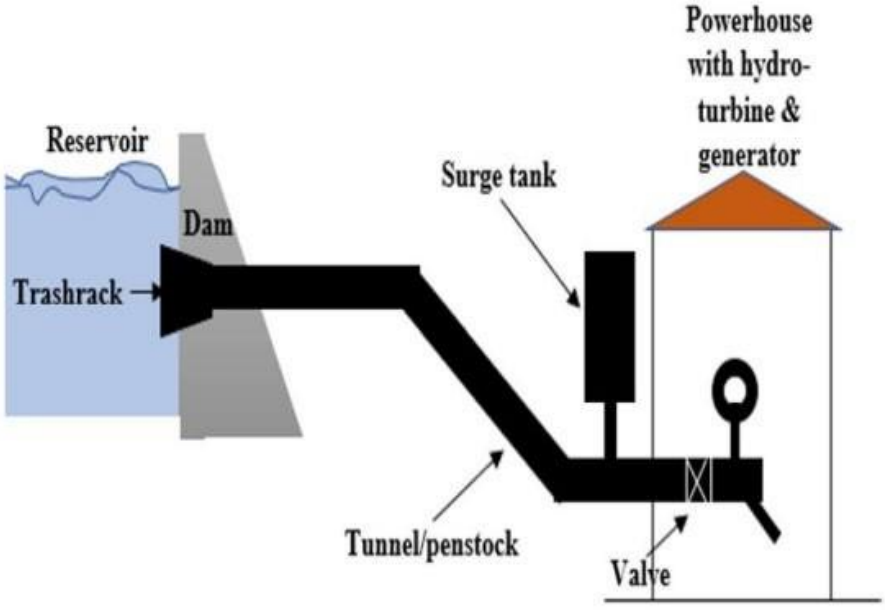


Figure 2.7 Typical hydropower plant with reservoir [43]

This source is a clean and renewable energy source that generates electricity without producing greenhouse gas emissions or other harmful pollutants, making it a key component in efforts to reduce the negative environmental impacts of energy production and mitigate the effects of climate change on both a local and global scale [44]. As a result, hydropower represents a significant replacement for non-renewable energy sources which are limited and will ultimately run out. Overall, hydropower energy is an environmentally responsible and sustainable way to satisfy people energy demands.

This energy is regarded as a variable energy source since it is simple to manage and control to meet the demand for power [45]. This is feasible because the quantity of water that can be used to create electricity from hydropower relies on how much of the system is being used and how much of it can be changed by adjusting how much water is passing through the turbines. The quantity of energy produced may be raised or lowered to fit the fluctuating demand for power by altering the water flow.

Although hydropower is seen as a clean and sustainable energy source, it does have certain negative effects on the environment. Ecosystems and nearby communities may be significantly impacted by the building of hydropower projects [46]. The natural flow of rivers can be changed by dams which may have a negative impact on fish populations, aquatic ecosystems and water quality. Communities may be uprooted by reservoir construction, significant resources and land may be lost. In addition, running hydropower plants may use a lot of water, which might be problematic in places where there is already a water shortage.

The cost of hydropower energy can vary based on a number of variables, including the project's size and location, the building cost, the degree of maintenance and improvement spending [47]. Large-scale hydropower projects can be expensive to build initially but it generally lasts a long time and can be a dependable source of electricity for many years. However, the high upfront costs of building and maintaining hydropower facilities can make it a less competitive option when compared to other sources of renewable energy such as wind and solar power. Additionally, as maintenance and repair expenses mount up over time, the cost of maintaining hydropower plants may rise.

2.8 Typical of Tidal Energy

Tidal energy is a type of renewable energy that harnesses the power of tides by converting the cyclical movement of ocean swells caused by the gravitational pull of the moon and sun into usable forms of electricity [48]. Unlike other forms of renewable energy such as solar or wind power, tidal energy is completely predictable and reliable. Tidal range technologies, which utilize the height difference between high and low tides can be implemented through systems like tidal barrage or lagoon technologies that convert the energy of the moving water into electricity using turbines as mentioned in figure 2.8 below.

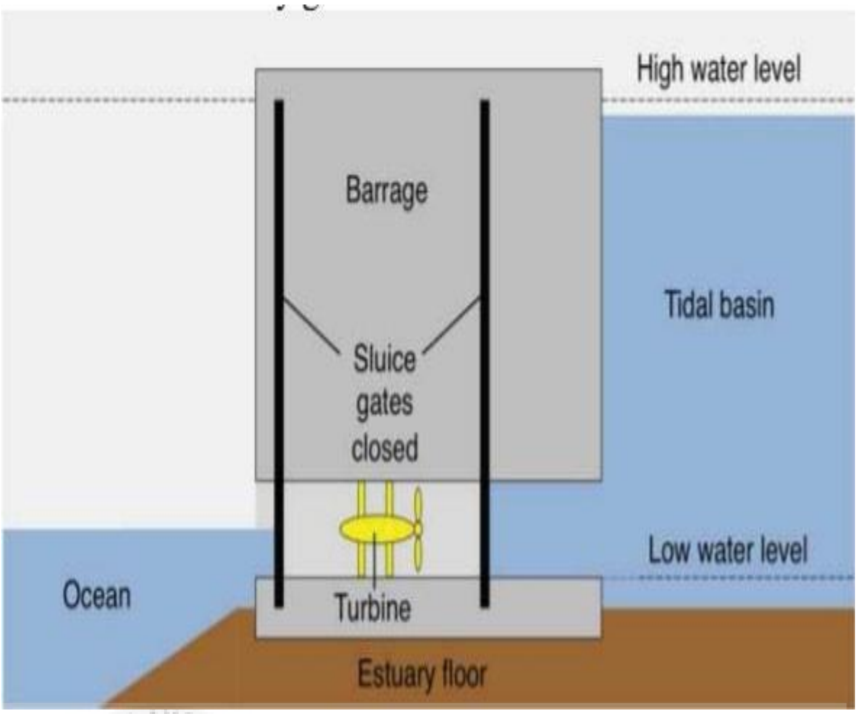


Figure 2.8 Tidal barrage (Flood generation) [49]

Tidal energy has several advantages including that it is a very reliable source of electricity [50]. The tides are influenced by predictable astronomical cycles, specifically the gravitational forces of the moon and the sun. This means that the frequency, amplitude and timing of tidal movements can be predicted with a high degree of accuracy, sometimes years in advance. Unlike other renewable energy sources such as wind or solar, which can be intermittent and difficult to predict, tidal energy can be relied upon to produce a steady and consistent supply of energy. This makes tidal energy particularly useful as a baseload energy source, which means it can provide a constant supply of power to the electrical grid over extended periods of time.

The harsh and corrosive sea environment where tidal energy installations are situated might make maintenance quite expensive[48]. Due to continual exposure to saltwater and strong currents, the turbines and other equipment used in tidal energy systems are vulnerable to wear and tear, which can raise the likelihood of equipment failure and downtime. Furthermore, many tidal energy plants are located in distant areas which can complicate, raise the expense of maintenance and repair work [51]. To guarantee the safe and effective functioning of tidal energy systems and to reduce the danger of damage or failure, routine maintenance is crucial. The goal of ongoing research and development is to make tidal energy systems more economically viable and accessible in the future by lowering maintenance costs and enhancing their dependability and efficiency.

2.9 Microcontroller

A microcontroller is a tiny computer built on a single integrated circuit and is intended to manage particular equipment and operations [52]. Input/output ports, memory, a central processing unit (CPU), numerous peripherals including timers, analog-to-digital converters and communication interfaces are frequently included. Microcontrollers are frequently seen in battery-operated gadgets since it is made to run on little electricity. Additionally, microcontroller is frequently employed in embedded systems including industrial control systems, consumer electronics and automotive applications [53].

The challenges are in agreement with the low-level control of hardware that is regularly hidden by the operating system in a PC or single-board computer. The controller is programmed to carry out specified tasks. Last but not least, it is built to process data in real-time, making it appropriate for applications like robotics and automation that demand quick responses [54]. In general, microcontrollers are strong and adaptable devices that can be utilised in a variety of applications where real-time processing, low power consumption and low cost are key factors. Figure 2.9 below show the overview of a system.

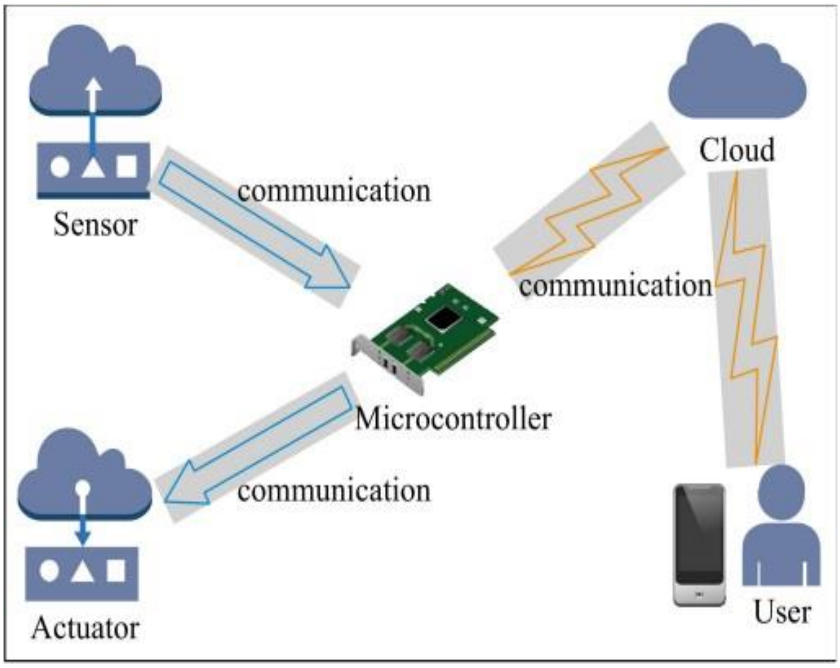


Figure 2.9 The overview of an IoT system [55]

2.10 Typical of Raspberry Pi

The Raspberry Pi is a reasonably priced, little computer that can be used with a regular keyboard, mouse and linked to a computer display or TV [56]. With the help of this capable small gadget, individuals of all ages may learn about computing and how to programme in languages like Scratch and Python. Despite its little size, it is capable of carrying out all the functions of a standard desktop computer including accessing the internet, watching high-definition films, making spreadsheets, writing documents and playing games. For users that need a cheap computer solution or wish to learn more about computers, this little gadget is a great tool. The pinout of this microcontroller has shown in figure 2.10 below.

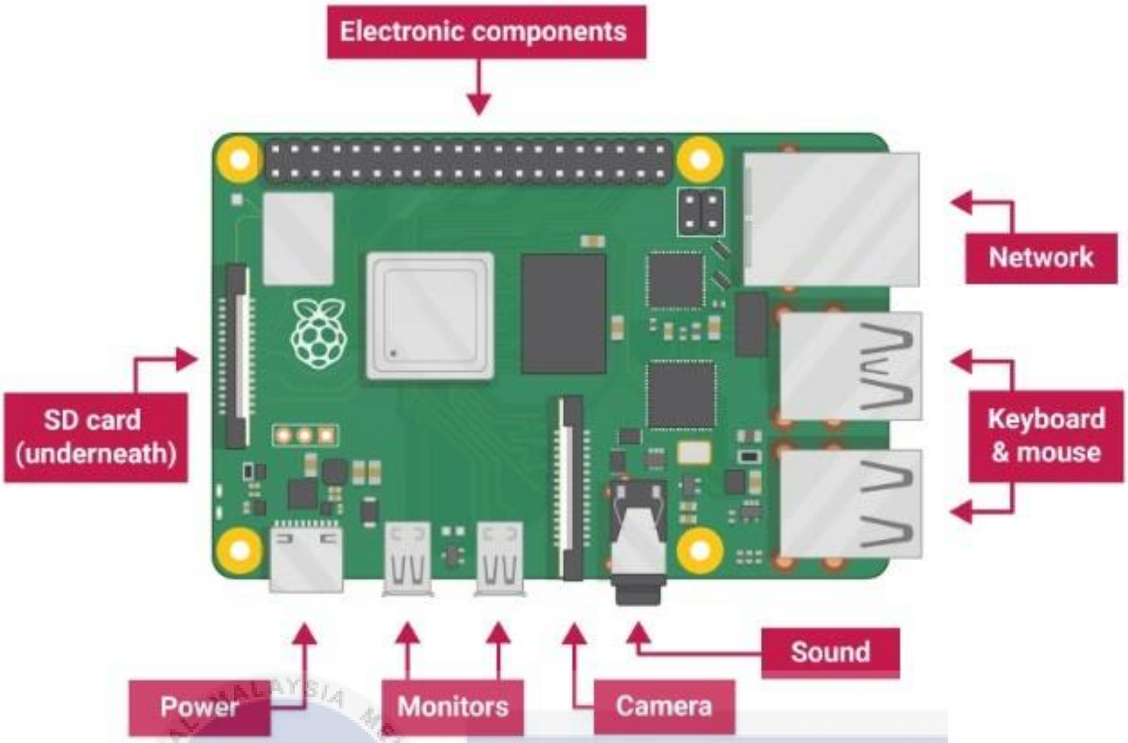


Figure 2.10 Raspberry Pi 4B pinout [57]

The Raspberry Pi is a flexible gadget with lots of advantages. The Raspberry Pi's aptitude for adaptive technology is one of its key advantages. The ability to play high-definition films and display photos makes it a fantastic choice for creating multimedia systems [58]. It is also suitable for developing prototypes of embedded systems. Because of how reasonably priced this gadget is, it is feasible to design intricate systems that work well without going over budget. The Raspberry Pi is quite adaptable and suitable for a range of tasks. Due to its small form factor and low cost, it's a fantastic option for any users looking to experiment with creating own projects or needs a cheap computing solution.

Next, this controller is a gadget that is simple to use and doesn't require substantial programming knowledge. All age groups, especially younger ones that are interested in learning about programming, should find it easy to use. Python is a simple and user-friendly programming language that is used by the Raspberry Pi [59]. Python helps users to express concepts with fewer lines of code and offers greater code readability when compared to other programming languages. Additionally, Python has automated memory management tools that can make programming simpler and easier to understand for newcomers. Anyone may learn useful programming skills and develop their programming knowledge by utilising the Raspberry Pi.

The Raspberry Pi computer has certain restrictions despite its numerous benefits. Its inability to manage several jobs on the same system is one of its shortcomings [59]. This implies that a Raspberry Pi might not be the greatest option for people who need to multitask frequently because it's primarily made to do straightforward tasks. It's crucial to remember that the Raspberry Pi can still do a range of activities and is a great choice for people that want a cheap computer solution for simple computing jobs. A desktop or laptop computer can be a better choice for folks that need more powerful computing skills.

Other than that, one of the drawbacks of the Raspberry Pi is that it lacks internal storage, hence a micro-SD card is needed to serve as an internal storage device [60]. Micro-SD cards are not noted for its speed, despite being readily accessible and reasonably priced. Users can utilise premium micro-SD cards as one example or people might think about utilising an external hard drive or SSD for more capacity. It's possible to improve the performance of the Raspberry Pi and get better results by configuring it properly and choosing wisely for storage.

2.11 Typical of Arduino Uno

The Arduino Uno is a well-known microcontroller board that is designed to be an accessible and simple-to-use platform for a variety of electrical projects from straightforward robotics and automation systems to more complicated LED lighting installations [61]. The Arduino Uno is a great option for hobbyists, students and professionals that want to experiment with electronics and learn more about embedded systems and microcontrollers because of its small form factor, straightforward programming interface, large library of code examples and hardware add-ons. The Arduino Uno has established itself as a standard in the world of DIY electronics because to its low price, adaptability, large user and developer community [62]. It is a fantastic tool for anybody wishing to realise their ideas. Figure 2.11 below shows the structure of this controller.

Figure 2.11 Arduino UNO [63]

One of the Arduino's main benefits is its ready-to-use design [61], which makes it very simple to start programming and making electronic creations. The Arduino is sold as a complete kit that contains all the parts required for its fundamental operation such as a 5V regulator, a burner, an oscillator, a microcontroller, a serial communication interface, an LED and headers for connections. As a result, whether programming or using the Arduino, users won't have to worry about tricky programmer connections or any other interface problems. Users only need to connect the Arduino to the computer's USB port to begin programming.

The other privilege of this microcontroller is an open-source community [64], which offers users a plenty of online tools and support. A useful site where users may exchange information, ask questions and interact with another Arduino expert is the Arduino forum. Additionally, because Arduino projects are open source, there has already been a lot of work done on a variety of subjects, making it simple for users to locate examples and code snippets to expand on. Numerous Arduino projects have already been created and shared by the community, ranging from fan controllers to smart houses, giving users access to a vast ecosystem of tools and inspiration.

The fact that popular Arduino boards like the Uno lack built-in support for certain communication technologies like Wi-Fi, Bluetooth or Ethernet is one of its potential drawbacks [64]. This implies that users must connect extra hardware modules with the board in order to enable certain features, which might complicate and increase the cost of projects. Even though some more recent Arduino boards do support these technologies, it is often more expensive than simpler boards like the Uno. Users who are working on projects with limited resources or like to keep things simple may find this to be a weakness.

The other drawback of Arduino boards is that this board are frequently not suggested for professional or industrial applications or large-scale projects [65]. The main uses of Arduino boards are teaching and small- to medium-scale project prototyping. Its capabilities including as processor speed, memory size and I/O prowess might not be sufficient to satisfy the requirements of intricate industrial systems or significant business undertakings. Furthermore, it may be difficult to use Arduino boards in industrial contexts if strict safety standards, certifications and legal requirements are needed.

2.12 Typical of ESP 8266

A popular microcontroller with outstanding features and capabilities for IoT (Internet of Things) applications is the ESP8266 as shown in figure 2.12 below. With its combination of a powerful 32-bit CPU, built-in Wi-Fi connection [66] and plenty of RAM, this little and reasonably priced gadget is perfect for a variety of tasks. The ESP8266 can easily connect to the internet thanks to its integrated TCP/IP stack, enabling remote control, data transmission and connectivity with other devices or cloud services. The ESP8266 is a well-liked option among developers and hobbyists aiming to develop creative and connected solutions for various IoT applications because of its adaptability, low power consumption and strong community support.

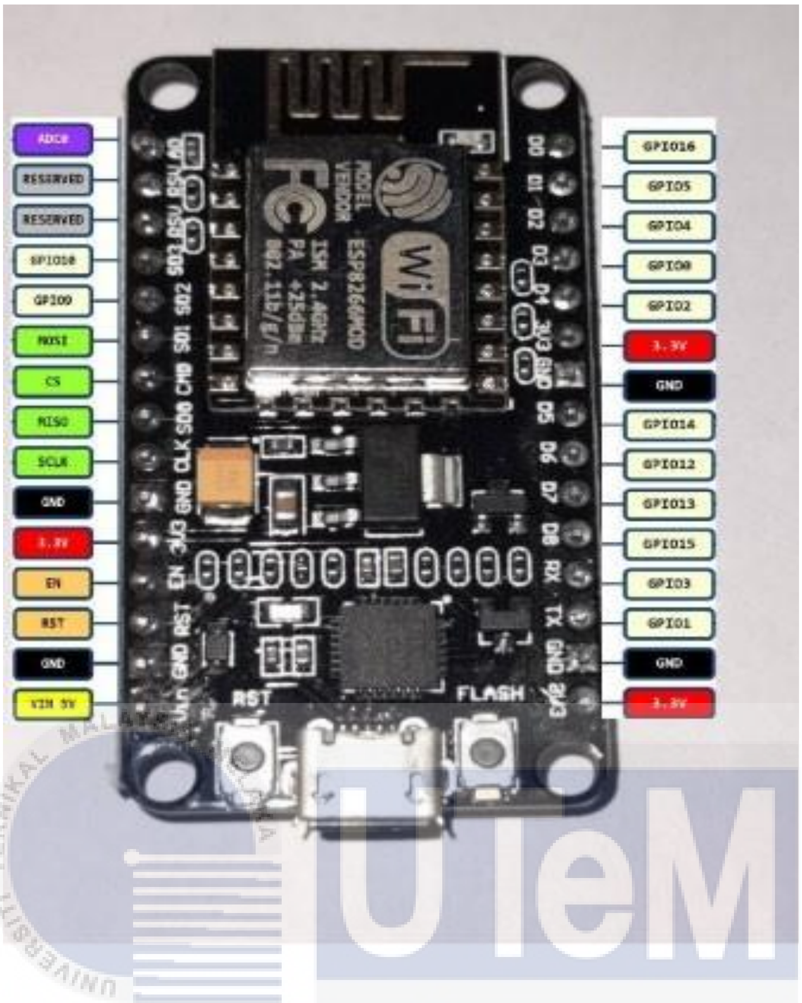


Figure 2.12 Pin Definitions or layout of 1st generation ESP8266 NodeMCU development board [67]

The ESP8266 microcontroller's outstanding speed and processing capability are among its standout benefits [68]. The ESP8266 microcontroller is built to provide effective performance, enabling quick and responsive job execution. It can analyse data and perform complex computations with relative ease because to its strong processing capabilities. This makes it possible for it to manage a variety of applications and activities including wireless communication, IoT devices and home automation systems that need for speedy data processing. The ESP8266 microcontroller is a flexible and dependable option for developers and hobbyists looking to construct effective and high-performance projects because to its mix of good speed and processing capability.

