TITLE: A HYBRID SOLAR PHOTOVOLTAIC (PV) SYSTEM DESIGN FOR RURAL AREAS/SCHOOL

JULIAN ANAK RABING

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

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JULIAN ANAK RABING

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
Electrical and Electronics Engineering with Honours

Faculty of Engineering
Universiti Malaysia Sarawak

2023

ACKNOWLEDGEMENT

First of all, I would like to express my greatest appreciation to Universiti Malaysia Sarawak (UNIMAS) for giving me the chance to do my Final Year Project as it has given me valuable amount of experience. My sincerest thank to my supervisor, Ap Dr Tay Kai Meng for giving me who had given me a helpful and useful guidance throughout this project. Finally, I would express my sincerest apologies if in any time that I have done anything that is not to his liking.

Next, to my brothers and sisters in arm from Electrical and Electronic Engineering Department, I hope that our bond here will last forever and my sincerest appreciation for always be there for me in my time of need in supporting me throughout this journey of maturity. Your support, however small it is, very helpful to me. May God bless all of you.

Finally, I would like to my strongest supporter which is my family. They have been the spark to my fighting spirit to complete this research. Without their support, I am alone in this fight and there is no hope for me to proceed in fighting.

ABSTRACT

The increasing demand in electrical supply has been rising over the years. However, the implementation of solar PV system is not in a steady state as the technology still require a large cost to install. As the location of Malaysia is strategic to farm solar energy, we should utilize the solar PV system in order to improve our socioeconomic and lifestyle. This research discusses on designing a hybrid solar PV system for rural areas or schools. The main objective of this project is to utilize solar energy as the main electrical supply in the rural areas or school. The first chapter is the introduction about where the study is carried out and the background of energy generation is the rural areas in Malaysia. The second chapter discuss on the research done on the application and efficiency of solar PV system including the materials used, technique and design of the solar PV system. The next chapter is the methodology where the design development of hybrid solar PV system will be discussed. The working principle of the hybrid solar PV system will be explained in this chapter. After the methodology, the result of the project will be discussed entirely in the next chapter. The final chapter conclude this paper about the A Hybrid Solar PV System Design for Rural Areas or Schools.

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LIST OF ABBREVIATIONS

Notations

AC- Alternating-Current

BIPV- Building Integrated Photovoltaic

DC- Direct-Current

EU- European Union

FYP- Final Year Project

GCPV- Grid-Connected Photovoltaic

HRESs- Hybrid Renewable Energy Systems

MPPT- Maximum Power Point Tracking

OGPV- Off-Grid Photovoltaic

PV- Photovoltaic

PSH- Peak Sun Hour

SSC- Solar Charge Controller

USA- United States of America

CHAPTER 1

INTRODUCTION

1.1 Background Study

Electricity is the flow of electrical charge or power through a conductor, such as a wire, to power an electrical device. It is a conversion of energy from different types of energy, for example coal, natural gas, nuclear power, renewable energy such as solar power, and wind power. Electrical systems and components must be designed, built, and maintained by electrical engineers. They design effective and secure electrical systems for a range of applications using their electrical expertise.

Electricity in rural areas has always been a crucial component of any country's infrastructure. Malaysia has struggled to provide electricity to its rural communities for as long as it has been a developing nation. Due to the small number of residents, suburban areas cannot be wired into the national power system [1]. The diesel generator's high levels of greenhouse gas emissions are horrible thing for locals. There are several outlying regions in Malaysia that are not connected to the national power system. Most of Malaysia's outlying communities can be found on islands off the coast or in heavily wooded regions. Independent diesel generators are the standard for providing power in Malaysia's outlying settlements.

Energy that can be replenished naturally is widely used and has been the subject of extensive research for decades. The term "renewable energy" is commonly used to describe power that comes from infinitely replenishing resources. The sun provides an unlimited supply of clean, renewable energy. About 10000 TW of solar energy strikes Earth each day. According to The World Counts, it is estimated that annual worldwide energy usage is roughly 580 million terajoules (TJ) [2]. Considering the current rate of

consumption, the projected rate of growth over the next 20 years, and the amount of solar radiation hourly allows us to begin imagining the potential of solar energy.

There are renewable energy resources such as wind, hydro, and solar throughout the world, but the potential of each resource varies on region. However, in terms of environmental issues and as a prospective replacement for the millennium goals in the future, its accessibility looks to be a good development for humanity. These objectives include are not limited to eliminate or reduce the emission of carbon dioxide into the atmosphere as a result of the production of electric power from conventional energy sources as well as the reliance of countries on these fuels for their energy requirements.

Most researchers prefer solar energy to address the rising demand for power in several regions around the world. As common knowledge, solar technology's ability to produce power is highly dependent on sun radiation’s intensity and expected generation may only be according to the accuracy of weather forecast [3].

1.2 Problem Statement

In Malaysia, specifically Sarawak, most of the community in the rural areas still use diesel generator as their main electricity supply. The emission of hazardous gases into the environment, such as nitrogen oxide, carbon dioxide, and particulate matter, is one of the major drawbacks of diesel generators. On the other hand, due to the high cost of diesel and maintenance issues, the restricted hours of generator running restrict any substantial activity for socioeconomic improvement. A socioeconomic of community condition can be improved by making power more readily available.

In addition, having access to reasonably priced electricity is crucial for reducing local poverty. However, grid extension is an expensive alternative due to the minimal residential of isolated suburban areas, and it is not efficient in expenditures for majority of utility companies to develop their grid services to rural areas. [4].

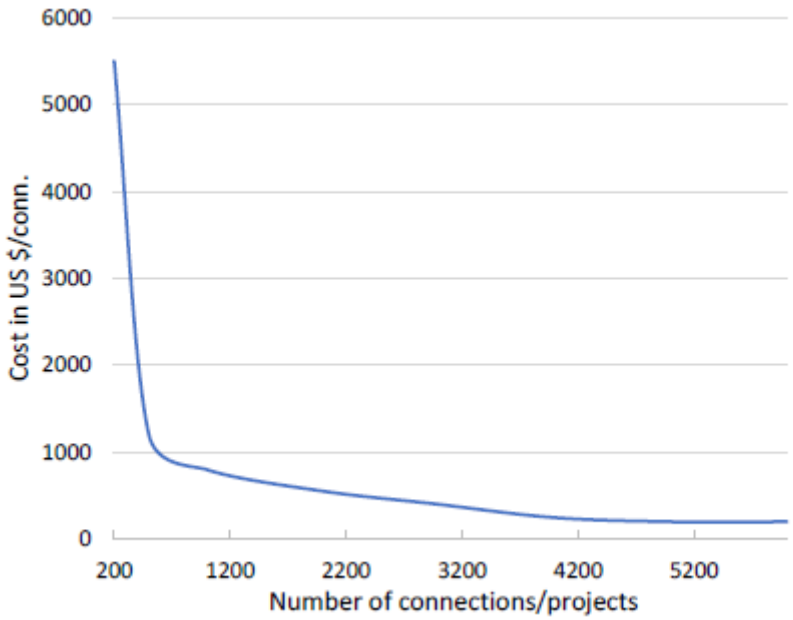

Figure 1.1 The relationship between the number of connections/project and cost in US $/connections [5].

It is not viable to provide electricity to these rural communities by extending the current system due to the huge geographic region and hilly terrain. Sarawak's household power coverage was estimated to be 91% in 2018 [5]. By 2025, the Ministry of Utilities of the Sarawak government aims to fully supply electricity throughout the state by supplying power that is dependable, renewable, and reasonably priced to every home in Sarawak.

Malaysia is one of the countries located along the Equator of the Earth where the solar radiation exposed for a longer time throughout the years compare to the country located in the Artic, Cancer's Tropic, Capricorn's Tropic and circle of Antarctic. Thus, to not develop a renewable energy generation, specifically the solar energy, is implying us not fully utilized the replenishable energy source. A major development of solar energy generation shall be carried out in order to improve the electricity supply throughout the country especially the suburban areas where there is no electricity grid existed.

1.3 Objectives

The main objective of this study is to provide an effective design of solar PV power plants with batteries and the electricity grid as a backup to maintain supply continuity and dependability of the grid. This design will be used to achieve the following objectives:

1. To utilize solar energy as the main electrical supply in the rural areas or school.
2. To implement an efficient solar PV design.
3. To evaluate the need of improvement of the rural areas' socioeconomic.

1.4 Project Scope

1. Develop a solar PV system which consists of storage batteries and grid to provide electricity in SK Ijok, Engkilili.
2. Analyse the intensity of solar irradiance which will power up the solar panels.
3. Comparison between Grid-Connected Photovoltaic (GCPV), Off-Grid Photovoltaic (OGPV) and Hybrid Solar Photovoltaic systems.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This section discusses on the research and current views on the solar PV system globally and in Malaysia. Research on the application and efficiency of the solar PV system has been carried out in the recent years as the popularity of solar PV system has been rising the past decade. Researchers believe that solar energy is the solution to fulfil the global energy demand.

2.2 Global Application of a Solar PV System

In 2021, China has become the main solar PV generating country in the world where they contribute for about 38% in the growth of solar PV generation. Another technology-leading country in the world, the United States of America (USA) contributed 17% of solar PV generation followed by the European Union (EU) with 10% [6]. Numerous of countries in the world has taken a major step to generate power using solar PV as it is a reliable and affordable choice.

The total of solar PV capacity had reached 710 GW globally by the end of 2020. With an additional 125 GW of solar PV capacity in 2020, solar energy experienced the fastest capacity growth of all replenishable energy sources. Installations on the rooftop of 3 to 20 kW to systems with a capacity of several hundred megawatts are all possible with solar photovoltaic (PV) technology. Power generation has moved toward greater democracy.

Solar PV system has been applied in various fields worldwide providing renewable energy solutions and contributing to a sustainable future. Here are some of global applications of solar PV system.

i. Residential.

Solar PV systems installed on residential rooftops enable homeowners to generate their own electricity. The system consists of solar panels, which convert sunlight into electricity through the photovoltaic effect. This electricity can be used to power appliances, lighting, heating, and cooling systems within the home. By relying on solar energy, homeowners can reduce their dependence on the traditional power grid, leading to lower electricity bills and decreased carbon emissions.

ii. Commercial and Industrial.

