Faculty of Electrical Technology and Engineering

DEVELOPMENT OF PORTABLE SOLAR PV GENERATOR POWERED FOR CCTV SYSTEM

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Bachelor of Electrical Engineering Technology with Honours

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in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "Development of Portable Solar PV Generator Powered for CCTV System" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date	:	3/1/2025

APPROVAL

I approve that this Bachelor Degree Project 2 (PSM2) report entitled "Development of Portable Solar PV Generator Powered for CCTV System" is sufficient for submission.

Signature : ....

Supervisor Name : Mohamad Na'im Bin Mohd Nasir

Date : 3/1/2025

APPROVAL

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

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Signature	:	
Co-Supervisor Name (if any)	:	
Date	:	

DEDICATION

This research paper is dedicated to my dear parents, whose unwavering love, support, and sacrifices have provided me with the foundation to pursue my education and dreams. They have been a constant source of inspiration, motivating me to remain focused and resilient throughout every challenge. Their encouragement has always given me the strength to strive for excellence.

I would also like to extend my sincere gratitude to my family for their unconditional support, understanding, and patience during this project. Their belief in my abilities has been a driving force behind my success.

To my supportive friends, thank you for being there during times of difficulty, for offering your advice, and for motivating me to keep going. Your presence and encouragement have made this journey more meaningful.

A special appreciation goes to my supervisor, whose expertise, guidance, and valuable insights have been instrumental in the development and completion of this project. Their unwavering support and constructive feedback have been a beacon of light throughout this academic journey.

Above all, I am deeply grateful to ALLAH SWT, who has blessed me with the strength, good health, and perseverance to complete this project. It is through His guidance and mercy that I was able to overcome the challenges and accomplish this work successfully.

Finally, I thank myself for the hard work, dedication, and commitment I have shown in completing this research.

ABSTRACT

This project addresses the challenge of ensuring continuous operation of CCTV systems in remote or off-grid locations by utilizing a solar-powered energy system, aligning with the Sustainable Development Goal (SDG) 7 of promoting affordable and clean energy. The primary objective is to design and evaluate a sustainable energy system capable of continuous operation for a CCTV setup. The methodology includes using simulation tools such as Tinkercad for project design, Fritzing for circuit design, and hardware performance testing using a PV system analyzer and a thermal imager. Key experiments involve analyzing the system's charging and discharging cycles during day and night under ideal conditions. Results demonstrate that the battery can sustain 12 hours of night operation with a voltage drop to 12.566V and recharge fully within 5 hours of daylight, ensuring continuous operation. The conclusion confirms the viability of the solar-powered CCTV system for uninterrupted surveillance, offering an eco-friendly and reliable alternative to traditional power-dependent systems.

ABSTRAK

Projek ini menangani cabaran dalam memastikan operasi berterusan sistem CCTV di lokasi terpencil atau luar grid dengan menggunakan sistem tenaga berasaskan tenaga solar, selaras dengan Matlamat Pembangunan Mampan (SDG) 7 yang mempromosikan tenaga mampu milik dan bersih. Objektif utama projek ini adalah untuk mereka bentuk dan menilai sistem tenaga mampan yang mampu operasi berterusan untuk pemasangan CCTV. Metodologi yang digunakan termasuk penggunaan alat simulasi seperti Tinkercad untuk reka bentuk projek, Fritzing untuk reka bentuk litar, dan pengujian prestasi perkakasan menggunakan penganalisis sistem PV dan pengimejan terma. Eksperimen utama melibatkan analisis kitaran pengecasan dan nyahcas sistem pada waktu siang dan malam dalam keadaan ideal. Keputusan menunjukkan bahawa bateri mampu menyokong operasi pada waktu malam selama 12 jam dengan penurunan voltan kepada 12.566V dan dicas semula sepenuhnya dalam masa 5 jam cahaya siang, memastikan operasi berterusan. Kesimpulan mengesahkan kebolehgunaan sistem CCTV berkuasa solar untuk pengawasan tanpa gangguan, menawarkan alternatif yang mesra alam dan boleh dipercayai berbanding sistem yang bergantung kepada kuasa tradisional.

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Additionally, I would like to extend my heartfelt appreciation to my family for their unwavering support, love, and encouragement throughout this journey. Their belief in me and their constant motivation have given me the strength to persevere through difficult moments.

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LIST OF SYMBOLS

V	-	Voltage
I	-	Current (A)
P	-	Power (W)
W	-	Watt
Ah	-	ampere hour
Wh	-	watt-hour
E	-	Energy
t	-	Time
Vm	-	Voltage at maximum power (V)
Pmax	-	Maximum power at STC (W)
Vmp	-	Maximum operating voltage (V)
Vmp	-	Maximum operating current (A)
Isc	-	Short Circuit Current (A)
Voc	-	Open Circuit Voltage (V)
y	-	
x	-	

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
CCTV	-	Closed-circuit television
Wi-Fi	-	Wireless Fidelity
NASA	-	National Aeronautics and Space Administration
IoT	-	Internet of Things
UAV	-	Unmanned Aerial Vehicle
IEA	-	International Energy Agency
PSH	-	Peak Sun Hour

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CHAPTER 1

INTRODUCTION

1.1 Background

Solar power and CCTV systems intertwines technological advancement with societal needs. Solar power, originating from photovoltaic technology, has evolved as a sustainable energy solution, driven by concerns about climate change and energy sustainability. Concurrently, the development of CCTV systems arises from the necessity for surveillance and security in public and private spaces. From analog closed-circuit systems to modern digital networks, CCTV technology has expanded its scope, offering higher resolution and functionality. The convergence of solar power and CCTV systems responds to several trends, including the quest for off-grid capability, energy efficiency, cost savings, flexibility, and environmental benefits. By integrating solar power into CCTV systems, users can leverage renewable energy sources, reducing dependence on non-renewable fuels and minimizing environmental impact while enhancing surveillance capabilities in various settings, from urban areas to remote locations.

1.2 Promoting Energy Sustainability and Reducing Carbon Emissions

By developing a portable solar PV generator to power CCTV systems, the project actively contributes to mitigating climate change and environmental degradation. Traditional power sources, such as fossil fuels, contribute significantly to greenhouse gas emissions, exacerbating global warming and climate-related challenges. However, by harnessing solar energy, a clean and renewable resource, the project facilitates a transition towards sustainable energy practices. Solar-powered CCTV systems offer an eco-friendly alternative that reduces reliance on non-renewable energy sources, thereby minimizing carbon emissions associated with electricity generation. Furthermore, by demonstrating the feasibility and effectiveness of solar technology in powering surveillance systems, the project advocates for the broader adoption of renewable energy solutions across diverse sectors. Ultimately, the project's commitment to promoting energy sustainability not only fosters environmental stewardship but also contributes to building a more resilient and sustainable future for communities worldwide.

1.3 Problem Statement

Access to reliable and sustainable energy is critical for modern surveillance systems, particularly in remote or off-grid locations. Traditional CCTV systems heavily depend on grid electricity, leading to challenges such as high energy costs, carbon emissions, and susceptibility to power outages. These issues are especially problematic in areas with limited access to stable electrical infrastructure.

In line with the United Nations Sustainable Development Goal (SDG) 7, which aims to ensure affordable, reliable, and sustainable energy for all, the integration of solar energy into surveillance systems presents an opportunity to address these challenges. However, achieving continuous operation requires effective energy management, including optimized charging cycles, efficient battery usage, and seamless operation across day and night cycles.

This study identifies the need for a solar-powered CCTV system that leverages renewable energy to promote sustainability while addressing the limitations of conventional surveillance systems.

1.4 Project Objective

The main aim of this project is to develop a portable solar PV generator to power a CCTV system with built-in Wi-Fi for remote monitoring. Specifically, the objectives are as follows:

a) To develop the CCTV system.

b) To supply the system for continuous operation independently

c) To investigate performance in terms of efficiency, output performance and solar performance

1.5 Scope of Project

The scope of this project are as follows:

a) Calculation of the CCTV system load and solar panel saiz with its efficiency.

b) CCTV system design including the selection of solar panels, batteries and charge controllers.

c) Build and test prototypes of the portable solar PV and CCTV system to validate design concepts and functionality.

d) Conduct testing of the integrated system under various operating conditions, including solar charging and battery storage.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review component of this project provides a comprehensive investigation of the current research, studies, and technical breakthroughs concerning portable solar PV generators and CCTV systems that are powered by renewable energy sources. The combination of solar electricity with surveillance technology is a viable answer to the ongoing difficulties of energy sustainability and security enhancement that society is now facing. This introduction is to offer a comprehensive summary of the existing knowledge in the subject, emphasising important topics, patterns, and areas of study that shape the goals and extent of the project. This study establishes a foundation for a thorough comprehension of the difficulties and possibilities involved in creating a portable solar PV generator for powering CCTV systems with integrated Wi-Fi for remote monitoring, by combining insights from pertinent literature.

2.2 The Development of Solar-Powered Surveillance Technologies Throughout History

Solar-powered surveillance devices have come a long way over many years, starting with the first attempts to combine solar energy with surveillance tools. In the 1970s, NASA sent camera systems into space that were driven by the sun. This showed how reliable and long-lasting solar energy can be in harsh settings [18, 19]. Even though these early systems were very basic, they showed that solar power could be used in remote areas.

As solar panel technology improved and became more efficient and less expensive, more and more people started using solar power for security on land. Solar-powered CCTV cameras became a good option because they can be used from afar and have little effect on the environment [12]. These systems were useful for many things, like keeping an eye on wildlife, keeping rural sites safe, and managing traffic, especially in places where connecting to the grid would be too hard or too expensive.

2.3 Solar-Powered CCTV Cameras

In the past few years, solar-powered CCTV cameras have come a long way, revolutionising the way monitoring is done in many situations. These systems use solar energy to keep running all the time [20]. They usually have a solar panel array, a charge driver, a battery bank, and high-definition cams. The solar panels take in light from the sun and turn it into electricity. This electricity is then saved in the battery bank so that the cams can be powered even when it's cloudy or dark outside [21].

One interesting place where solar-powered CCTV cameras are used is in wildlife refuges that are far away. These cameras are used by conservationists and experts to watch how animals behave without disturbing their natural environments [22]. Solar-powered systems don't need to be connected to the grid or have batteries replaced often, so they can be used for longer periods of time without getting in the way of wildlife activities.

These CCTV systems that are driven by the sun have many benefits, such as being better for the environment, more reliable, and cheaper. By using solar energy that can be used over and over, these systems lower their reliance on fossil fuels and their carbon emissions, which is in line with environmental goals. Also, because they don't need to be connected to the power grid, solar-powered CCTV systems are especially good for places that are far away or not connected to the power grid.

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2.4 Understanding the Importance of Solar

The very important role that solar photovoltaic (PV) technology plays as a long-lasting and green energy source in solving the world's energy problems [1]. A lot of research has shown that solar PV is good for the environment because it lowers carbon emissions, slows down climate change, and makes us less dependent on fossil fuels [2]. Traditional energy sources like coal and natural gas aren't as clean or green as solar PV systems [3]. This makes the future of energy more stable and sustainable. Solar PV panels are also easier to get and more cost-effective for a wider range of uses, from small setups on rooftops of homes to big utility projects [4]. This is because their prices are going down and their efficiency is going up. In this project, solar PV is important because it can provide a stable and eco-friendly power source for portable monitoring systems, allowing them to work without being connected to a power grid and depending less on them [5]. By using the sun's energy, solar PV technology can help people become energy independent, protect the environment, and make communities safer by installing CCTV systems that are driven by the sun and can be watched from afar.

2.4.1 Peak Sun Hour in Malaysia

The Malaysian peak sun hour is a key part of figuring out if and how well solar photovoltaic (PV) systems will work in the country. Studies show that Malaysia gets an average of 4 to 5 peak sun hours per day, though this can change based on where you live and the time of year [6]. Malaysia has a lot of sunlight, which makes it a good place to use solar energy and shows how important solar PV technology is to the country's move to green energy [7]. Solar PV systems can use Malaysia's solar resources to make power in a way that is safe and good for the environment. They help with energy security, lowering carbon emissions, and economic growth [8]. This project's goal is to improve security by using data on Malaysia's peak sun hours to improve the design and placement of portable solar PV generators that power CCTV systems. This will encourage the use of green energy in the region while also making security better. Peak Sun Hour, shown in Figure 2.1, is the amount of solar insolation a place would get if the sun were at its strongest (1 kW/m2) for a certain number of hours. Solar PV power output can work better when the sun is out for longer.

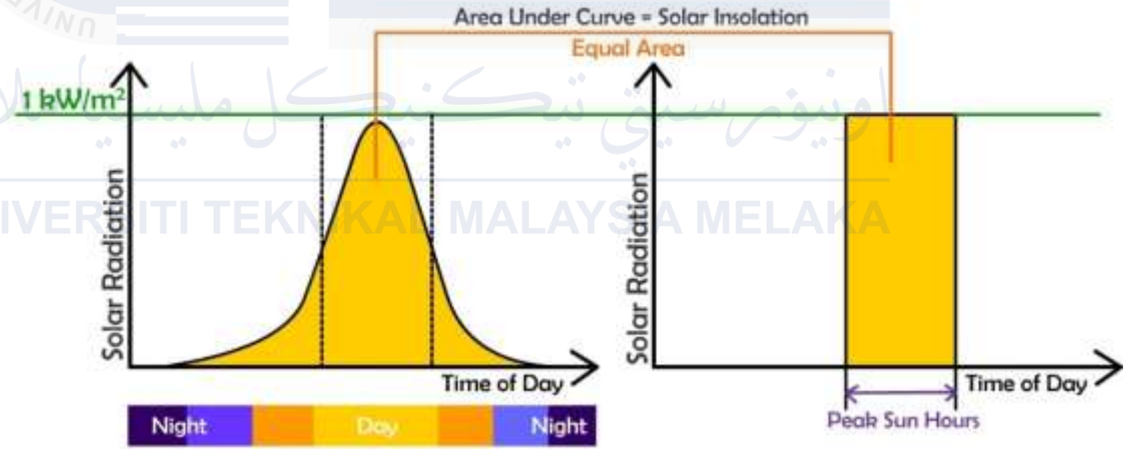


Figure 2.1 Peak Sun Hour [28]

2.5 Understanding the Importance of CCTV

CCTV (Closed-Circuit Television) systems have a lot of importance in the research world, especially when it comes to improving security and monitoring [9]. According to studies, CCTV systems are very important for keeping people safe, preventing crime, and protecting property in many places, like cities, travel hubs, and businesses [10]. Security cameras have been shown to stop illegal activity, make investigations easier, and give police important proof [10]. Furthermore, improvements in CCTV technology, like high-definition cameras, smart video analytics, and the ability to watch systems from afar, have made surveillance systems more useful and effective [11]. Because it can improve security and situational awareness while also letting people watch and handle surveillance assets from afar, CCTV is an important part of this project. As a result of combining CCTV systems with portable solar PV generators, the project wants to make surveillance equipment more useful and reachable, solving safety concerns in both urban and rural areas [12].