The price of the ESP8266 microcontroller is another noteworthy benefit [69]. The ESP8266 microcontroller is a popular choice for projects and applications because of how reasonably priced it is. Its price makes it available to a wider group of customers by enabling developers and hobbyists to access a capable microcontroller without breaking the bank. The ESP8266 microcontroller's cheaper price does not diminish its features or abilities. It nevertheless offers a broad variety of features and functions, allowing customers to carry out a variety of tasks while adhering to financial restrictions. The ESP8266 microcontroller is a fantastic choice for people looking for a cost-effective solution without sacrificing performance, whether it is for prototyping, small-scale production or educational reasons.

The ESP8266 microcontroller's lack of an integrated Bluetooth system is one of its flaws [70]. The ESP8266 does not come built-in with Bluetooth capabilities, unlike some other microcontrollers. Due to this restriction, Bluetooth technology cannot be used by the ESP8266 to directly create wireless communication or connectivity. Projects or applications that expressly require Bluetooth connectivity may face difficulties due to the ESP8266 microcontroller's lack of Bluetooth functionality [67]. Users must take into account alternative microcontrollers that offer integrated Bluetooth support if the users want to create a project that strongly relies on Bluetooth connection such as wireless music streaming or connecting to Bluetooth-enabled peripherals.

The ESP8266 microcontroller has fewer General-Purpose Input/Output (GPIO) pins [71] than the ESP32, which is another disadvantage. Because the ESP8266 microcontroller has fewer GPIO pins, it may not be suitable for applications that call for numerous input and output connections to sensors or other devices. Due to the ESP8266 microcontroller's limited GPIO availability, users may need to carefully plan and rank the connectivity needs for certain projects. Users may have trouble fitting all the essential components within the number of GPIO pins accessible if the project calls for several sensors, actuators or peripheral devices that rely on GPIO connections.

2.13 Solar Charging System

A solar charging system uses the sun's energy to directly power electronics or charge batteries [72]. It generally consists of solar panels that absorb sunlight and transform it into power which is then either immediately delivered to devices or stored in batteries for later use. As people use renewable energy and emit no emissions, solar charging systems provide a sustainable and eco-friendly alternative. The energy is especially helpful in distant locations with limited access to conventional electrical systems. Solar charging systems are becoming a more appealing choice for a variety of uses such as off-grid living, outdoor activities and emergency power backup as the efficiency and dependability have increased over time [29]. Solar charging systems offer a reliable and accessible source of electricity that may lessen dependency on traditional energy sources and help create a more sustainable future by utilising the sun's plentiful energy. Figure 2.13 below shows the solar power system.

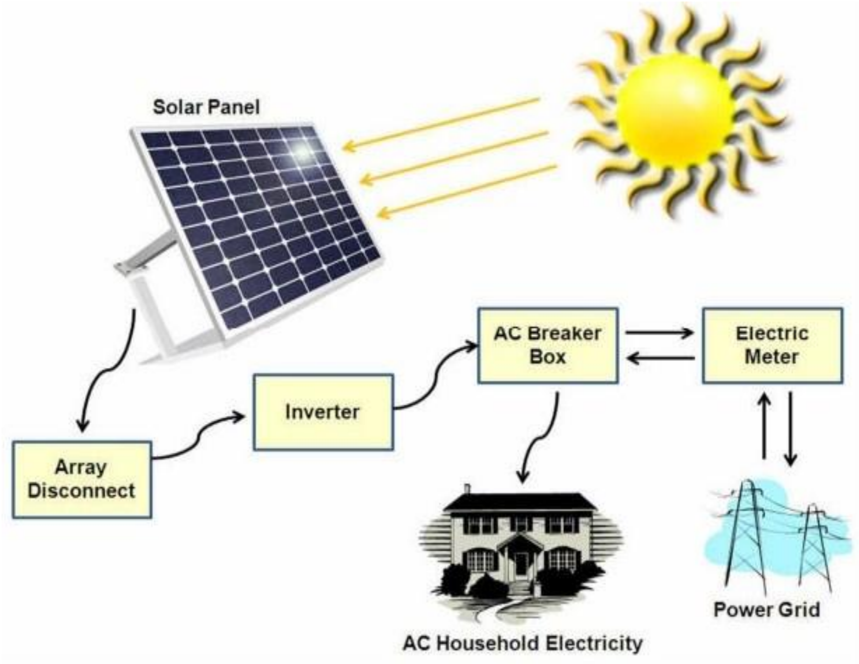


Figure 2.13 Solar Power System [73]

2.14 Typical of Grid-Tied System

A solar power system that is grid-tied [74] to the electrical grid is sometimes referred to as a grid-connected or grid-interconnected system as show in figure 2.14 below. It is made up of a bidirectional metre, an inverter and solar panels. Sunlight-generated electricity from the solar panels is transformed into useable AC power via the inverter. Grid-tie systems send the extra electricity produced by the solar panels back into the grid, as opposed to off-grid systems, which only rely on energy that has been stored in batteries [74]. Through net metering agreements, this enables the system owner to obtain credits or payment for the power they supply to the grid. In regions with a dependable electrical infrastructure and supportive regulations that encourage renewable energy, grid-tie systems are common. The system has the benefit of allowing energy to be drawn from the grid when solar output is insufficient and giving the grid more power when solar generation is greater than the demand. Grid-tie systems give individuals and companies the potential to offset the power costs, lessen their environmental impact and improve the general sustainability and reliability of the electrical grid.

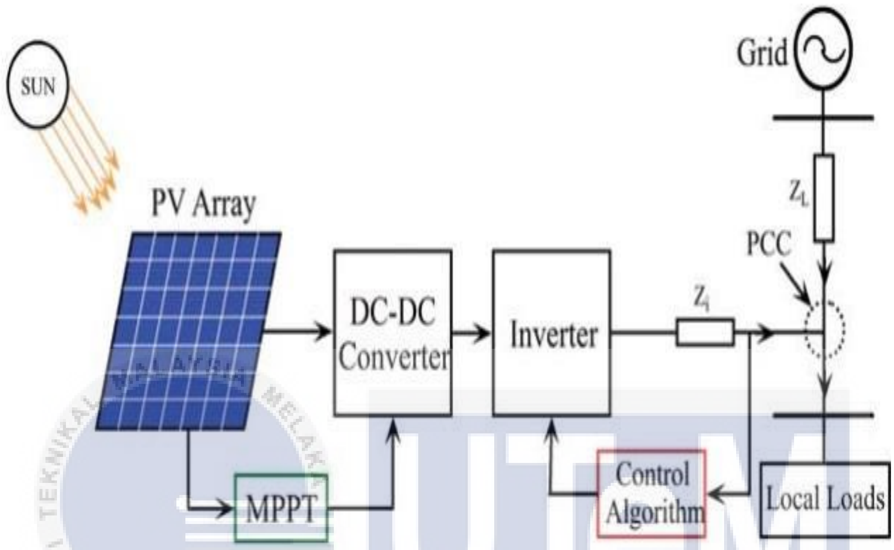


Figure 2.14 Grid-Interfaced Solar Photovoltaic System [75]

Grid-tied solar systems, the most basic kind of solar installation have a streamlined design that uses less hardware than other solar setups [76]. The absence of batteries which separates grid-tied systems from off-grid or hybrid configurations, is a crucial component in this simplicity. Grid-tied systems may do away with extra parts like charge controllers and battery banks since the system don't rely on battery storage. Instead, real-time consumption or direct feed into the grid of the power produced by the solar panels reduces system complexity. Grid-tied solar systems are an accessible and cost-effective choice for individuals primarily focused on balancing the energy use and gaining access to net metering agreements due to this simplicity, which not only lowers upfront costs but also streamlines the installation and maintenance processes.

In contrast to off-grid or hybrid systems, grid-tied solar systems lack battery storage which means it cannot provide backup power [77]. Grid-tied systems are unable to deliver electricity during grid outages or disturbances since the system only rely on the electrical grid for power supply. This implies that grid-tied solar systems are immediately turned off for safety reasons when the grid goes down, preventing the solar-generated power from being utilised inside the building. In order to ensure an ongoing supply of power, households and businesses with grid-tied systems must rely on the stability and dependability of the grid. The absence of battery storage simplifies the system and lowers overall costs, but it also emphasises the value of looking into alternative backup power options such as grid-independent battery backup systems or standalone generators.

2.15 Typical of Off-Grid System

A solar power system that runs off the grid, commonly referred to as a stand-alone system is one that does not connect to the electrical grid. It is intended to offer power in isolated regions or places where a grid connection is not feasible or available. Solar panels, a charge controller, batteries for energy storage and an inverter are the main components of off-grid systems [78]. The inverter transforms the stored DC electricity into AC power for usage by appliances and gadgets. Off-grid systems' capacity to store extra solar energy in batteries which enables power delivery at times when the sun is not shining like at night or during cloudy weather, is its primary distinguishing feature [79]. Off-grid systems may now supply a steady and dependable source of energy even in the absence of grid infrastructure thanks to its battery storage. In isolated residences, RVs and other applications where grid independence is sought, off-grid solutions are frequently employed. The system is a great option for people looking for energy independence in off-grid regions since it provides autonomy, self-sufficiency and the flexibility to create and store renewable energy for daily requirements. The system of off grid is shown in figure 2.15 below.

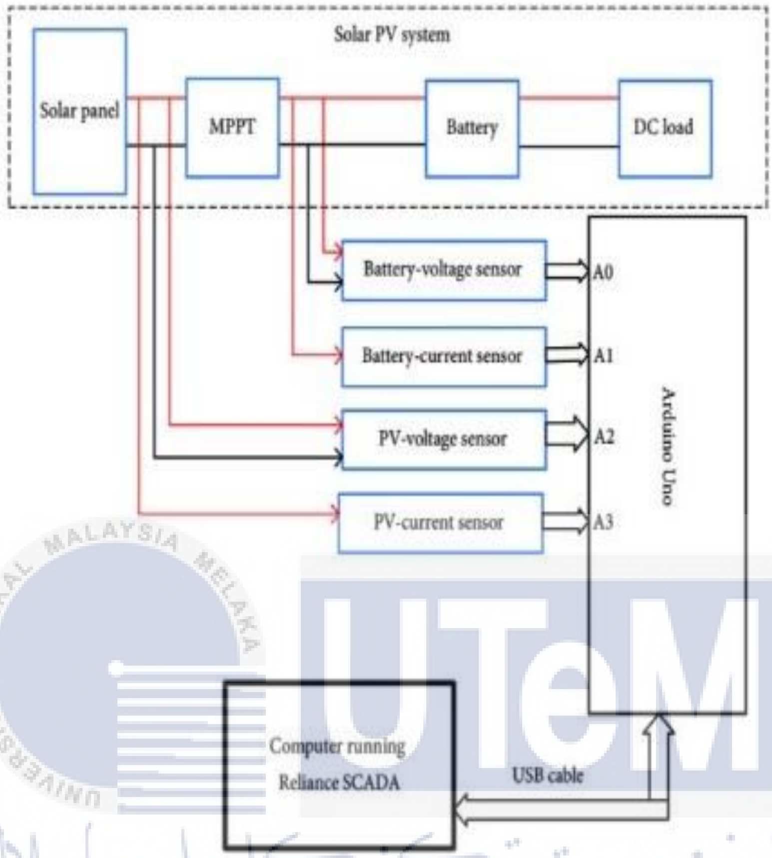


Figure 2.15 Hardware configuration of SCADA system [80]

Off-grid solar power systems have the amazing capacity to supply electricity to isolated areas that are far from the infrastructure of the conventional electrical grid [81]. For regions where connecting electricity lines from the grid is unfeasible, costly or just not practicable, these systems provide an indispensable answer. Off-grid systems can generate electricity and offer dependable power to remote homes, cabins or facilities located in isolated or off-the-grid places by using the sun's plentiful energy [78]. This capacity makes it possible for people and groups to create sustainable living arrangements, take use of contemporary conveniences and perform necessary tasks without relying on centralised power networks. Off-grid solar systems provide independence and the flexibility to access energy in locations that would otherwise be devoid of such necessary services, whether it's a lonely cottage in the woods, an off-grid research station or a mobile home exploring rural regions.

Off-grid solar systems have the benefit of being disconnected from the electrical grid, but one drawback is the limited amount of energy storage it can provide [82]. Batteries are used in off-grid systems to store extra solar energy for use at night or during cloudy weather or other times when sunshine is scarce. Off-grid systems must carefully control the energy consumption since batteries have a limited amount of storage space. This is necessary to prevent the stored energy from being used up too soon. Long periods of bad weather or heavy energy use may possibly exhaust the stored energy, resulting in temporary power constraints until the batteries can be recharged, depending on the size of the battery bank and the energy requirements of the system. This constraint highlights the necessity for energy economy, appropriate system size and responsible energy consumption habits to maximise the available energy storage and provide a dependable power supply in off-grid scenarios.

2.16 Typical of Hybrid Solar PV System

Combining the advantages of both grid-tied and off-grid systems, a hybrid solar PV (photovoltaic) system [83] provides a versatile and dependable method of generating power as shown in figure 2.16 below. Solar panels, an inverter, energy storage batteries and a link to the electrical grid are all included in this kind of setup. The hybrid system uses grid-tied operation, allowing surplus solar energy to be sent back into the grid and earn credits while also including battery storage to store extra energy for later use. This makes it possible for the system to offer backup power during grid failures or times when solar output is minimal. The hybrid solar PV system maintains a constant power supply by drawing on stored energy when necessary, making it perfect for areas with unpredictable grid supplies [84]. It has the benefit of minimising dependency on the grid while increasing solar energy self-consumption. The hybrid system optimises energy efficiency, lowers power costs and helps build a more robust and sustainable energy infrastructure by intelligently controlling energy flows.

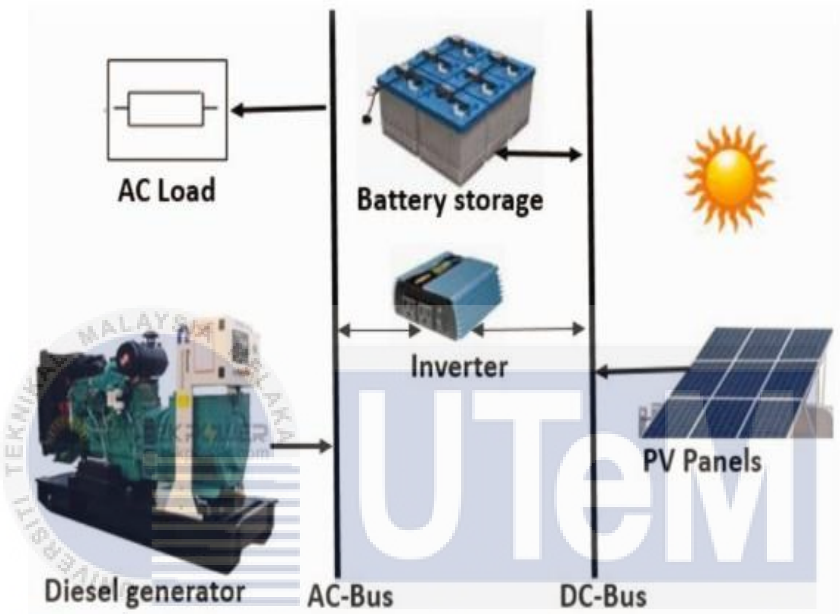


Figure 2.16 Solar PV-diesel with battery backup [85]

In order to effectively store extra solar energy, a hybrid solar PV (photovoltaic) system is essential. This system can absorb, and store extra power produced by the solar panels by integrating battery storage [86]. When energy output is higher than the immediate need during times of high solar generation, the hybrid system diverts the extra energy to the batteries for later use. It is possible to use solar energy during periods of low solar irradiation such as at night or on overcast days because to this energy storage capabilities. The hybrid solar PV system delivers a more regular and stable power source, even when sunlight is scarce, by efficiently storing and controlling extra solar energy. The system's capacity to satisfy energy demands, maximise self-consumption and lessen dependency on the electrical grid is improved by this storage feature. It encourages more energy independence, financial savings and an environmentally friendly, sustainable method of using power.

One of the drawbacks of hybrid solar PV (photovoltaic) systems is that it often cost more to install than conventional grid-tied or off-grid systems. The system's overall initial costs are increased by the incorporation of battery storage and extra components [87]. The price of the batteries together with the price of the necessary inverters and auxiliary gear, is a factor in the higher installation costs. Furthermore, it takes specialised knowledge and may result in higher labour costs to design and configure a hybrid system to smoothly combine solar panels, batteries and the electrical grid. The long-term advantages of a hybrid solar PV system such as less dependency on the grid and possible power bill savings can eventually surpass the upfront expenses, despite the fact that the initial investment may be larger [88]. Hybrid systems are also becoming more popular, which lowers the cost of the structure and makes it more widely available and economical in the long run.

2.17 Comparison of Charging Monitoring System

Table 2.1 Comparison of Charging Monitoring System

Sector	Microcontroller	Charging System
Healthcare [89]	ESP 32	Wireless
Renewable Energy Source [90]	ATmega16	Solar
Automotive [91]	SPC58	Battery
Agricultural [92]	ESP 8266	Wireless
Industrial and Manufacturing [93]	PIC	Solar
Technology [94]	PIC	Battery
Construction [95]	LM3S1968	Solar
Biotechnology [96]	ATmega328P	Wireless
Healthcare [97]	Arduino Uno	Wireless
Healthcare [98]	ESP32	Wireless

CHAPTER 3

METHODOLOGY

3.1 Introduction

The solar charge monitoring system using an Arduino Uno for lighting applications uses an effective way to track and manage the solar panel system's charging process. This system makes the most of solar sunlight while supplying dependable electricity for lighting applications by using the Arduino Uno as the central processing unit. The approach comprises connecting the Arduino Uno to the solar charge controller, battery and ESP8266 to enable the monitoring and control features required to efficiently manage the charging process.

3.2 Justification for sustainable development on the project

The solar charge monitoring system for lighting applications utilising an Arduino Uno supports sustainable development according to box number 7 and 13 in terms of "affordable and clean energy" and "climate action" by solving major global issues. By utilising solar electricity, a renewable resource that is easily accessible and cost-free, it first encourages the use of inexpensive and clean energy. This lessens reliance on expensive, dirty fossil fuels, making it affordable and available to a variety of populations. Second, the method greatly lowers greenhouse gas emissions, aiding in the fight against climate change. Utilising solar energy in place of traditional energy sources reduces air pollution and carbon footprints, hence reducing the effects of climate change. The Arduino Uno platform also enables effective monitoring and control, which optimises energy usage and lowers waste. This solar charging monitoring system, which offers inexpensive and clean energy while taking prompt action to combat climate change, thereby corresponds with the goals of sustainable development. Figure 3.1 below show the sustainable development goals.

Figure 3.1 Sustainable development goals

3.3 Workflow of Project

The flow diagram below shows how a complex solar lighting and charging system's linked parts work together. First, solar panels collect sunlight, and then current and voltage sensors keep an eye on the electricity that is produced. Before the stored energy is sent towards a battery, the solar charge controller controls the charging procedure. LED lights are then powered by the battery, resulting in energy-efficient lighting. The LED lights are controlled by an Arduino Uno that is linked to a relay module and an LDR sensor module in order to sense the surrounding light levels. On-site status information regarding the system is provided by an LCD monitor. Furthermore, an ESP8266-interfaced SD card module works in combination with the Blynk application to facilitate remote monitoring and management. This enables users to effectively manage and optimise the solar charging system via an intuitive interface. This flow diagram shows how different parts are carefully and intelligently integrated to create a functional solar-powered lighting solution.