Solar PV systems are increasingly adopted by commercial and industrial sectors to meet their energy needs. Businesses and factories often have large roof spaces or open land areas where solar panels can be installed. These systems generate clean electricity, which can be used to power various operations, including lighting, machinery, refrigeration, and air conditioning. By utilizing solar power, commercial and industrial entities can significantly reduce their energy costs, improve their environmental footprint, and showcase their commitment to sustainability.

iii. Agriculture

Solar PV systems have multiple applications in agriculture. They can power irrigation systems, which are essential for maintaining crop health and productivity. Solar-powered pumps can draw water from wells or other sources, reducing the reliance on manual labour or fossil fuel-powered pumps. Solar energy can also be utilized for drying agricultural products, such as grains or fruits, increasing their shelf life and value. Additionally, solar PV systems can power farm equipment, such as electric fences or machinery, reducing operational costs and promoting sustainable farming practices.

iv. Transportation.

Solar energy is increasingly being utilized to power electric vehicles (EVs). Solar charging stations, equipped with solar panels, can be installed in public

areas, parking lots, or highways, enabling EV users to recharge their vehicles with renewable energy. This integration of solar power and EVs promotes sustainable transportation and reduces reliance on fossil fuel-based vehicles. It also helps to decrease air pollution and mitigate the impact of transportation on climate change.

Nowadays, solar panels are affordable and frequently chosen as the reasonable source of electricity due to the major reduction in the solar panel cost of production over the prior decade. From 2010 to 2020, the price of solar modules decreased by as much as 93% [7].

2.2.1 Malaysia

In Malaysia, the government has taken an initiative to develop its own solar farm. The main objective is to eliminate the carbon emission by 11,800 Malaysian household. In addition, Malaysia has set a new goal to be able to generate energy for at least 25% of renewable energy by 2025. One of the approaches taken is by operating a solar farm in Kerian, Perak [9]. This solar farm is expected to supply more than 212GWh of power annually and has a capacity of 100MW. This has been a significant approach by the government as they want to fully utilize the renewable energy and provide a more affordable energy resources for the people. According to nextenergy.my (2019), the solar panel cost in Malaysia is around RM15,000. For the entire installation, the price of installation ranging from RM 40,000 to RM 100,000. Most preferable solar panel in Malaysia are Canadian Solar, Hanwha Q Cells, JA Solar, Jinko and GCL.

Figure 2.1 Kerian Solar Farm located in Perak, Malaysia

2.2.2 Sarawak

In 2022, Premier of Sarawak, has stated the commitment to make Sarawak a powerhouse of Southeast Asia. Sarawak is the main exporter of renewable energy to the neighbouring country, West Kalimantan, Indonesia [10]. Due to the success of being able to supply renewable energy, Sarawak Energy will push for a sustainable energy future and work to enhance the amount of alternative and renewable energy. One of the future major contributors to the renewable energy source is Batang Ai Hydropower plant and Sarawak's first floating solar farm at. In parallel to our country mission, Sarawak determine to reduce the carbon emission by 52kilotonnes annually.

Figure 2.2 Batang Ai Hydropower plant where installing floating solar farm is planned.

The only obstacle that existed in Sarawak to fully utilize the solar energy production is the monsoon season and night-time. During monsoon season, the solar radiation performance deteriorates significantly, and the system will not be able to supply sufficient energy to power up the residents. The implementation of the OGPV does assist in supplying electricity when there is no sun radiation, however, the weather is rainy for days the battery storage will not be able to supply electricity as the depth of discharge of the battery is empty.

2.3 Sarawak Alternative Rural Electrification Scheme (SARES) [20]

SARES represents an innovative partnership model between the government and local communities. This integrated initiative, led by the State Government, aims to address the challenge of providing round-the-clock electricity to remote communities that are not feasible to connect to the State Grid.

The primary objective of the SARES scheme is to mobilize government machinery and agencies in assisting villagers to establish, own, and operate sustainable and affordable electricity generating systems. The scheme specifically focuses on 300 isolated

villages, encompassing 8,700 households, and spans from 2016 to 2020. Micro-hydro and solar systems are utilized as the primary technologies for this community-based initiative.

Since its inception in December 2016, SARES has successfully electrified 57 villages situated in Ulu Skrang, Sebauh, Katibas, Bukit Mabong, Nanga Medamit, and Ulu Pelagus. In the current year, approximately 32 villages in Tatau, Sg Pila, Katibas, Sg Gaat, Marudi, and Limbang are slated to be illuminated. Furthermore, an additional 27 villages in Marudi, Telang Usan, Sg Oyan, and Julau are expected to receive electricity by July 2018.

The implemented systems cater to the basic electricity needs of rural households, facilitating lighting, fans, television, freezer, and cooker functionality. They are designed to be simple yet effective, prioritizing safety without compromising on essential functionalities. By adopting these sustainable energy solutions, SARES effectively alleviates the financial burden on villagers, eliminating their dependence on costly diesel generators that only provide limited hours of electricity supply.

In conclusion, SARES stands as an innovative government-community partnership model that strives to provide sustainable electricity solutions to remote communities. By harnessing the potential of micro-hydro and solar technologies, the scheme offers reliable and affordable electricity access, enhancing the overall quality of life for rural households. Through its implementation, SARES addresses the challenges associated with remote electrification while promoting economic and social development in these underserved areas.

2.4 Type of solar PV system

There are two types of solar PV system which are available on the current market, Grid-Connected Solar PV (GCPV) and Off-Grid Solar PV (OGPV) system.

2.4.1 Grid-Connected Photovoltaic System (GCPV)

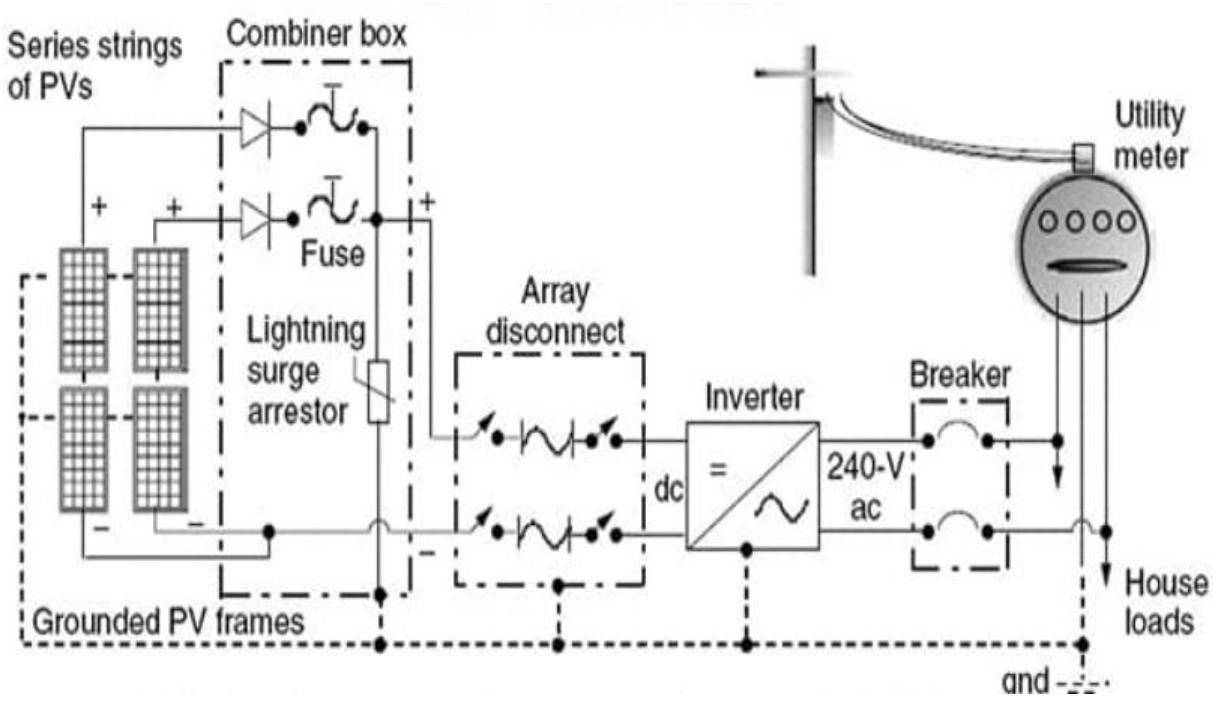

Figure 2.3 An example of GCPV system diagram

The escalating demand for electricity, coupled with the urgency to reduce greenhouse gas emissions, has fuelled the adoption of grid-connected solar photovoltaic (PV) systems. A grid-connected solar PV system, also known as an on-grid or grid-tied system, is designed to generate electricity from solar energy and feed it directly into the utility grid. This integration allows users to offset their electricity consumption from the grid while contributing clean energy to the overall electricity supply.

GVPV is a type of solar PV system that consist of solar panels, solar charge controller, inverter, and electricity grid. The system does not have backup storage to store the direct-current from the solar panel. The working concept of GCPV is at the output terminals of the PV arrays where DC is generated whenever the incoming light energy hit on the photovoltaic module to produce electrons. This direct current power is then flow through inverters, which facilitate in the conversion of direct current to alternating current. The alternating current energy can either be sent to the utility grid using net metering or used directly to power electrical loads.

A freestanding PV system is one in which the energy produced is applicable for a different load at the generation level itself. A GCPV is one in which the energy produced is continually fed into the electricity grid [12]. One of the advantages of GCPV system is the system is cost savings and financial incentives. Grid-connected solar PV systems significantly reduce electricity bills by offsetting consumption from the grid. Users benefit from lower energy costs and potential financial incentives offered by governments and utilities, such as feed-in tariffs, net metering, or performance-based incentives. The system also enhances grid stability and reliability. Solar power generation often aligns with peak demand periods, reducing strain on the grid and minimizing transmission losses. Distributed generation from multiple grid-connected solar PV systems improves grid resilience by decentralizing energy production.

However, the GCPV system rely on a stable and accessible grid connection. Grid outages or maintenance can temporarily interrupt the system's operation. The Net metering policies, which allow users to receive credits for excess electricity exported to the grid, vary across regions. Understanding local regulations and ensuring favourable net metering policies can influence the financial viability and return on investment of a grid-connected solar PV system.

Grid-connected solar PV systems have emerged as a sustainable and economically viable solution to meet the growing electricity demand while reducing environmental impact. By integrating with the utility grid, these systems offer significant cost savings, environmental sustainability, and the potential for financial incentives. While challenges

such as grid dependency and net metering policies exist, advancements in technology and supportive regulatory frameworks are continuously addressing these concerns. As the world moves towards a cleaner and more sustainable energy future, grid-connected solar PV systems play a vital role in facilitating the widespread adoption of renewable energy, enabling individuals and communities to contribute to a greener and more resilient grid.