2.6 Environmental Impacts of Traditional Surveillance Systems

Traditional monitoring systems that use non-renewable energy sources have big effects on the environment that need to be looked at. Many studies have shown that surveillance operations use a lot of energy. For example, CCTV cameras, recording tools, and networking systems all use a lot of electricity [14]. For instance, standard surveillance systems in cities can use a lot of energy and release a lot of carbon dioxide. This is especially true in areas with a lot of people where surveillance equipment is widely used. Using fossil fuels to make energy increases carbon emissions, air pollution, and resource loss, which makes climate change and environmental damage worse. Also, making, installing, and getting rid of surveillance equipment all have extra environmental costs, such as the cost of getting raw materials, industrial emissions, and electrical trash [13]. The IEA study talks about how monitoring systems affect the environment throughout their whole lifetime, from being made to being thrown away when they're no longer useful. It stresses the need for long-lasting alternatives to reduce these effects. Researchers have found that standard surveillance systems have a lot of negative effects on the environment, such as using a lot of energy, releasing carbon into the air, and using up resources. They want to find environmental-friendly options that are also more secure [15]. Understanding how standard surveillance systems affect the environment is important for this project because it helps us see the benefits of switching to CCTV systems that are driven by renewable energy sources, like solar PV generators.

2.6.1 Portable Solar PV Technology

There has been a big increase in research and development work on portable solar photovoltaic (PV) technology over the past few years. This is because more and more people want green energy options for a wide range of uses. Portable solar PV systems are a great option to standard sets that are tied to the power grid. This is especially true when movement, freedom, and operating without the power grid are very important[16]. Take the example of portable solar PV systems that can power small electronics and outdoor gear. This shows how flexible and useful it can be to use green energy in portable settings. Because these systems are small, light, and easy to move, they can be used in rural or temporary areas where regular power sources aren't available or aren't practical (Ahmad et al., 2020). Ahmad et al. (2020) looked into different design methods, such as using flexible solar cells and foldable designs, to make the devices easier to move around and use in different places. Also, improvements in energy storage technologies like lithium-ion batteries have made portable solar PV systems more reliable and their ability to run on their own energy [17]. How important energy storage options are for making sure there is a steady source of power, especially when sunlight changes or when power needs last past daylight hours. In general, the research shows that portable solar PV technology has the ability to change things by offering clean, renewable energy options for a wide range of portable uses. For example, solar-powered CCTV systems can be used for remote tracking.

2.7 The Advantages of Solar-Powered Surveillance Systems

The use of solar-powered surveillance technologies marks the start of a new era in security and tracking solutions. These technologies have many benefits that solve some of the problems that traditional surveillance systems have. One great thing about solar-powered monitoring is that it doesn't need any other power source. These systems run on their own and depend on sunlight to make energy. This means that tracking can continue even in remote or off-grid places where access to stable grid power may be limited. This freedom not only makes things safer by lowering the risks that come with power outages, but it also makes important infrastructure and rural areas more resilient.

Also, solar-powered security systems show that they are cost-effective in the long run. The original costs of installing solar panels and batteries may be pretty high, but the ongoing costs of running the system are much lower. Solar energy is free and easy to get, so you don't have to pay for expensive fuel or power bills. It also doesn't need much upkeep, which lowers the total cost of ownership [23, 24]. Solar-powered video systems are a good investment for businesses and governments that want long-lasting and cost-effective security solutions because they are so cheap.

Solar-powered security systems are also very good for the earth. These systems lower greenhouse gas pollution and depend less on fossil fuels by using renewable solar energy. This is in line with environmental duty and sustainability goals. This environmentally friendly way of keeping an eye on things shows a dedication to battling climate change and supporting a better future.

Also, solar-powered security systems give you more options than any other type. Their ability to be set up quickly, the fact that they don't need much infrastructure, and the fact that they don't connect to the grid make them perfect for temporary installations, crisis relief, and environments where monitoring needs may change quickly [23]. This gives organisations the freedom to quickly adjust to new security issues and business needs.

Also, solar-powered security systems give you more options than any other type. They can be set up quickly and don't require a lot of equipment or grid links. This makes them good for temporary setups, crisis response situations, and settings that change over time and have changing monitoring needs.

2.8 Solar-Powered Monitoring Implementation

Solar-powered monitoring equipment is widely used because it works well and can be changed to fit different needs. Cameras and sensors that are driven by the sun are set up in national parks and other protected places around the world to help protect wildlife. For instance, in Kenya's Maasai Mara National Reserve, these cameras take pictures and movies of animals that are hard to see. This helps experts study population and migration trends [25].

In many countries, border security services also use solar-powered cameras. Remote border areas are watched over by solar-powered CCTV cameras and drones, which send real-time information and spot criminal activities [26]. Because they can work on their own and are flexible, these systems are very important and perfect for big, hard-to-reach border areas.

Responding to and getting back on your feet after a disaster also needs solar-powered security. Drones with cameras that are driven by solar panels can quickly look at damage, find dangers, and find people who have survived natural disasters. Because they are on duty for a long time, they can fully cover crisis areas [27].

2.9 Comparison of Previous Work

Using solar power for monitoring has been looked at in a number of studies, but their main goal and method are different from the present project. Previous studies, like the ones by Gilbreth et al. [29] and Balantac et al. [32], set up camera networks on the ground. Some of these networks allowed cameras to move around a little within them [29]. Farooq et al. [30] and Zhang et al. [31], on the other hand, looked into using unmanned aerial vehicles (UAVs) for monitoring. The goals were also different. For [29], video tracking was the main goal, while for [32], crime prevention was the main goal. At the same time, [30] and [31] focused on efficiency and self-operation, with [31] focusing on how to make UAVs track targets while using as little energy as possible. The studies also used a range of different technologies. Some used cheap, flexible designs and computer vision to save energy [29], while others used the Internet of Things (IoT) for connection and machine learning to process data [30, 31]. Zhang et al. [31] specifically looked at how to make path planning better so that UAVs could track objects more effectively. This project makes a unique addition by creating a portable solar PV generator that is meant to power CCTV systems. This method fills a gap in the current study scene by providing a mobile and renewable energy option for video monitoring applications.

Table 2.1 Comparison of Previous Work

No.	Reference	Title	Function	Application	Remarks	Comment
1	[29]	A solar-powered wireless smart camera network for outdoor video monitoring.	Monitor	Outdoor video monitoring	Low-cost, modular design with computer vision software to save energy.	The article does not specify the wattage required by the cameras or the exact size of the solar panels
2	[30]	A Solar-powered UAV Designed using IoT and Machine Learning for Sustainable and Autonomous Aerial Missions	Monitor	Aerial missions	Solar-powered design with IoT for communication and machine learning for data processing	The article lacks detailed electrical specifications, such as the efficiency of the solar cells or the power consumption of onboard electronics.

No.	Reference	Title	Function	Application	Remarks	Comment
3	[31]	Energy-Efficient Autonomous Navigation of Solar-Powered UAVs for Surveillance of Mobile Ground Targets in Urban Environments	Surveillance of mobile ground targets	Urban environments	Path planning method to minimize target revisit time	The absence of precise wattage requirements for the UAVs and the exact specifications of the solar panels used.
4	[32]	The Effectiveness of CCTV Cameras in Crime Prevention	Crime prevention	Public spaces	CCTV cameras deter crime, record scenes for solving crimes, and monitor activity	The journal does not address the power requirements, energy consumption, or the efficiency of the electrical components involved

2.9.1 A solar-powered wireless smart camera network for outdoor video monitoring

A new study [29] looks at a smart idea for keeping an eye on things outside: using smart cams that are powered by the sun and connected wirelessly. They suggest this method as a way to keep an eye on outdoor areas without using regular power sources like electricity. Because they use solar power, the cameras can keep working even in places where it's hard to get electricity. This makes them more environmentally friendly and long-lasting.

The experts also talk about how these camera networks can be more flexible and easier to set up if they use wireless connections. The cameras can talk to each other and to a central control point through the air, so they don't need a lot of wires. This helps cover a lot of ground and keeps the cost of building infrastructure low. Real-time tracking also works, so people can see what's going on outside right away, even if they are far away.

Finally, [29] talk about what makes these smart cameras different from regular cameras. In order to make tracking more effective, they can do things like find movement and identify items. These features not only help you find problems faster, but they also help you store all the video data in less space. In general, their study shows a smart and long-lasting way to watch over outdoor areas using technology that works well and doesn't hurt the environment.

2.9.2 A Solar-powered UAV Designed using IoT and Machine Learning for Sustainable and Autonomous Aerial Missions

In a study [30], talk about a cool idea: powering drones with solar power. These drones, which are called UAVs, can do many things, such as collecting data and keeping an eye on areas. The Internet of Things (IoT) and machine learning technology have made them better. The researchers are looking into how using solar energy can make these drones move farther without using fuel. This is better for the world and makes the drones more useful.

Aside from that, the study also talks about how these solar-powered drones can be made even better by connecting them to the internet and using machine learning. The IoT lets the drones talk to control units on the ground and share data in real time. This makes it easier to fly and control the drones from a distance. Drones can do their jobs better without constant human input because machine learning helps them make decisions on their own, like how to avoid hurdles and plan their routes.

In general, [30] study shows that putting solar power, IoT, and machine learning together can make drones more useful and long-lasting. Their work makes it possible to use these smart drones for a wide range of jobs, from surveillance to tracking the environment, while also lowering the damage they do to it.

2.9.3 Energy-Efficient Autonomous Navigation of Solar-Powered UAVs for Surveillance of Mobile Ground Targets in Urban Environments

They looked into a cool idea in their study released in [31]: using solar-powered drones to keep an eye on cities. They work on making these drones move quickly and use little power while keeping an eye on targets on the ground that are moving.

Making sure these drones don't run out of power while flying over cities is very important, according to the study. These smart guidance tricks help the drones find the best ways, use less power, and keep working longer. When they use solar power, this is very important because they need to make the most of the sun they get.

[31] also talks about how these drones can handle the difficulties of keeping an eye on busy city streets. They have found ways to make it easier for the drones to fly around buildings and keep an eye on targets that are moving. This makes them great for keeping an eye on things in cities, where things are always changing and old ways of doing things might not work as well.

2.9.4 The Effectiveness of CCTV Cameras in Crime Prevention

Look into how well CCTV cameras work to stop crime in their study [32]. They look into how these cams, which are placed in different places, can keep people from stealing or damaging property, which will make public places safer.

The study shows that CCTV cameras can serve as an obvious deterrent to would-be criminals, making them think twice before breaking the law. By putting these cameras in key locations, like parking lots or streets, the government can help stop crimes. The study also talks about how CCTV video can help police investigations by giving them proof to catch criminals and make communities better.

But the study also talks about privacy and justice issues that come up because CCTV cams are used so much. There should be a balance between safety and respecting people's rights, even though these cameras can make things safer. This means thinking about how CCTV is used and making sure it doesn't invade people's privacy or pick on certain groups without a good reason.

2.10 Summary

This topic provides an in-depth examination of solar-powered surveillance technologies, tracing their historical development from early NASA applications to modern advancements in solar-powered CCTV systems. It highlights the significance of solar energy, especially in regions like Malaysia with abundant sunlight, and underscores the vital role of CCTV in security. It also discusses the environmental impacts of traditional surveillance systems and the benefits of portable solar PV technology. The review concludes by emphasizing the advantages of solar-powered surveillance, such as energy independence, cost-effectiveness, and environmental sustainability, and notes practical implementations in wildlife conservation, border security, and disaster response.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This part describes how to make a movable solar photovoltaic (PV) generator that can power a CCTV system. By using renewable solar energy, the way aims to solve the two problems of long-term energy use and better protection. It will go over the planning, choosing of parts, putting the system together, and testing steps that need to be taken to make sure the CCTV system works continuously and reliably. By using a planned method, this project aims to make a tracking system that works well, doesn't cost too much, and doesn't hurt the environment.

3.2 Selecting and Evaluating Tools for a Sustainable Development

The main focus of this part is on choosing and evaluating the right tools and technologies for making a portable solar PV generator that can power a CCTV system. A lot of practical factors are considered, such as how well the parts work together, how compatible the tools are, and how the project will affect the environment.

Several approaches can be used to back up these points of view. Life cycle studies can figure out how much damage a project does to the earth and make sure it will last. Open-source software can make a project more open and easier to use, which can increase its social effect. Field tests can check the accuracy and dependability of data collection by checking how precise it is. Researchers and professionals can make their work on making a portable solar PV generator for CCTV systems more useful, long-lasting, and efficient by carefully choosing and testing the right technologies. This process makes sure that the project meets all of its technical requirements and has the biggest good effect on saving energy and the environment.

3.3 Methodology

By using a structured approach that puts both usefulness and environmental effect first, our methodology explains the steps for creating a portable solar photovoltaic (PV) generator that can power a Wi-Fi-enabled CCTV system. Within the first step, current CCTV systems are carefully examined, paying special attention to the problems they have when they count on electricity from the power grid. Finding problems with putting CCTV systems in rural areas that don't have access to normal power sources is easier with this research. Later, clear project goals are set describing the features that the solar-powered CCTV system with Wi-Fi connection should have. Gathering important background information through a thorough literature review is done to make sure that all current solutions and best practices are fully understood.

3.3.1 Flowchart

The goal of this organised project is to make a movable solar PV generator that can power CCTV systems. Figure 3.1 shows the flow of the project, the first step is to take a close look at current CCTV systems and see what problems they have, like the fact that they need energy from the power grid, which makes them hard to use in rural areas. After this, the project goals are set, and a thorough literature study is used to gather important background information. This step is all about the technical side of things. It includes designing and building the hardware parts for both the solar PV plant and the CCTV system. After careful planning and development, a thorough testing phase starts to make sure all the parts work as they should. Any problems found during tests need to be fixed and troubleshooted before moving on. Once the hardware works properly, data collection can begin. During this time, important data about the system's overall performance, efficiency, and ability to use solar energy is gathered. At the end of the project, a thorough report is written that describes the whole process and the results of the tests. This report is a key part of getting the project approved, and there will probably be a presentation to show off what the project has done.