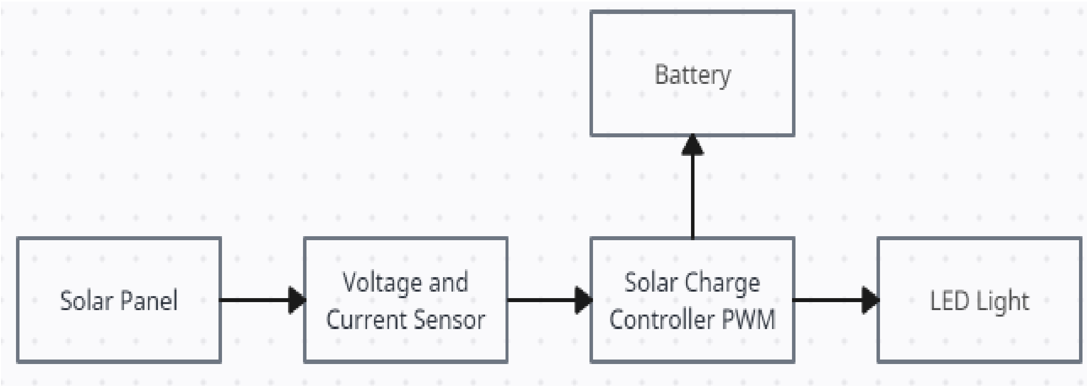


Figure 3.2 Block diagram 1

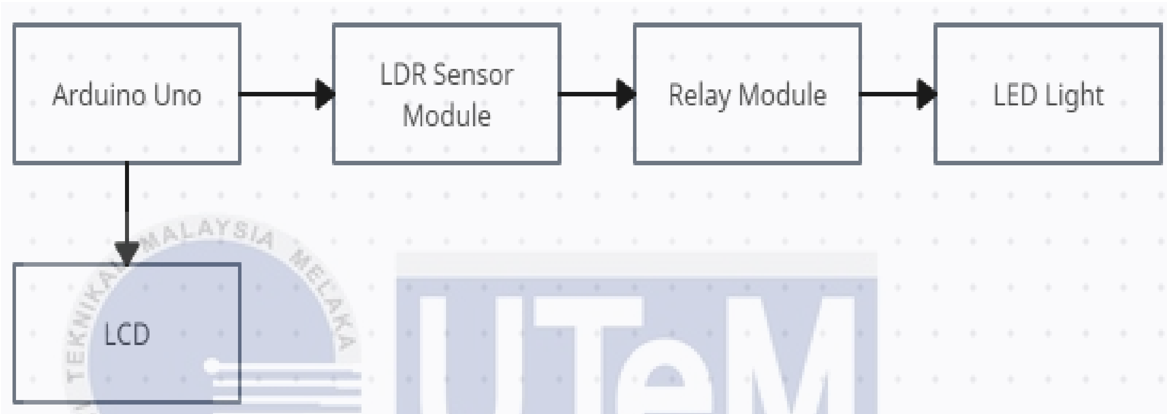


Figure 3.3 Block diagram 2

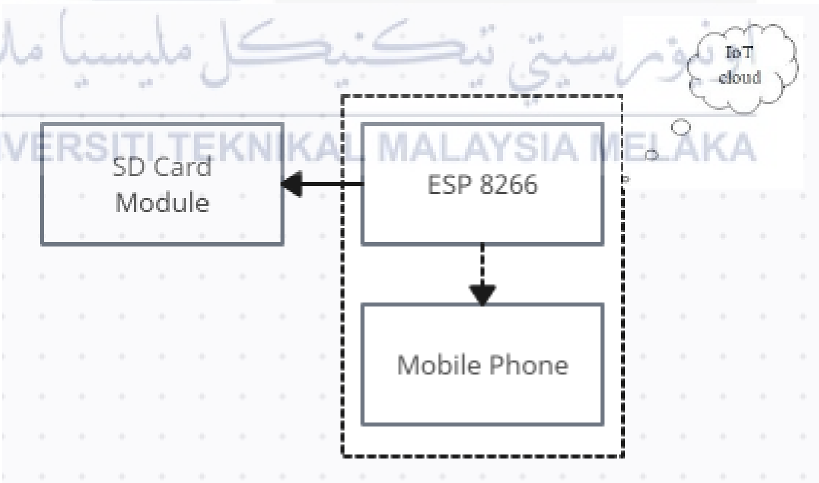


Figure 3.4 Block diagram 3

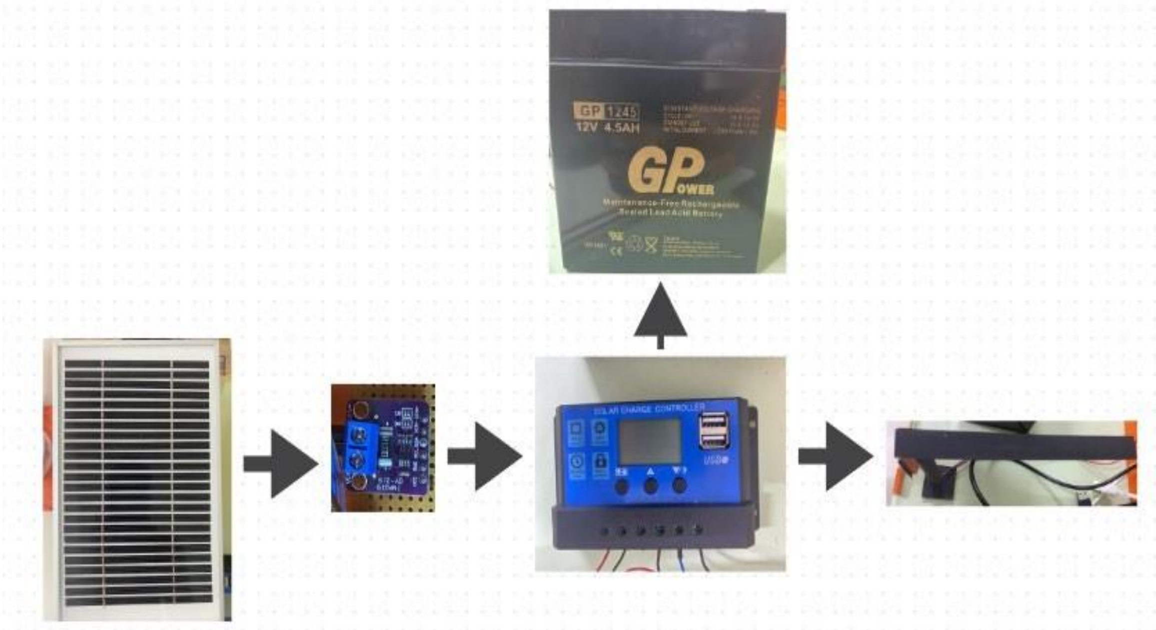


Figure 3.5 Block diagram 1

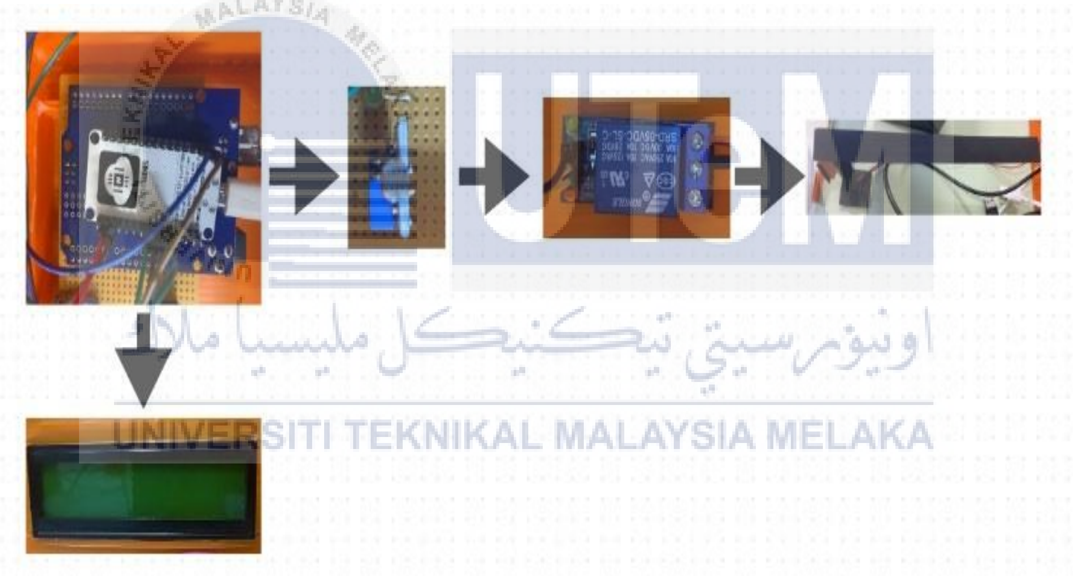


Figure 3.6 Block diagram 2

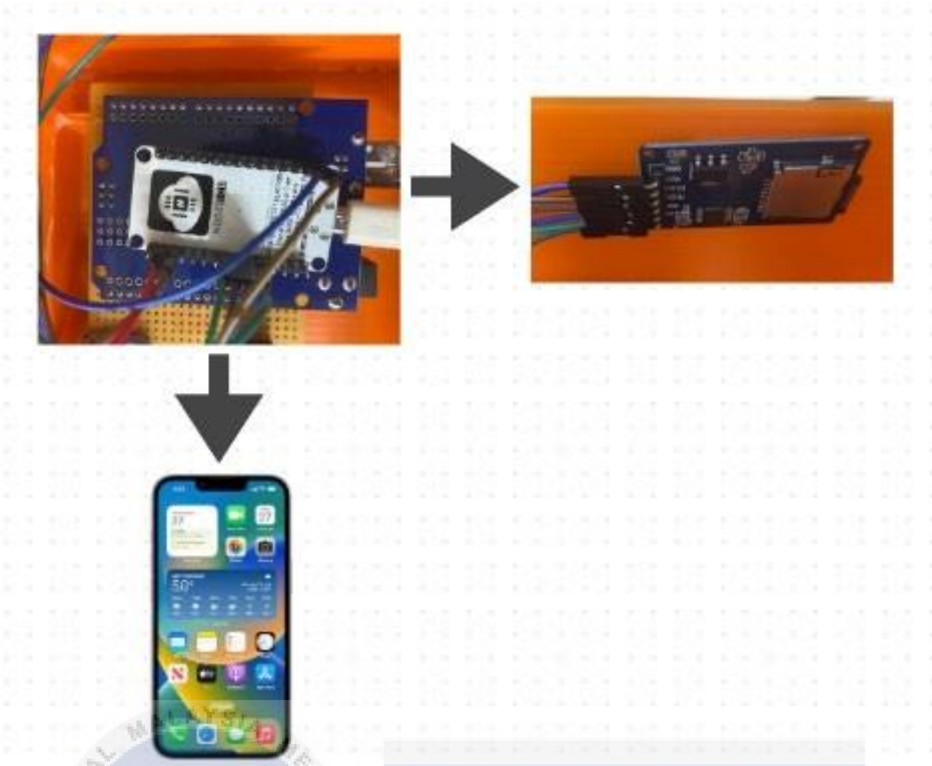
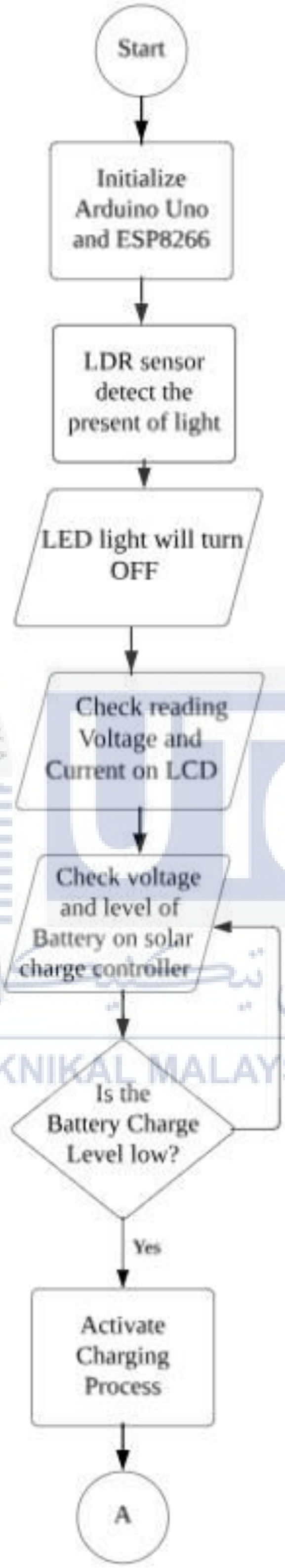
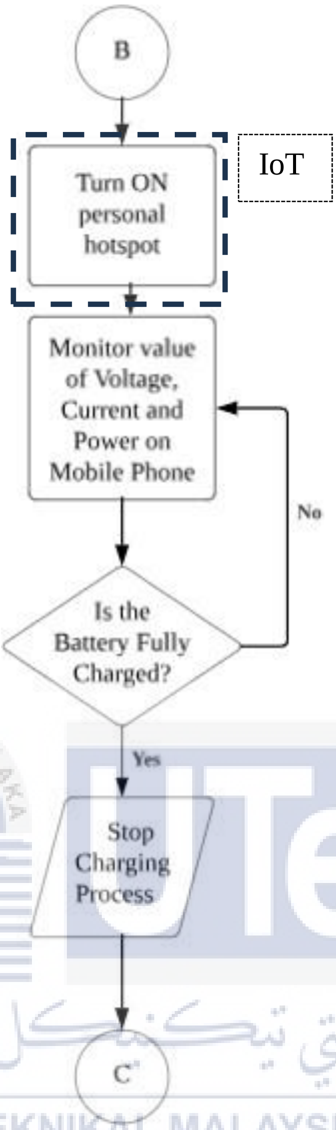


Figure 3.7 Block diagram 3


Start
Initialize Arduino Uno and ESP8266
LDR sensor detect the present of light
LED light will turn OFF
Check reading Voltage and Current on LCD
Check voltage and level of Battery on solar charge controller
No
Is the Battery Charge Level low?
Yes
Activate Charging Process
A


B
Turn ON personal hotspot
IoT
Monitor value of Voltage, Current and Power on Mobile Phone
No
Is the Battery Fully Charged?
Yes
Stop Charging Process
C

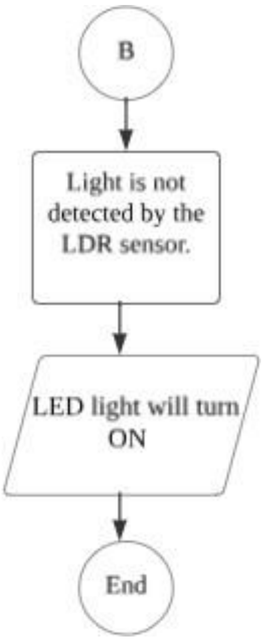


Figure 3.8 Flowchart of the system

3.4 Implement Solar Charging Monitoring System

To maximise the effectiveness and dependability of solar power systems, a solar charging monitoring system must be put in place. Real-time tracking of energy output, battery state, and overall system health is made possible by this system, which is made up of parts including solar panels, charge controllers, and monitoring sensors. The Solar Charging Monitoring System guarantees optimal performance of solar power infrastructure, maximising energy output, minimising downtime, and making a substantial contribution to the shift towards sustainable and clean energy solutions through continuous data analysis and instantaneous fault detection.

3.4.1 Polycrystalline Solar Panel

A photovoltaic panel that uses polycrystalline silicon solar cells is known as a polycrystalline solar panel as shown in figure 3.9 below. These solar cells have a less uniform crystal structure than monocrystalline ones since they are created by melting many silicon pieces together. Multiple grain boundaries and a unique blue colour that distinguish polycrystalline solar panels from monocrystalline ones. This solar panel are a well-liked option in the solar business because of its affordability and comparatively high efficiency. Solar energy may be converted into useful electrical power using polycrystalline panels which are well renowned for its capacity to generate electricity from sunlight. This panel are appropriate for a variety of uses including industrial-sized solar power facilities as well as residential and commercial installations. Despite having somewhat lower efficiency than monocrystalline panels, polycrystalline solar panels are nevertheless an appealing alternative for people looking to harvest solar energy and lessen the reliance on conventional power sources because of its affordable price. The specification of the solar panel is shown in table 3.2 below.

Figure 3.9 Solar Panel

Table 3.1 Technical Specification

Type	Polycrystalline
Power Maximum	5W
Tolerance	+- 5%
Vmp	12V

Imp	0.42A
Voc	14.5V
Isc	0.45A
Maximum System Voltage	750V
Size	275mm x 180mm x 17mm

This is a 5W polycrystalline solar panel with a tolerance of ±5% that is intended for flexible energy collection. This panel performs dependably while operating at a maximum power voltage (Vmp) of 12V and a matching current (Imp) of 0.42A. It has a short-circuit current (Isc) of 0.45A and an open-circuit voltage (Voc) of 14.5V. It guarantees system compatibility with a maximum system voltage of 750V. The solar panel's small size (275 x 180 x 17 mm) allows it to be used in a variety of ways while combining efficiency and flexibility in the use of solar energy.

3.4.2 Solar Charge Controller PWM

The charging of batteries in solar energy systems may be regulated and optimised with the use of a solar charge controller with pulse width modulation (PWM) as in figure 3.10 below. PWM is a technology that quickly toggles the output of the solar panel on and off to regulate the voltage provided to the battery. The charge controller keeps track of the battery's level of charge and modifies the switching frequency to keep the charging voltage constant. The charge controller effectively regulates the amount of power provided to the battery by adjusting the pulse width, resulting in a seamless and effective charging process. This helps preserve the battery's general wellbeing and durability by preventing overcharging, which can harm the battery. Table 3.3 below show the technical specification of this charge controller.

Figure 3.10 Solar Charge Controller

Table 3.2 Technical Specification

Model	W88-B
Rated Voltage	12V / 24V
Rated Current	20A
Max. PV Voltage	50V
Max. PV Input Power	260W (12V), 520W (24V)

The W88-B solar charge controller is a multifunctional model intended for effective photovoltaic (PV) system management. It can support moderate-sized solar setups with a rated voltage of 12V or 24V and a rated current of 20A. The controller is compatible with a variety of solar panel designs and can manage a maximum PV power of 50V. It is noteworthy for its capacity to control and optimise solar energy harvesting, as seen by its ability to manage a maximum PV input power of 260W for 12V systems and 520W for 24V systems, indicating versatility. With its efficient voltage and current control characteristics, the W88-B is an essential part of keeping solar power systems operating at peak health.

3.4.3 Sealed Lead Acid Battery

A particular kind of rechargeable battery frequently used in many applications is a sealed lead acid (SLA) battery with a 12V and 4.5AH rating. The 12V symbol denotes the battery's nominal voltage, which, when completely charged, is about 12 volts of electrical potential. The battery's capacity or 4.5AH (Ampere-Hour) rating, indicates how much charge it can store for a certain amount of time. Small-scale electronics, alarm systems, emergency lights and other low-power applications frequently make use of this specific SLA battery which has a 4.5AH capacity. Because of the battery's sealed design, which prevents electrolyte leakage, it requires no maintenance and is safer to use. A considerable quantity of energy can be saved thanks to the 4.5AH capacity, making it appropriate for applications with lower power needs. To maximise the battery's performance and longevity, it's crucial to follow the suggested charging and using procedures. Figure 3.11 show the image of battery while table 3.4 show the technical specification of the battery.

Figure 3.11 SLA Battery 12V 4.5AH

Table 3.3 Technical Specification

Type	Sealed Lead Acid
Cycle Use	14.5 - 14.9 V
Standby Use	13.6 – 13.8 V
Initial Current	< 1.35A

What makes the Sealed Lead Acid (SLA) battery described here suitable for a wide range of applications is that it provides different voltage ranges for different use cases. The suggested voltage range for cyclic usage is 14.5–14.9 V, which guarantees peak performance over repeated cycles of discharge and recharge. When not actively cycling, the battery operates in the range of 13.6 to 13.8 V for standby use, which offers stability during idle times. Furthermore, a maximum current of 1.35A is allowed during the first charging phase, highlighting the need of regulated current input when the battery is first connected to a charging source. Together, these requirements provide essential principles that support the safe and effective functioning of sealed lead acid batteries in a range of real-world applications.

3.4.4 Voltage and Current Sensor

The DC current sensor module INA219 is an extremely accurate and adaptable electronic part that may be used to measure current in a range of circuit types. The module makes exact measurements of the voltage drop and the current flow across the circuit by utilising an external shunt resistor. With its I2C interface, it interacts with well-known microcontrollers such as Arduino and Raspberry Pi with ease, making it easier to include current measuring features into digital projects. For applications requiring precise current assessments and power consumption monitoring, the INA219 module's dual bus voltage and current measurement capabilities are very suitable. In a variety of applications, the INA219 enhances precision and control over current-related parameters, whether it is utilised in embedded systems or electronics prototyping. Figure 3.12 below show the picture of the hardware.

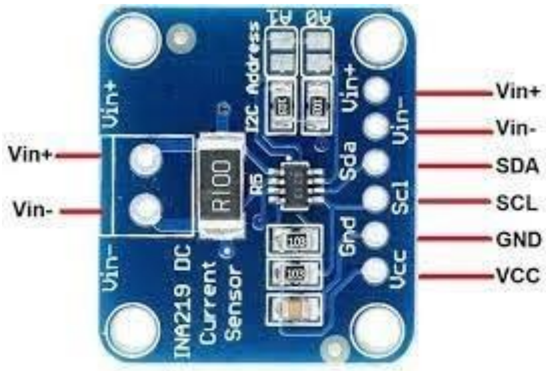


Figure 3.12 Voltage and Current Sensor

3.4.5 Arduino Uno R3

ATmega328P is the microcontroller used in Arduino Uno. It features 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB port, a power jack, an ICSP header and a reset button. It includes everything necessary to support the microcontroller, simply connect it to a computer through USB or power it with an AC-to-DC adapter or battery to get started. The name "Uno" was chosen to commemorate the debut of Arduino Software (IDE) version 1.0. The Uno board and version 1.0 of the Arduino Software (IDE) were the original versions of Arduino, which newer version have since replaced. The Uno board is the first of a series of USB Arduino boards and the reference model for the Arduino platform. The Arduino UNO R3 are shown in Figure 3.13 and the technical specification for the board are shown in Table 3.5.

Figure 3.13 Arduino Uno R3

Table 3.4 Technical Specification

Microcontroller	**ATmega328P**
Operating Voltage	5V
Input Voltage (Recommended)	7-12V
Input Voltage (Limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Pwm Digital I/O Pins	6
Analog Input Pins	6
Dc Current Per I/O Pin	20mA
Dc Current For 3.3v Pin	50mA
Flash Memory	3 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
Eeprom	1 KB (ATmega328P)

The adaptable integrated solution with an operating voltage of 5V and a suggested input voltage range of 7V to 12V, with a limit of 6V to 20V, is displayed in the above table. It has versatile interface capabilities with 14 digital I/O pins, including 6 with PWM output and 6 analogue input pins. A DC current of 20 mA per I/O pin and 50 mA for the 3.3V pin may be supported by the microcontroller. With its 3 KB of flash memory (ATmega328P), 2 KB of SRAM (ATmega328P), and 1 KB of EEPROM (ATmega328P), it provides several embedded applications with both processing power and memory resources. This ATmega328P microcontroller is a versatile and feature-rich platform that may be used for many different electrical systems and applications.