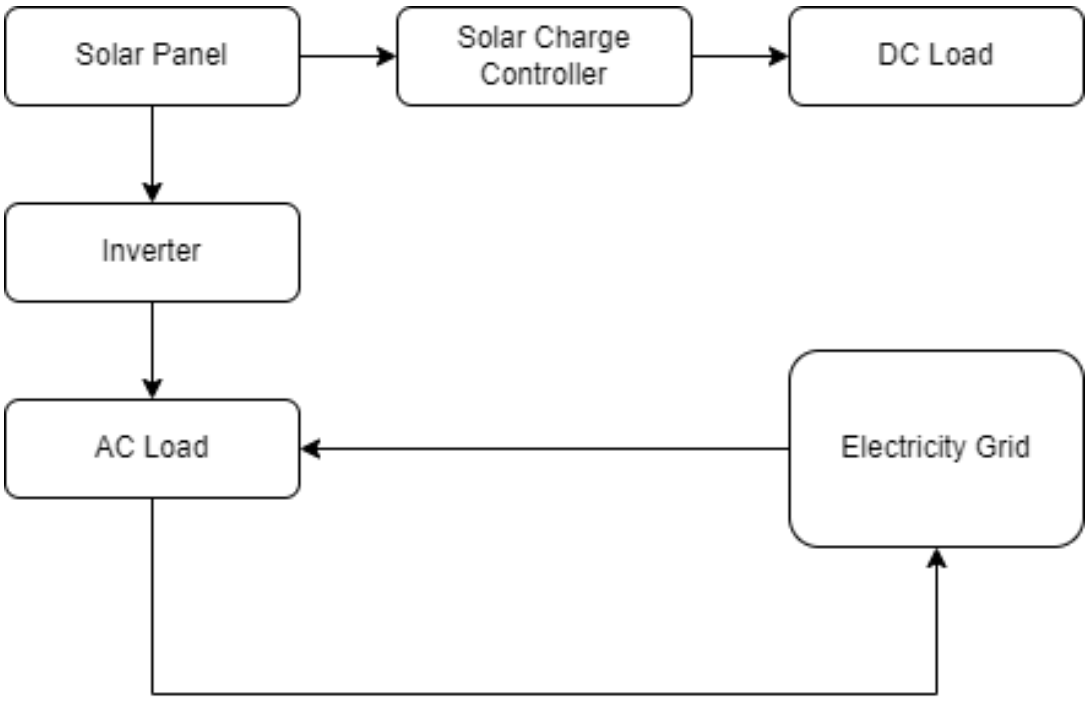

Figure 2.4 Block Diagram of the working principle of GCPV

2.4.2 Off-Grid Photovoltaic System (OGPV)

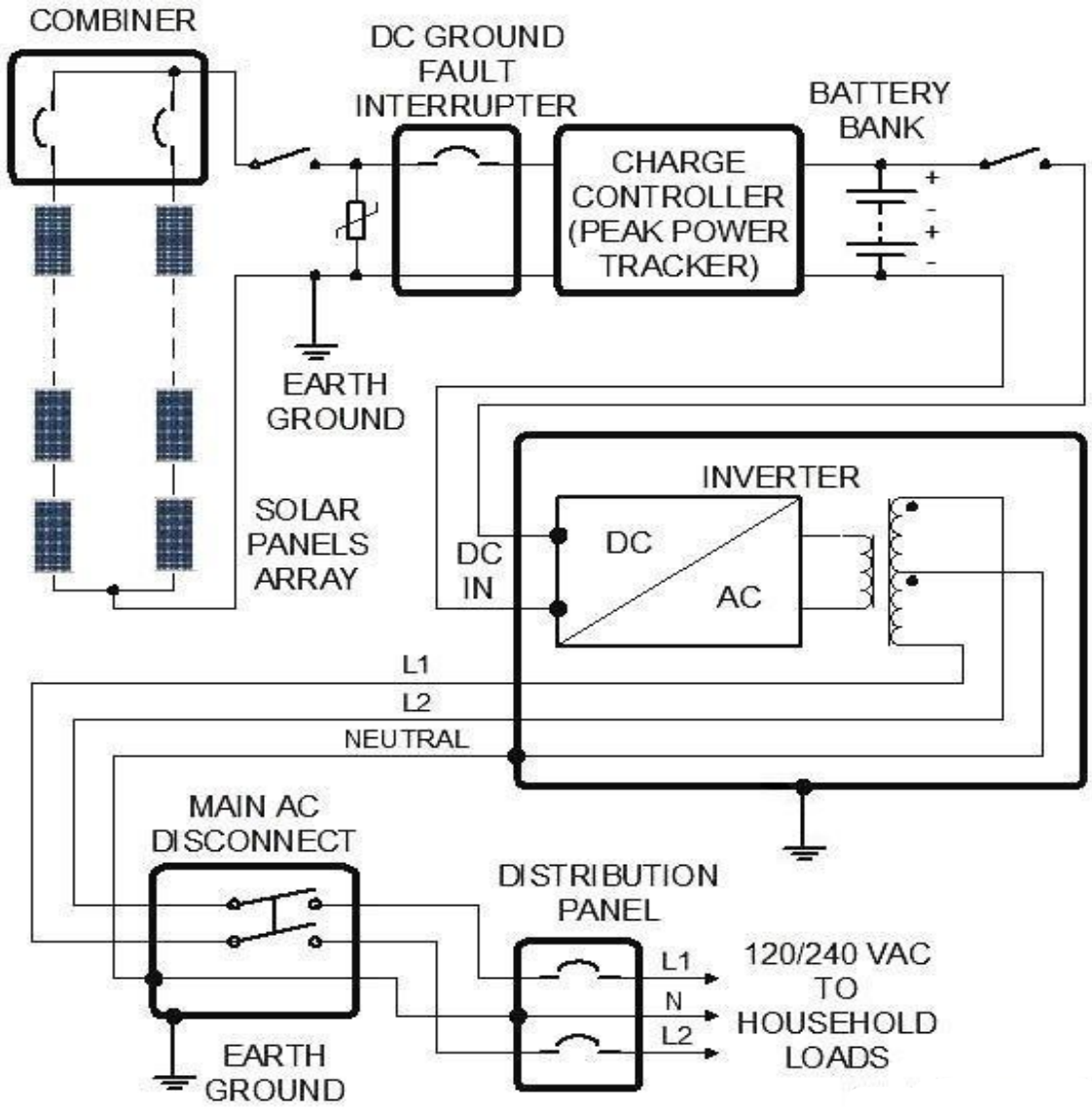

Figure 2.5 An example of GCPV system diagram.

The rapid depletion of fossil fuel reserves, coupled with the increasing global demand for electricity, has driven the need for sustainable and reliable energy solutions. In this context, off-grid solar photovoltaic (PV) systems have emerged as a promising alternative to conventional energy sources. An off-grid solar PV system is designed to generate electricity independently from the grid, utilizing solar energy through photovoltaic panels and storing excess power in batteries for later use. This self-sufficient energy solution is gaining popularity in both developed and developing regions, providing clean and affordable electricity to remote areas, eco-friendly homes, and emergency situations. In this comprehensive overview, we will delve into the key components, working principles, advantages, and challenges associated with off-grid solar PV systems.

An OGPV is a stand-alone solar PV system where it does not rely on the electricity grid. The component in OGPV is similar to GCPV except the electricity grid is replaced with battery storage. The battery storage will act as a backup power supply especially during night-time or rainy season where there is minimal solar radiation on the solar panel. An OGPV system comprises several essential components that work harmoniously to generate and store electricity. The primary components include solar panels, charge controllers, batteries, inverters, and a backup generator (if required). Solar panels, typically mounted on rooftops or in open areas, consist of photovoltaic cells that convert sunlight into direct current (DC) electricity.

By implementing OGPV system, users will be able to be energy independence. An OGPV systems provide a reliable and sustainable energy source, enabling users to be self-sufficient and less reliant on the grid. This is particularly advantageous in remote areas where grid connection is unavailable or economically unviable. Users also will be able to maintain the environmental sustainability by harnessing the sun's energy, off-grid solar PV systems produce clean, renewable electricity, reducing greenhouse gas emissions and environmental pollution. This contributes to combating climate change and preserving the planet for future generations. The versatility and scalability of OGPV systems can be tailored to meet diverse energy demands, from small-scale residential installations to large-scale applications in commercial buildings, schools, and healthcare centres. Additionally, these systems can be expanded or upgraded over time to accommodate increased electricity needs.

In an isolated suburban area where alternative sources of power are either impractical or inaccessible to supply power for lighting, electrical equipment, and other uses, a system of stand-alone PV is very relevant to implement [13]. In these situations, installing a single stand-alone PV system is a more cost-effective system than paying for the local power company to expand the power lines and cables to the residence as part of a GCPV system. An electrical system made up of a combination of single or more PV modules, electrical appliances, and one or more loads is called a stand-alone PV system.

Off-grid solar PV systems offer a sustainable and reliable solution for meeting electricity needs in remote areas, eco-friendly homes, and emergency situations. With their ability to harness solar energy and store excess power, these systems provide energy independence, environmental sustainability, cost savings, and power reliability. However, proper system sizing, battery performance, energy management, and backup power considerations are vital for ensuring the efficiency and longevity of off-grid solar PV systems. As advancements in technology continue, coupled with favourable government policies and increased awareness of renewable energy, the adoption and deployment of off-grid solar PV systems are expected to accelerate, enabling a cleaner and more resilient energy future for all.

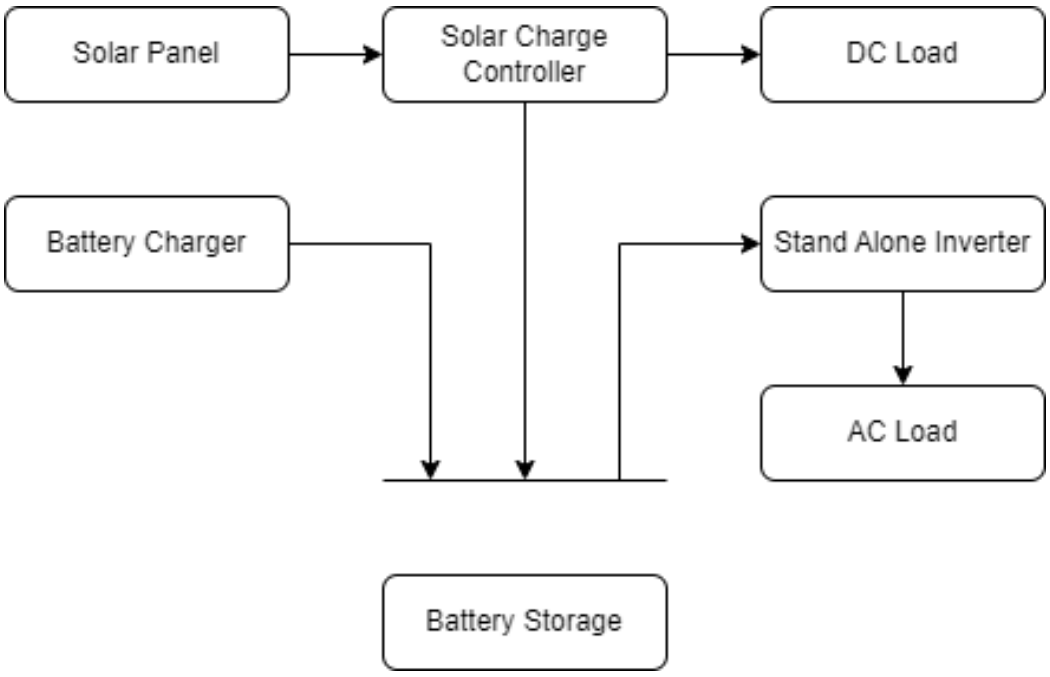

Figure 2.6 An example of OGPC system diagram.