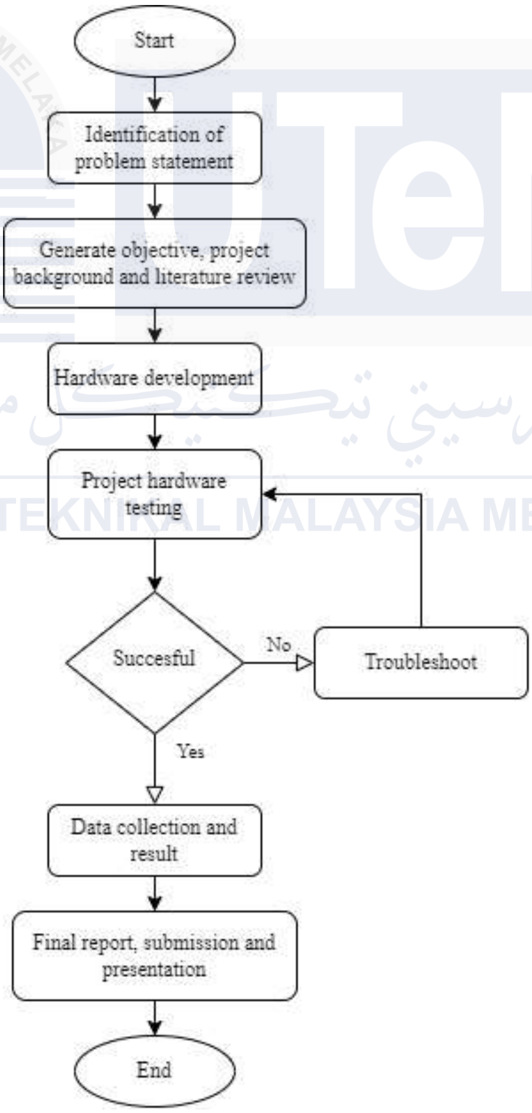


Figure 3.1 General Flowchart

3.3.1.1 Project Flowchart

Figure 3.2 demonstrates the operational flow of a solar-powered CCTV system designed to ensure uninterrupted functionality through the efficient use of solar energy and battery backup. The process begins with the system checking the current time to determine the appropriate power source. During the daytime, the solar panels generate electricity, which is routed to the charge controller. The charge controller manages the power distribution by directly supplying the CCTV system while simultaneously charging the battery. At night, when solar power is unavailable, the system seamlessly switches to battery power to maintain operation.

The charge controller plays a crucial role in regulating the power flow. It prevents overcharging of the battery during the day and protects it from deep discharges at night. The regulated voltage from the charge controller is passed to a buck converter, which steps down the voltage to a level compatible with the CCTV system. This ensures that the CCTV receives a stable and consistent power supply for reliable performance. The cycle repeats continuously, allowing the system to operate 24/7 under ideal conditions by leveraging solar energy during the day and battery power at night.

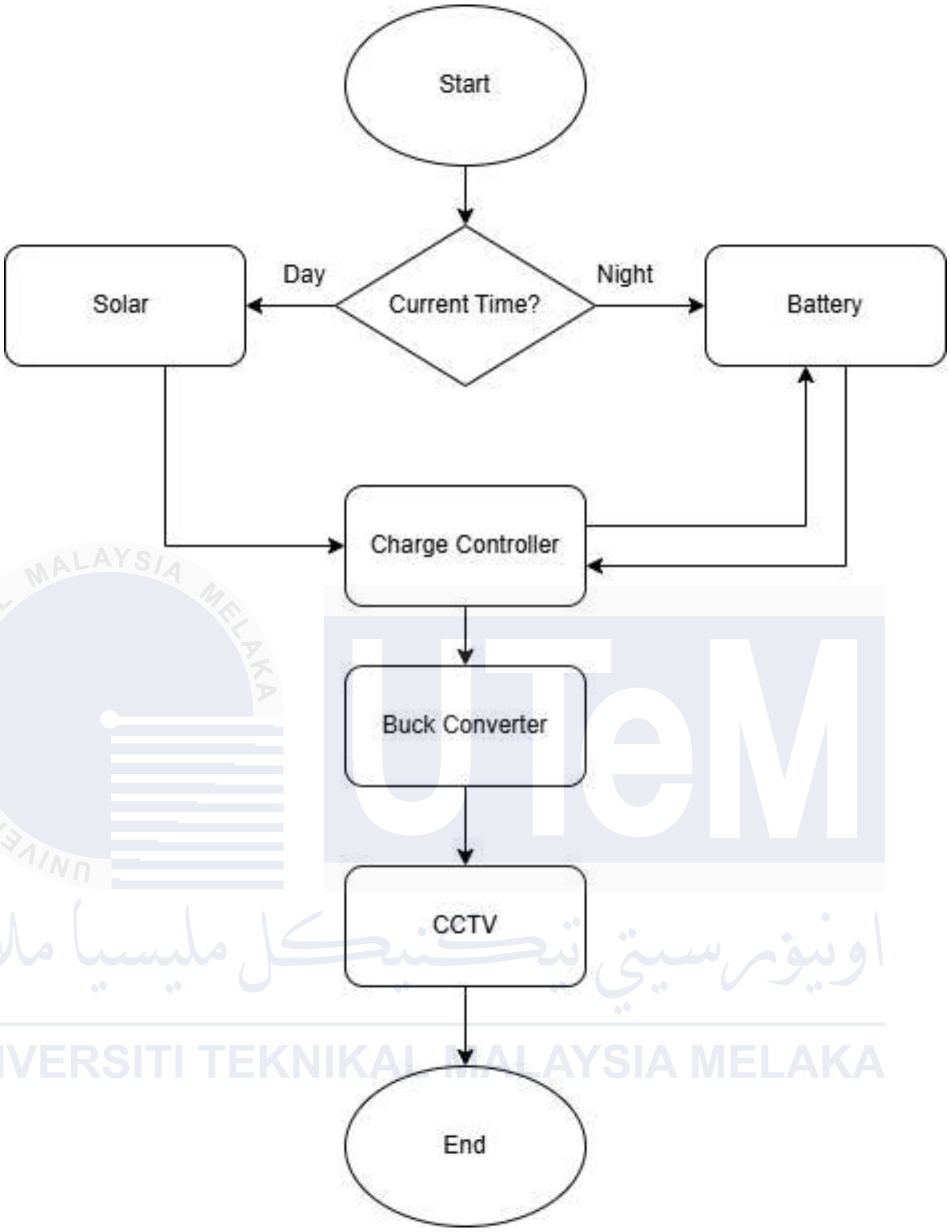


Figure 3.2 Project Flowchart

3.3.1.2 Block Diagram

Figure 3.3 This block diagram illustrates the operational flow of a solar-powered system designed to power a CCTV device using renewable energy. The system consists of several key components: the solar panel, solar charge controller, battery, buck converter, and the CCTV device. The solar panel is the primary energy source, converting sunlight into electrical energy during daylight hours. This energy is transmitted in direct current (DC) form to the solar charge controller. The solar charge controller regulates the flow of energy from the solar panel to the battery and the CCTV. Its main function is to protect the battery from overcharging and ensure efficient energy transfer, while also preventing the battery from discharging excessively.

The battery acts as an energy storage device, storing the excess energy generated by the solar panel. This stored energy is essential for powering the CCTV during the night or when sunlight is not available. The solar charge controller manages how the battery charges during the day and discharges at night. To ensure that the voltage delivered to the CCTV is consistent, the system includes a buck converter. The buck converter steps down the voltage from the solar panel or battery to a level suitable for the CCTV, providing stable power even as the battery's voltage fluctuates. Finally, the CCTV represents the load in this system, relying on the solar panel for energy during the day and the battery at night.

In summary, the solar panel powers the CCTV and charges the battery during the day. The battery provides backup power at night, and the buck converter ensures a stable voltage supply to the CCTV. The solar charge controller regulates the energy flow, maintaining the system's efficiency and protecting the components from damage. This system allows for continuous operation of the CCTV using renewable solar energy.

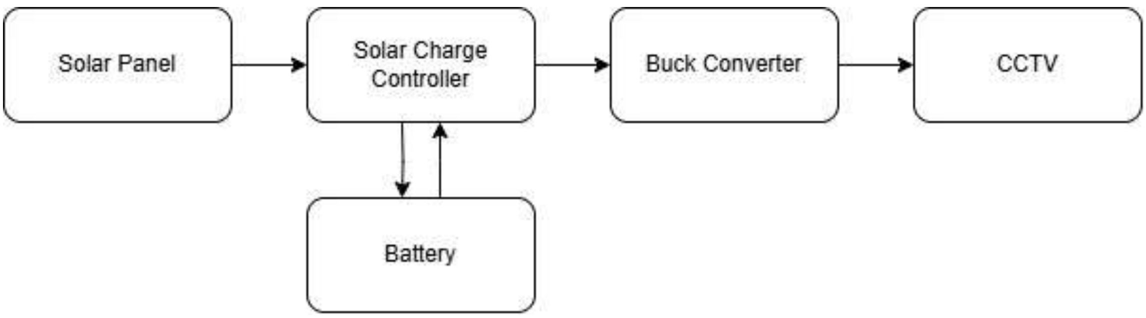


Figure 3.3 Block Diagram

3.3.2 Material and Equipment Setup

This section outlines the materials and equipment used in the development and implementation of the solar-powered CCTV system. The selection of components was guided by the system's requirements, such as energy efficiency, reliability, and compatibility with the project's objectives. Each item was carefully chosen to ensure optimal performance under real-world conditions, including variable solar irradiance and continuous operation of the CCTV. The setup process involved assembling and configuring these components to create an integrated system capable of harvesting solar energy, storing it efficiently, and supplying consistent power to the CCTV. This section provides a detailed description of the components used and their roles in achieving the system's functionality.

3.3.2.1 Circuit Layout and Component

Figure 3.4 illustrates the integration of the solar panel, battery, solar charge controller, voltage regulator, and CCTV system. Each component is strategically connected to ensure the system functions efficiently by harvesting, storing, and utilizing solar energy to power the CCTV.

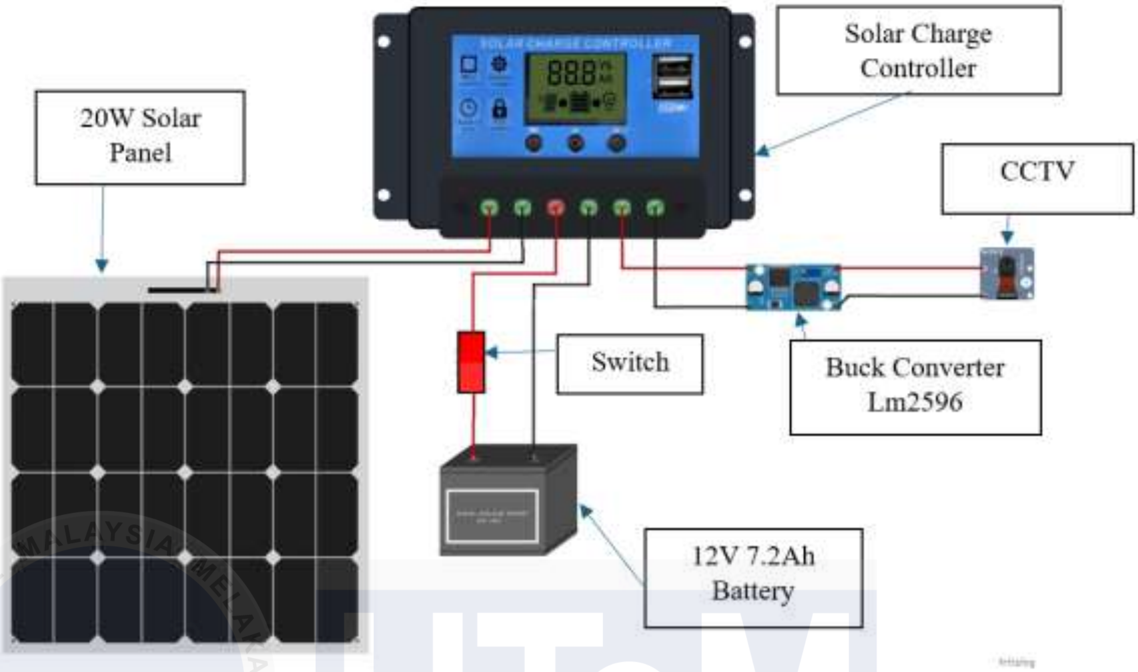


Figure 3.4 Circuit Design

a) 20W Solar Panel:

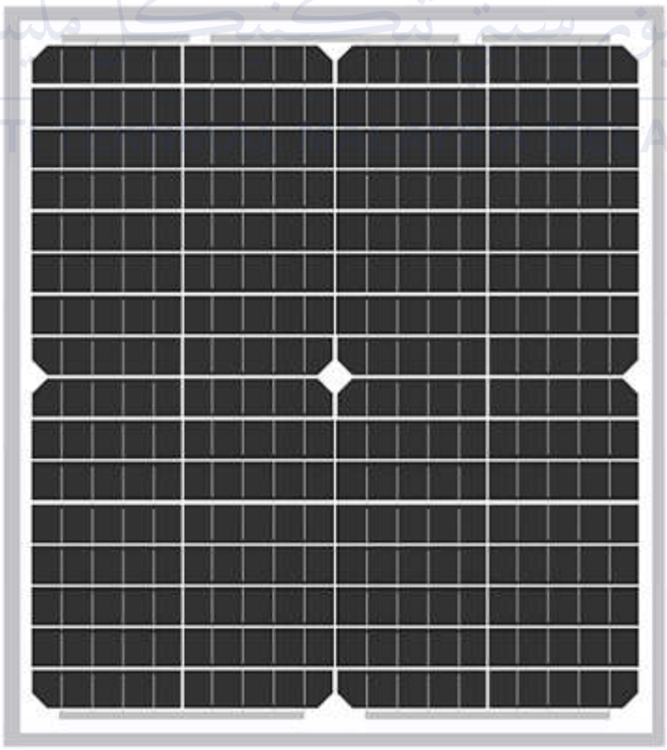


Figure 3.5 20W Solar Panel

The solar panel serves as the primary energy source, converting sunlight into electrical energy. It is connected to the solar charge controller, which regulates the energy flow and protects the battery from overcharging.

b) Solar Charge Controller:

Figure 3.6 Solar Charge Controller

This component acts as the central hub of the system, managing the energy flow between the solar panel, battery, and load. The charge controller prevents overcharging and over-discharging of the battery, ensuring its longevity. The connections include the solar panel input, battery terminals, and load output.

c) 12V 7.2Ah Battery:

Figure 3.7 12V 7.2Ah Battery

The battery, a sealed lead-acid type, stores excess energy generated by the solar panel. This stored energy powers the system during periods of low solar activity, such as at night or during cloudy weather. The connection between the battery and the charge controller ensures safe charging and discharging.

d) Buck Converter LM2596:

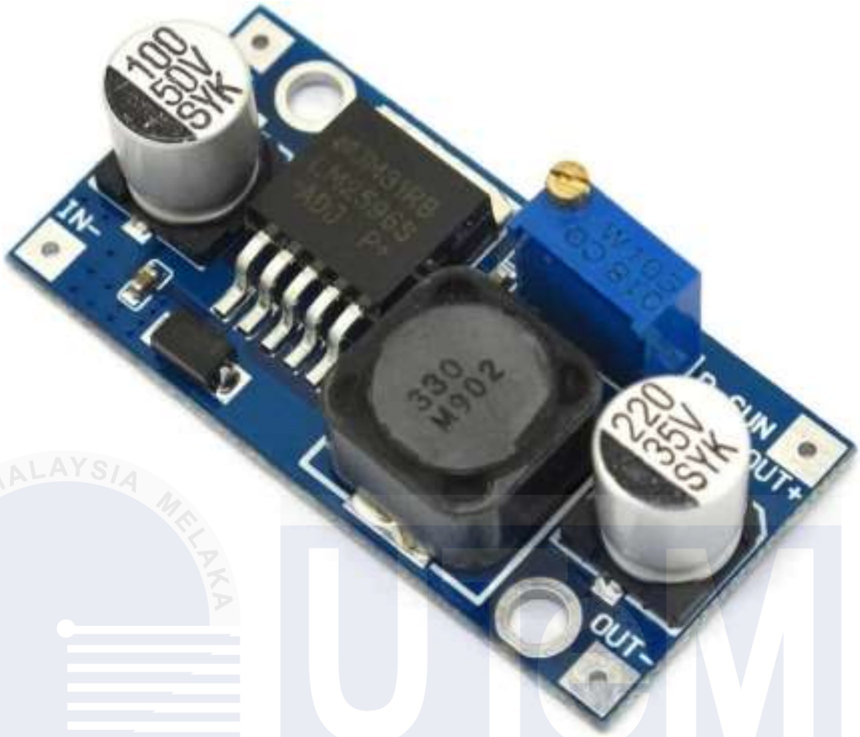


Figure 3.8 LM2596

A buck converter is included between the charge controller and the CCTV system to step down the voltage from the battery's 12V to 5V, which is suitable for powering the CCTV system. It provides a stable and regulated output, ensuring the safety of the CCTV electronics.

e) CCTV :

Figure 3.9 CCTV

The CCTV serves as the load, drawing power from the system to operate continuously. The connection to the voltage regulator ensures the system delivers the precise voltage and current needed for efficient operation.

f) Switch:

Figure 3.10 Switch

The switch is placed between the battery and the charge controller to provide manual control over the energy flow. It allows safe isolation of the battery for maintenance or emergencies without disrupting the rest of the system.

The circuit layout ensures seamless energy flow, from solar harvesting to battery storage and load operation. The integration of the charge controller and voltage regulator highlights the focus on system protection and efficiency. This setup guarantees that the CCTV system remains operational even under fluctuating environmental conditions.

3.3.2.2 Actual Prototype Design

Figure 3.11 showcases the physical implementation of the system, with detailed top, front, left, and right views. These perspectives highlight the arrangement of components and wiring, providing a clear representation of the prototype’s structure and functionality.

Figure 3.11 Prototype Design

3.3.2.3 Project Design

Figure 3.12 created using Tinkercad, provides a detailed visualization of the system's final layout. Featuring top, front, left, and right views, this design highlights the precise placement of components. It serves as a blueprint for the system, ensuring clarity and accuracy in its assembly.

Figure 3.12 Project Design

3.3.2.4 Project Development Qoutation

Table 3.1 provides a detailed breakdown of the costs for the materials required to construct the system. Each component has been carefully selected to balance functionality and affordability. The total cost for all materials amounts to RM 213.00, ensuring the project remains cost-effective while meeting all operational requirements. The table below outlines the price of each item used in the project.

Table 3.1 Project Development Quotation

Materials	Price
20W Solar Panel	RM 92.00
Solar Charge Controller	RM 21.30
Battery 12V 7.2Ah	RM 36.10
LM2596 Buck Converter	RM 8.50
CCTV	RM 28.10
Switch	RM 3.00
Junction Box	RM 24.00
Total	RM 213.00

3.3.3 Software

In this project, two software tools were employed to design and simulate the system:

1. Tinkercad for Project Design

Figure 3.13 Thinkercad

Tinkercad was used as the primary tool for project design and simulation. It allowed for the creation of virtual prototypes and ensured that the system's components worked together effectively before implementation. Tinkercad's user-friendly interface made it possible to simulate various electronic components, visualize their interactions, and identify potential design flaws early in the development process.

2. Fritzing for Circuit Design

Figure 3.14 Fritzing

Fritzing was used for the detailed circuit design. This software helped create clear and professional schematics of the system's wiring and connections. Fritzing's breadboard view and schematic view were particularly helpful in translating the conceptual design into a practical implementation, ensuring accurate connections during the hardware assembly phase.

3.3.4 Solar and Battery Configuration

Configuring the solar and battery systems so that the battery can operate as a backup power source in the case of nocturnal solar inactivity is essential to ensuring the project's goals are met. For the load to operate well, the arrangement of the solar panels and batteries is essential. Consequently, a series of calculations have been carried out to enhance the accuracy of the photovoltaic and battery arrangement.

- Total load for system

$$E = p \times t \tag{1}$$

1.52W x 24 hours = 36.48W

- Solar panel size

$$E \,/\, peak\ sun\ hours \,/\, system\ efficiency \tag{2}$$

=36.48 / 4 / 0.9

=10.13W

- Average daily

=36.48W

- Battery bank capacity

$$(Average\ daily\ \times\ Day\ of\ Autonomy\ \times\ Battery\ Bank\ Multiplier)/\ Depth\ of\ Discharge \tag{3}$$

= (36.48W × 1 × 1) / 0.6

=60.8Wh

- Battery bank

60.8Wh / 12

=5.06Ah

In this project, the solar and battery configuration was carefully selected to ensure reliable and uninterrupted performance of the system, particularly during periods of limited solar input, such as nighttime or cloudy conditions. Although the calculations recommended a 10.13W solar panel and a 12V, 5.06Ah battery, I chose to use a 20W solar panel and a 12V, 7.2Ah battery for several important reasons.

First, the larger solar panel and battery provide a safety margin to account for real-world variability, such as reduced sunlight during cloudy days or higher energy losses within the system. This ensures that the system remains reliable even under less-than-ideal conditions. Additionally, the larger battery capacity allows for extended autonomy, enabling the system to operate for longer periods without solar input, which is crucial for maintaining uninterrupted CCTV operation during prolonged periods of low sunlight.

Moreover, the upgraded components offer scalability, allowing for potential future expansions, such as integrating additional devices or increasing system operating hours. Using a larger battery also reduces its depth of discharge during operation, which improves its longevity and overall efficiency by minimizing wear and tear.

By selecting a 20W solar panel and a 12V, 7.2Ah battery, the system is better equipped to handle real-world challenges, providing enhanced reliability, flexibility, and durability beyond the minimum calculated requirements.

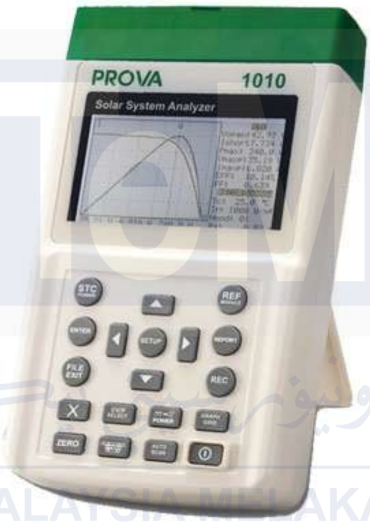
3.3.5 Peak Sun Hour in Malaysia

Gathering data for solar-powered CCTV systems in Malaysia involves focusing on Peak Sun Hours (PSH), representing the average daily hours when solar irradiance reaches 1,000 W/m^2. Typically, Malaysia experiences about 4 to 5 PSH due to its equatorial location. Measurements are primarily taken during these peak hours, typically from 11 AM to 2 PM, using a multimeter and clampmeter to measure current (I) and voltage (V) for power calculation (P = IV). Additionally, data collection extends beyond PSH to capture performance during other times of the day. This comprehensive approach aims to provide a detailed understanding of the system's performance under varying solar conditions.

3.3.6 Data Gatherings for Result and Analysis

The data gathering process for this project involves several key steps to ensure the accurate collection and analysis of information related to the design and implementation of a solar-powered CCTV system. This section outlines the methods and tools used to gather data effectively. Table 3.2 shows the tools used.

Table 3.2 Tools

Name	Tools
PV System Analyzer	
Thermal Imager	

Multimeter	
Clampmeter	

3.3.6.1 Case A: Performance of Solar Panel

The primary objective in this case was to evaluate the performance of the solar panel under different environmental conditions, including variations in temperature and sunlight intensity. The PV system analyzer was utilized to record I-V (current-voltage) and P-V (power-voltage) curves, enabling a comprehensive understanding of the solar panel's operational efficiency. Simultaneously, the thermal imager was employed to detect surface temperature inconsistencies, identifying potential hotspots that could affect performance or longevity. The data collected provided insights into both the electrical and thermal behaviour of the solar panel. Figure 3.15 shows how the PV system analyzer is positioned to record the electrical characteristics, while the thermal imager is directed at the solar panel for thermal readings.

Figure 3.15 Solar panel testing setup

Tools used:

- PV System Analyzer: To capture electrical performance metrics such as voltage, current, and power.
- Thermal Imager: To identify and visualize temperature variations on the solar panel surface.

3.3.6.2 Case B : System Performance without Solar Panel

This case focused on monitoring the battery's charging and discharging processes, as well as the integration of the charge controller and CCTV system. A multimeter was used to measure the voltage across the battery terminals, providing insights into the battery's state of charge. Simultaneously, a clamp meter measured the current flow during charging and discharging cycles. These measurements helped evaluate the efficiency of the charge controller in managing the power supply and ensuring the CCTV system received stable energy. Figure 3.16 illustrates the connections between the battery, charge controller, and CCTV system. The setup highlights the precise points where measurements were taken.

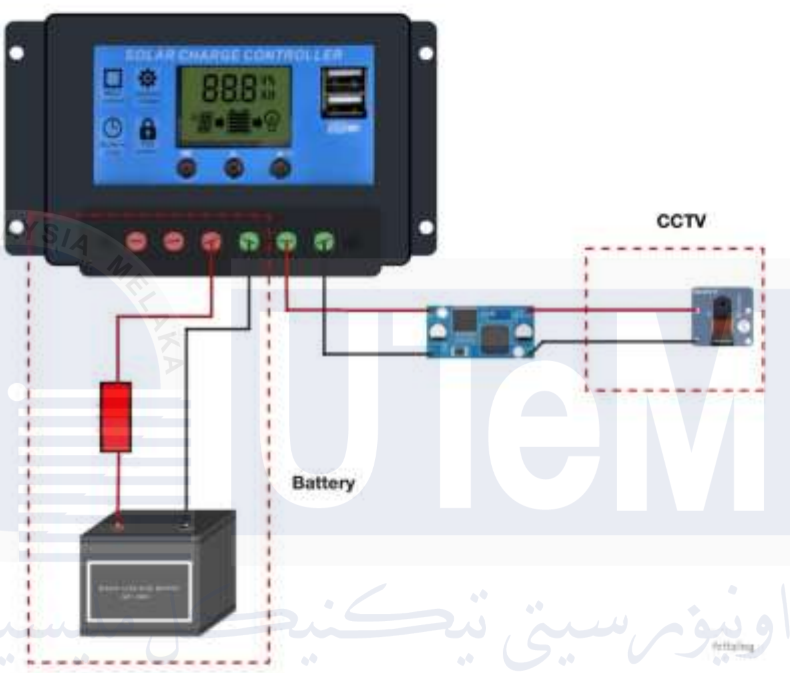


Figure 3.16 Data collection setup for Case B.

Tools used:

- Multimeter: To measure the voltage levels of the battery.
- Clamp Meter: To measure current flow during charging and discharging.

3.3.6.3 Case C: System Performance with Solar Panel

In this case, the fully integrated solar power system, comprising the solar panel, charge controller, battery, and CCTV, was evaluated under real-world operating conditions. A multimeter was employed to measure the voltage at various critical points in the system, while a clamp meter measured the current flow. The primary goal was to ensure efficient power delivery and stable operation of the CCTV system, while also identifying any inefficiencies or power losses in the integrated setup. Figure 3.17 illustrate the overall configuration, showcasing how the components interact and where the data collection tools were utilized. This comprehensive evaluation ensured all aspects of the system's functionality were analysed.