3.4.6 LED Light

A light-emitting diode (LED) that runs on a 12-volt power source is referred to as a 12-volt LED light. Energy-efficient lighting sources called LED lights use the passage of electrons inside a semiconductor substance to transform power into light. The LED needs 12 volts to be powered and this voltage is commonly provided by batteries, solar panels or low-voltage electrical systems. These lights are well-liked for a variety of applications including automobile illumination, recreational vehicles, off-grid lighting and other indoor and outdoor lighting configurations because to this light's benefits including extended lifespan, low power consumption and durability. 12-volt LED lights are a well-liked option for both residential and business lighting needs due to its adaptability and efficiency. Figure 3.14 below show the picture of LED light.

Figure 3.14 LED Light 12V

3.4.7 Relay Module

Relay modules as shown in figure below are an essential part of the electronics world. They are multipurpose switches that allow low-power microcontrollers or digital circuits to operate high-power devices. Relays are essentially electromechanical devices that mechanically switch electrical circuits by activating an electromagnetic coil. The relay module improves and streamlines the interface between high-power appliances or equipment and low-voltage electronic systems, such microcontrollers or Arduino boards. This gives a microcontroller the ability to command and isolate power circuits, which facilitates smooth automation and control in a variety of applications, including as robots, industrial operations, and home automation. The relay module adds a layer of flexibility to electronic systems and is a vital tool for projects requiring safe and effective management of electrical loads due to its versatility and dependability.

Figure 3.15 Relay Module

3.4.8 LDR Sensor Module

One important aspect of many electrical applications is the Light Dependent Resistor (LDR) sensor module as shown in figure below, especially those that need to sense light intensity. The LDR sensor, sometimes referred to as a photoresistor, is a useful tool for developing systems that react to changing lighting conditions since it displays a change in resistance dependent on ambient light levels. The LDR sensor module is a basic component of light detecting technology that is used in security devices, dusk-to-dawn controllers, and automated lighting systems. This module is a crucial component of projects that aim to improve energy efficiency, promote automation, and guarantee optimal performance in response to ambient lighting conditions because of its adaptability and ease of use in sensing light changes.

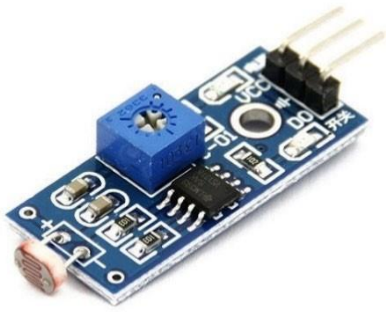


Figure 3.16 LDR Sensor Module

3.5 Fabricate Charging Monitoring System

The Fabricated Charging Monitoring System is a cutting-edge technology solution that provides an extensive and adaptable platform for charging process optimisation and monitoring. Tracking charging parameters, battery state, and overall performance, this system is painstakingly developed to be used with electric cars, portable gadgets, or renewable energy systems. It offers real-time insights into the charging process using a mix of sensors, data recorders, and communication modules, guaranteeing effective energy transfer and extending battery life. A significant development in charging technology, the Fabricated Charging Monitoring System promotes sustainability, improves user ease, and aids in the development of clever, environmentally friendly charging solutions for a range of businesses.

3.5.1 ESP 8266

The Internet of Things (IoT) and wireless communication have seen a revolution thanks to the ESP8266, a very adaptable and affordable Wi-Fi module. This small and strong module, created by Espressif Systems, combines a microcontroller with integrated Wi-Fi capabilities to offer a seamless platform for connecting devices to the internet. The ESP8266 is a popular choice for a broad range of applications, from industrial automation to smart home devices and sensor networks, because to its compact form size and low power consumption. Its open-source design and strong community backing have helped it gain popularity among developers and electronics enthusiasts, making it a crucial part of projects needing IoT integration and wireless communication. The ESP8266 has established itself as a mainstay in the field of embedded systems thanks to its cost and ease of use, enabling creators to integrate connection into a wide range of electrical gadgets. Figure 3.17 below show the image of ESP 8266.

Figure 3.17 ESP 8266

3.5.2 Micro SD Card Module

The Micro SD card module as shown in figure below, facilitates the easy integration of Micro SD cards into a variety of applications, making it a portable and effective storage option for electronic projects. Usually, this module has an SD card port built-in and uses SPI (Serial Peripheral communicate) communication to communicate with microcontrollers. It enables simple data store and retrieval in projects like data logging, multimedia applications, and data transfer across devices because of its tiny form size and ease of usage. The module makes it easier to integrate SD card functionality, which makes it a crucial part of projects that call for expandable and portable memory solutions. The Micro SD card module is a dependable way to store and retrieve data that improves the adaptability and storage capacity of electronic applications, whether the modules are used in embedded systems, robotics, or IoT devices.

Figure 3.18 Micro SD Card Module

3.5.3 Donut Board

A donut board as in figure 3.19 below, also known as a round PCB (Printed Circuit Board), is a type of circuit board that features a circular or donut-like shape instead of the traditional rectangular or square shape. It is made to fit electrical parts and make it simple to connect circuits in a circular arrangement. Donut boards provide a number of benefits including enhanced signal flow, space efficiency and compactness. It frequently employed in tiny-footprint or circular-design-preferred applications including as LED lights, automobile electronics and compact electronic gadgets. Donut boards may be visually beautiful and enable for effective trace routing. This board provide for component placement freedom and may be tailored to match certain design specifications. Donut boards provide an alternate form factor to conventional rectangular PCBs and give electronic projects a distinctive visual touch.

Figure 3.19 Donut Board

3.5.4 Voltage and Current Sensor

The DC current sensor module INA219 is an extremely accurate and adaptable electronic part that may be used to measure current in a range of circuit types. The module makes exact measurements of the voltage drop and the current flow across the circuit by utilising an external shunt resistor. With its I2C interface, it interacts with well-known microcontrollers such as Arduino and Raspberry Pi with ease, making it easier to include current measuring features into digital projects. For applications requiring precise current assessments and power consumption monitoring, the INA219 module's dual bus voltage and current measurement capabilities are very suitable. In a variety of applications, the INA219 enhances precision and control over current-related parameters, whether it is utilised in embedded systems or electronics prototyping. Figure 3.20 below show the picture of the hardware.

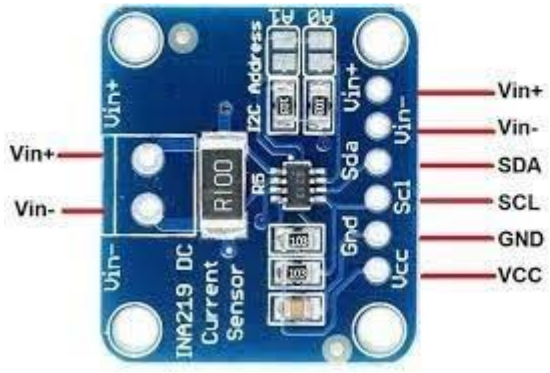


Figure 3.20 Voltage and Current Sensor

3.5.5 Sealed Lead Acid Battery

A particular kind of rechargeable battery frequently used in many applications is a sealed lead acid (SLA) battery with a 12V and 4.5AH rating. The 12V symbol denotes the battery's nominal voltage, which, when completely charged, is about 12 volts of electrical potential. The battery's capacity or 4.5AH (Ampere-Hour) rating, indicates how much charge it can store for a certain amount of time. Small-scale electronics, alarm systems, emergency lights and other low-power applications frequently make use of this specific SLA battery which has a 4.5AH capacity. Because of the battery's sealed design, which prevents electrolyte leakage, it requires no maintenance and is safer to use. A considerable quantity of energy can be saved thanks to the 4.5AH capacity, making it appropriate for applications with lower power needs. To maximise the battery's performance and longevity, it's crucial to follow the suggested charging and using procedures. Figure 3.21 show the image of battery while table 3.6 show the technical specification of the battery.

Figure 3.21 SLA Battery 12V 4.5AH

Table 3.5 Technical Specification

Type	**Sealed Lead Acid**
Cycle Use	14.5 - 14.9 V
Standby Use	13.6 – 13.8 V
Initial Current	< 1.35A

What makes the Sealed Lead Acid (SLA) battery described here suitable for a wide range of applications is that it provides different voltage ranges for different use cases. The suggested voltage range for cyclic usage is 14.5–14.9 V, which guarantees peak performance over repeated cycles of discharge and recharge. When not actively cycling, the battery operates in the range of 13.6 to 13.8 V for standby use, which offers stability during idle times. Furthermore, a maximum current of 1.35A is allowed during the first charging phase, highlighting the need of regulated current input when the battery is first connected to a charging source. Together, these requirements provide essential principles that support the safe and effective functioning of sealed lead acid batteries in a range of real-world applications.

3.5.6 Solar Charge Controller PWM

The charging of batteries in solar energy systems may be regulated and optimised with the use of a solar charge controller with pulse width modulation (PWM) as in figure 3.22 below. PWM is a technology that quickly toggles the output of the solar panel on and off to regulate the voltage provided to the battery. The charge controller keeps track of the battery's level of charge and modifies the switching frequency to keep the charging voltage constant. The charge controller effectively regulates the amount of power provided to the battery by adjusting the pulse width, resulting in a seamless and effective charging process. This helps preserve the battery's general wellbeing and durability by preventing overcharging, which can harm the battery. Table 3.7 below show the technical specification of this charge controller.

Figure 3.22 Solar Charge Controller

Table 3.6 Technical Specification

Model	**W88-B**
Rated Voltage	12V / 24V
Rated Current	20A
Max. PV Voltage	50V
Max. PV Input Power	260W (12V), 520W (24V)

The W88-B solar charge controller is a multifunctional model intended for effective photovoltaic (PV) system management. It can support moderate-sized solar setups with a rated voltage of 12V or 24V and a rated current of 20A. The controller is compatible with a variety of solar panel designs and can manage a maximum PV power of 50V. It is noteworthy for its capacity to control and optimise solar energy harvesting, as seen by its ability to manage a maximum PV input power of 260W for 12V systems and 520W for 24V systems, indicating versatility. With its efficient voltage and current control characteristics, the W88-B is an essential part of keeping solar power systems operating at peak health.

3.5.7 Arduino Uno R3

ATmega328P is the microcontroller used in Arduino Uno. It features 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB port, a power jack, an ICSP header and a reset button. It includes everything necessary to support the microcontroller, simply connect it to a computer through USB or power it with an AC-to-DC adapter or battery to get started. The name "Uno" was chosen to commemorate the debut of Arduino Software (IDE) version 1.0. The Uno board and version 1.0 of the Arduino Software (IDE) were the original versions of Arduino, which newer version have since replaced. The Uno board is the first of a series of USB Arduino boards and the reference model for the Arduino platform. The Arduino UNO R3 are shown in Figure 3.23 and the technical specification for the board are shown in Table 3.8.

Figure 3.23 Arduino Uno R3

Table 3.7 Technical Specification

Microcontroller	**ATmega328P**
Operating Voltage	5V
Input Voltage (Recommended)	7-12V
Input Voltage (Limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Pwm Digital I/O Pins	6
Analog Input Pins	6
Dc Current Per I/O Pin	20mA
Dc Current For 3.3v Pin	50mA
Flash Memory	3 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
Eeprom	1 KB (ATmega328P)

The adaptable integrated solution with an operating voltage of 5V and a suggested input voltage range of 7V to 12V, with a limit of 6V to 20V, is displayed in the above table. It has versatile interface capabilities with 14 digital I/O pins, including 6 with PWM output and 6 analogue input pins. A DC current of 20 mA per I/O pin and 50 mA for the 3.3V pin may be supported by the microcontroller. With its 3 KB of flash memory (ATmega328P), 2 KB of SRAM (ATmega328P), and 1 KB of EEPROM (ATmega328P), it provides several embedded applications with both processing power and memory resources. This ATmega328P microcontroller is a versatile and feature-rich platform that may be used for many different electrical systems and applications.

3.6 Experimental setup and Data Measurement

The foundation of all scientific studies and research projects is the Experimental Setup and Data Measurement system, which offers a controlled setting for carrying out experiments and collecting accurate data. Several instruments, sensors, and measuring devices are integrated into this painstakingly built system to enable precise data collection and processing. Researchers may control variables, observe events, and gather trustworthy data for well-informed conclusions by using the Experimental Setup and Data Measurement system, whether they are working in physics, chemistry, engineering, or other scientific fields. This approach, which emphasises repeatability and accuracy, is essential to the advancement of science, creativity, and the creation of novel technology in a variety of sectors.

3.6.1 Open Circuit Voltage (VOC) and Short Circuit Current (ISC) values

The Experimental Setup, which measures Open Circuit Voltage (OCV) and Short Circuit Current (ISC) using a multimeter and solar panel in figure below, is an important investigation into the performance features of solar photovoltaic systems. This arrangement combines the accuracy of a multimeter with the renewable energy potential of a solar panel to examine important elements impacting power generation. Researchers and amateurs can learn more about the electrical behaviour of solar cells and get a greater comprehension of their functionality and efficiency by using this experimental setup. This practical technique bridges the gap between theoretical knowledge and real-world application in the field of solar energy research and technology, while also yielding insightful data on OCV and ISC.

Figure 3.24 Hardware Setup

3.6.2 Full System Data Collection

Through the integration of a wide range of components, the Experimental Setup provides a thorough investigation into the optimisation of solar energy use. In a photovoltaic setup, this complex system seeks to accurately measure and analyse Maximum Power Voltage (Vmp) and Maximum Power Current (Imp). Through the utilisation of the individual components' capabilities and the adaptability of Arduino-based control, the experiment offers a platform for data collecting and monitoring in real time. By integrating the Blynk application, users may remotely monitor and manipulate the system, adding an interactive element. This experimental project explores the complexities of optimising solar power production while also taking an inventive and instructional tack, fusing physical elements with contemporary networking technologies to enhance our comprehension and use of sustainable energy solutions. Figure 3.25 below show the experimental setup.

Figure 3.25 Experimental Setup

3.7 Software

The digital world is greatly influenced by software, the intangible foundation of contemporary computing. It includes an enormous variety of software, apps, and operating systems that control how electronic devices work, ranging from smartphones and PCs to complex network systems. The encoded collection of instructions that control the functions and interactions of physical components is fundamentally what software is. It includes a wide range of products and services, like operating systems, productivity tools, games, and industry-specific software. Software development has been a major factor in the development of technology, facilitating innovation, automation, and the smooth transmission of data. Software development is a rapidly developing discipline that involves writing, testing, and maintaining code. It reflects the dynamic interaction between human creativity and the needs of a world that is becoming more linked.

3.7.1 Arduino IDE

A vital resource for makers, amateurs, and experts exploring the realm of embedded electronics and microcontroller programming is the Arduino Integrated Development Environment (IDE). An easy-to-use platform for creating, developing, and uploading code to Arduino microcontroller boards is offered by this open-source software, which was developed by the Arduino team. Particularly well-known for being user-friendly for novices and providing robust functionality for more experienced users is the Arduino IDE. Its user-friendly interface allows it to handle both C and C++ programming languages. It also offers a large library of pre-written code, or sketches, which makes it easier to construct a variety of projects. From simple blinking LED projects to complex Internet of Things applications, the Arduino IDE has become the go-to environment for realising a wide range of electronic breakthroughs thanks to its real-time feedback through the Serial Monitor and easy connection with a number of Arduino-compatible boards. Figure below show the picture of the software.

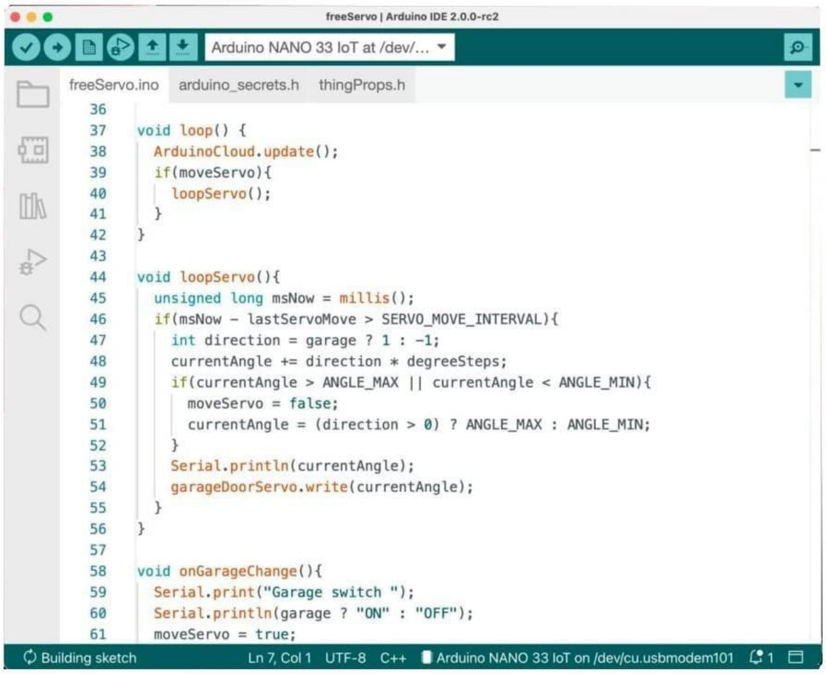


Figure 3.26 Arduino IDE

3.7.2 Blynk Application

With the help of the flexible and user-friendly smartphone application Blynk as shown in figure 3.22, manufacturers and developers can effortlessly manage and keep an eye on their Internet of Things (IoT) projects. Blynk's user-friendly interface makes it easy for users to develop bespoke dashboards, or "Blynk apps," that communicate with a range of Internet of Things devices. Numerous hardware platforms are supported by the programme, including well-known microcontrollers like Arduino, Raspberry Pi, and ESP8266/ESP32. Widgets are interactive graphical interfaces that users may create to visualise data, operate connected devices, and obtain real-time updates. Building Internet of Things apps is made easier with Blynk's drag-and-drop feature and large widget library. It also makes cloud-based collaboration easier, enabling users to oversee and manage their projects remotely from any location with an internet connection. Blynk offers a quick and easy way to create interactive and connected projects without requiring a lot of programming knowledge, whether being an IoT enthusiast or a professional developer.

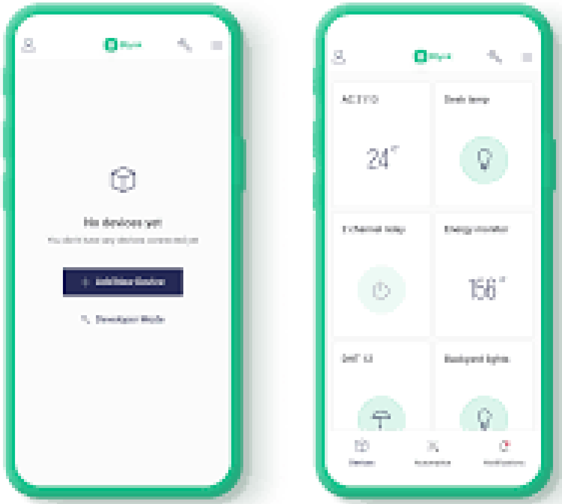


Figure 3.27 Blynk Application

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The performance and efficacy of the solar charge monitoring system employing an Arduino Uno for lighting applications are evaluated and analysed in the result and discussion section. A solar charge controller, a voltage and current sensor, ESP8266 and an LCD display are some of the components that are integrated into this system. The findings offer insightful information on the system's capacity to monitor and manage the solar charging procedure, guaranteeing effective solar energy utilisation for lighting applications. In order to prevent overcharging or undercharging of the battery, the precision and dependability of the solar charge controller performance are assessed. Additionally, the LCD display and Blynk application gives real-time feedback on the charging state while the voltage and current sensors enable exact monitoring of the solar panel characteristics. The discussion further examines the findings, contrasting this system with anticipated results and addressing any shortcomings or potential areas for system performance enhancement.

4.2 Results and Analysis

The Arduino Uno enables accurate monitoring of solar charging parameters and assesses efficiency in different climatic situations when combined with current and voltage sensors. The ESP8266 Wi-Fi module enables smooth wireless connectivity, enabling real-time data transfer to the Blynk application for control and monitoring from a distance. The system's ability to collect solar energy, maintain dependable charging performance, and maximise energy use for lighting applications is demonstrated by the results.

4.2.1 The Open Circuit Voltage (VOC) and Short Current Circuit (ISC) results and graph

The Open Circuit Voltage (VOC), Short Circuit Current (ISC) and Power values of the solar panel for a single data collection day are displayed in the table and figure below.