Table 2.1 Summary of GCPV and OGPV

Type of solar PV System	Advantages	Limitations
GCPV	- Relatively low operating and maintenance costs. - Can be installed in vacant roof space without requiring any additional land.	- Rely on the electricity grid and if there is fault on grid, the system will fail. - Initial installation cost is high.
OGPV	- Relevant for rural areas without the reach of electricity grid. - Energy independence and free from uncertain electricity tariff.	- Limited energy storage as it relies on the battery capacity. - Battery has its own lifespan and require a high maintenance cost in a span of 5-15 years.

2.5 Efficiency of solar PV system

In the research paper, there are a lot of topics that has been discussed on how efficient a solar PV system can be. This includes the installation of solar PV system, the hybrid-energy implementation and material used on producing the solar panels.

The building-integrated PV (BIPV) system has been introduced since 1990s. The idea of BIPV is the assimilation of PV into the interior and exterior structure of the building. This indicates that the solar PV panels are one of the structures of a building whether the roof or façade. It expands the area exposed to the solar radiation which will maximise the generation of solar energy. However, the BIPV system does not fit to the existing old houses and buildings in the rural area. As the BIPV needs to be built during a building's construction, thus, the initial cost will be higher.

Research done by Md. Mustafizur Rahman (2019) on the deployment of comprised systems with different configurations of renewable sources to discuss the effect of renewable system on environment. A Hybrid Renewable Energy Systems (HRESs) is developed to study the effectiveness and to justify the best system. HRESs is carried out with different configuration of 100%, 80%, 65%, 50%, 35% and 21% of system of renewable-based. The result of the research is that HRESs produced less CO2 emission but the cost of building a system is high. This reflects the decision on implementing a HRESs as it does not provide a good return of investment compared to the diesel generator.

A material to make the solar panels is a key component indicating the efficiency of the system. Mitchell et al. [16] proposed the use of monocrystalline silicon as the main material in solar panels instead of the polycrystalline silicon and thin film. The monocrystalline silicon grants the highest efficiency at 17-22% compared to the others.

Monocrystalline silicon, also known as single-crystal silicon, is a highly pure form of silicon that consists of a single crystal lattice structure. This means that the entire silicon wafer used in solar panels is composed of a single, continuous crystal structure, which results in higher efficiency and superior performance compared to other types of silicon.

The key advantage of monocrystalline silicon is its higher efficiency compared to other silicon-based solar cell technologies. The single-crystal structure allows for better electron flow, minimizing energy loss during the conversion of sunlight into electricity. This results in higher power output and a greater energy yield from a given surface area, making monocrystalline silicon panels an attractive choice where space is limited.

Another benefit of monocrystalline silicon is its uniformity and reliability. The consistent crystal structure of monocrystalline silicon wafers ensures that each solar cell within a panel performs consistently, leading to a more reliable and predictable power output. This uniformity also contributes to the longevity of monocrystalline silicon panels, as they tend to have a longer lifespan compared to other solar cell technologies.

However, the cost to produce monocrystalline silicon is high. This is primarily attributable to the process of manufacturing as solar cells are produced from a single silicon crystal and producers must pay huge amount of money for the process. This technique, also known as the *Czochralski* process, uses a ton of energy and silicones are wasted, that can later be used to create polycrystalline solar cells.

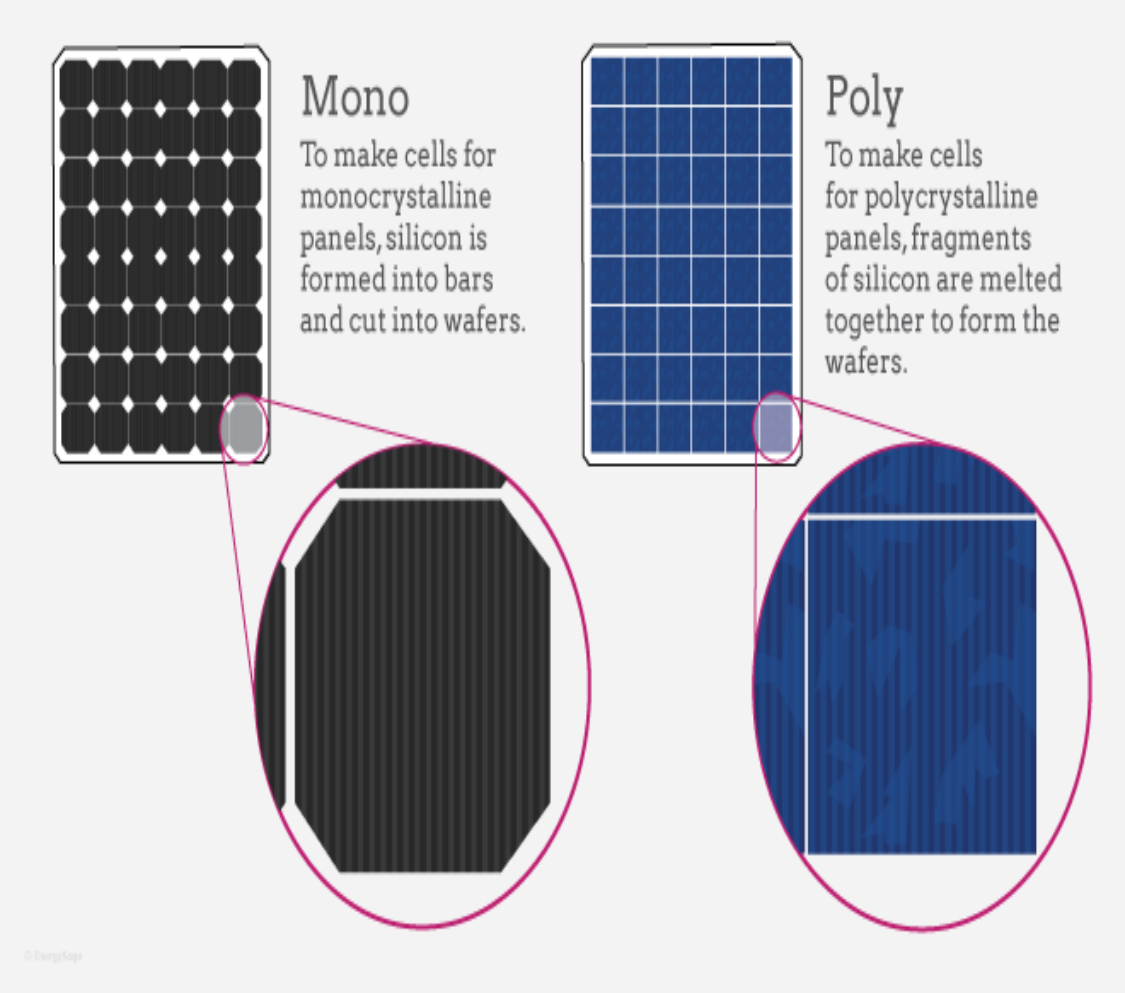

Figure 2.7 Difference between monocrystalline and polycrystalline solar panel

Figure 2.8 Diagram of thin film of solar panel

In summary, monocrystalline silicon is a highly efficient and reliable material used in solar panels. Its single-crystal structure allows for better electron flow, resulting in higher power output and increased energy yield. While the production process is more complex and costly, the benefits of monocrystalline silicon panels make them a popular choice in the solar industry.

Table 2.2 Method comparison on efficiency of solar PV system

Ref.	Study	Method	Advantage	Disadvantage
[14]	Solar PV installations.	Building-integrated photovoltaic (BIPV) system	Solar energy generation can be applied for a more spacious area than the rooftop solar PV systems.	Inconvenient for old-fashioned residences and premises.
[15]	Comprised systems with different configurations of renewable sources	Implementation of off-grid Hybrid Renewable Energy Systems (HRESs)	Lower CO2 Emission	Installation cost of HRES is higher than diesel generators.
[16]	Solar panel technology	Monocrystalline silicon PV panels	Grants the highest level of efficiency at 17-22%.	Levels of performance most likely to deteriorate from a rising of temperature.

2.6 Research Gap

The study of design a solar PV system has a number of possible improvement and more research needed. Below are some of the example of potential research areas:

For a location to implement a solar PV system, environmental factors such as dirt, soil and substances in the air need to be taken as a consideration as they may affect the efficiency of a solar PV system. In order to optimise the efficiency of the system, a research gap must be solved.

Specific research on the production and invention of a more effective and affordable material to produce a solar panel would be necessary. It will increase the number of clean energy resources available for every individual and thus, it will contribute to declining the climate issues.

Chapter 3

METHODOLOGY

3.1 Overview

This chapter discusses the methodology used in study. All elements of model development, from data collection to model validation, are covered by the study of technique. For the FYP I, the methodology will be until design development of a hybrid solar PV system as the next step will be done in FYP II. The processes in the FYP I are preliminary research, data collection and design development of the hybrid solar PV system. In the preliminary research, the main activities done is conducting a literature review to find latest information on the state of solar PV system either globally or in Malaysia. Next is the data collection. Data collection is a step where the calculation of the important aspects of solar PV system is done to finally conclude the rating each of the components. Lastly, is the design development of hybrid solar PV system. When the values in the data collection is sufficient, it will proceed to finally design the system. The design of hybrid solar PV system is done by using MATLAB Simulink.