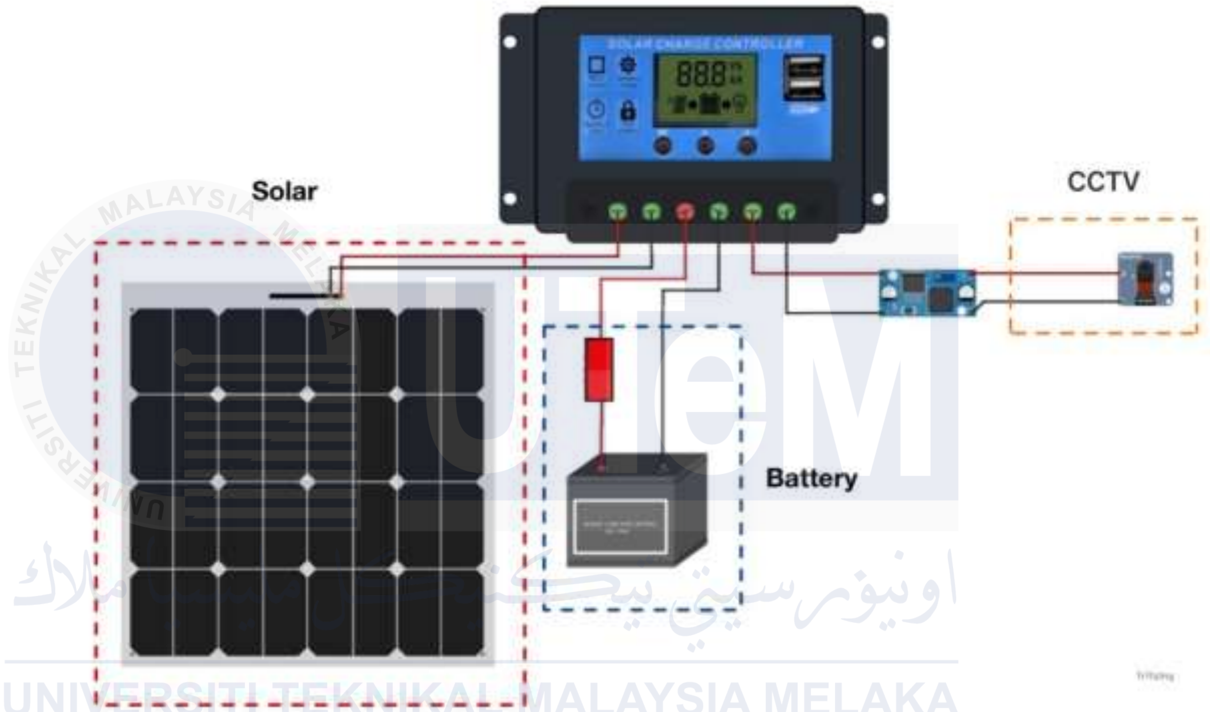


Figure 3.17 Full system setup for Case C

Tools used:

- Multimeter: For measuring the voltage levels at various points in the system.
- Clamp Meter: For measuring current flow across the integrated system.

3.3.7 CCTV System Energy Consumption

The energy consumption of a CCTV system can vary depending on several factors, but here's a breakdown of the typical scenarios. The energy consumption data for the CCTV system in this analysis reflects its operation in standby mode. According to Table 3.3, the typical power consumption of the CCTV system in standby mode is calculated as (0.304 A)(5 V)=1.52 W. Throughout the monitoring period, all the recorded data corresponds to this mode, ensuring that the energy measurements accurately represent the system's baseline power consumption when not actively recording or moving. This consistency in operating conditions provides a reliable basis for evaluating the system's energy efficiency and overall performance.

Table 3.3 Energy Consumption

Scenario	Typical Power Consumption
Starting and Moving (on)	$(0.53A)(5V) = 2.65W$ [4]
Standby Mode (on)	$(0.304A)(5V) = 1.52W$[5]

3.4 Gantt Chart

Table 3.4 Gantt Chart

NO	TASK	PSM1														PSM2													
	WEEK	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Briefing for PSM 1 by JK,PSM,FTKEE																												
2	Project title conformation and registration																												
3	Briefing with supervisor																												
4	Study the project background																												
5	Drafting chapter1 : Introduction																												
6	Task progress evaluation 1																												
7	Drafting chapter 2 : Literature Review																												
8	Table summary Literature review																												
9	Drafting Chapter 3: Methodology																												
10	Work on the software/hardware																												
11	First draft submission to supervisor																												
12	Task progress evaluation 2																												
13	Submission Report to the panel																												
14	Presentation of BDP1																												
15	Drafting Chapter 4: Analyse Data and result																												
16	Data Analyse and result																												
17	Record the result																												
18	Drafting Chapter 5: Conclusion and recommendation																												
19	Compiling Chapter 4 and 5																												
20	Submit latest report to supervisor																												
21	Finalize the report																												
22	Presentation of BDP2																												

3.5 Summary

This chapter outlined a well-defined, step-by-step methodology for developing a portable solar PV generator to power a Wi-Fi-enabled CCTV system, prioritizing both functionality and environmental impact. We began by analyzing existing CCTV systems, particularly their grid dependence, to identify challenges in remote locations. Clear project objectives were then established, outlining the desired functionalities of the solar-powered CCTV system. A comprehensive literature review provided a strong foundation in existing solutions and best practices. The technical phase involved designing and constructing both the solar generator and CCTV hardware, followed by rigorous testing to ensure proper function. Data collection assessed system efficiency, output performance, and solar energy utilization. Finally, a detailed report documenting the entire process, including analysis, design, construction, testing, and data collection, paves the way for project approval and dissemination of this new sustainable security solution.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents a comprehensive analysis of the results obtained from testing the solar-powered CCTV surveillance system. The focus lies on assessing the system's efficiency and performance across three distinct cases: the behaviour of the solar panel under various sky conditions, the interactions of the battery and associated components, and the overall performance of the integrated system. By examining key parameters such as voltage, current, power output, and thermal characteristics, this chapter aims to evaluate the viability of the system in maintaining reliable CCTV operation under varying environmental conditions.

4.2 Data Gathering

In this project, data collection is divided into three main cases to assess the performance and efficiency of the solar-powered CCTV surveillance system. Each case focuses on specific components and their interactions within the system.

4.2.1 Case A: Performance of Solar Panel

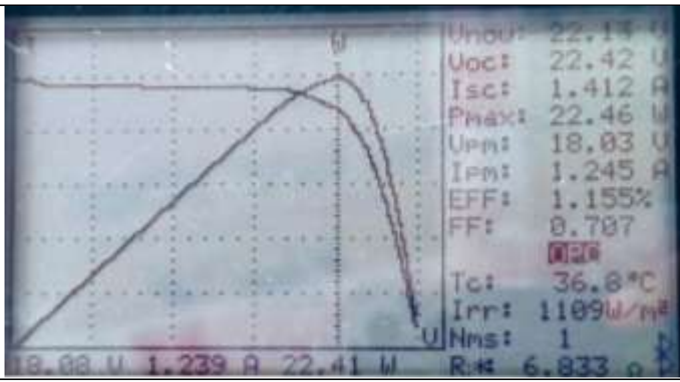
In Case A, the performance of the photovoltaic (PV) system was analyzed using a PV system analyzer and a thermal imager. The PV system analyzer was utilized to measure and record key electrical parameters, including voltage, current, and power output of the solar panel. This tool provided precise insights into the efficiency and performance of the solar panel under varying conditions.

Additionally, a thermal imager was employed to capture the thermal profile of the solar panel during operation. This helped identify potential hotspots or uneven heating across the panel's surface, which could affect its overall efficiency and reliability. By combining the data from the PV system analyzer and the thermal imager, a comprehensive evaluation of the PV system's performance was conducted, ensuring an in-depth understanding of its operational behaviour.

4.2.1.1 Result of PV System Analyzer

This case focused on measuring the I-V and P-V curves of the solar panel under different sky condition including sunny, slightly cloudy, and cloudy. Table 4.1 and Table 4.2 show the result of a PV system analyzer, the relationship between current, voltage, and power was captured, giving insight into the panel's performance in variable weather.

Table 4.1 Solar Panel Performance

Sky Condition	Graph
Sunny	

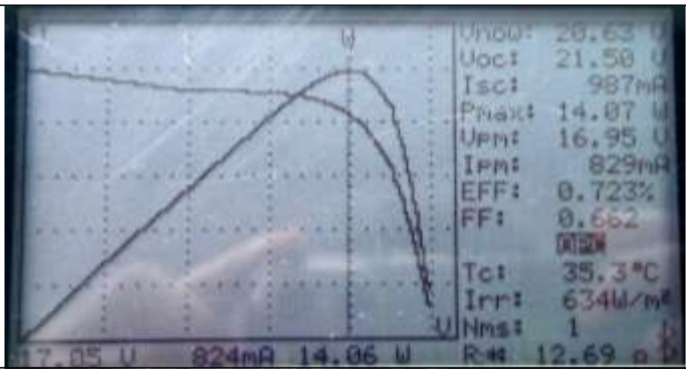
Slightly cloudy	
Cloudy	

Table 4.2 Solar Panel Data

Condition	Voc (V)	Isc (A)	Pmax (W)	Irradiance (W/m²)
Sunny	22.48	1.412	22.46	1109
Slightly Cloudy	21.5	497m	14.07	634
Cloudy	20.48	365m	5.17	254

4.2.1.1.1 Sunny

Figure 4.1 illustrates the I-V (current vs. voltage) and P-V (power vs. voltage) characteristics of a solar panel operating under sunny conditions, providing insights into its performance and efficiency.

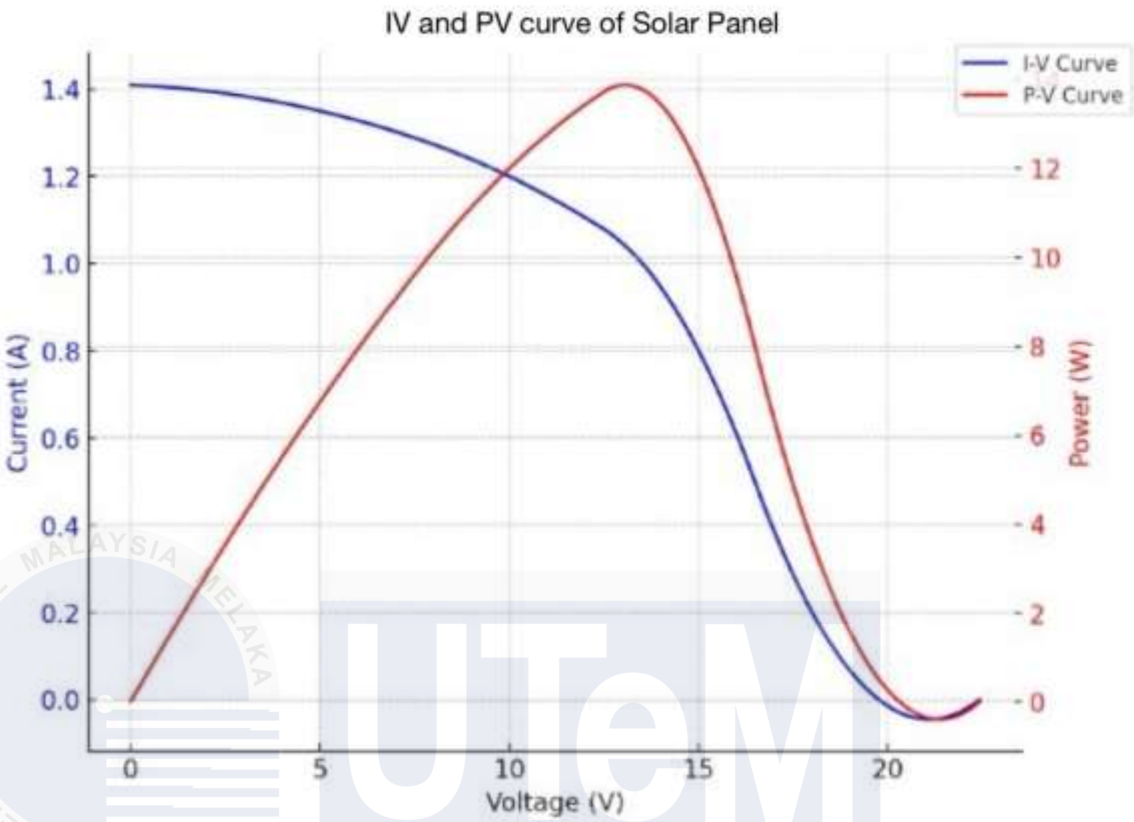


Figure 4.1 Sunny

The panel's open circuit voltage (Voc) is measured at 22.42 V, while the short circuit current (Isc) is 1.412 A. These values represent the maximum voltage and current the panel can generate under no-load and short-circuit conditions, respectively. At its maximum power point (MPP), the panel produces a peak power output (Pmax) of 22.46 W, achieved at a voltage of 18.03 V (VPM) and a current of 1.245 A (Ipm). These parameters indicate the panel's optimal operating point under the given conditions.

The fill factor (FF), calculated as 0.707, reflects the "squareness" of the I-V curve and indicates the panel's ability to perform close to its theoretical maximum output. A higher fill factor is desirable, as it signifies efficient energy conversion.

The blue curve represents the I-V characteristics of the panel, showing the relationship between current and voltage. It begins at the short circuit current (Isc), where the voltage is zero, and gradually decreases to zero current at the open circuit voltage (Voc). This typical shape indicates normal operation and the expected behavior of a solar panel. The red curve represents the P-V characteristics, showing the power output as a function of voltage. The power increases with voltage until it reaches the maximum power point (MPP) and then declines as the voltage continues to rise, reflecting the optimal operating conditions for energy generation.

The sunny conditions provide an irradiance of 1109 W/m², slightly higher than the standard test condition of 1000 W/m². This high irradiance level enhances the panel's performance, allowing it to generate higher power. However, the cell temperature is recorded at 36.8°C, which is typical for sunny weather but can negatively impact efficiency. Solar panels typically experience a reduction in efficiency as temperature increases, due to increased resistive losses and a decrease in the voltage output.

Overall, the solar panel demonstrates stable performance with a well-defined maximum power point and a moderately high fill factor, indicating efficient energy conversion under sunny conditions. However, the relatively low efficiency suggests that there may be opportunities for improvement, such as optimizing the panel's design, reducing thermal losses, or operating the panel under conditions that minimize temperature-related efficiency drops. Regular maintenance, including cleaning to prevent dirt and debris accumulation, and monitoring for potential shading or electrical faults, can also help improve the panel's overall performance.

4.2.1.1.2 Slightly Cloudy

Figure 4.2 illustrates the I-V (current-voltage) and P-V (power-voltage) characteristics of a solar panel, essential for evaluating its performance. The I-V curve (red line) shows the relationship between the current produced by the panel and the voltage across its terminals, with current on the left vertical axis and voltage on the horizontal axis. The P-V curve (blue line) depicts the panel's power output as a function of voltage, with power on the right vertical axis. Both curves share the same voltage axis for consistency.