Table 4.1 Data collected for VOC and ISC value

TIME	VOLTAGE (V)	CURRENT (A)	POWER (W)
8.00 a.m	13.16	0.04	0.53
10.00 a.m	13.17	0.05	0.66
12.00 p.m	13.73	0.26	3.57
1.00 p.m	14.02	0.33	4.63
2.00 p.m	13.97	0.42	5.87
3.00 p.m	13.82	0.39	5.39
4.00 p.m	13.98	0.18	2.52
5.00 p.m	13.42	0.08	1.07
6.00 p.m	13.08	0.05	0.65

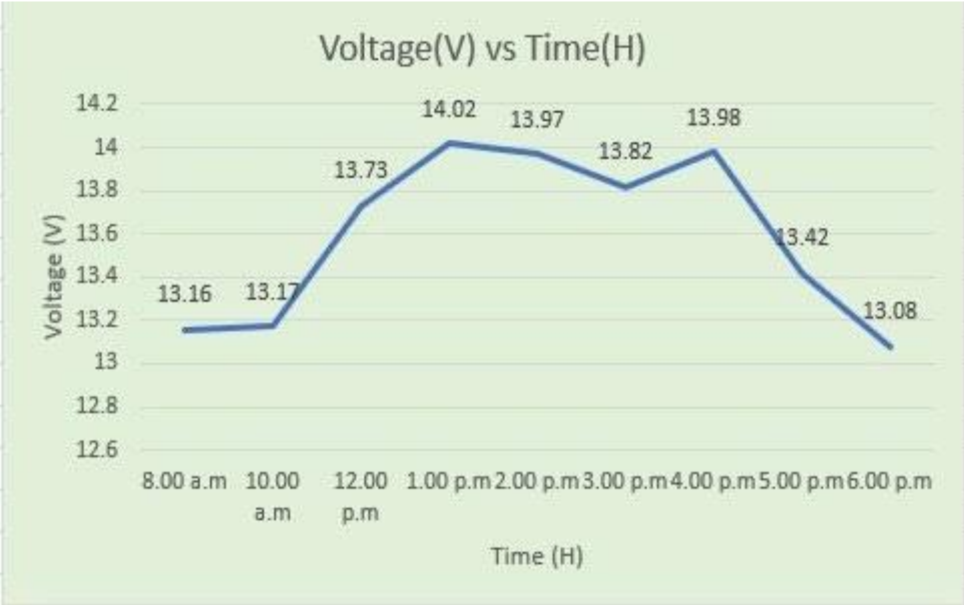


Figure 4.1 Voltage vs Time

The voltage variation over a certain period is succinctly shown in the preceding graph 4.1. Throughout the day, the voltage is mostly constant, ranging from 13.08 V to 14.02 V.

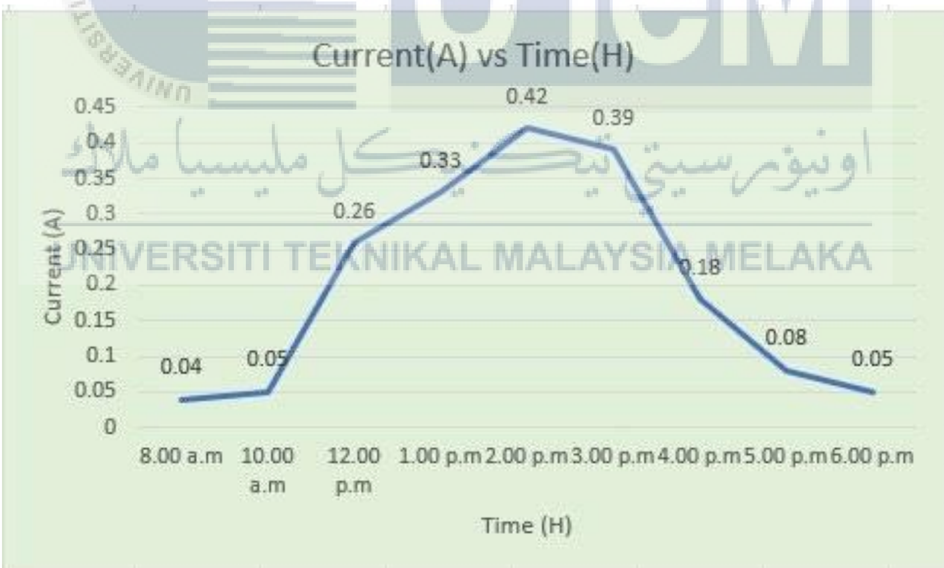


Figure 4.2 Current vs Time

The horizontal axis of the current–time graph above shows the values of time, while the vertical axis shows values of current.

Figure 4.3 Power vs Time

A power vs. time graph shows the variation in a system's or device's power usage over a certain time span. Time is represented by the horizontal axis in hours, while power is represented by the vertical axis in watts.

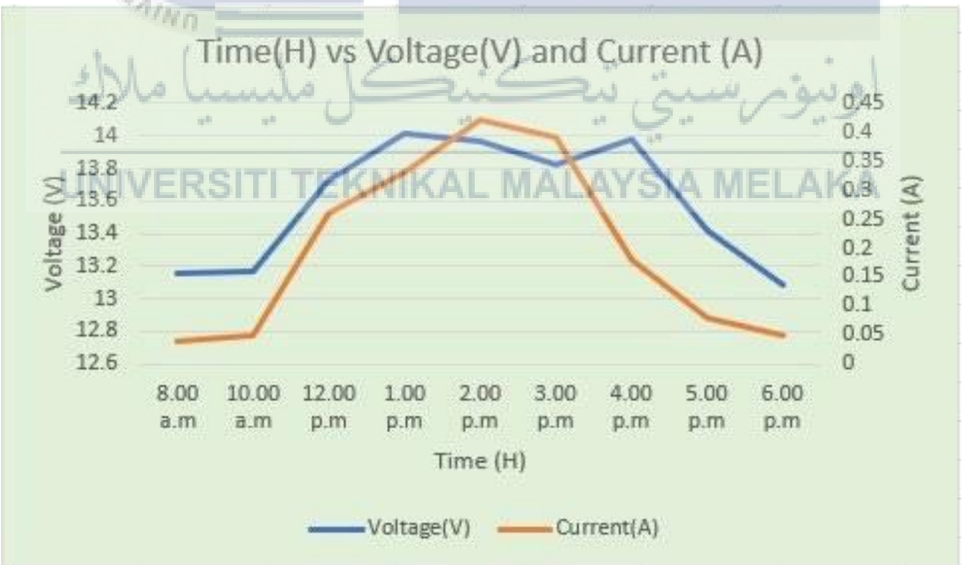


Figure 4.4 Time vs Voltage and Current

The voltage and current changes over a certain time period are shown on a time vs. voltage and current graph. The vertical axes display voltage and current, while the horizontal axis represents time. This graph, which shows variations, maximum values, and general trends in voltage and current over time, sheds light on the dynamic behaviour of an electrical system.

Figure 4.5 Solar panel specification

This time frame's variety in sunlight angles and intensity makes it possible to evaluate the solar panel's reaction to shifting environmental factors in full detail. By examining the data over this longer period of time, one may get understanding of the dynamic behaviour of the panel and its effectiveness in absorbing solar energy at different periods of the day.

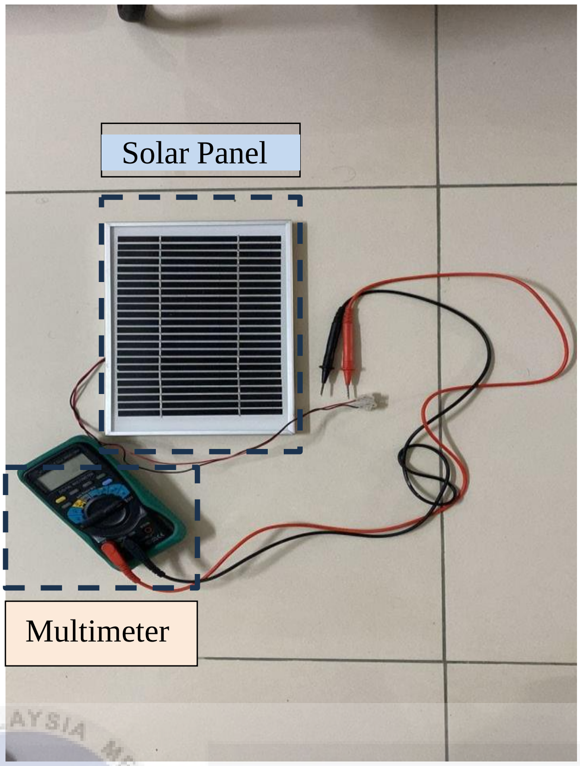


Figure 4.6 Data measured setup

4.2.2 Collecting data over three days across the entire system

Table and figure below show that the system was tested and measured throughout a period of three days, from 8 a.m. to 6 p.m.

Table 4.2 Data Collection for Day 1

TIME	VOLTAGE (V)	CURRENT (A)	POWER (W)
8.00 a.m	12.10	0.02	0.24
10.00 a.m	12.70	0.11	1.40
12.00 p.m	12.68	0.15	1.90
2.00 p.m	12.92	0.12	1.55
4.00 p.m	12.78	0.02	0.26
6.00 p.m	12.30	0.01	0.12

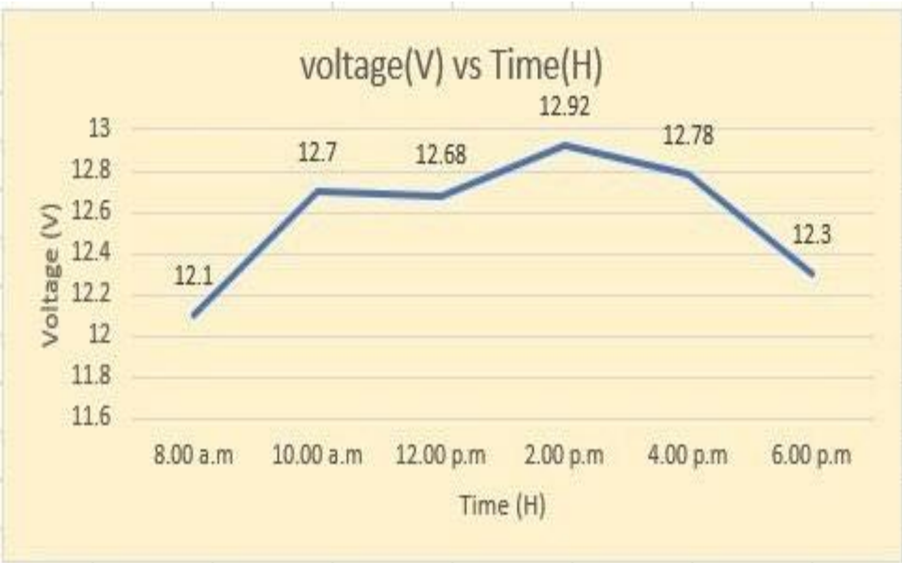


Figure 4.7 Voltage vs Time

Based on the data presented, a voltage vs. time graph shows a rather stable electrical system with slight voltage swings. Throughout the day, the voltage stays constant, ranging from 12.10 V to 12.92 V. The data exhibits a discernible maximum around 12:00 p.m., which is probably indicative of heightened power use, followed by a decline at 4:00 p.m. Overall, the graph shows a steady and constant voltage profile that provides information on the behaviour of the system over time.

Figure 4.8 Current vs Time

Based on the above data, a current vs. time graph shows variations in current throughout the day. The current values fluctuate and peak at 0.15 A at 12:00 p.m., suggesting that noon is when there is a greater demand for electricity. The graph indicates a decrease in current at 6:00 p.m., indicating a decrease in energy use throughout the evening. In general, the current vs. time graph helps to analyse patterns of energy use throughout the day by offering insights into dynamic variations in electrical current.

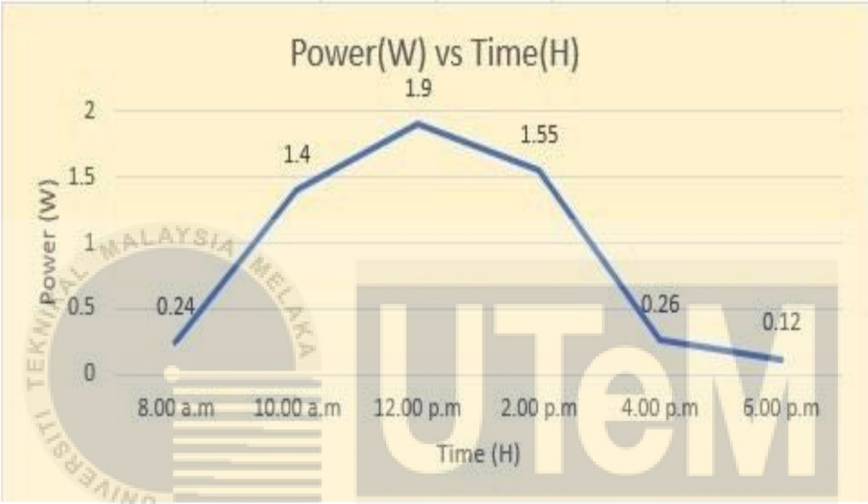


Figure 4.9 Power vs Time

The data supplied was used to create a power vs. time graph that shows daily fluctuations in power use. The power values exhibit a peak-trough pattern, with the maximum consumption of 1.55 W around 2:00 p.m. and the lowest consumption in the early morning and evening. This graph gives an overview of the dynamic power use trends and sheds light on times throughout the reported time frame when energy demand was higher and lower.

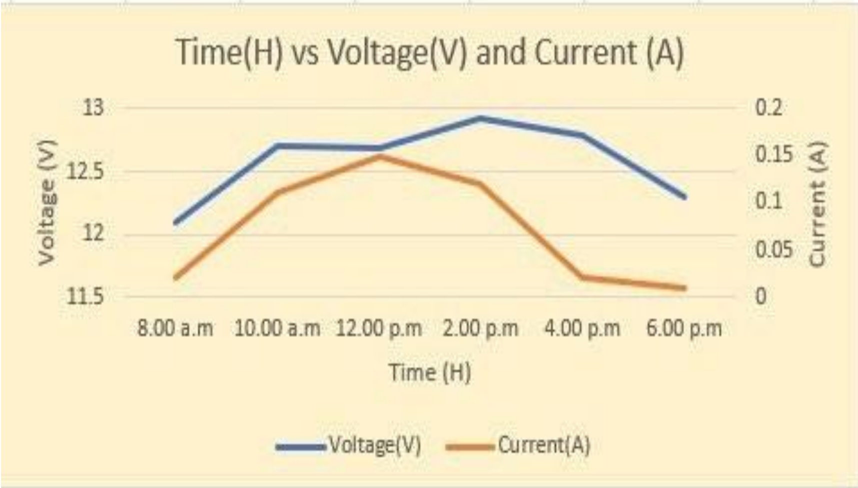


Figure 4.10 Time vs Voltage and Current

A voltage and current vs. time graph shows the changes in voltage and current over a certain time interval. The horizontal axis displays time, and the vertical axes display voltage and current. With its displays of voltage and current variations, peak values, and general trends over time, this graph sheds light on the dynamic behaviour of an electrical system.

Table 4.3 Data Collection for Day 2

TIME	VOLTAGE (V)	CURRENT (A)	POWER (W)
08:00	11.50	0.03	0.36
10:00	11.80	0.07	0.87
12:00	12.20	0.25	3.05
14:00	12.10	0.12	1.45
16:00	12.00	0.04	0.48
18:00	10.90	0.07	0.78

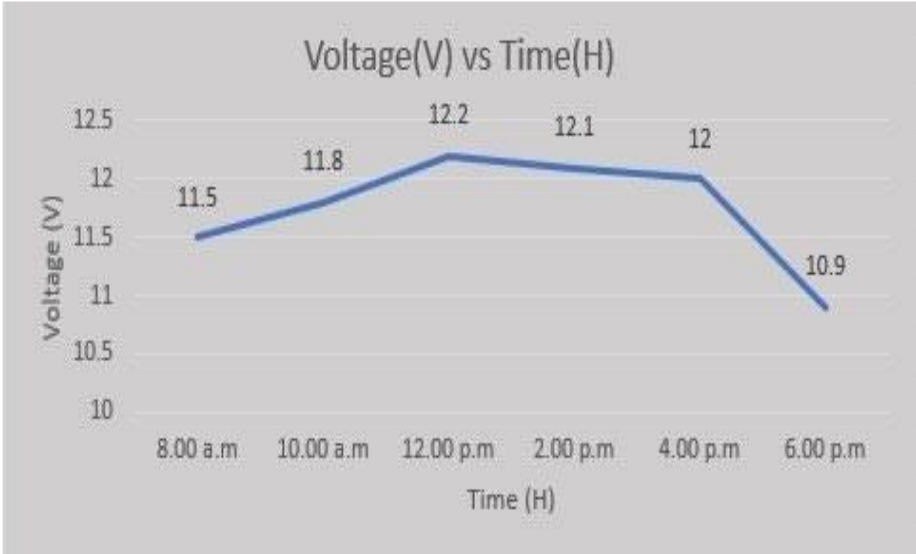


Figure 4.11 Voltage vs Time

Based on the above data, a voltage vs. time graph shows dynamic variations in voltage throughout the day. The voltage rises to a peak of 12.20 V at 12:00 p.m. from 11.50 V at 8:00 a.m., then drops to 10.90 V at 6:00 p.m. The graph, which shows a discernible noon peak and an evening power fall, depicts the shifting electrical circumstances. All in all, it offers a moment in time view of the voltage behaviour of the system.

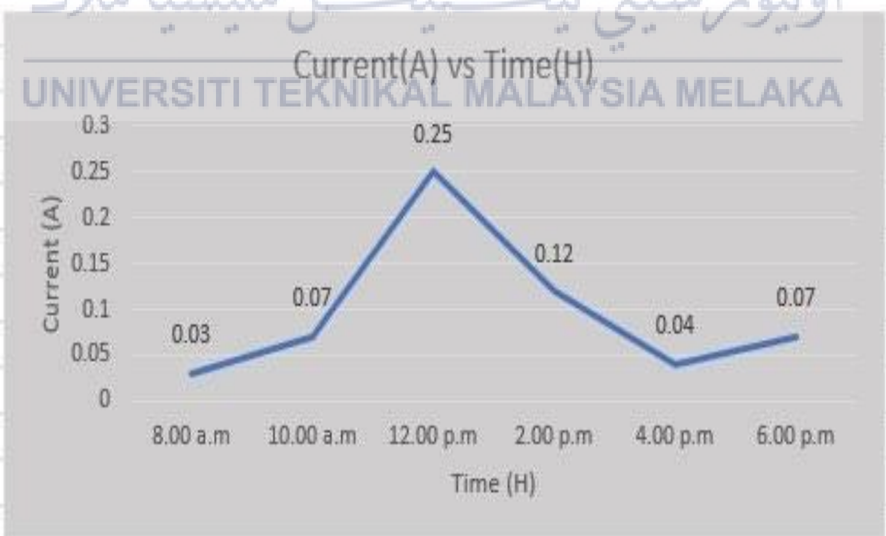


Figure 4.12 Current vs Time

The current vs. time graph that was created using the provided data shows how the current changes during the course of the day. The current readings exhibit fluctuations, with a high of 0.25 A recorded around 12:00 p.m., suggesting a rise in power use at noon. At 4:00 p.m., the graph also displays a decrease in current (0.04 A). All things considered, the current vs. time graph offers a visual depiction of the system's behaviour over time and sheds light on the dynamic variations in electrical current.

Figure 4.13 Power vs Time

The power consumption of a system or device is shown changing over a given time period in a power vs. time graph. Power is shown in watts on the vertical axis, and time is represented in hours on the horizontal axis.

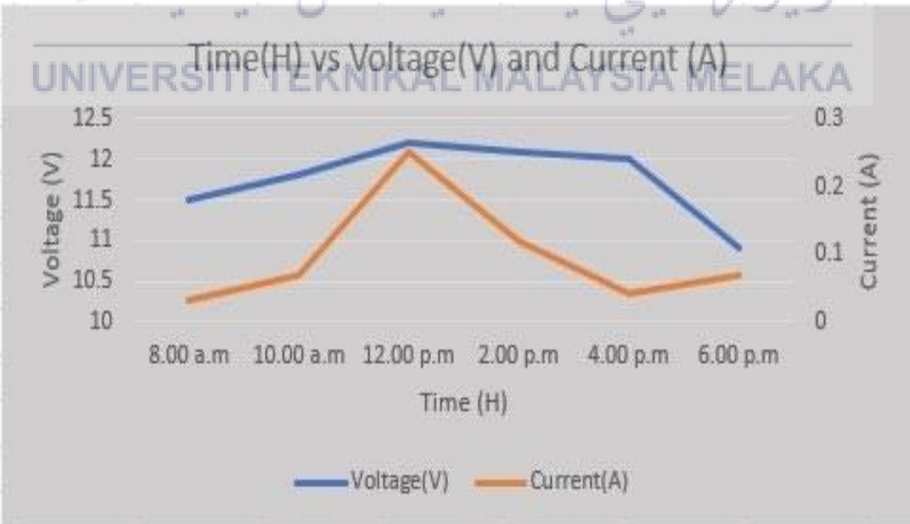


Figure 4.14 Time vs Voltage and Current

Based on the above data, a time versus voltage and current graph shows the dynamic electrical behaviour throughout the day. At eight in the morning, the voltage is 11.50 V. It peaks at 12.20 V at noon and then drops to 10.90 V at six in the evening. Present readings vary, reaching a maximum of 0.25 A at 12:00 p.m. and a minimum of 0.04 A at 4:00 p.m. The graph shows peak times and changes in the electrical system over time, giving a thorough understanding of both voltage and current trends.