3.2 Flowchart of the Project

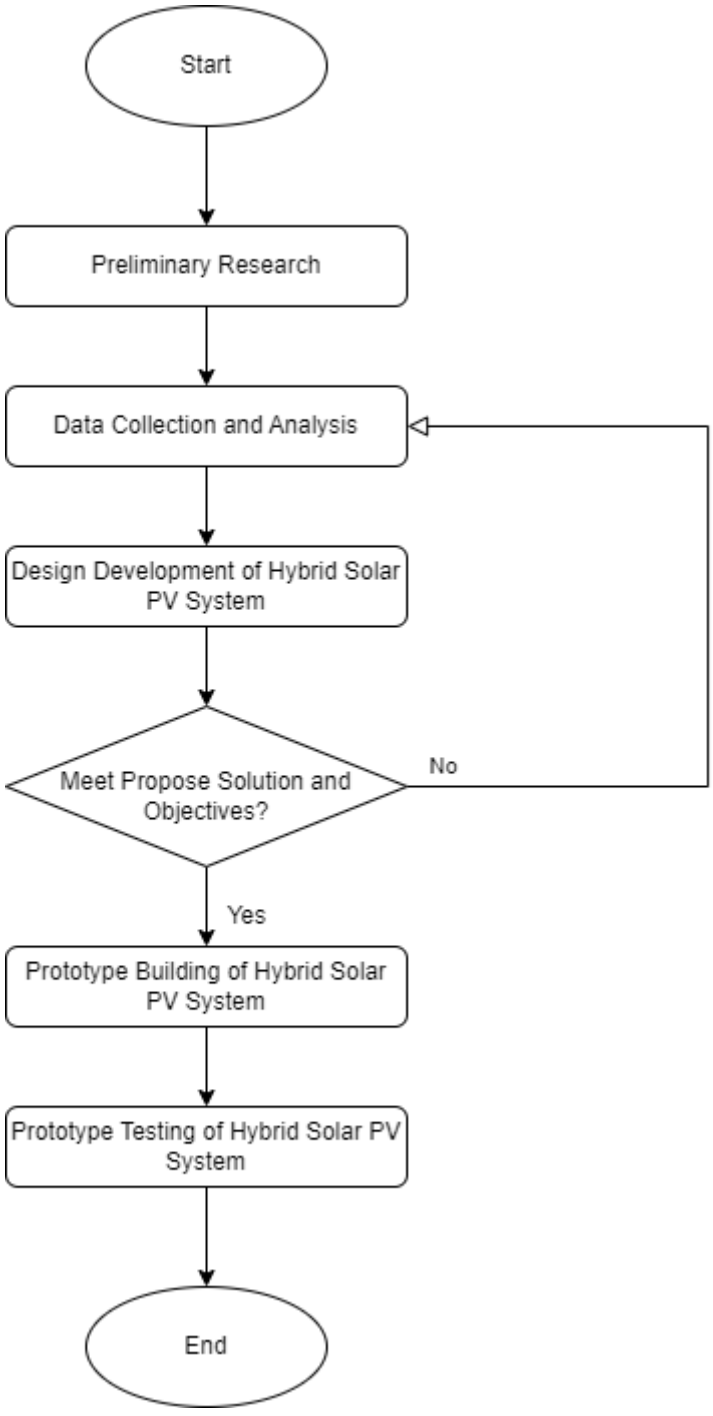

Figure 3.1 General Flowchart of the Project

This Final Year Project of designing a hybrid solar PV system in rural areas or schools has its own general flow of work. It starts with preliminary research where the configuration of the system is discussed in order to carry on designing the system. For the next step, data collection and analysis is a crucial part as it will provide the details need to fulfil the parameter and data needed in the solar PV system. After that, it will come to a simple conclusion whether the proposed idea will be able to meet the problem statement and objectives' criteria. If it does not able to fulfil the criteria, it will go back to the data collection and analysis stage where a more detailed and accurate data will be revised and chosen to design the solar PV system. Once it fulfils the criteria, the designing of the hybrid solar PV design will undergo. For this paper, the method used is through simulation by using MATLAB Simulink. The last stage of this project is to test or run the simulation in order to get the result on the functionality of the hybrid solar PV system.

3.3 Preliminary Research

Sekolah Kebangsaan Ijok is a rural primary school in the district of Engkilili which is in Sri Aman Division. It is a located 10.9 KM from the nearest town Sri Aman, Sarawak. It is a suitable location to be the symbolise the rural area or school. As in 2021, the school has a number of 40 students and 13 teachers. The school, including the villages near the area, still rely on diesel generator as their main supply of electricity due to the low population density in the area. The locals have to buy the fuel in the nearest petrol station which is located 19.1 KM away from the school and it can take up to 40 min due to the underdeveloped infrastructures and it has made life difficult for the people.

They need to spend a lot of money in order to get their diesel supply. However, the money spent is varies as the price of diesel is not constant throughout the month and it will directly affect the locals' economic. As of 22nd December 2022, the price of diesel per litre is RM3.35 while for the past week (15th December 2022) is RM3.55 per litre [11]. The price difference is not significant if it is analysed per litre. However, when the local refill fuel in bulk, for example 10 litres of diesel, they will need to pay extra RM2.00 on 15th December compared to 22nd December.

Malaysia is located in the Equator, and it has given us the one of the longest Peak Sun Hour (PSH) and high solar radiation daily. The introduction of hybrid solar PV system will reduce the school's dependency on diesel generator thus will have a cleaner and environmental-friendly source of energy supply.

Figure 3.2 Satellite image of SK Ijok, Engkilili

3.4 Data Collection and Analysis

Data collection is a crucial part of this research as it provides the information needed to design and implement the hybrid solar PV system. The process of gathering, organising, and analysing data from various sources in order to gain insights and make informed decisions is known as data collection. It entails gathering information from internal and external sources, such as surveys, interviews, focus groups, customer feedback, and market research. Data collection necessitates advanced analytical and technical skills, as well as knowledge of data sources and data itself.

Data collection involves gathering relevant information or observations to address a research question or objective. The process begins with careful planning and design, ensuring that the data collected is reliable, valid, and aligned with the research goals. Various methods can be employed for data collection, depending on the nature of the research and the type of data required.

One commonly used method is primary data collection, which involves collecting data firsthand from original sources. This can be done through techniques such as surveys, interviews, observations, or experiments. Surveys involve gathering information from a sample of individuals or organizations through structured questionnaires or interviews. Interviews, on the other hand, provide an opportunity for in-depth exploration and capturing nuanced responses. Observations involve systematically watching and recording behaviours or phenomena, while experiments allow researchers to manipulate variables to study cause-and-effect relationships.

Secondary data collection involves utilizing existing data that has been collected by others for a different purpose. This can include data from research studies, government reports, organizational records, or publicly available datasets. Secondary data can be a valuable resource, as it can save time and resources. However, researchers need to critically evaluate the quality and relevance of the data to ensure its suitability for their research objectives.

For this research, there will be several data needed to fulfil the requirements of the hybrid solar PV system's design.

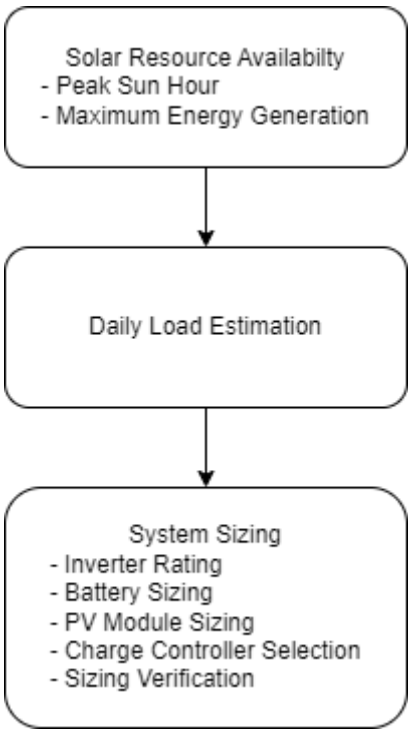

Figure 3.3 Flowchart of Data Collection and Analysis

Once the data is collected, the next step is data analysis. Data analysis involves organizing, cleaning, transforming, and interpreting the collected data to extract meaningful insights and draw conclusions. The analysis process may involve several steps, depending on the complexity of the research question and the nature of the data. Data may need to be transformed or standardized to facilitate analysis, such as converting categorical variables into numerical ones or normalizing data distributions. Descriptive statistics provide a summary of the data, including measures of central tendency, dispersion, and graphical representations. These techniques help researchers gain an overall understanding of the data and identify patterns or trends.

Inferential statistics are used to make inferences or draw conclusions about a larger population based on the sample data. This involves hypothesis testing, confidence intervals, and regression analysis, among other techniques. Researchers use inferential statistics to determine the statistical significance of relationships or differences observed in the data.

Qualitative data analysis involves analysing non-numerical data, such as textual or visual data. This can be done through techniques such as content analysis, thematic analysis, or grounded theory. Qualitative analysis aims to identify themes, patterns, or meanings within the data, allowing for a deeper understanding of subjective experiences or perspectives.

Throughout the data analysis process, researchers must ensure rigor and validity. This includes conducting sensitivity analyses, addressing potential biases, and applying appropriate statistical tests to support the conclusions drawn from the data. Additionally, researchers should maintain detailed documentation of the analysis process to ensure transparency and reproducibility.

Data collection and analysis are essential components of any research or analysis process. By carefully planning and executing data collection methods, researchers can gather reliable and relevant information. The subsequent analysis of the collected data allows for the extraction of meaningful insights, supporting evidence-based decision-making. By employing appropriate methodologies and adhering to rigorous standards, researchers can ensure the validity and integrity of their findings.

3.4.1 Solar Resource Availability [18]

Understanding solar resource availability is crucial for effective harnessing of this energy. Solar resource availability refers to the measurement and assessment of sunlight intensity and duration at a particular location. It determines the potential for solar energy generation, making it a fundamental aspect of solar power planning and implementation.

Solar radiation levels vary based on a location's latitude, altitude, and proximity to large bodies of water. Equatorial regions receive higher solar energy throughout the year, while polar regions experience significant seasonal variations. The angle and intensity of sunlight change during the day and across different seasons. The sun's position affects the amount of solar energy that can be captured by solar panels.

Cloud cover, air pollution, and atmospheric water vapor content can reduce the amount of sunlight reaching the Earth's surface. These factors cause diffuse radiation, which spreads sunlight over a larger area and decreases its intensity.