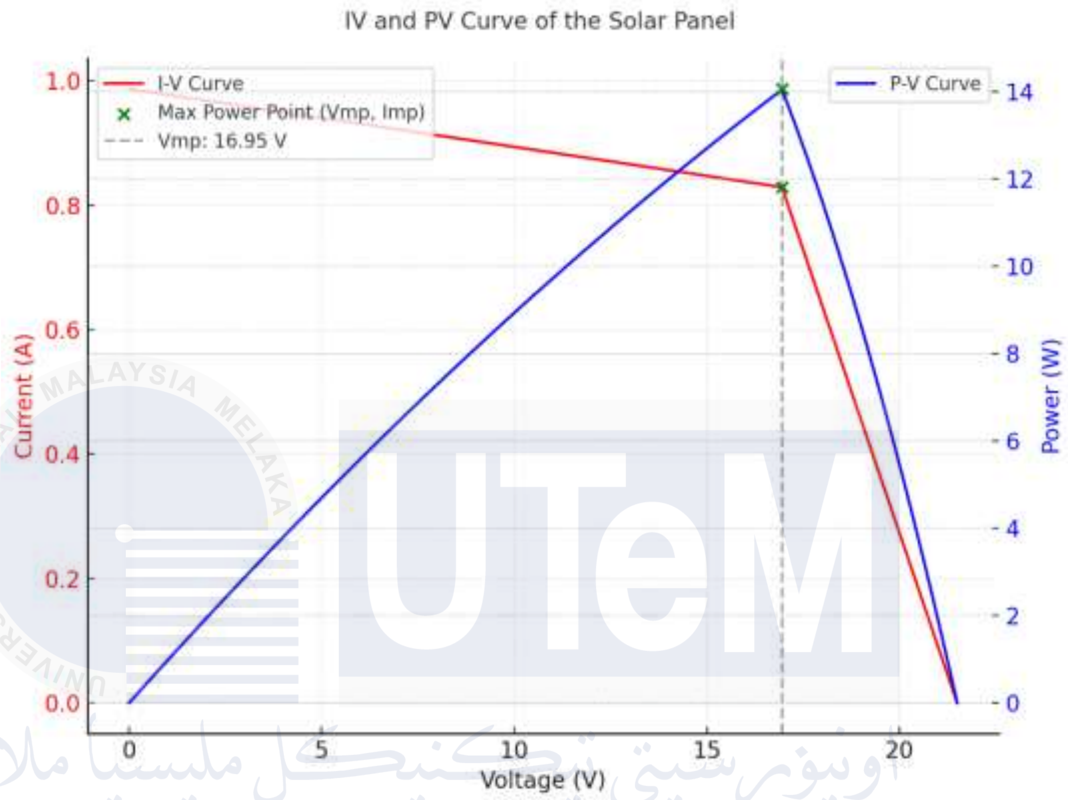


Figure 4.2 Slightly Cloudy

The graph highlights key points such as the maximum power point (MPP), where the product of current and voltage is maximized. At this point, the voltage (Vmp) is 16.95 V, and the current (Imp) is 829 mA, resulting in a maximum power output (Pmax) of 14.07 W. The open-circuit voltage (Voc) is 21.50 V, representing the maximum voltage when no current flows, and the short-circuit current (Isc) is 987 mA, indicating the maximum current when the voltage is zero. The fill factor (FF), calculated as 66.2%, reflects the panel's quality, with higher values indicating lower resistive losses. The slightly cloudy condition showing the proportion of incident solar energy converted into electrical energy under an irradiance of 634 W/m^2 and a panel temperature of 35.3°C.

The graph's shape reveals critical insights. The steep slope near Voc and gentle slope near Isc on the I-V curve indicate how the panel responds to varying loads, while the P-V curve peaks at the MPP, where the panel operates most efficiently. However, the relatively low fill factor suggests potential for improvement, possibly due to shading, dirt, or cell degradation. This analysis provides a comprehensive view of the panel's performance, guiding both system optimization and troubleshooting.

4.2.1.1.3 Cloudy

Figure 4.3 represents the performance of a photovoltaic (PV) system collected under cloudy sky conditions. It includes two key curves: the Current-Voltage (I-V) curve and the Power-Voltage (P-V) curve. The I-V curve shows how the current from the solar panel changes with the applied voltage.

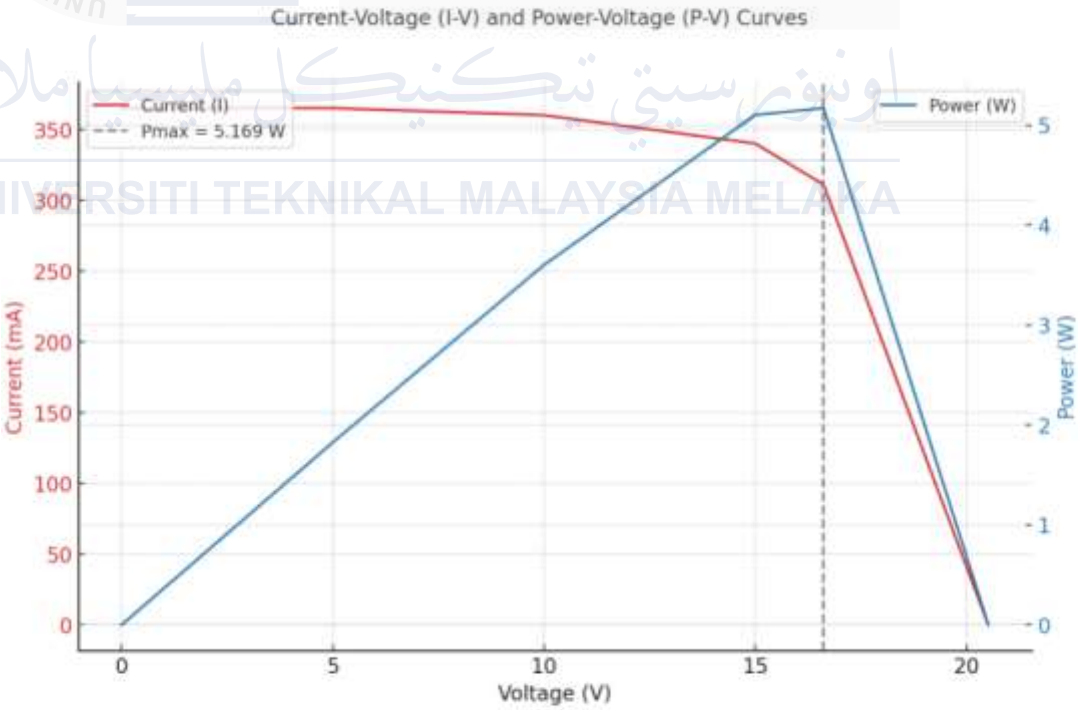


Figure 4.3 Cloudy

Initially, at low voltage, the current remains almost constant at around 365 mA, known as the short-circuit current (Isc). As the voltage increases, the current gradually decreases, and it reaches zero at the open-circuit voltage (Voc), which is approximately 20.48V. This is the highest voltage the panel can generate with no current flowing.

The P-V curve illustrates how the panel's power output varies with voltage. The power starts near zero at very low voltages and rises as the voltage increases, reaching a peak (the maximum power point, or Pmax) at around 16.62V, where the panel produces 5.17W. Beyond this point, the power decreases sharply as the voltage continues to increase.

Several important parameters are identified in the graph. The open-circuit voltage (Voc) is 20.48V, representing the maximum voltage with no load, while the short-circuit current (Isc) is 365mA, the highest current when the voltage is zero. The maximum power point (Pmax) is 5.17W, occurring at 16.62V and 311mA.

The cloudy sky significantly impacts the panel's performance, leading to low solar irradiance and reduced current and power output. The maximum power point indicates the voltage and current combination that optimizes energy production even when sunlight is limited.

4.2.1.2 Result of Thermal Imager

The purpose of this experiment is to analyse the thermal performance and temperature distribution of a solar panel under operational conditions. Solar panels convert sunlight into electrical energy, and their efficiency is directly influenced by their thermal characteristics. Uneven temperature distribution or the presence of hotspots can indicate underlying issues such as shading, dirt accumulation, or electrical faults, which may reduce the panel's efficiency and lifespan. By using thermal imaging technology, this experiment aims to identify any irregularities in heat distribution and assess the overall thermal behaviour of the panel. The insights gained from this study can help optimize the maintenance and operation of solar panels, ensuring their long-term performance and reliability.

Figure 4.4 highlights a temperature distribution with an average temperature of approximately 46°C. The temperature ranges from 46.7°C at the top to 47.8°C at the bottom, indicating a relatively uniform heat distribution across the panel surface.

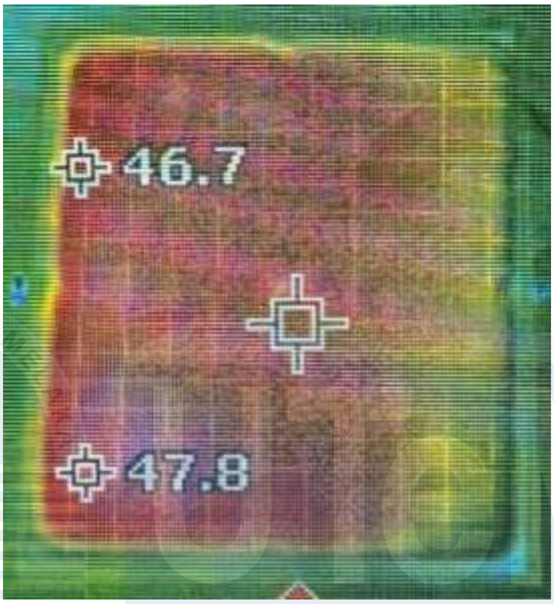


Figure 4.4 Thermal Imager

This slight gradient in temperature, with the bottom being marginally warmer, is generally acceptable and reflects proper panel functioning. However, the observed gradient warrants closer analysis to identify any underlying causes. A consistent temperature distribution is essential for optimal solar panel efficiency, as significant variations can indicate inefficiencies or potential issues that may reduce the panel's overall performance.

The slightly higher temperature at the bottom could be attributed to various environmental or operational factors. These include heat dissipation patterns influenced by airflow, the orientation or tilt of the panel, or even localized shading caused by debris or dirt accumulation. Additionally, variations in temperature can be a result of electrical resistance within specific areas of the panel. Such hotspots can occur due to internal issues, such as degraded cells, microcracks, or poor connections in the panel circuitry. While the current variation in temperature is minor, regular monitoring of the panel's thermal performance using thermal imaging is critical to identifying any developing issues early.

Hotspots are particularly concerning as they can lead to localized overheating, potentially causing irreversible damage to the solar cells or compromising the panel's lifespan. They can also lead to a significant drop in energy conversion efficiency, as overheated areas may generate less electricity compared to cooler regions. This highlights the importance of proactive maintenance, such as cleaning the panel surface to remove dirt, leaves, or other debris that could obstruct sunlight and contribute to uneven heating. Additionally, inspecting and repairing electrical connections or replacing degraded cells can prevent further thermal imbalances.

In summary, the thermal image reveals a solar panel that is currently operating efficiently, with only a slight temperature gradient. While this variation is within acceptable limits, it is essential to remain vigilant and address any developing hotspots or inefficiencies to ensure the long-term performance and reliability of the panel. Regular maintenance, cleaning, and thermal monitoring can mitigate potential risks, ensuring the solar panel continues to operate at optimal efficiency.

4.2.2 Case B: System Performance without Solar Panel

Table 4.3 show collected to monitor the battery's current, voltage, and power flow to the CCTV system. Measurements were taken between the battery, charge controller, buck converter, and CCTV to assess the energy distribution and efficiency in powering the load.

Table 4.3 Data for Case B

Hours	Battery (A)	Battery(V)	CCTV (A)	CCTV (V)
0	0.18	12.88	0.34	5
1	0.18	12.86	0.32	5
2	0.18	12.84	0.34	5
3	0.17	12.81	0.32	5
4	0.17	12.78	0.3	5
5	0.18	12.75	0.31	5
6	0.15	12.72	0.29	5
7	0.15	12.71	0.3	5
8	0.17	12.67	0.27	5
9	0.16	12.64	0.29	5
10	0.16	12.62	0.28	5
11	0.17	12.59	0.3	5
12	0.18	12.57	0.31	5
13	0.18	12.54	0.32	5
14	0.17	12.51	0.3	5
15	0.15	12.49	0.28	5

4.2.2.1 Battery Capacity

Figure 4.5 shows the battery voltage dropping over time while powering the CCTV. The linear regression equation $y = -0.0266x + 12.886y$ represents the voltage decline, where:

- y is the battery voltage (in volts),
- x is the time (in hours).

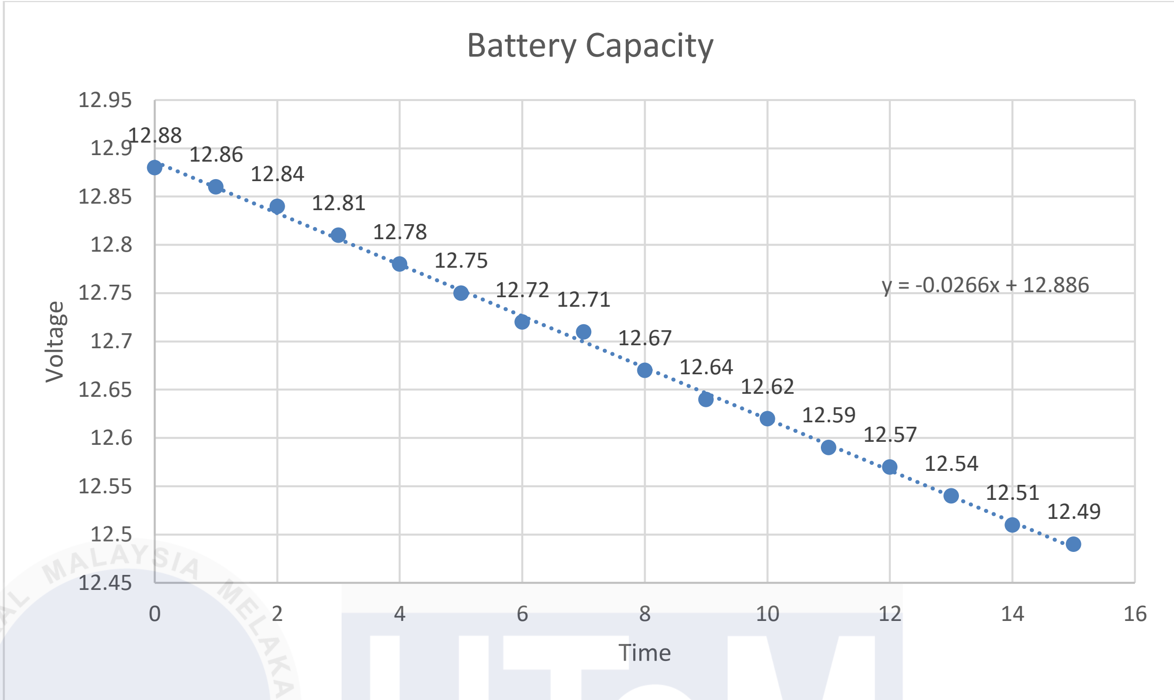


Figure 4.5 Battery Capacity

$$y = -0.0266x + 12.886 \quad [6]$$

$$11.63 = -0.0266x + 12.886$$

$$x = 47.218$$

Initially, the battery starts at 12.88V, and over time, its voltage steadily decreases. When the battery voltage reaches 11.63V, this signifies that the battery is at 0% charge and can no longer effectively power the system.