Table 4.4 Data Collection for Day 3

TIME	VOLTAGE (V)	CURRENT (A)	POWER (W)
08:00	11.90	0.05	0.60
10:00	12.00	0.04	0.48
12:00	12.30	0.12	1.48
14:00	12.20	0.05	0.61
16:00	12.10	0.01	0.12
18:00	12.10	0.02	0.24

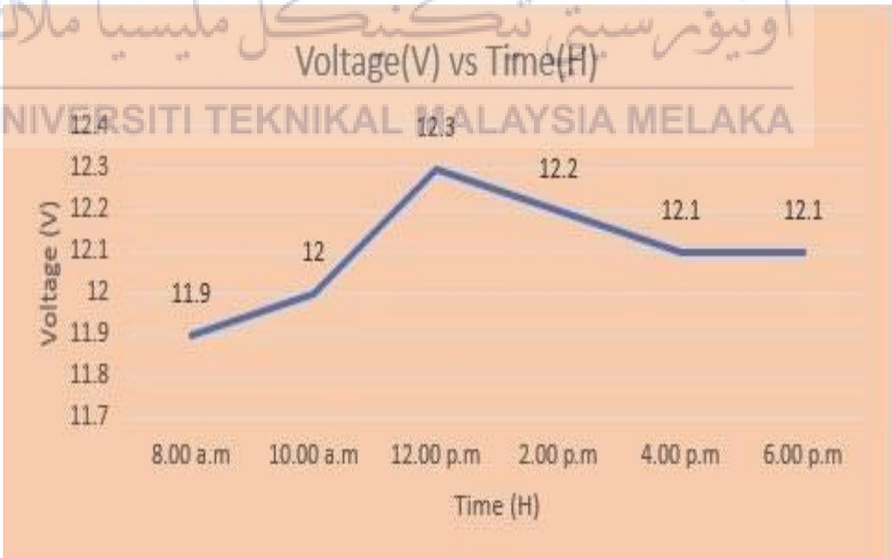


Figure 4.15 Voltage vs Time

Based on the above data, a stable electrical system with few variations is depicted in the voltage vs. time graph. From 11.90 V at 8:00 a.m. until 12.30 V at 12:00 p.m., the voltage is almost steady. It then gradually drops to 12.10 V in the evening. With a possible midday peak around 12:00 p.m., the graph shows a constant voltage profile throughout the day. All in all, it points to a consistent and constant voltage supply within the time frame that was observed.

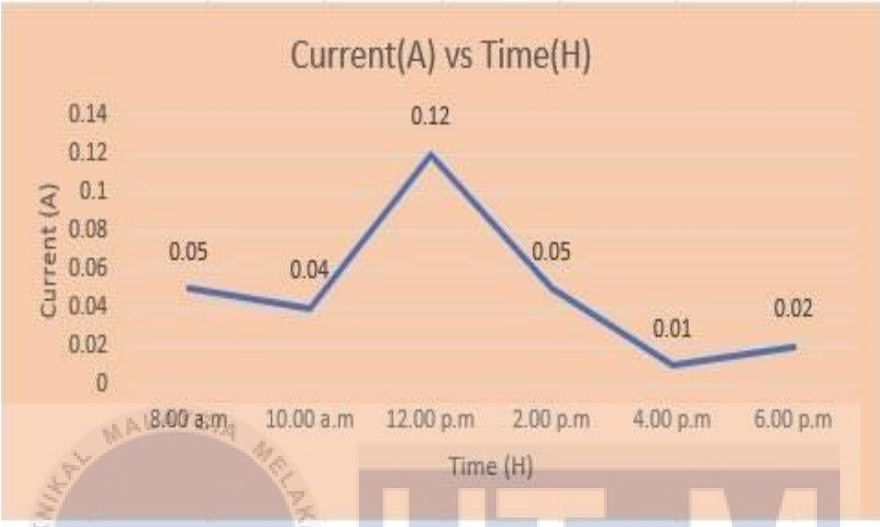


Figure 4.16 Current vs Time

The given data was used to create a current vs. time graph, which displays fluctuations in current throughout the day. The current measurements show a high of 0.12 A at 12:00 p.m. and then normally stay at lower levels at other times. A rather constant current profile across the observed time period is suggested by the graph's low oscillations. With a possible noon peak in electricity consumption, it offers insights into the present dynamics overall.

Figure 4.17 Power vs Time

A power vs. time graph shows the variation in a system's or device's power usage over a certain time frame. Time is shown on the horizontal axis in hours, while power is shown on the vertical axis in watts.

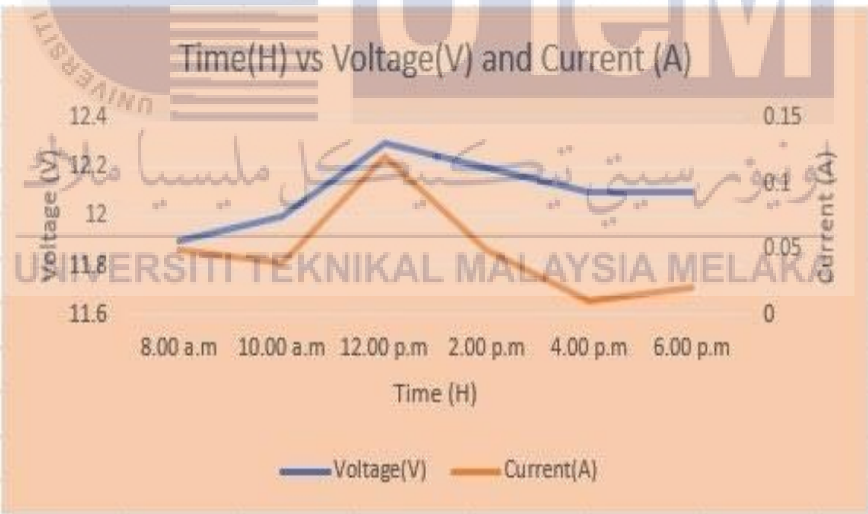


Figure 4.18 Time vs Voltage and Current

Based on the data supplied, a stable electrical system with constant voltage and current profiles is depicted in the time vs. voltage and current graph. The current fluctuates very little, peaking at 0.12 A around 12:00 p.m., but the voltage stays comparatively steady, ranging from 11.90 V to 12.30 V. With possible signs of a noon surge in power consumption, the graph indicates a consistent supply of electricity throughout the day. In general, it depicts the stability and dependability of the system over the noted duration.

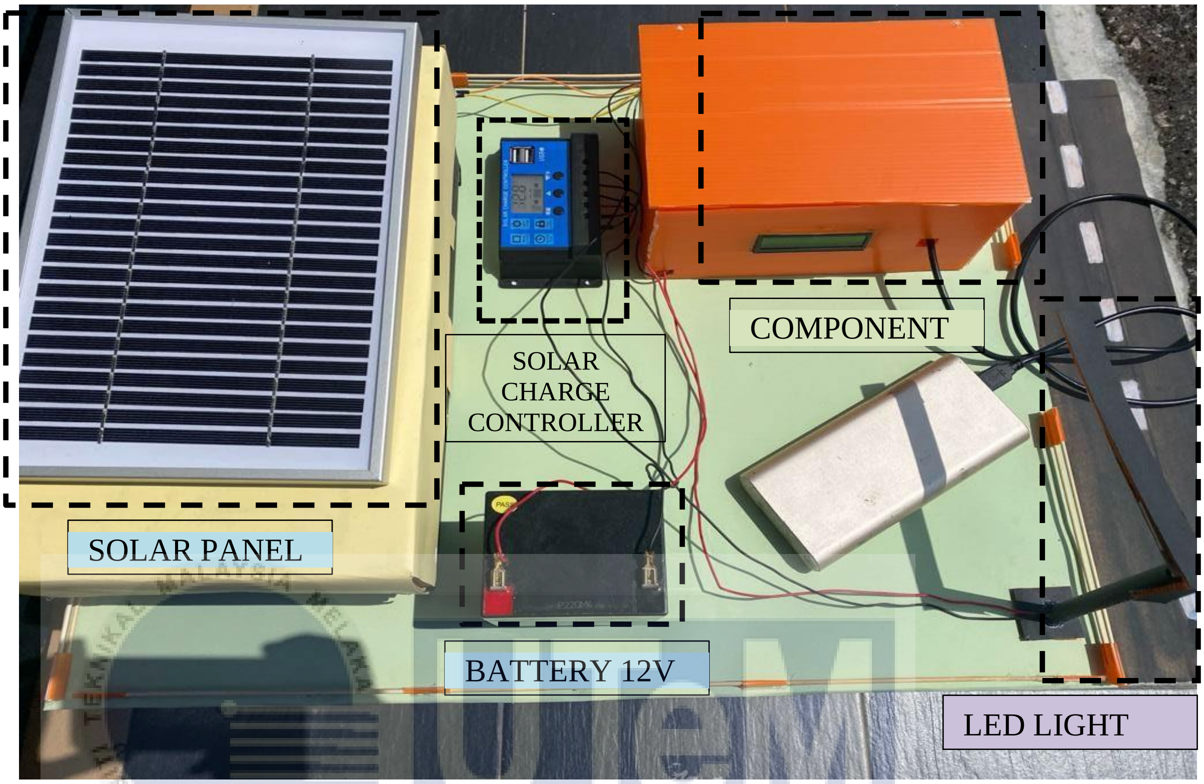


Figure 4.19 Experimental Setup

The experimental setup applied in this work to assess a solar-powered system's performance is shown in Figure 4.19. A solar panel, an LCD display for monitoring the voltage and current the solar panel generates for the system, a solar charge controller, and a 12V battery are all part of the setup. Due to increased solar irradiance and the ideal sun position, the system's voltage, current, and power rise from morning to afternoon, as shown by the curve in the above figure. Following that, it decreases as a result of shifting sun positions and reduced solar irradiation.

From the data collected over the course of three days, it seems that the voltage levels mostly stayed constant during the observed periods. The current readings fluctuated over the day, peaking at particular periods, such midday. Similar trends were seen in power usage, with higher values denoting times when current flowed more freely.

4.2.3 Comparison between the result of data collection

Table 4.5 Comparison between data collection

Time	Solar Panel			Full System (D1)		
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
8.00 a.m	13.16	0.04	0.53	12.10	0.02	0.24
10.00 a.m	13.17	0.05	0.66	12.70	0.11	1.40
12.00 p.m	13.73	0.26	3.57	12.68	0.15	1.90
2.00 p.m	13.97	0.42	5.87	12.92	0.12	1.55
4.00 p.m	13.98	0.18	2.52	12.78	0.02	0.26
6.00 p.m	13.08	0.05	0.65	12.30	0.01	0.12

It is obvious that there are differences in the trends between the maximum power voltage (Vmp) and maximum power current (Imp) of the entire system and the properties of the solar panel. For example, the solar panel reaches its maximum power production of 5.87 W at 2:00 p.m., while the total system power is far lower at 1.55 W. Power generation from solar panels is affected by variations in sunlight intensity and angle during the day as well as environmental factors like cloud cover. Disparities between the specified performance of the solar panel and the actual performance of the entire system are caused by system losses, such as resistive losses and conversion inefficiencies. Variations in temperature, load parameters, system design, and the existence of conversion and control losses all have a substantial impact on how efficient the system is ultimately.

4.2.4 The data presentation of the Blynk application

The following table and figure illustrate how the system was measured and display on Blynk app over the course of three days, from 8 a.m. to 6 p.m.

Table 4.6 Data Collection for Day 1

TIME	VOLTAGE (V)	CURRENT (mA)	POWER (mW)
8.00 a.m	12.09	20.2	244.2
10.00 a.m	12.68	110.1	1396.1
12.00 p.m	12.67	150.0	1900.5
2.00 p.m	12.91	119.6	1544.0
4.00 p.m	12.78	20.4	260.7
6.00 p.m	12.30	14.4	177.1

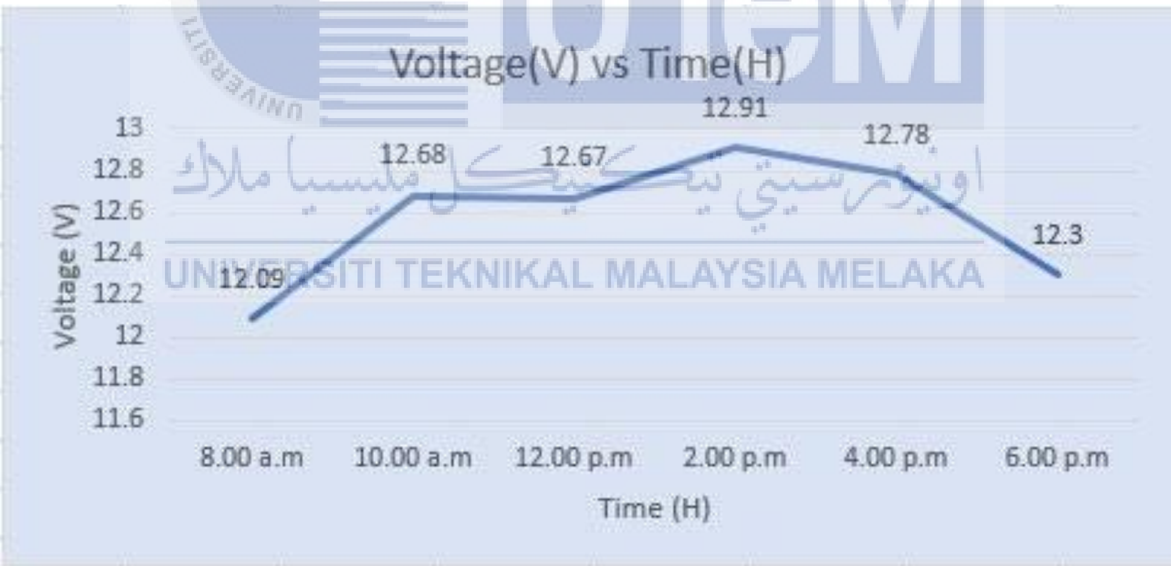


Figure 4.20 Voltage vs Time

Based on the data presented, a voltage vs. time graph shows an electrical system that is comparatively stable. Throughout the day, voltage fluctuates between 12.09 V and 12.91 V, staying constant. Over the course of the observation period, the graph points to a consistent supply of electricity, with possible signs of a noon peak. Overall, it shows how stable and dependable the electrical system's voltage profile is.

Figure 4.21 Current vs Time

The given data was used to create a current vs. time graph, which shows fluctuations in current throughout the day. There are variations in the current figures; around 12:00 p.m., there is a high of 150.0 mA, suggesting a midday spike in power use. The graph indicates a rather constant current profile during the observed time span, despite these changes. It sheds light on the dynamic character of current consumption and may even provide signs of a midday power demand peak.

Figure 4.22 Power vs Time

The power vs. time graph, based on the provided data, shows the power consumption patterns throughout the day. Power values exhibit fluctuations, with a peak of 1900.5 mW at

12:00 p.m., aligning with the highest current and voltage. The graph indicates varying power demands over time, with potential insights into peak usage during midday and stable or reduced consumption in the evening. Overall, it provides a visual representation of the dynamic power consumption behavior in the electrical system.

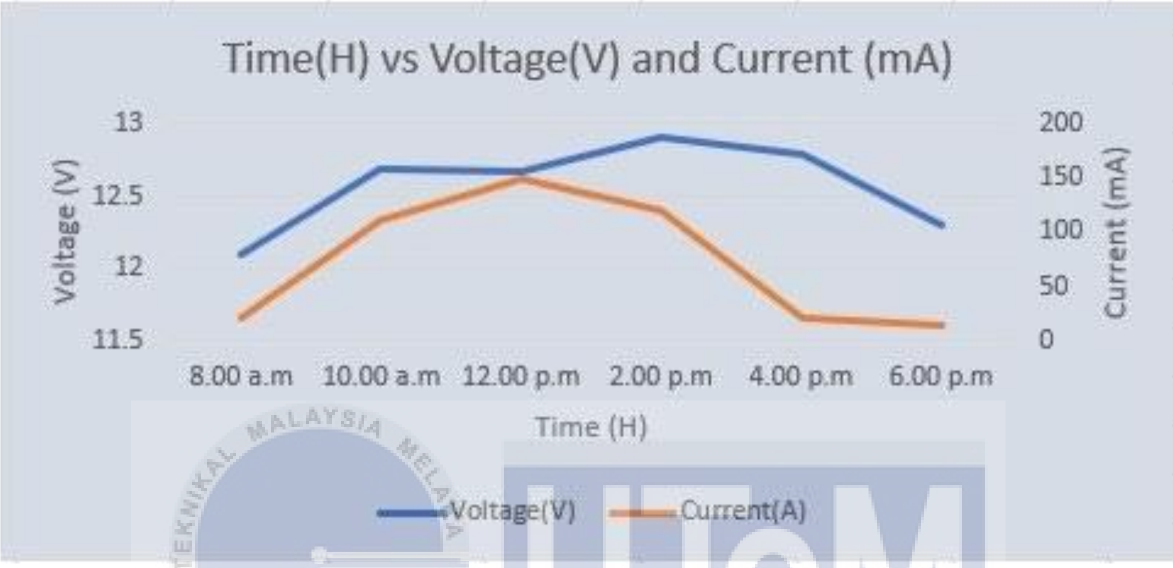


Figure 4.23 Time vs Voltage and Current

The behaviour of the electrical system during the day is depicted in the time vs. voltage and current graph. Between 12.09 V and 12.91 V, the voltage fluctuates but stays comparatively constant. Variations are seen in the current, which peaks at 150.0 mA at 12:00 p.m. The graph shows a continuous supply of electricity, with a significant noon peak in voltage and current. In general, it provides insights into the dynamic interaction among time, voltage, and current, emphasising the electrical system's stable phases and peak power demand.

Table 4.7 Data Collection for Day 2

TIME	VOLTAGE (V)	CURRENT (mA)	POWER (mW)
8.00 a.m	11.53	33.6	387.4
10.00 a.m	11.81	70.2	829.1
12.00 p.m	12.19	248.0	3023.1
2.00 p.m	12.11	115.3	1396.3
4.00 p.m	12.05	40.4	486.82
6.00 p.m	10.90	70.4	767.4

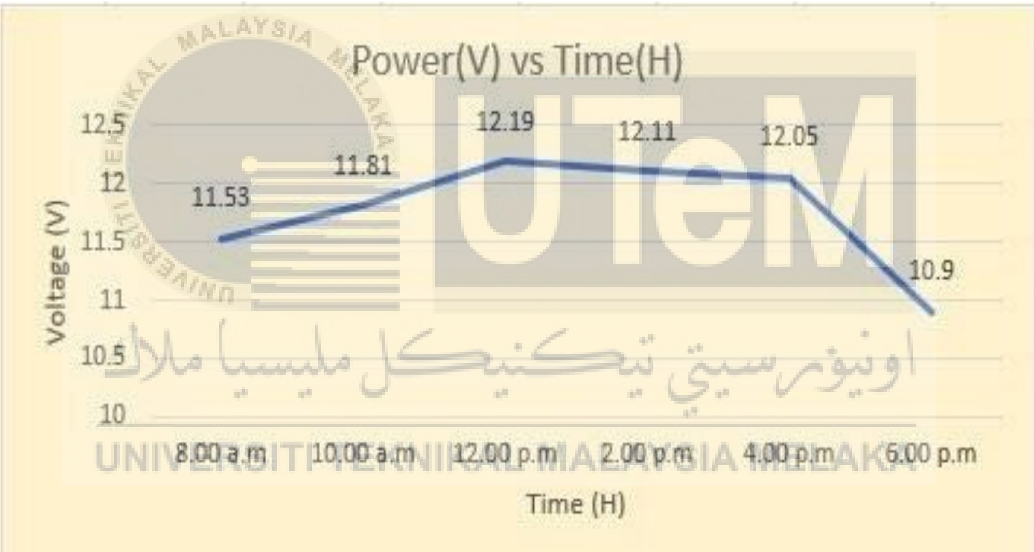


Figure 4.24 Voltage vs Time

Drawing from the available data, the voltage vs. time graph shows how the voltage changes throughout the course of the day. At eight in the morning, the voltage is 11.53 V, and at noon, it peaks at 12.19 V. Then, around 6:00 p.m., it slightly declines to 10.90 V. A notable midday peak is seen on the graph, which illustrates how voltage levels are dynamic. To evaluate the stability and functionality of the electrical system, one must comprehend these voltage patterns.

Figure 4.25 Current vs Time

Based on the data supplied, the current vs. time graph illustrates how the current dynamically fluctuates during the day. The current numbers show oscillations; around 12:00 p.m., they peak at 248.0 mA, suggesting a period of higher power consumption. The system's current dynamics are clearly depicted on the graph, which has a noticeable noon peak and then stabilises towards the evening. Comprehending these fluctuations is essential for effectively handling electrical loads and enhancing system efficiency.

Figure 4.26 Power vs Time

An electrical system's dynamic power consumption patterns are depicted throughout the day in the power vs. time graph, which was created using the data that was supplied. Power readings vary, reaching a maximum of 3023.1 mW around 12:00 p.m., which coincides with the highest voltage and current levels. The graph shows notable fluctuations in the amount of electricity consumed, especially during noon. Evenings see a stabilisation of both voltage and current, which lowers power usage. All things considered, the graph offers a graphic depiction of the shifting power dynamics during the noted time frame.