Solar resource availability will determine the relevancy of designing the hybrid solar PV system in SK Ijok, Engkilili.

a) Peak Sun Hour (PSH)

The PSH can be determined by using the formula:

$$PSH = \frac{H(\frac{Wh}{m^2})}{G_0(\frac{W}{m^2})}$$

where,

H = solar irradiance (the intensity of solar power)

G_0 = solar irradiation (the intensity of solar energy, $G_0 = 1\frac{kW}{m^2}$

b) Maximum Energy Generation

Annual average maximum energy production potential,

$$E_{\max_ann} = A \times PSH \times t \times \mu$$

A = Effective area of solar panels

t = time (365 days)

μ = system efficiency

3.4.2 Daily Load Estimation

Daily load estimation is a crucial aspect of energy management and planning. It involves predicting the electricity consumption or load patterns of a given region over a 24-hour period. Accurate load estimation helps utilities and grid operators optimize generation, transmission, and distribution, leading to enhanced efficiency, reduced costs, and improved system reliability. This article provides an overview of daily load

estimation, its significance, and various methodologies employed to achieve accurate load predictions.

Daily load estimation is needed to set a standard of the amount of energy used by direct-current (DC) and alternating-current (AC) loads monthly in a year. The pattern of load demand for a school is varies during weekday and weekend. During weekday, the peak load demand is from 7.00am to 5.00pm where the school session start and end. During weekend, the load demand is low as there is no academic session is going on and most the activities done are minimal. Daily load estimation can be calculated by revising the DC and AC electrical appliances used in the school.

Understanding the electricity consumption patterns enables utilities to determine the required capacity, plan infrastructure upgrades, and make informed decisions regarding power generation and distribution. Accurate load estimation helps balance supply and demand, avoiding underutilization or overloading of resources. It aids in load balancing, load shedding, and demand response programs, promoting energy conservation and grid stability. Moreover, load estimation supports efficient maintenance scheduling and facilitates the integration of renewable energy sources by predicting peak demand and accommodating their intermittent nature.

Daily load estimation is a critical aspect of energy management and grid operations. Accurate load predictions help utilities optimize resource allocation, plan infrastructure, and ensure efficient electricity delivery. Statistical approaches, machine learning techniques, data mining approaches, and hybrid methodologies provide diverse options for load estimation. The selection of the appropriate method depends on the available data, computational resources, and specific requirements of the utility. The continuous advancements in data analytics, machine learning, and computational capabilities contribute to more precise load estimation, enabling a smarter and more sustainable grid system.

3.4.3 System Sizing

a) Inverter rating

Since the majority of today's utility grids run on AC, this specification is required for the DC to AC power conversion. The selected inverter should be able to handle the entire AC load, therefore for excellent performance, its output power must be more than that of the AC load (appliances). The required inverter size:

$$Peak\ Demand\ \times Surge\ Factor$$

b) Battery Sizing

Battery capacity can be determined:

$$Charge\ required\ ,\ C_{Ah_req} = \frac{E_{req}(Wh)}{V_{sys}(V)} \times \frac{k_{sto}}{DOD_{max}(\%)} \times T_{aut}(day(s))$$

$$Discharge\ rate,\ T_{disch} = \frac{E_{req}(Wh)}{TMD} \times \frac{k_{sto}}{DOD_{max}(\%)} \times T_{aut}(day(s))$$

$$Number\ of\ batteries\ in\ series, N_{s_batt} = \frac{V_{sys}(V)}{V_{nom\ batt}(V)}$$

$$Number\ of\ battery\ strings\ in\ parallel:\ N_{p_batt} = ru\left(\frac{C_{Ah_req}(Ah)}{C_{Ah_batt}(Ah)}\right)$$

$$Battery\ bank\ capacity: C_{Ah_batt}(Ah) = N_{p_batt} \times C_{Ah_req}(Ah)$$

$$Number\ of\ battery\ required, N_{batt} = \frac{C_{Ah_req}}{C_{Ah_batt}}$$

where,

C_{Ah_req}: Charge storage capacity required (Ah)

k_{sto}: correction factor of storage unit

DOD_{max}: Maximum DOD of storage unit

T_{aut}: number of autonomy days (d)

$V_{nom\ batt}$: Nominal battery voltage

c) PV Module Sizing

PV module sizing is a crucial step in designing an efficient and cost-effective solar power system. PV modules, also known as solar panels, are the building blocks of solar energy systems, responsible for converting sunlight into usable electricity. Proper module sizing ensures that the system generates the desired amount of electricity, maximizing energy production and return on investment.

Solar PV array is sized depending on the total daily energy requirement and should be able to supply the needed electricity throughout the entire year. The temperature factor will be taken into account throughout the sizing process because it can affect the system's efficiency. A minimum of 10% increase in the size of the proposed system should be added to the implementation system.

Considering factors such as energy demand, available space, solar resource availability, and system characteristics, the appropriate size and configuration of PV modules can be determined. By utilizing methods such as rule of thumb, system simulation software, performance ratio analysis, and manufacturer's datasheets, designers and installers can achieve an optimal balance between energy generation, system performance, and cost-effectiveness. Proper PV module sizing is essential for harnessing the full potential of solar energy and accelerating the transition to a sustainable future.

d) Solar Charge Controller (SSC) Selection

The following equation can be used to determine the requirement for SCC. SSC is a electrical component that is used to monitor and optimize the voltage and current flow from the solar module, the capacity that can be received by the battery.

$$I_{rated} = \sum PV_{parallel} \times I_{sc}$$

where,

I_{rated} = rated current.

$PV_{parallel}$ = number of PV module in parallel

I_{SC} = short-circuit current when the voltage across the solar cell is zero.

3.4.4 Sizing Verification

The sizing verification process plays a crucial role in ensuring the optimal design and performance of solar photovoltaic (PV) systems that incorporate both battery storage and grid connectivity. As solar PV systems become more popular, integrating battery storage allows for increased self-consumption and energy independence. Sizing verification ensures that the system components, including the PV array, battery capacity, and inverter ratings, are appropriately dimensioned to meet energy demand, maximize self-consumption, and efficiently utilize grid connectivity.

When determining the cable sizing of a line, particularly for a low voltage system, it is imperative to examine the voltage drop. Inadequate cable sizing could result in a system fault. The outcome may be worse if the cable is too short since it may heat up and catch fire. Maximum DC system voltage, maximum DC current, and maximum conductor current all need to be taken into account while sizing cables.

In order to protect the panel from overvoltage caused by lightning, a surge protector device is needed. For the PV system to operate safely, fuses and switches must also be installed. Sizing verification is crucial in designing efficient and reliable solar PV systems with battery and grid-connected integration. By considering factors such as energy demand, solar resource availability, battery capacity, and inverter sizing, accurate sizing ensures optimal system performance, enhanced self-consumption, and effective grid integration. Utilizing methods such as system simulation software, load flow analysis, battery performance modeling, and manufacturer's guidelines, designers and installers can achieve an optimized system design that meets energy requirements while maximizing the benefits of solar energy and battery storage integration.

3.5 Design Development of Hybrid Solar PV System

The last step of this Final Year Project I is the design development of a Hybrid Solar PV System. The proposed system is shown in the figure below.

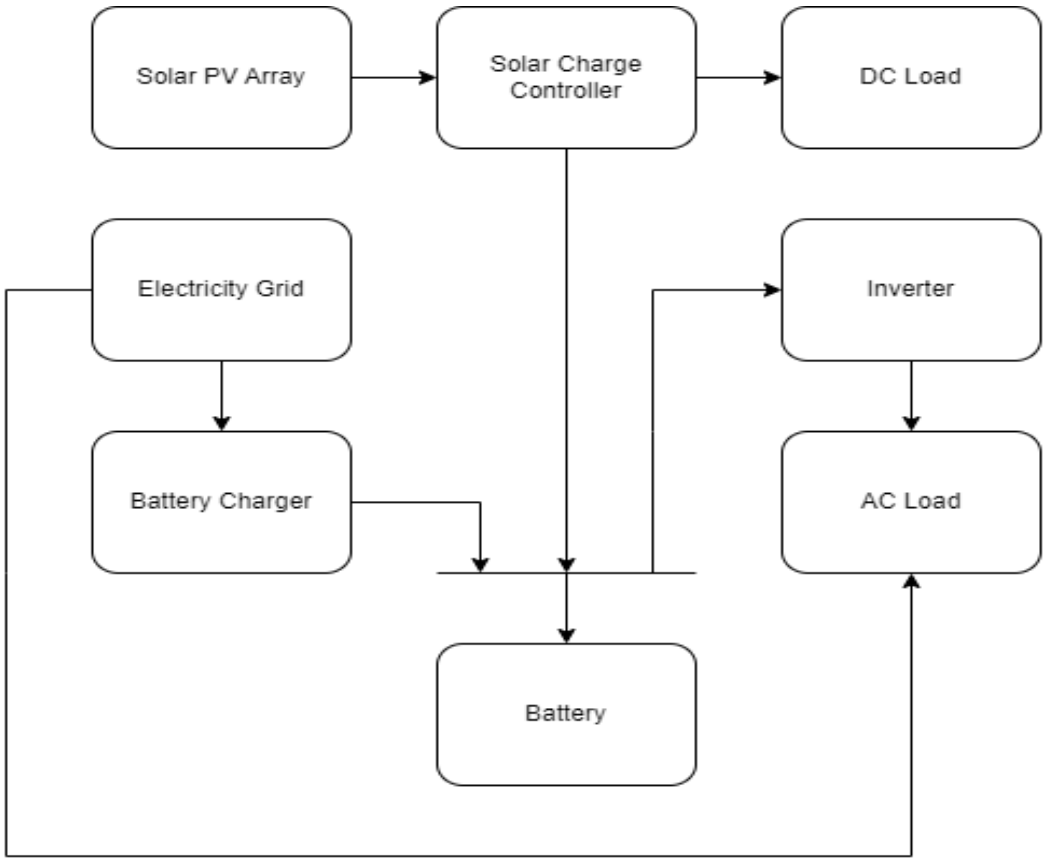

Figure 3.4 Block Diagram of Hybrid Solar PV System

Solar energy will be converted to electricity when the sun radiation hits the solar panels. They utilize the principles of the photovoltaic effect theory. When exposed to the sunlight, photons will be absorbed by the monocrystalline solar PV panels and free electrons will be released. This phenomenon is known as the photoelectric effect. The photovoltaic effect is a technique for producing direct current that is based on the photoelectric effect theory. The DC will flow to the solar charge controller where it will regulate the voltage and current issued from the solar module. This step is to allow the charge produced by solar PV to flow into the battery banks when voltage of the battery is below the maximum voltage. The DC will continue to flow directly to the DC loads and the battery. The battery will flow DC to the inverter in order to fulfil the AC loads demand. The backup system, electricity grid, will supply electricity directly to the AC loads and charge the battery through the battery charger.