By solving the equation, we estimate that this cutoff point is reached after approximately 47.2 hours. This indicates that, under ideal conditions, a fully charged battery will power the CCTV for about 47 hours before it completely discharges. The slope of the line, approximately -0.0266V per hour, represents the rate at which the battery voltage drops. Factors such as the efficiency of the battery, environmental conditions, and power consumption consistency may influence this time, but based on the data, the system can run for close to 47 hours before the battery depletes to 0%.

4.2.2.2 Battery Power Consumption

Figure 4.6 shows the battery's performance over the 15-hour period shows a slow but steady decline in voltage and current, indicating the natural discharge process of the battery. Initially, the battery starts with a voltage of 12.88V and current of 0.18A, which translates to a power output of 2.32W. As the hours progress, the voltage and current slightly drop, reaching 12.49V and 0.15A at hour 15, with a corresponding power output of 1.87W.

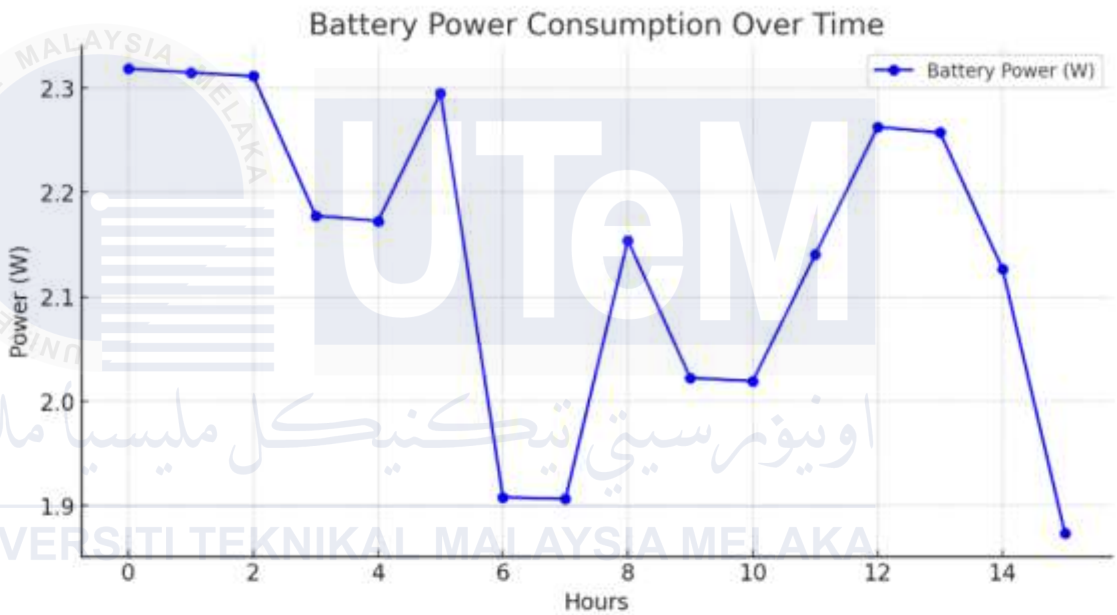


Figure 4.6 Battery Power Consumption

This gradual decline in power output is typical of battery behaviour during discharge. Several factors may contribute to this decline:

1. Battery Discharge Rate

As the battery supplies energy to the system (CCTV and other components), its stored energy is depleted, causing a decrease in voltage and current.

2. Load Variability

Even though the battery's output fluctuates only slightly, its ability to maintain consistent power depends on how stable the load (the CCTV and other connected devices) draws power. Small variances in the load, even as minor as 0.03V or 0.02A, can affect battery discharge performance.

3. Internal Resistance

As the battery discharges, internal resistance can increase, leading to a decrease in the efficiency of power delivery. This is particularly noticeable as the battery's voltage approaches lower limits towards the end of the measurement period.

The battery still delivers acceptable power for the system throughout the 15-hour period, indicating that the setup is designed to provide sufficient energy over a standard monitoring period. However, as the battery discharges, its output becomes less efficient, which may affect the long-term sustainability of the power supply if the system runs continuously without sufficient recharge periods.

4.2.2.3 CCTV Power Consumption

Figure 4.7 shows the CCTV operates with relatively stable power consumption throughout the 15-hour period, drawing a consistent voltage of 5V and varying slightly in current from 0.34A to 0.28A. The CCTV's power consumption remains between 1.35W and 1.70W, indicating that the energy demand is fairly predictable and stable.

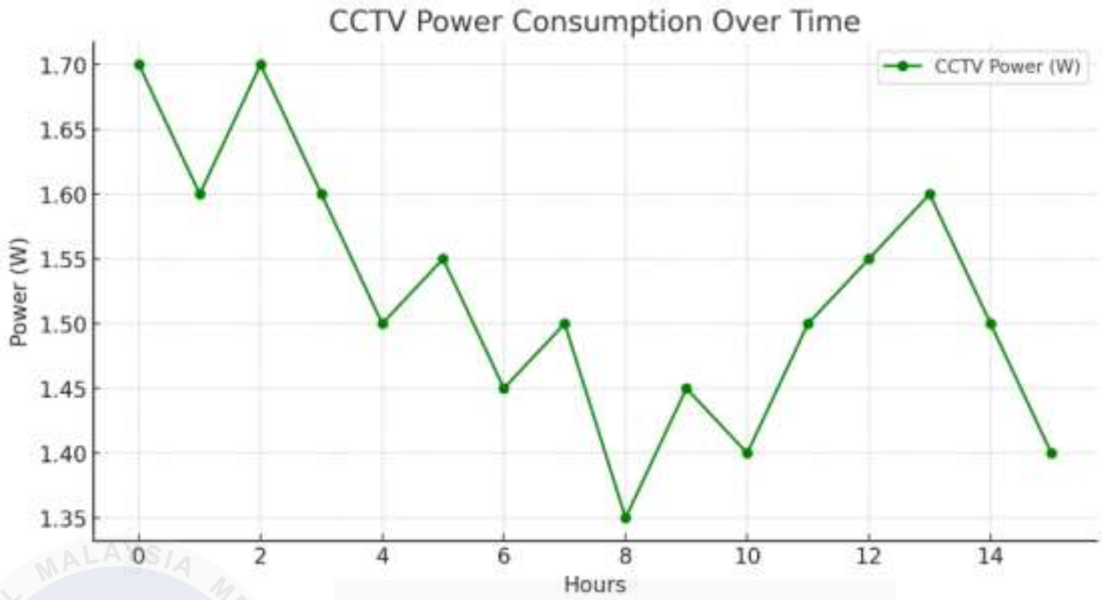


Figure 4.7 CCTV Power Consumption

4.2.2.4 Case B System Efficiency Analysis

Figure 4.8 represents the power output of the battery compared to the power consumed by the CCTV system over a 15-hour period. The power supplied by the battery (shown in blue) starts off at approximately 2.4 watts, while the CCTV (shown in orange) consumes around 1.7 watts in the initial hour. This power difference between the battery and CCTV highlights the surplus energy available from the battery.

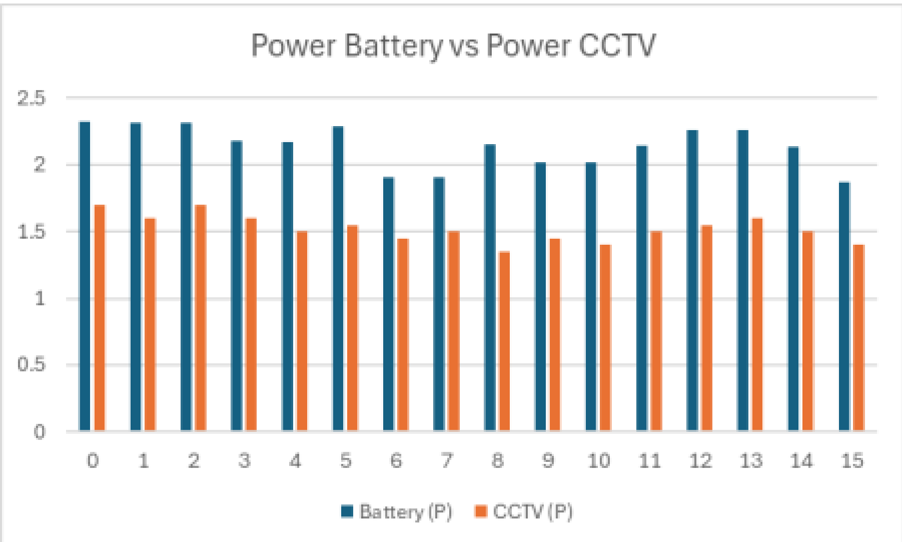


Figure 4.8 Power Battery vs Power CCTV

Throughout the 15 hours, the battery continues to deliver more power than the CCTV consumes, with the gap between the two gradually narrowing. The battery power decreases steadily from 2.4 watts to approximately 1.6 watts by hour 15, while the CCTV power consumption remains relatively stable, fluctuating between 1.4 and 1.7 watts over the entire time period.

This gradual decrease in battery power can be attributed to the discharging process, as energy is used to maintain the operation of the CCTV system. However, the battery is able to maintain sufficient power for the CCTV even after 15 hours, which indicates a well-balanced power system for this duration of time.

The stable energy consumption by the CCTV, alongside the slowly declining battery output, indicates that while the battery is capable of sustaining the load for a prolonged period, recharging will eventually be necessary to continue normal operation. This highlights the importance of energy management, ensuring that the battery is charged effectively during periods of sunlight to support continuous CCTV operation.

Table 4.4 provides detailed data on the performance of the battery and CCTV system over a 15-hour period. It includes measurements of battery voltage (V), battery current (A), and battery power (W) to assess the energy storage and discharge behavior of the system. Additionally, CCTV voltage (V), CCTV current (A), and CCTV power (W) are recorded to evaluate the energy consumption of the CCTV system. This data helps analyze the system's efficiency and sustainability under continuous operation

Table 4.4 Power Data for Battery and CCTV

Hours	Battery Voltage (V)	Battery Current (A)	Battery Power (W)	CCTV Voltage (V)	CCTV Current (A)	CCTV Power (W)

0	12.88	0.18	2.3184	5	0.34	1.7
1	12.86	0.18	2.3148	5	0.32	1.6
2	12.84	0.18	2.3112	5	0.34	1.7
3	12.81	0.17	2.1777	5	0.32	1.6
4	12.78	0.17	2.1726	5	0.3	1.5
5	12.75	0.18	2.295	5	0.31	1.55
6	12.72	0.15	1.908	5	0.29	1.45
7	12.71	0.15	1.9065	5	0.3	1.5
8	12.67	0.17	2.1539	5	0.27	1.35
9	12.64	0.16	2.0224	5	0.29	1.45
10	12.62	0.16	2.0192	5	0.28	1.4
11	12.59	0.17	2.1403	5	0.3	1.5
12	12.57	0.18	2.2626	5	0.31	1.55
13	12.54	0.18	2.2572	5	0.32	1.6
14	12.51	0.17	2.1267	5	0.3	1.5
15	12.49	0.15	1.8735	5	0.28	1.4

Sum of battery power:

$$Ebattery = \sum Pbattery \times 1h = 2.3184 + 2.3148 + 2.3112 + \cdots + 1.8735 = 34.57W \quad [7]$$

Sum of CCTV power:

$$ECCTV = \sum PCCTV \times 1h = 1.7 + 1.6 + 1.7 + \cdots + 1.4 = 24.57Wh \quad [8]$$

Efficiency Calculation:

$$Efficiency = (24.57/34.57) \times 100 = 71.07\% \quad [9]$$

The overall system efficiency, calculated at 71.07%, indicates that most of the energy supplied by the battery is being effectively utilized to power the CCTV. However, approximately 28.93% of the energy is lost due to inefficiencies within the system, primarily through components such as the charge controller, buck converter, wiring, and the battery itself. The charge controller is responsible for regulating energy flow between the solar panel and battery, and inefficient controllers can result in significant energy loss. Similarly, buck converters, which step down the voltage from the battery to the CCTV's required 5V, can also lose energy during conversion, especially if they operate below 90% efficiency. The battery's internal resistance, which increases over time, leads to additional voltage drops and heat generation, further reducing efficiency. Energy losses can also occur in the system wiring, particularly if long or thin wires are used, as they introduce more resistance.

4.2.3 Case C: System Performance with Solar Panel

This case monitored the complete system, including the solar panel, charge controller, battery, and CCTV. Voltage and current were measured during battery charging and discharging cycles, allowing for real-time analysis of energy usage and storage.

Table 4.5 provides a detailed overview of the performance of a solar-powered system over a 5-hour period, focusing on the interaction between the solar panel, battery, and CCTV, and highlighting the charging state of the battery.

The data is organized into time intervals of 0.5 hours, showing key parameters such as solar and battery voltages, currents, and the state of the charging process.

Table 4.5 Data for Case C

Hours	Solar (V)	Solar (A)	Batt (V)	Batt (A)	CCTV (A)	Charging Status
0	12.89	-0.86	12.84	0.68	0.31	Charging
0.5	13.45	-1	13.35	0.75	0.29	Charging
1	13.51	-1.11	13.4	0.81	0.3	Charging
1.5	13.58	-0.83	13.48	0.71	0.27	Charging
2	13.52	-1.06	13.44	0.98	0.29	Charging
2.5	13.53	-0.71	13.48	0.44	0.28	Charging
3	13.84	-0.98	13.75	0.84	0.3	Charging
3.5	14.13	-1.06	14.03	0.76	0.31	Charging
4	13.61	-0.5	13.52	0.29	0.32	Charging
4.5	13.78	-0.67	13.64	0.58	0.3	Charging
5	13.89	-0.95	13.72	0.63	0.32	Charging

The solar voltage fluctuates between 12.89V and 14.13V, peaking at 3.5 hours when sunlight intensity is optimal. Similarly, the solar current remains negative throughout the observation, indicating that energy is flowing into the battery. The highest solar current, -1.11A, occurs at 1 hour, representing efficient energy transfer during strong sunlight conditions.