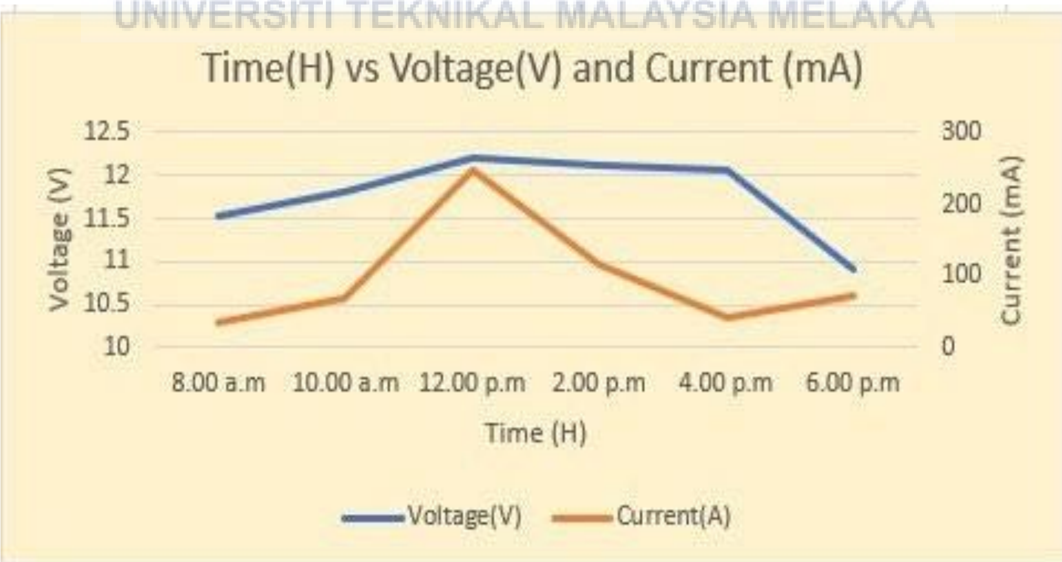


Figure 4.27 Time vs Voltage and Current

Based on the data supplied, the time vs. voltage and current graph shows how an electrical system behaves during the day. The voltage increases gradually between 8:00 a.m. and 12:00 p.m., reaching a peak of 12.19 v, and then declining to 10.90 v at 6:00 p.m. The current levels are not constant; around 12:00 p.m., they peak at 248.0 mA. The graph indicates a period of increased power demand since it shows a notable noon peak in both voltage and current. The data provides insights into patterns of power consumption across the observed time period by illuminating the dynamic interaction between time, voltage, and current.

Table 4.8 Data Collection for Day 3

TIME	VOLTAGE (V)	CURRENT (mA)	POWER (mW)
8.00 a.m	11.90	53.1	631.9
10.00 a.m	12.05	41.6	501.3
12.00 p.m	12.30	120.4	1480.9
2.00 p.m	12.21	50.3	614.2
4.00 p.m	12.10	14.2	171.8
6.00 p.m	12.09	20.9	252.7

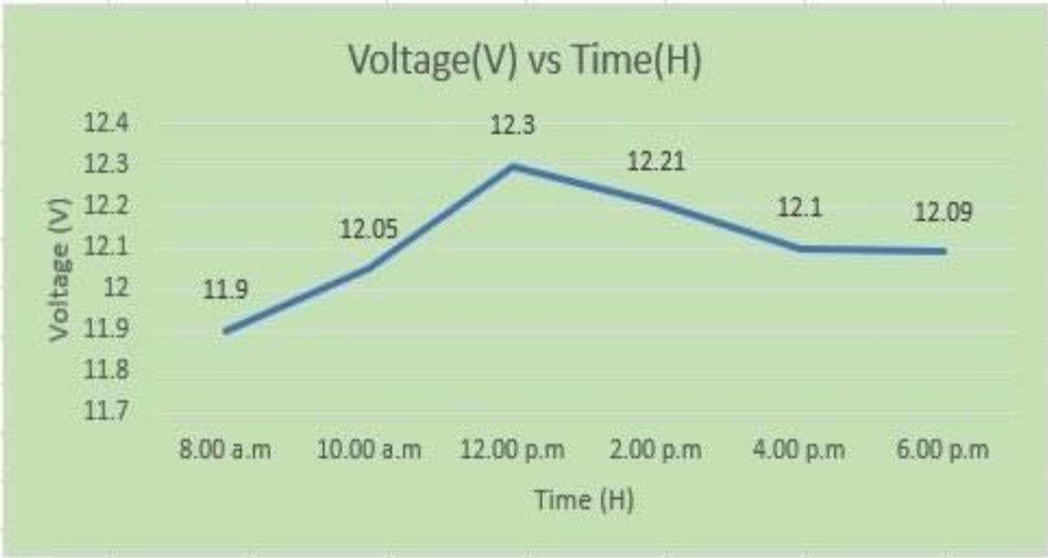


Figure 4.28 Voltage vs Time

A reasonably stable electrical system is depicted in the voltage vs. time graph using the data that was supplied. Over the course of the day, the voltage stays constant, varying between 11.90 and 12.30 V. A noon peak may be shown by the graph, which indicates a consistent supply of electricity throughout the observed time period. The voltage profile of the electrical system is shown to be stable and dependable overall.

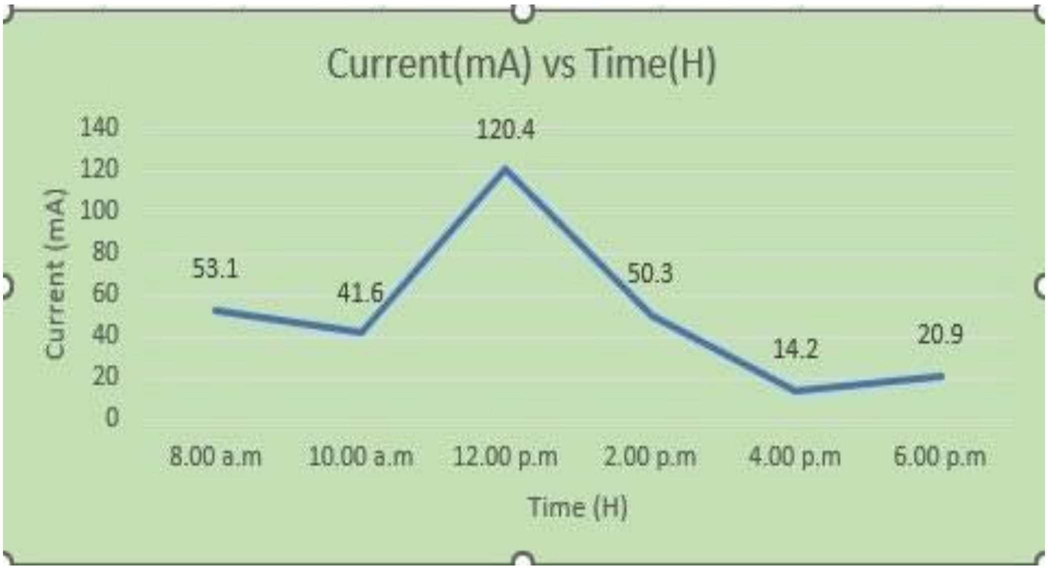


Figure 4.29 Current vs Time

The current vs. time graph, which shows fluctuations in current throughout the day, was created using the data that was supplied. The current measurements show oscillations, peaking at 120.4 mA around 12:00 p.m., suggesting a midday spike in power use. The graph indicates a rather constant current profile during the observed time span, despite these changes. It sheds light on the dynamic character of current consumption and may even provide signs of a midday power demand peak.

Figure 4.30 Power vs Time

Based on the data supplied, the power vs. time graph shows the dynamic power consumption patterns of an electrical system over the course of the day. Power readings vary, peaking at 1480.9 mW at 12:00 p.m., when voltage and current are at their greatest. The graph shows notable fluctuations in the amount of electricity consumed, especially during noon. Evenings see a stabilisation of both voltage and current, which lowers power usage. All things considered, the graph offers a graphic depiction of the shifting power dynamics during the noted time frame.

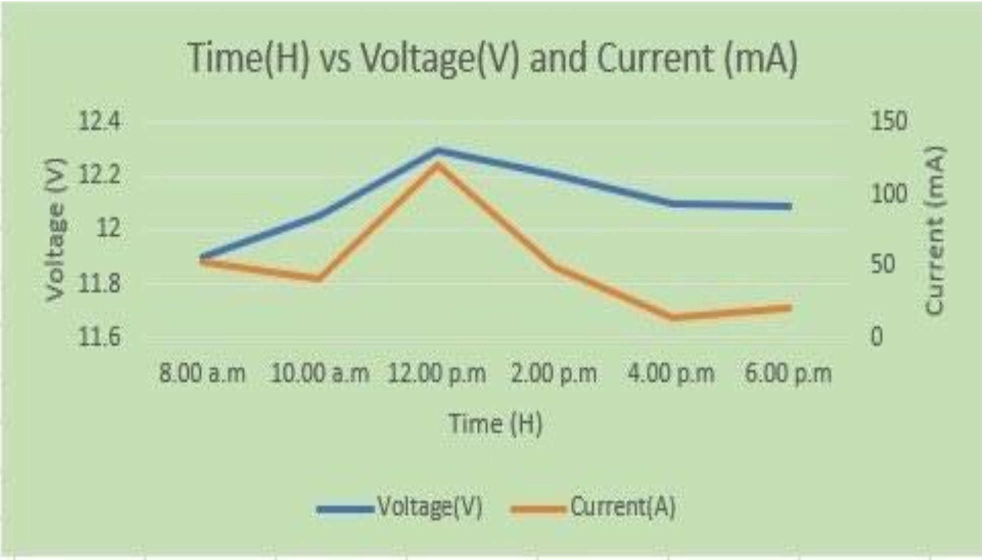


Figure 4.31 Time vs Voltage and Current

Based on the data supplied, the time vs. voltage and current graph shows how an electrical system behaves during the day. While current levels vary, peaking at 120.4 mA at 12:00 p.m., voltage is comparatively constant, ranging between 11.90 V and 12.30 V. The graph indicates a period of increased power demand since it shows a notable noon peak in both voltage and current. The data provides insights into patterns of power consumption across the observed time period by illuminating the dynamic interaction between time, voltage, and current.

4.2.5 Data on a battery's State of Charge (SOC)

The "State Of Charge" (SOC) of a battery shows the proportion of energy left in the battery while no load is connected to it. The data obtained from the display of the solar charge controller is displayed in the table below.

Table 4.9 State of Charge at no load

State of Charge (%)	Open Circuit Voltage (OCV)	
	12V (Lead Acid)	9V (GP Supercell)
100	12.93	9.48
75	12.47	9.22
50	12.20	9.07
25	11.97	8.83
0	11.52	8.58

Figure 4.32 Data obtained for the OCV value

The methods for gathering data for a battery's state of charge based on voltage parameter and an indicator within the solar charge controller are depicted in the above image.

4.2.6 Functionality test results

Through the complete inspection of the system's overall performance, these tests seek to guarantee the correctness and appropriate operation of each component inside the system.

Table 4.10 Functionality test

Test Step	Description	Expected Result	Actual Result									
1	Solar Charge Controller	Simulate fully charged battery and confirm the system cuts off charging	✓	✓	✓	✓	✓					
2	Voltage and Current Sensor	Check if the system accurately measures charging / discharging current and voltage from the supply	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Blynk Application	Display accurate real-time voltage, current and power values	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	LCD Display	Show precise voltage and current values.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	LED Light	Light up if the LDR sensor module detects no light.	✓	✓	✓	✓	✓					

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The project's main goals were accomplished with success. First off, the Solar Charging Monitoring System implemented with an Arduino Uno showed that employing microcontroller-based devices for effective energy use is feasible. A smooth communication interface for real-time data monitoring and control was made possible by the combination of the Arduino Uno, ESP8266, and solar charge controller.

Second, the development of the Charging Monitoring System with an Arduino Uno, solar panels, and a solar charge controller demonstrated how renewable energy sources can be used in real-world situations. With the addition of voltage and current sensors, precise measurements were made possible, guaranteeing the attached battery would be charged to its full potential.

Thirdly, important insights into the system's dependability and efficiency were gained via the performance assessment of the system using an experimental setup and data measurements. An extensive examination of the system's behaviour under various circumstances is facilitated by the LDR sensor module's ability to monitor parameters including voltage, current, and light intensity as well as the SD card module's data logging capabilities.

Lastly, the initiative provides an economical and sustainable substitute for conventional power sources in addition to promoting energy efficiency. This system has the potential to empower communities, lessen environmental impact, and open the door for creative, localised energy solutions that will benefit society for a long time, as clean energy and resilience become more and more important to societies.

5.2 Potential for Commercialization

This solar charging monitoring system has tremendous commercialization potential since it meets the growing need for off-grid and sustainable energy solutions worldwide. The system caters to a wide range of markets with a flexible design that may be used for emergency response situations as well as residential regions. Due to its cost-effectiveness, which is fueled by the utilisation of solar energy and effective monitoring systems, it is a desirable choice for customers looking for options that are both affordable and eco-friendly. In light of current trends favouring smart and connected devices, its attractiveness is further enhanced by the incorporation of IoT technologies, real-time monitoring capabilities, and data logging. The commercialization of the system might be accelerated by possible partnerships with solar panel manufacturers, energy storage firms, and sustainable development organisations, in addition to regulatory assistance for renewable energy initiatives. This project is positioned as a potential competitor in the growing market for clean and efficient energy solutions because of its innovative technology, environmental sustainability, and flexibility.

5.3 Future Works

The precision of the analysed collected results can be increased as follow for future improvement recommendation:

1. Improving accuracy during bad weather.
2. Optimising the storage and use of energy.
3. Expanding compatibility with different battery types.

4. Provide a specialised smartphone application with an easy-to-use interface.
5. Construct a strong Internet of Things (IoT) framework that enables remote control and monitoring.

REFERENCES

[1] P. Zare, H. Ghadimi, R. Zare, A. B. Bork Abad, B. Sabery, and I. F. Davoudkhani, "The Study Impact of Restructuring on Efficiency of Iran's Electricity Distribution and Transmission Network," in *2023 8th International Conference on Technology and Energy Management, ICTEM 2023*, Institute of Electrical and Electronics Engineers Inc., 2023. doi: 10.1109/ICTEM56862.2023.10083558.

[2] S. F. Hui, H. F. Ho, W. W. Chan, K. W. Chan, W. C. Lo, and K. W. E. Cheng, "Floating Solar Cell Power Generation, Power Flow Design and its Connection and Distribution."

[3] M. I. Fahmi, Hidayatullah, J. E. Hutagalung, and S. Sembiring, "Electrical automation of solar cell-based Arduino Uno with 16×2 LCD display," in *Emerald Reach Proceedings Series*, vol. 1, Emerald Group Holdings Ltd., 2018, pp. 629–639. doi: 10.1108/978-1-78756-793-1-00099.

[4] T. M. Belay and S. M. Atnaw, "CFD Simulations and Experimental Investigation of a Flat-Plate Solar Air Heater at Different Positions of Inlet and Outlet," *Journal of Renewable Energy*, vol. 2023, pp. 1–16, Oct. 2023, doi: 10.1155/2023/3911228.

[5] Q. Mu *et al.*, "Research on power prediction of clean energy and operation optimization of clean energy supply system for typical regions," in *2023 3rd International Conference on Neural Networks, Information and Communication Engineering, NNICE 2023*, Institute of Electrical and Electronics Engineers Inc., 2023, pp. 745–750. doi: 10.1109/NNICE58320.2023.10105787.

[6] H. Liu, B. Wu, A. Maleki, F. Pourfayaz, and R. Ghasempour, "Effects of Reliability Index on Optimal Configuration of Hybrid Solar/Battery Energy System by Optimization Approach: A Case Study," *International Journal of Photoenergy*, vol. 2021, 2021, doi: 10.1155/2021/9779996.

[7] M. IEEE Systems, *2022 World Automation Congress hybrid, San Antonio, TX, USA, online, October 11-15*.

[8] M. Nithya, N. R. Karthik, and K. Meenakshi, "E MONITOR-EB-Charge Monitoring System Using IoT," in *ICPECTS 2020 - IEEE 2nd International Conference on Power, Energy, Control and Transmission Systems, Proceedings*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020. doi: 10.1109/ICPECTS49113.2020.9336969.

[9] *2017 9th IEEE-GCC Conference and Exhibition (GCCCE)*. IEEE, 2017.

[10] M. Rumbayan, I. Pundoko, D. Ruindungan, and N. V. Panjaitan, "Development of internet of things-based monitoring system for application solar energy technology in Bunaken island," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2022. doi: 10.1088/1755-1315/1041/1/012023.

[11] S. Khanam *et al.*, "Smart Solar Tracker With Energy Monitoring," in *Proceedings of the International Conference on Electronics and Renewable Systems, ICEARS 2022*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 80–85. doi: 10.1109/ICEARS53579.2022.9752255.

[12] T. T. E. Vo, H. Ko, J. H. Huh, and N. Park, "Overview of solar energy for aquaculture: The potential and future trends," *Energies*, vol. 14, no. 21. MDPI, Nov. 01, 2021. doi: 10.3390/en14216923.

[13] J. John, A. M. George, and C. P. Kurian, "Indoor PV system for IOT Applications with Battery Charge Microcontroller," in *2022 International Conference on Intelligent Controller and Computing for Smart Power, ICICCSP 2022*, Institute of

Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/ICICCSP53532.2022.9862394.
[14] Y. Zhang, Q. Zhou, L. Zhao, Y. Ma, Q. Lv, and P. Gao, "Dynamic reactive power configuration of high penetration renewable energy grid based on transient stability probability assessment," in *2020 IEEE 4th Conference on Energy Internet and Energy System Integration: Connecting the Grids Towards a Low-Carbon High-Efficiency Energy System, EI2 2020*, Institute of Electrical and Electronics Engineers Inc., Oct. 2020, pp. 3801–3805. doi: 10.1109/EI250167.2020.9346594.
[15] N. Haegel and S. Kurtz, "Global Progress Toward Renewable Electricity: Tracking the Role of Solar," *IEEE J Photovolt*, vol. 11, no. 6, pp. 1335–1342, Nov. 2021, doi: 10.1109/JPHOTOV.2021.3104149.
[16] Jāmiʻat al-Imārāt al-ʻArabīyah al-Muttaḥidah and Institute of Electrical and Electronics Engineers, *5th International Conference on Renewable Energy: Generation & Application : Mon to Wed, Feb 26-28, 2018, CIT Building.*
[17] Z. Shi, W. Wang, Y. Huang, P. Li, and L. Dong, "Simultaneous optimization of renewable energy and energy storage capacity with the hierarchical control," *CSEE Journal of Power and Energy Systems*, vol. 8, no. 1, pp. 95–104, Jan. 2022, doi: 10.17775/CSEEJPES.2019.01470.
[18] L. Jia, J. Ma, P. Cheng, and Y. Liu, "A perspective on solar energy-powered road and rail transportation in China," *CSEE Journal of Power and Energy Systems*, vol. 6, no. 4, pp. 760–771, Dec. 2020, doi: 10.17775/CSEEJPES.2020.02040.
[19] H. Abubakr, J. C. Vasquez, K. Mahmoud, M. M. F. Darwish, and J. M. Guerrero, "Comprehensive Review on Renewable Energy Sources in Egypt-Current Status, Grid Codes and Future Vision," *IEEE Access*, vol. 10. Institute of Electrical and Electronics Engineers Inc., pp. 4081–4101, 2022. doi: 10.1109/ACCESS.2022.3140385.
[20] Universidade da Madeira, Madeira Interactive Technologies Institute, and Institute of Electrical and Electronics Engineers, *Internet of Things for the Global Community 2017 : proceedings : July 10-12, 2017, Madeira, Portugal*.
[21] R. C. Mendoza, G. D. Aguilar, and A. T. Demetillo, "Design of Floating Solar Power System for a Local Community Application with Sample Prototype for a Single Panel," in *ICDRET 2021 - 6th International Conference on Development in Renewable Energy Technology*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/ICDRET54330.2021.9751795.
[22] M. Nageswara Rao and V. S. N. K. Chaitanya, "Experimental analysis of partial shading on solar panels with theuse of aluminium reflectors," in *Proceedings of 2020 IEEE International Conference on Advances and Developments in Electrical and Electronics Engineering, ICADEE 2020*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020. doi: 10.1109/ICADEE51157.2020.9368910.
[23] M. U. Shujun, Z. You, Y. Ye, Z. Ding, J. Lin, and S. Kai, "A Curtailed Wind Power Accommodation Strategy Based On Wind-Hydrogen-Heat-Storage Integrated Energy Network."
[24] S. D. Ahmed, F. S. M. Al-Ismail, M. Shafiullah, F. A. Al-Sulaiman, and I. M. El-Amin, "Grid Integration Challenges of Wind Energy: A Review," *IEEE Access*, vol. 8. Institute of Electrical and Electronics Engineers Inc., pp. 10857–10878, 2020. doi: 10.1109/ACCESS.2020.2964896.
[25] *2018 International Conference on Wind Energy and Applications in Algeria (ICWEAA)*. IEEE, 2018.
[26] S. D. Ahmed, F. S. M. Al-Ismail, M. Shafiullah, F. A. Al-Sulaiman, and I. M. El-Amin, "Grid Integration Challenges of Wind Energy: A Review," *IEEE Access*, vol.