3.6 MathWorks MATLAB Simulink

Figure 3.5 MATLAB & Simulink

MathWorks Matrix Laboratory Simulink, also known as MATLAB Simulink, is a popular simulation and modelling tool widely used in engineering, science, and research fields. Simulink offers a graphical environment for designing and simulating dynamic

systems, making it an essential tool for system analysis, control design, and algorithm development. Simulink offers a range of features and functionalities that make it a versatile tool for various applications. It supports a wide range of domains, including control systems, signal processing, communications, image processing, and more. Users can create models by selecting and arranging blocks from Simulink's extensive block libraries, which consist of predefined components representing mathematical operations, signal sources, sensors, actuators, and other system elements.

The connections between blocks represent the flow of signals and data within the system. Simulink allows users to specify the mathematical relationships between blocks, enabling the simulation of complex system behaviour. Users can define the parameters, initial conditions, and simulation settings for their models.

In this project, MATLAB Simulink is used to design a hybrid solar PV system for rural areas or schools.

3.6.1 Design of Hybrid Solar PV System Using MATLAB Simulink

The proposed model is created and simulated using the MATLAB/Simulink software environment. It is based on mathematical analysis and average modelling. The choice of mathematical modelling allows for flexibility and adjustment of model parameters. In engineering, it is common to focus on specific system behaviours while disregarding insignificant phenomena. Hence, through mathematical modelling, the switching ripples are disregarded, and the averaged model of all converters (PV boost converter, battery and supercapacitor bidirectional converters, grid inverter) is examined. Nevertheless, the model accurately captures the system dynamics and small ripple signals to ensure accuracy.

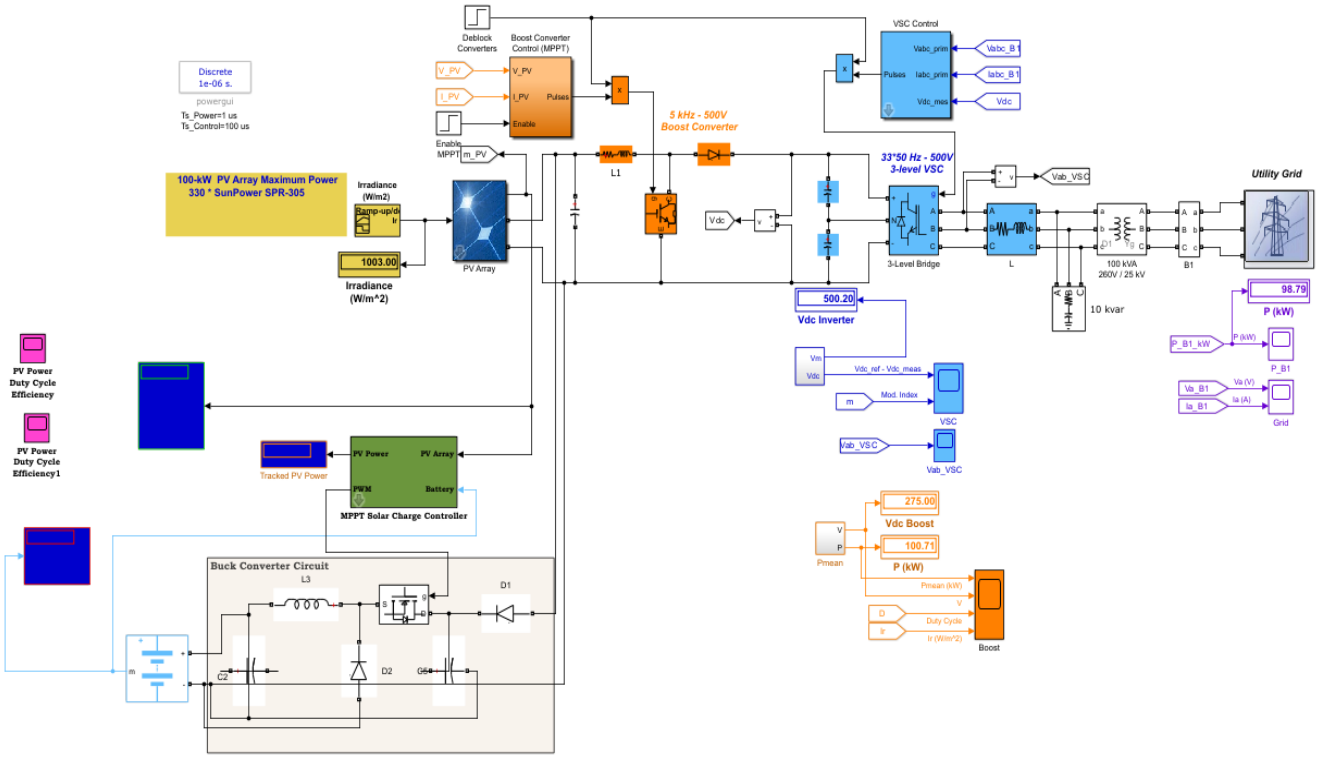

Figure 3.6 Hybrid Solar PV System Design using MATLAB Simulink

To design a hybrid solar PV system using MATLAB Simulink, there are several steps considerations need to be involved. Designing a solar PV system with battery storage and grid connection requires careful consideration of various factors to ensure optimal performance, reliability, and compatibility with the existing infrastructure. Here is the list of considerations:

i. PV Panel Modelling
ii. Maximum Power Point Tracking (MPPT)
iii. Power Electronics Modelling
iv. Battery Energy Storage System Integration
v. Grid Connection and Stability Analysis

These factors have been observed and evaluated in order to design a solar PV system as shown in Figure 3.5. designing a hybrid solar PV system with battery storage and grid connection using MATLAB Simulink involves modelling and simulating the components, optimizing control strategies, and analysing system performance to achieve an efficient and reliable design. MATLAB Simulink's capabilities facilitate this design process by providing a powerful platform for system modelling, simulation, and analysis.

3.6.1.1 PV Panel Modelling

Simulink provides a variety of ways to model PV panels. You can use electrical circuit models based on the diode equation, equivalent circuits such as the single-diode model or double-diode model, or detailed physical models that consider factors like irradiance, temperature, and shading effects. Simulink's blocks and components enable you to create an accurate representation of the behaviour of PV panel. For this project, SunPower SPR-305-WHT is used to be solar panel which will gain the solar irradiance to power up the system.

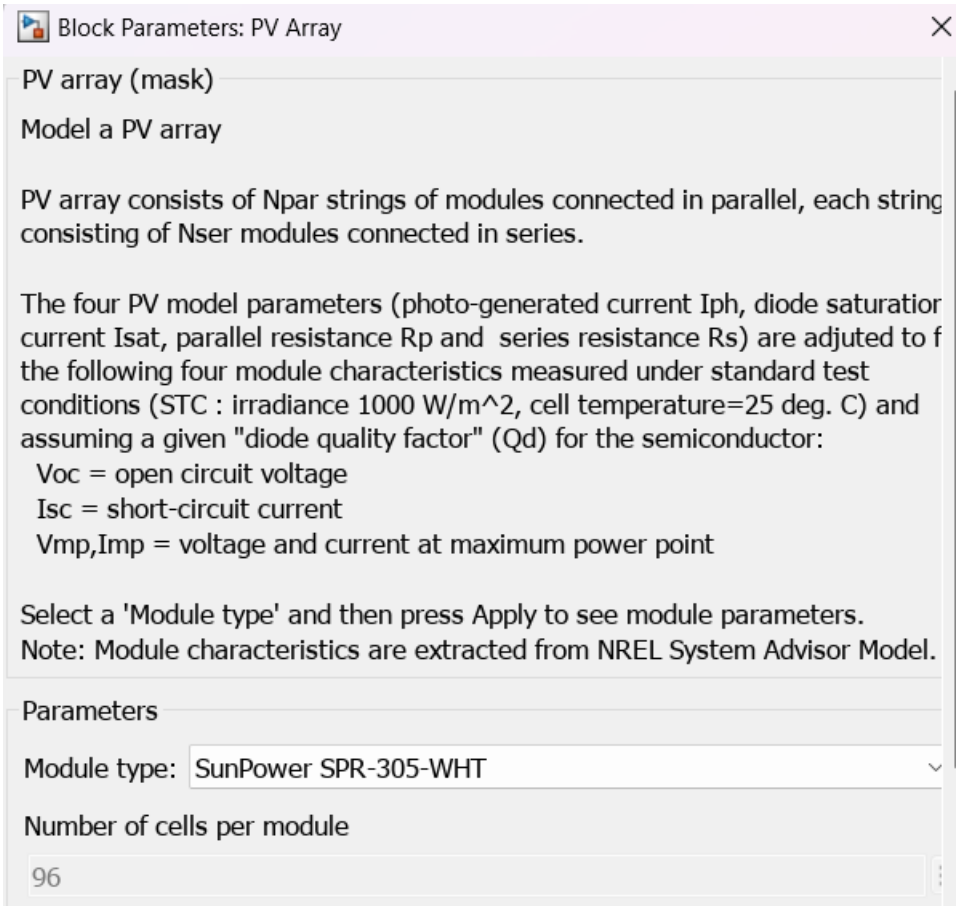

Figure 3.7 Parameter of Solar Panel

SunPower's High Efficiency Advantage - Up to Twice the Power

Comparable systems covering 1000 m² / 10,750 ft²			
	Thin Film	Conventional	SunPower
Watts / Panel	65	165	305
Efficiency	9.0%	12.0%	18.7%
kWs	**90**	**120**	**187**

Figure 3.8 Efficiency of SunPower-305-WHT

3.6.1.2 Maximum Power Point Tracking (MPPT)

Figure 3.9 MPPT Solar Charge Controller

MPPT stands for Maximum Power Point Tracking, and it is a crucial technique used in solar photovoltaic (PV) systems to maximize the power output from the PV panels. The MPPT algorithm continuously adjusts the operating point of the PV system to ensure that it operates at its maximum power point (MPP), where the panels generate the most power. The primary objective of the MPPT function in solar PV systems is to maximize the energy harvest from the PV panels.

The method used to set up the MPPT algorithm is the Perturb and Observe (P&O). The Perturb and Observe algorithm is a straightforward and easy-to-implement method for maximum power point tracking (MPPT) in photovoltaic (PV) systems. One of its advantages is that it does not require prior knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature. This makes it suitable for implementation with both analog and digital circuits.

The P&O algorithm operates by perturbing the operating point of the PV system, causing the terminal voltage of the PV array to fluctuate around the maximum power point (MPP) voltage. This occurs even if the solar irradiance and cell temperature remain constant. Due to its simplicity and satisfactory performance, the P&O algorithm is widely used and considered a workhorse in the field of MPPT [21].