The battery voltage increases steadily from 12.84V to 13.72V, demonstrating effective charging. Battery current peaks at 0.98A at 2 hours and then gradually decreases as the battery approaches full capacity. This behaviour is consistent with standard charging processes, where current tapers off to prevent overcharging. The charging state column reflects this dynamic, with the battery transitioning from active charging to a reduced charging rate in the later hours, ensuring the system operates safely and efficiently.

The CCTV current remains stable, ranging between 0.27A and 0.32A, highlighting the system’s ability to provide a consistent power supply. This stability ensures uninterrupted operation of the CCTV, even as the solar input and battery charging rates vary.

Overall, this table demonstrates the system's ability to efficiently harvest and store solar energy while maintaining reliable operation of the CCTV. The gradual changes in battery charging current and voltage underline the system's intelligent energy management, balancing solar input and battery output to ensure consistent performance under varying conditions. This analysis underscores the effectiveness of the solar-powered system in maintaining energy flow and supporting critical operations.

4.2.3.1 Solar and Battery Over Time

Figure 4.9 illustrates the behaviour of solar and battery voltages over a 5-hour period. The solar voltage shows an initial increase as the solar panel captures energy from sunlight.

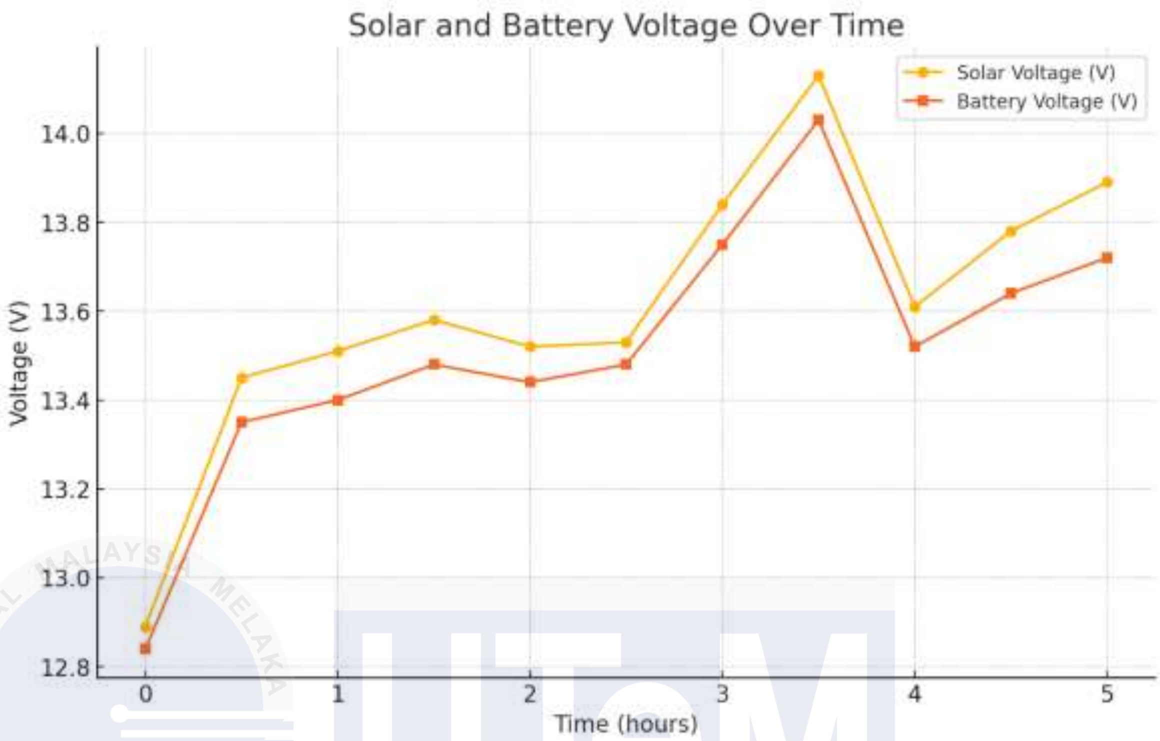


Figure 4.9 Solar and Battery Voltage vs Time

It is peaking at around 3.5 hours with a value of approximately 14.13V. This peak corresponds to optimal sunlight conditions during the test period. Afterward, the solar voltage slightly declines, likely due to variations in sunlight intensity, such as cloud cover or the angle of sunlight.

Similarly, the battery voltage demonstrates a steady increase throughout the charging process, starting at 12.84V and gradually reaching a peak of 14.03V. This consistent rise indicates that the solar panel effectively transfers energy to the battery, allowing it to charge efficiently. The slight leveling off of the battery voltage towards the end of the period reflects the battery approaching its maximum charge capacity, where charging efficiency typically decreases.

4.2.3.2 CCTV Current Over Time

Figure 4.10 shows CCTV current remains relatively stable throughout the observation period.

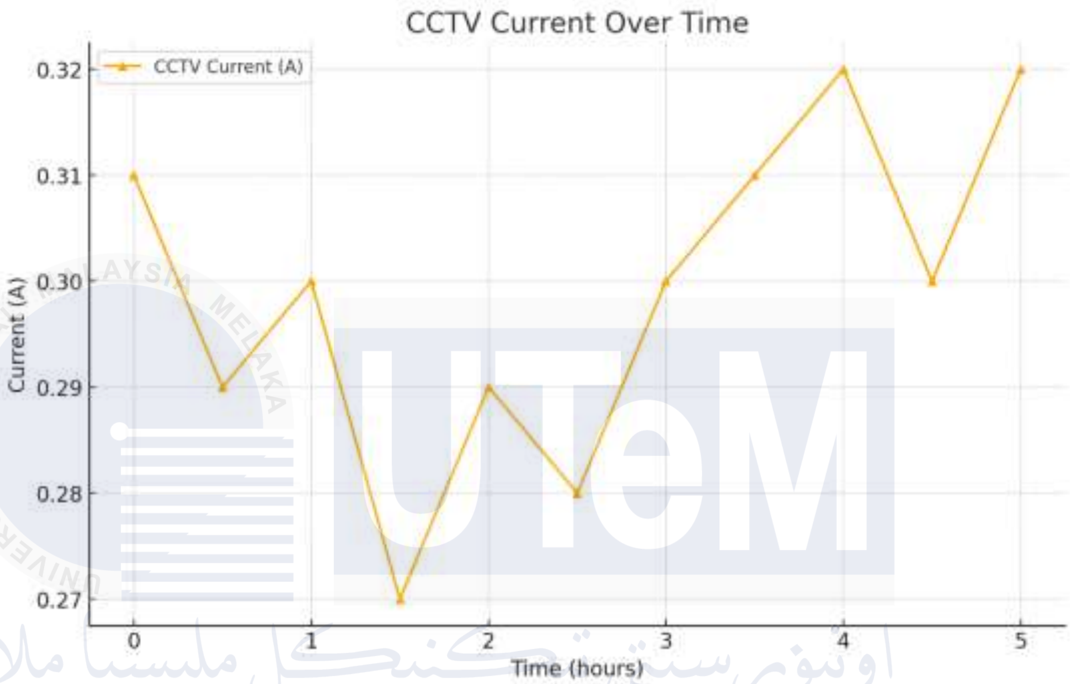


Figure 4.10 CCTV Current vs Time

It is fluctuating between 0.27A and 0.32A. This stability demonstrates the system’s ability to maintain a consistent power supply to the CCTV system, ensuring reliable operation. The slight variations in current draw are normal and can be attributed to minor fluctuations in the energy requirements of the CCTV system or variations in the battery's output. The consistent performance highlights the battery's role as a reliable buffer, ensuring uninterrupted CCTV operation even during changes in solar input.

4.2.3.3 Solar and Battery Charging Current Over Time

Figure 4.11 shows the solar current, which represents the energy flowing from the solar panel to the battery, is negative, indicating active charging.

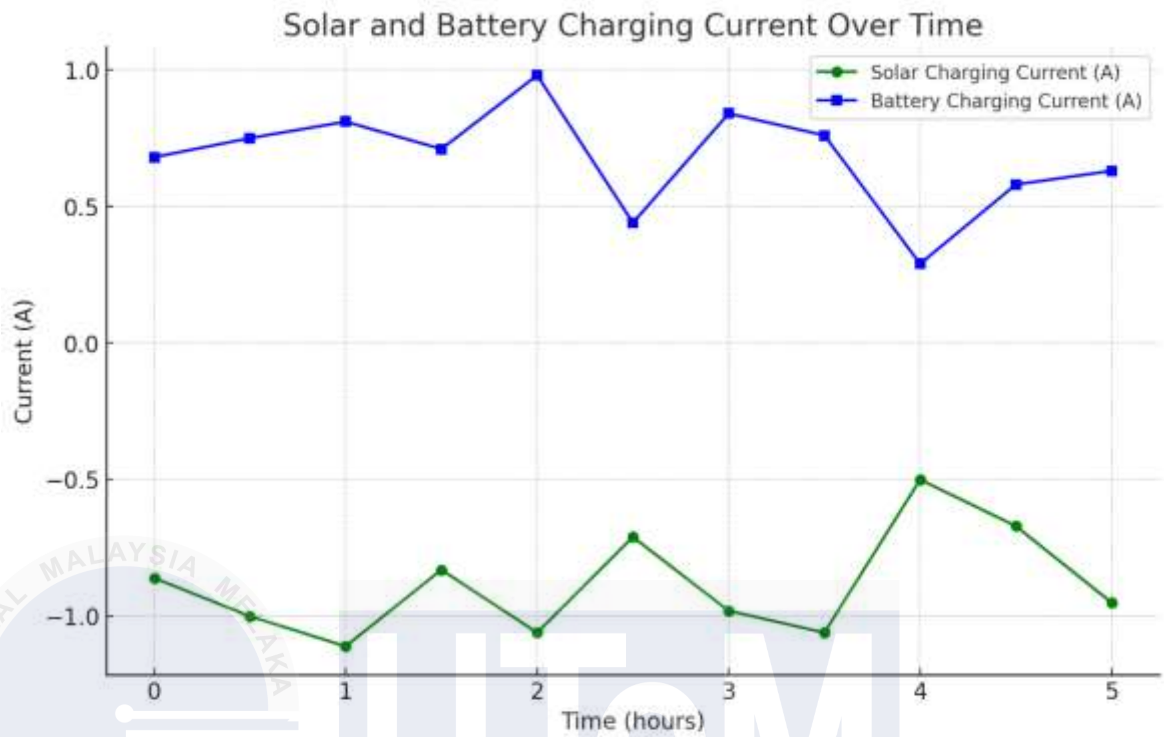


Figure 4.11 Solar and Battery Charging Current vs Time

This current varies over time, peaking around 1 hour with a value of approximately -1.11A before gradually decreasing. These variations are influenced by changes in sunlight conditions, such as intensity and angle.

The battery charging current closely follows the behaviour of the solar current, peaking around 2 hours at approximately 0.98A. This reflects efficient energy transfer from the solar panel to the battery. The current decreases over time as the battery becomes more charged, consistent with the characteristics of charging systems where the current reduces as the battery nears its full capacity.

Overall, the interaction between solar and battery charging currents demonstrates the system's ability to efficiently harvest and store solar energy, ensuring a consistent energy supply for the CCTV. The gradual decrease in charging currents towards the end of the period highlights the system's intelligent management of energy to prevent overcharging the battery.

4.3 Summary

The system is designed to operate continuously, discharging during the night and charging during the day. Assuming the battery is fully charged by sunset, its voltage starts to decrease as it powers the load during the night. Based on the linear discharge trend from Case B, the battery voltage after 12 hours of nighttime operation is calculated as follows:

The linear discharge equation is:

$$y = -0.0266x + 12.886 \quad [6]$$

Where:

• y is the battery voltage (V),

• x is the time (hours).

For 12 hours of discharge:

$$y = -0.0266(12) + 12.886$$

$$y = 12.566\,V$$

This calculation shows that after 12 hours, the battery voltage will drop to 12.566V, which is slightly lower than the minimum voltage observed in Case C during charging. This indicates that the system can handle the load without significant voltage depletion, maintaining sufficient reserve to ensure stable operation.

During the daytime, the battery begins recharging with the solar energy collected. From Case C, it is observed that the system charges at a steady rate and can fully recharge the battery within 5 hours. This rate ensures that the battery returns to full capacity before sunset, preparing it for another night of operation.

The continuous cycle of discharging and charging allows the system to function reliably 24/7 under ideal conditions. With this behaviour, the system demonstrates efficiency and robustness, making it well-suited for applications requiring uninterrupted power supply.

This observation is critical for confirming the system’s sustainability. The discharge rate in Case B and the charge rate in Case C work together to maintain the cycle. This ensures that the battery voltage always remains within the operating range, achieving a stable, self-sufficient operation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project successfully demonstrates the viability of a solar-powered CCTV system designed for continuous operation, aligning with SDG 7: Affordable and Clean Energy. Through thorough analysis and experimentation, the system was proven capable of sustaining continuous operation under ideal conditions. Case studies revealed that during nighttime, the battery voltage decreases to 12.566V after 12 hours of operation, which is within the acceptable range for system functionality. During the daytime, the solar charging system fully recharges the battery within 5 hours, completing a sustainable energy cycle. This ensures uninterrupted CCTV operation, providing an eco-friendly and cost-effective solution for remote or off-grid surveillance. The use of simulation tools such as Tinkercad and Fritzing, combined with real-time hardware testing, validated the system's design and performance.

5.2 Potential for Commercialization

The portable solar PV generator-powered CCTV system offers significant potential for commercialization in various sectors. Its sustainable energy design makes it suitable for deployment in remote areas, construction sites, and rural surveillance, where traditional power sources are limited or unavailable. Additionally, government agencies, security firms, and environmental monitoring organizations could adopt this technology due to its low operational cost and eco-friendly footprint. As renewable energy adoption continues to grow globally, products integrating solar energy with security technology are poised to become essential components of smart infrastructure solutions.

5.3 Future Works

In the future, it might be enhanced in the ways listed below:

i) Implement batteries with higher capacities or advanced energy storage solutions to enhance reliability during prolonged cloudy or rainy weather.

ii) Conduct environmental testing in diverse weather conditions and geographic locations to ensure the system's robustness.

iii) Explore the scalability of the system to support larger installations, such as multi-camera surveillance setups, for broader surveillance and security applications.

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APPENDICES

Appendix A Solar Module Specification