8. Institute of Electrical and Electronics Engineers Inc., pp. 10857–10878, 2020. doi: 10.1109/ACCESS.2020.2964896.
[27] B. Independent University, Institute of Electrical and Electronics Engineers. Bangladesh Section, and Institute of Electrical and Electronics Engineers., *2019 5th International Conference on Advances in Electrical Engineering (ICAEE) : 26-28 September, 2019, Independent University, Bangladesh Plot-16, Block-B, Bashundhara, Dhaka-1229, Bangladesh.*
[28] I. Rahoma and F. Obeidat, "Future Energy Mix Mapping for Jordan using Multi Criteria Decision Analysis," in *2021 12th International Renewable Engineering Conference, IREC 2021*, Institute of Electrical and Electronics Engineers Inc., Apr. 2021. doi: 10.1109/IREC51415.2021.9427861.
[29] A. Balal and F. Shahabi, "Designing and Simulation a Reliable Standalone Solar/wind Hybrid System," in *2021 12th International Conference on Computing Communication and Networking Technologies, ICCCNT 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/ICCCNT51525.2021.9579840.
[30] N. Tchertchian and D. Millet, "Eco-Maintenance for Complex Systems: Application on System of Renewable energy production."
[31] IEEE Power & Energy Society and Institute of Electrical and Electronics Engineers, *2017 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America).*
[32] "Energy and Economic Analysis of Flash Steam Geothermal Power Plants in Lebanon."
[33] B. Independent University, Institute of Electrical and Electronics Engineers. Bangladesh Section, and Institute of Electrical and Electronics Engineers., *2019 5th International Conference on Advances in Electrical Engineering (ICAEE) : 26-28 September, 2019, Independent University, Bangladesh Plot-16, Block-B, Bashundhara, Dhaka-1229, Bangladesh.*
[34] M. El, H. Assad, Z. Said, A. Khosravi, T. Salameh, and M. Albawab, "Parametric study of geothermal parallel flow double-effect water-LiBr absorption chiller."
[35] Y. Siregar, F. H. Siregar, E. Sinulingga, and Suherman, "Design of Geothermal and Solar Hybrid Renewable Energy in Sipoholon Village, North Tapanuli Regency, North Sumatera," in *2021 5th International Conference on Electrical, Telecommunication and Computer Engineering, ELTICOM 2021 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Sep. 2021, pp. 60–63. doi: 10.1109/ELTICOM53303.2021.9590173.
[36] Universitas Sumatera Utara and Institute of Electrical and Electronics Engineers, *2020 4th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM) : proceedings : Medan, Indonesia, September 3, 2020.*
[37] T. Nhubu, M. Belaid, and E. Muzenda, "Contribution of Biomass Valorization for Renewable Energy Generation in Low Emission Development Pathways: A Policy Review," in *Proceedings of 2021 9th International Renewable and Sustainable Energy Conference, IRSEC 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/IRSEC53969.2021.9741185.
[38] K. Zhang *et al.*, "Modeling and utilization of biomass-to-syngas for industrial multi-energy systems," *CSEE Journal of Power and Energy Systems*, vol. 7, no. 5, pp. 932–942, Sep. 2021, doi: 10.17775/CSEEJPES.2020.06190.
[39] G. T. Chala, F. M. Guangul, and R. Sharma, "Biomass Energy in Malaysia-A SWOT Analysis."
[40] Universitatea "Politehnică" Timișoara, IEEE Power & Energy Society, and Institute of Electrical and Electronics Engineers, *Proceedings of 2019 International*

Conference on Energy and Environment (CIEM) : Timisoara, Romania, 17-18 October 2019 : conference venue: Politehnica University of Timisoara, Timisoara - Romania.
[41] Universitas Gadjah Mada. Fakultas Teknik and Institute of Electrical and Electronics Engineers, *Proceedings : 2017 7th International Annual Engineering Seminar : 1-2 August 2017, Eastparc Hotel, Yogyakarta, Indonesia*.
[42] IEEE Power & Energy Society. General Meeting (2020 : Online) and Institute of Electrical and Electronics Engineers, *2020 IEEE Power & Energy Society General Meeting (PESGM).*
[43] D. Tsuanyo, B. Amougou, A. Aziz, B. Nka Nnomo, D. Fioriti, and J. Kenfack, "Design models for small run-of-river hydropower plants: a review," *Sustainable Energy Research*, vol. 10, no. 1, Feb. 2023, doi: 10.1186/s40807-023-00072-1.
[44] Institute of Electrical and Electronics Engineers. Canadian Region, IEEE Power & Energy Society, and Institute of Electrical and Electronics Engineers, *2017 IEEE Electrical Power and Energy Conference (EPEC).*
[45] Ga.) IEEE Power & Energy Society. General Meeting (2019 : Atlanta and Institute of Electrical and Electronics Engineers, *2019 IEEE Power & Energy Society General Meeting (PESGM).*
[46] D. H. B. Gai and E. Shittu, "Hydropower Replacement and the Nexus of Food-Energy-Water Systems: Impacts on Climate Performance," in *2021 IEEE International Conference on Industrial Engineering and Engineering Management, IEEM 2021*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 344–348. doi: 10.1109/IEEM50564.2021.9672812.
[47] Ga.) IEEE Power & Energy Society. General Meeting (2019 : Atlanta and Institute of Electrical and Electronics Engineers, *2019 IEEE Power & Energy Society General Meeting (PESGM).*
[48] Saveetha Engineering College and Institute of Electrical and Electronics Engineers, *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI) - 2017 : 21st & 22nd September 2017*.
[49] N. F. Mtukushe and E. E. Ojo, "The Study of Electrical Power Generation from Tidal Energy in South Africa," in *2021 Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa, SAUPEC/RobMech/PRASA 2021*, Institute of Electrical and Electronics Engineers Inc., Jan. 2021. doi: 10.1109/SAUPEC/RobMech/PRASA52254.2021.9377011.
[50] Institute of Electrical and Electronics Engineers, *2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO) : 28-31 May 2018.*
[51] S. Zaidi, M. K. Abbas, S. Saleem, B. M. Khan, and S. Haider, "Renewable Tidal Power Generation Significance and Challenges," in *Proceedings of 18th International Bhurban Conference on Applied Sciences and Technologies, IBCAST 2021*, Institute of Electrical and Electronics Engineers Inc., Jan. 2021, pp. 835–840. doi: 10.1109/IBCAST51254.2021.9393280.
[52] Di. E. Bolanakis, "A Survey of Research in Microcontroller Education," *Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 14, no. 2. Education Society of IEEE (Spanish Chapter), pp. 50–57, May 01, 2019. doi: 10.1109/RITA.2019.2922856.
[53] G. C. Sekhar and K. Vijayalakshmi, "Energy Efficient Street Light Controlling System on Detecting Vehicle Movement using Arduino Microcontroller in Comparison with 8051 Microcontroller," in *Proceedings of the 2022 International Conference on Innovative Computing, Intelligent Communication and Smart*

Electrical Systems, ICSES 2022, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/ICSES55317.2022.9914314.

[54] Y. Luo, Z. Chen, J. Li, and K. Sun, "Design of Solar Dual Streetlight Control System Based on Microcontroller," in *Proceedings - 2022 International Conference on Artificial Intelligence and Autonomous Robot Systems, AIARS 2022*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 196–201. doi: 10.1109/AIARS57204.2022.00051.

[55] Z. Wu, K. Qiu, and J. Zhang, "A smart microcontroller architecture for the internet of things," *Sensors (Switzerland)*, vol. 20, no. 7, Apr. 2020, doi: 10.3390/s20071821.

[56] Nagoya Kōgyō Daigaku and Institute of Electrical and Electronics Engineers, *ICCET 2019 : 2019 2nd International Conference on Communication Engineering and Technology : 12-15 April, 2019, Nagoya, Japan.*

[57] R. S. Abhishek, A. Dhanus Kanth, S. Hariharan, S. Hariharasudhan, and S. Saravanan, "Design of Solar PV Emulator using Raspberry Pi Controller," in *5th International Conference on Inventive Computation Technologies, ICICT 2022 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 581–584. doi: 10.1109/ICICT54344.2022.9850727.

[58] A. M. Abd-Elrahim, A. Abu-Assal, A. A. A. A. Mohammad, A. I. M. Al-Imam, A. H. A. Hassan, and M. A. M. Muhi-Aldeen, "Design and Implementation of Raspberry Pi based Cell phone," in *Proceedings of: 2020 International Conference on Computer, Control, Electrical, and Electronics Engineering, ICCCEEE 2020*, Institute of Electrical and Electronics Engineers Inc., Feb. 2021. doi: 10.1109/ICCCEEE49695.2021.9429601.

[59] *2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE)*. IEEE, 2018.

[60] V. Mathur, Y. Saini, V. Giri, V. Choudhary, U. Bharadwaj, and V. Kumar, "Weather Station Using Raspberry Pi," in *Proceedings of the IEEE International Conference Image Information Processing*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 279–283. doi: 10.1109/ICIIP53038.2021.9702687.

[61] *2017 9th IEEE-GCC Conference and Exhibition (GCCCE)*. IEEE, 2017.

[62] I. C. Mituletu, D. Anghel, L. Ardeljan, and M. Magda, "DC-DC Buck Converter Based on Arduino Uno Sliding Mode Controller," in *12th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2021*, Institute of Electrical and Electronics Engineers Inc., Mar. 2021. doi: 10.1109/ATEE52255.2021.9425185.

[63] K. Masykuroh, F. T. Syifa, G. R. Setiyanto, A. D. Ramadhani, D. Kurnianto, and N. Iryani, "Prototype Smart Door Lock by Using Wireless Network Based on Arduino Uno," in *10th IEEE International Conference on Communication, Networks and Satellite, Comnetsat 2021 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Jul. 2021, pp. 342–347. doi: 10.1109/COMNETSAT53002.2021.9530806.

[64] *2018 International Conference on Computing, Power and Communication Technologies (GUCON)*. IEEE, 2018.

[65] B. Xu, Institute of Electrical and Electronics Engineers. Beijing Section, and Institute of Electrical and Electronics Engineers, *Proceedings of 2018 2nd IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC 2018) : May 25-27, 2018, Xi'an China*.

[66] Slamin, Universitas Negeri Jember, Institute of Electrical and Electronics Engineers. Indonesia Section, Institute of Electrical and Electronics Engineers. Indonesia

Section. Computer Society Chapter, and Institute of Electrical and Electronics Engineers, *Proceedings, 2019 International Conference on Computer Science, Information Technology, and Electrical Engineering (ICOMITEE 2019) : October 16th-17th 2019, Jember, Indonesia*.

[67] Y. Singh Parihar and Y. S. Parihar, "Internet of Things and Nodemcu A review of use of Nodemcu ESP8266 in IoT products IoT based Controlled Soilless vertical farming with hydroponics NFT system using microcontroller View project Learning Management system View project Internet of Things and Nodemcu A review of use of Nodemcu ESP8266 in IoT products," JETIR, 2019. [Online]. Available: www.jetir.org

[68] Universitas Brawijaya. Electrical Engineering Department, Institute of Electrical and Electronics Engineers. Indonesia Section., and Institute of Electrical and Electronics Engineers, *2018 EECCIS : Electrical Power, Electronics, Communications, Controls and Informatics Seminar : Batu, East Java, Indonesia, October 9-11, 2018*.

[69] A. V. Zinkevich, "ESp8266 microcontroller application in wireless synchronization tasks," in *Proceedings - 2021 International Conference on Industrial Engineering, Applications and Manufacturing, ICIEAM 2021*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 670–674. doi: 10.1109/ICIEAM51226.2021.9446411.

[70] P. N. Astya, Galgotias University. School of Computing Science and Engineering, Institute of Electrical and Electronics Engineers. Uttar Pradesh Section, and Institute of Electrical and Electronics Engineers, *IEEE International Conference on Computing, Communication and Automation (ICCCA 2017) : proceeding : on 5th-6th May, 2017*.

[71] P. F. Gabriel and Z. Wang, "Design and Implementation of Home Automation system using Arduino Uno and NodeMCU ESP8266 IoT Platform," in *International Conference on Advanced Mechatronic Systems, ICAMechS*, IEEE Computer Society, 2022, pp. 161–166. doi: 10.1109/ICAMechS57222.2022.10003361.

[72] Sri Sivasubramaniya Nadar College of Engineering. Department of Electrical and Electronics Engineering, Institute of Electrical and Electronics Engineers, Institute of Electrical and Electronics Engineers. Madras Section, and IEEE Power Electronics Society, *Proceedings of the 2018 4th International Conference on Electrical Energy Systems (ICEES) : 7-9 February 2018, Department of Electrical and Electronics Engineering, SSN College of Engineering, Chennai*.

[73] A. Patil, "A Review Paper on Solar Energy-Generated Electricity," *Int J Res Appl Sci Eng Technol*, vol. 10, no. 6, pp. 2905–2910, Jun. 2022, doi: 10.22214/ijraset.2022.44369.

[74] H. Hu *et al.*, "Grid impedance impact analysis of the weak grid-tied VSC," in *IEEE Green Technologies Conference*, IEEE Computer Society, Apr. 2021, pp. 547–551. doi: 10.1109/GreenTech48523.2021.00091.

[75] A. Kumar, N. Gupta, and V. Gupta, "A Comprehensive Review on Grid-TiedSolar Photovoltaic System," *Journal of Green Engineering*, vol. 7, no. 1, pp. 213–254, 2017, doi: 10.13052/jge1904-4720.71210.

[76] A. A. Imam, J. O. Oladigbolu, S. M. A. Mustafa, and T. A. Imam, "The Effect of Solar Photovoltaic Technologies Cost Drop on the Economic Viability of Residential Grid-Tied Solar PV Systems in Saudi Arabia," in *International Conference on Electrical, Computer, and Energy Technologies, ICECET 2022*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/ICECET55527.2022.9872582.

[77] D. Venkatramanan and V. John, "A Reconfigurable Solar Photovoltaic Grid-Tied Inverter Architecture for Enhanced Energy Access in Backup Power Applications," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 12, pp. 10531–10541, Dec. 2020, doi: 10.1109/TIE.2019.2960742.

[78] B. Jia, H. Wu, and Y. Li, "Flexible On-grid and Off-grid Control Strategy of Photovoltaic Energy Storage System Based on VSG Technology," in *5th IEEE Conference on Energy Internet and Energy System Integration: Energy Internet for Carbon Neutrality, EI2 2021*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 1978–1985. doi: 10.1109/EI252483.2021.9712963.

[79] G. Nesterenko, G. Prankevich, S. Eroshenko, R. Chuvashev, and V. Zyryanov, "Technical and economic efficiency analysis of the energy storage systems use in off-grid power systems," in *Proceedings of the 7th International Conference on Electrical Energy Systems, ICEES 2021*, Institute of Electrical and Electronics Engineers Inc., Feb. 2021, pp. 68–72. doi: 10.1109/ICEES51510.2021.9383742.

[80] I. Allafi and T. Iqbal, "Low-Cost SCADA System Using Arduino and Reliance SCADA for a Stand-Alone Photovoltaic System," *Journal of Solar Energy*, vol. 2018, pp. 1–8, May 2018, doi: 10.1155/2018/3140309.

[81] A. Sinha, R. Ranjan, A. K. Gupta, and V. K. Jain, "Techno-economic feasibility analysis of off-grid electrification for remote areas: A review," in *Proceedings of the 2020 9th International Conference on System Modeling and Advancement in Research Trends, SMART 2020*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020, pp. 463–467. doi: 10.1109/SMART50582.2020.9337112.

[82] IEEE Power & Energy Society and Institute of Electrical and Electronics Engineers, *2019 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT).*

[83] I. Institut Teknologi 10 Nopember (Surabaya, Institute of Electrical and Electronics Engineers. Indonesia Section, IEEE Industrial Electronics Society. Indonesia Chapter, and Institute of Electrical and Electronics Engineers, *Proceedings, 2020 International Seminar on Intelligent Technology and Its Application (ISITIA 2020) : Humanification of reliable intelligent systems : 22-23 July 2020, virtual conference.*

[84] A. Balal and F. Shahabi, "Designing and Simulation a Reliable Standalone Solar/wind Hybrid System," in *2021 12th International Conference on Computing Communication and Networking Technologies, ICCCNT 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/ICCCNT51525.2021.9579840.

[85] S. Rehman, "Hybrid power systems – Sizes, efficiencies, and economics," *Energy Exploration and Exploitation*, vol. 39, no. 1. SAGE Publications Inc., pp. 3–43, Jan. 01, 2021. doi: 10.1177/0144598720965022.

[86] C. Ghenai, T. Salameh, and A. Merabet, "Design, Optimization and Control of Standalone Solar PV/Fuel Cell Hybrid Power System."

[87] IEEE Power & Energy Society, IEEE Industry Applications Society, and Institute of Electrical and Electronics Engineers, *IEEE PowerAfrica Conference 2020 : dates: 25th-28th August 2020, venue: virtual.*

[88] Z. Firdouse, S. M. Ashraf, K. Rahman, and H. Rehman, "Hybrid Solar PV System for Electric Vehicles Battery Charging," in *2023 International Conference on Power, Instrumentation, Energy and Control, PIECON 2023*, Institute of Electrical and Electronics Engineers Inc., 2023. doi: 10.1109/PIECON56912.2023.10085883.

[89] IEEE Power Electronics Society, IEEE Microwave Theory and Techniques Society, Institute of Electrical and Electronics Engineers, and K. O. Wireless Power Week (2020 : Seoul, *2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (Wow) : Nov. 15-19, 2020, Seoul, Korea.*

[90] Siddhant College of Engineering and Institute of Electrical and Electronics Engineers, *2017 2nd International Conference for Convergence in Technology (I2CT).*

[91] D. Sammartino, D. Pau, D. Denaro, and L. Zambrano, "Intelligent resource constrained battery management on automotive microcontrollers," in *2021 IEEE 10th Global Conference on Consumer Electronics, GCCE 2021*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 950–954. doi: 10.1109/GCCE53005.2021.9621984.

[92] C. Lin, G. Han, T. Xu, and L. Shu, "An Adaptive Path Planning Scheme towards Chargeable UAV-IWSNs to Perform Sustainable Smart Agricultural Monitoring," in *IEEE International Conference on Industrial Informatics (INDIN)*, Institute of Electrical and Electronics Engineers Inc., Jul. 2020, pp. 535–540. doi: 10.1109/INDIN45582.2020.9442082.

[93] T. Kesavan, K. Nagendran, M. Senthilkumar, G. Ravivarman, A. Madhan, and E. Sathyanaryanan, "Smart Monitoring System for Leakage Current and Excess Power Harvesting System for Industrial Applications," in *3rd IEEE International Virtual Conference on Innovations in Power and Advanced Computing Technologies, i-PACT 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/i-PACT52855.2021.9696585.

[94] A. S. Al-Fahoum, H. B. Al-Hmoud, and A. A. Al-Fraihat, "A smart infrared microcontroller-based blind guidance system," *Active and Passive Electronic Components*, vol. 2013, 2013, doi: 10.1155/2013/726480.

[95] D. Engin and M. Engin, "Design of a plant leaf area meter using PV cell and embedded microcontroller," *Advances in Materials Science and Engineering*, vol. 2013, 2013, doi: 10.1155/2013/393045.

[96] T. N. Dianorre, D. Eric Donald, M. Jules, N. Saeed, K. T. Alex Stephane, and B. M. Hubert, "Microcontroller Implementation, Controls, and Synchronization of Three-Dimensional Autonomous System with a Parabolic Equilibrium Point," *Math Probl Eng*, vol. 2022, 2022, doi: 10.1155/2022/7804440.

[97] H. Sattar *et al.*, "Smart Wound Hydration Monitoring Using Biosensors and Fuzzy Inference System," *Wirel Commun Mob Comput*, vol. 2019, 2019, doi: 10.1155/2019/8059629.

[98] S. and Communication Networks, "Retracted: Electronic Health Record Monitoring System and Data Security Using Blockchain Technology," *Security and Communication Networks*, vol. 2023, pp. 1–1, Dec. 2023, doi: 10.1155/2023/9856473.

APPENDICES

Appendix A Gantt Chart

Table 5.1 Gantt Chart PSM 1

PROGRESS	WEEK												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Application Mendeley	■					Mid Sem							
Download Journal	■												
Problem Statement		■											
Objective			■										
Abstract				■									
Writing Literature Review					■		■	■	■	■	■		
Buy Components									■	■	■		
Fabricate Methodology										■	■		
Collect Data & Measurement Pre-Project											■	■	
Conclusion of Preliminary Result											■	■	
Report Finalized											■	■	
Slide Presentation												■	■
Final Presentation Preparation													■

Table 5.2 Gantt Chart PSM 2

PROGRESS	WEEK												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Meeting with the Supervisor	■	■		■	■	Mid Sem		■	■	■	■	■	■
The Creation of a Prototype	■	■	■										
Soldering Components				■						■			
Add Component					■				■	■			
Testing and Upload Coding					■				■	■	■		
Collect Data & Measurement Project		■	■	■	■		■	■	■	■			
Writing Report										■	■	■	■
Making Poster												■	■
Report Finalized												■	■
Updating the Hardware Project												■	■
Final Presentation Preparation													■