By dynamically adjusting the operating parameters, such as voltage or current, the MPPT algorithm determines the optimal point on the current-voltage (I-V) curve where the power output is highest. This is crucial because the MPP of a PV panel changes with variations in solar irradiance, temperature, and other environmental factors. The MPPT algorithm continuously monitors the output of the PV panels and uses iterative techniques to track the MPP. It perturbs the operating point, either by incrementally changing the voltage or current, and observes the resulting change in power output. Based on the observed response, the algorithm adjusts the operating point further until the MPP is reached.

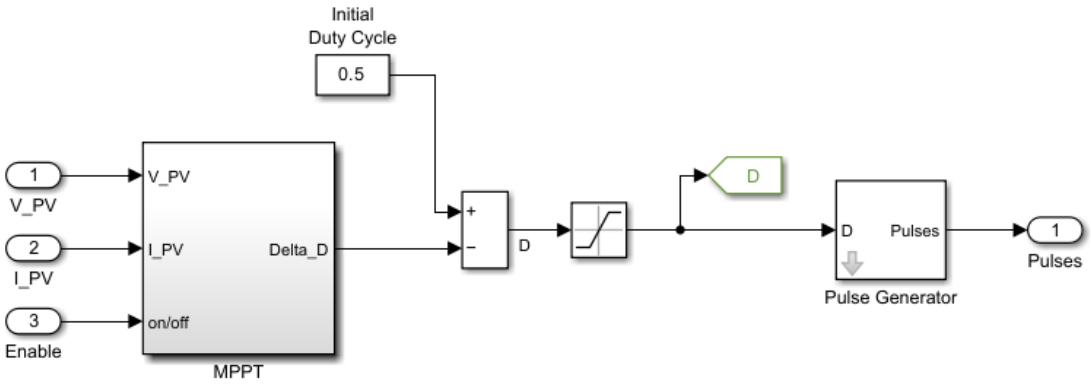

Figure 3.10 MPPT Block Diagram in MATLAB Simulink

By employing an accurate MPPT algorithm, the solar PV system can operate at the MPP, enabling it to extract the maximum available power from the PV panels. This function is critical for optimizing the energy production of the system, increasing its overall efficiency, and maximizing the utilization of solar energy resources.

3.6.1.3 Power Electronics Modelling

Power Electronics Modelling involves the representation and simulation of power electronic components and circuits used in various systems, including solar photovoltaic (PV) systems. It allows for the accurate analysis and evaluation of the behaviour and performance of these devices. Power Electronics Modelling encompasses the process of creating mathematical models and simulations for power electronic components, such as inverters, converters, and other devices utilized in diverse applications like solar PV systems. This modelling approach enables the accurate analysis and assessment of the electrical characteristics and dynamic performance of these components.

Power Electronics Modelling is particularly valuable in the design and optimization of solar PV systems. It allows engineers to simulate the behaviour of components like DC-DC converters, which are commonly employed to match the voltage levels between the PV panels and the load or energy storage systems. Inverters, which convert the DC output of PV panels into AC power for grid connection or local consumption, can also be accurately modelled.

By employing modelling techniques, engineers can represent power electronic components and circuits using mathematical equations and models that capture their electrical behaviour. These models take into account parameters such as voltage, current, switching characteristics, and control signals. Through simulation, the models can be used to predict and analyse various aspects of the power electronic devices' operation.

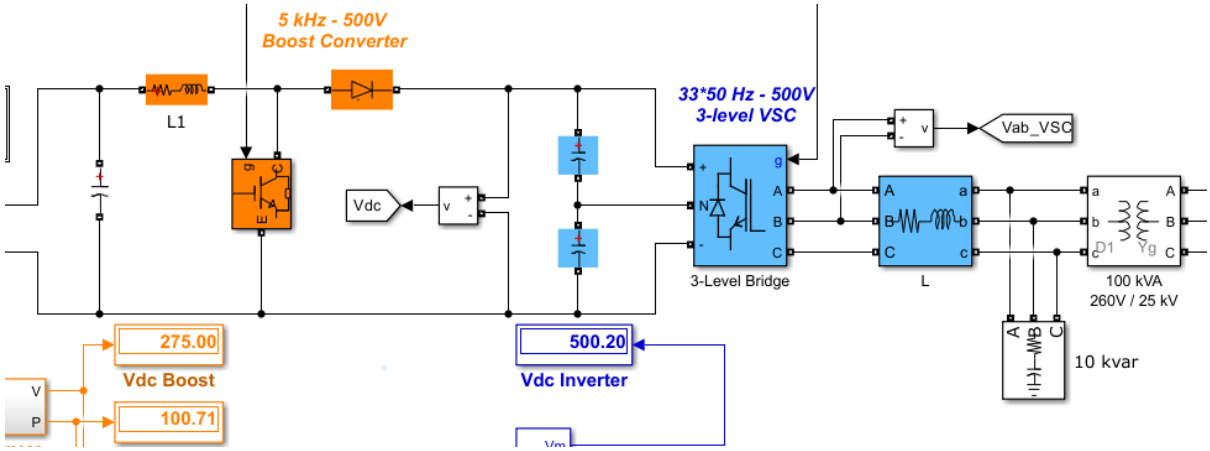

Figure 3.11 Power Electronics Modelling

Furthermore, Power Electronics Modelling enables engineers to assess the impact of power electronic devices on the overall system performance, including interactions with other system components, grid integration, and stability. This allows for comprehensive analysis and optimization of the power conversion and conditioning stages within a solar PV system.

3.6.1.4 Battery Energy Storage System Integration

Figure 3.12 MeritSun Solar PV panel Battery Pack

Battery Energy Storage System (BESS) Integration refers to the process of incorporating and optimizing battery energy storage within various systems, including renewable energy systems like solar photovoltaic (PV) systems. It involves the design, control, and management of batteries to enhance system performance, reliability, and energy management capabilities.

Battery Energy Storage System (BESS) Integration involves the seamless integration and effective utilization of battery energy storage in different applications, including renewable energy systems like solar PV systems. This integration encompasses the design, control, and management of batteries to enhance the overall performance, reliability, and energy management capabilities of the system. BESS Integration in solar

PV systems serves multiple purposes. Firstly, it enables the efficient storage of excess solar energy generated during periods of high solar irradiance. The energy stored in the batteries can then be utilized during periods of low solar generation or high energy demand, allowing for a more balanced and reliable power supply.

Secondly, BESS Integration plays a crucial role in grid support and stabilization. Battery systems can provide ancillary services such as frequency regulation, voltage control, and grid smoothing by injecting or absorbing power as required. This helps to maintain grid stability and improve the overall quality of the power supply. Thirdly, BESS Integration enables the optimization of self-consumption in solar PV systems. By intelligently managing the charging and discharging of batteries based on electricity demand and pricing, it allows for the maximization of self-consumed solar energy and the reduction of grid dependence. This can lead to cost savings and improved energy efficiency.

Simulation and modelling tools, such as MATLAB Simulink, can be utilized to design and evaluate the integration of battery energy storage in solar PV systems. By simulating the behaviour of the battery system under different operating conditions, engineers can assess its impact on the overall system performance, evaluate different control strategies, and optimize the sizing and operation of the battery for specific application requirements.

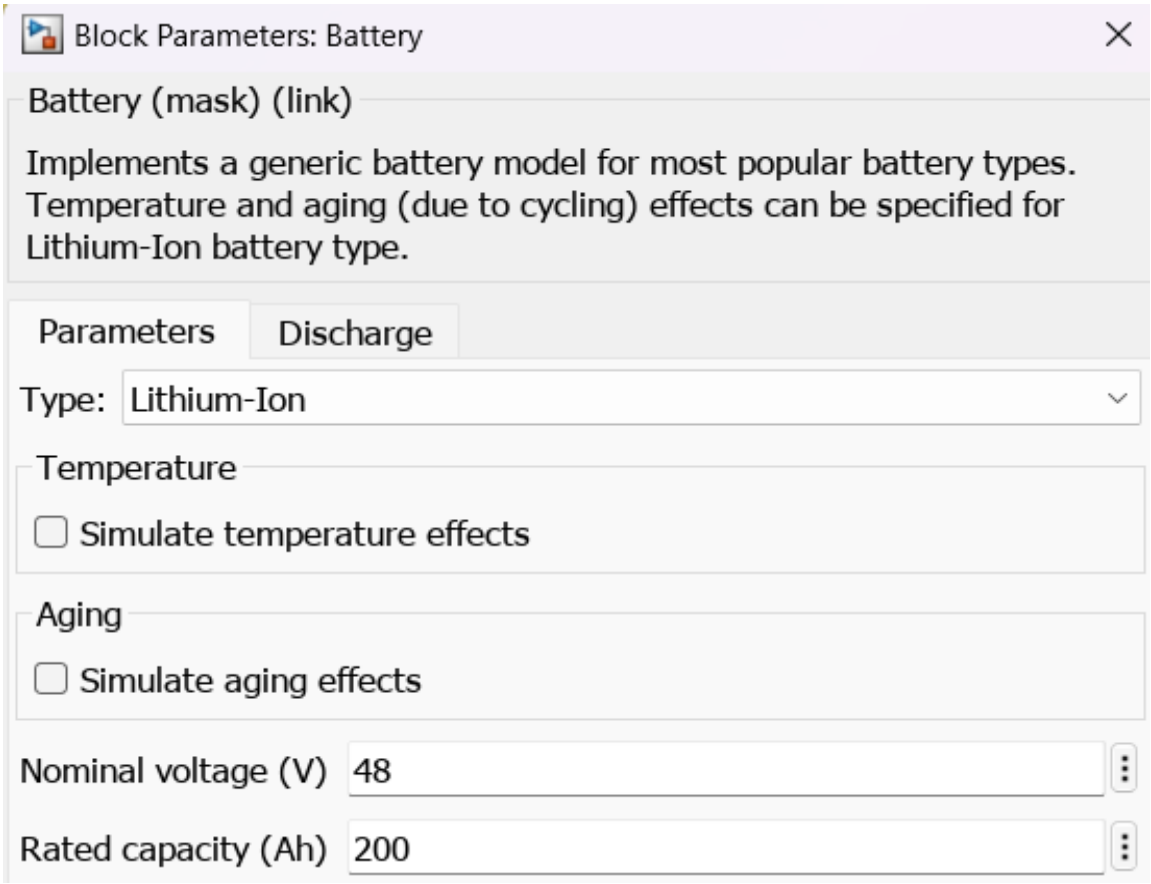

Figure 3.13 Parameter for Battery

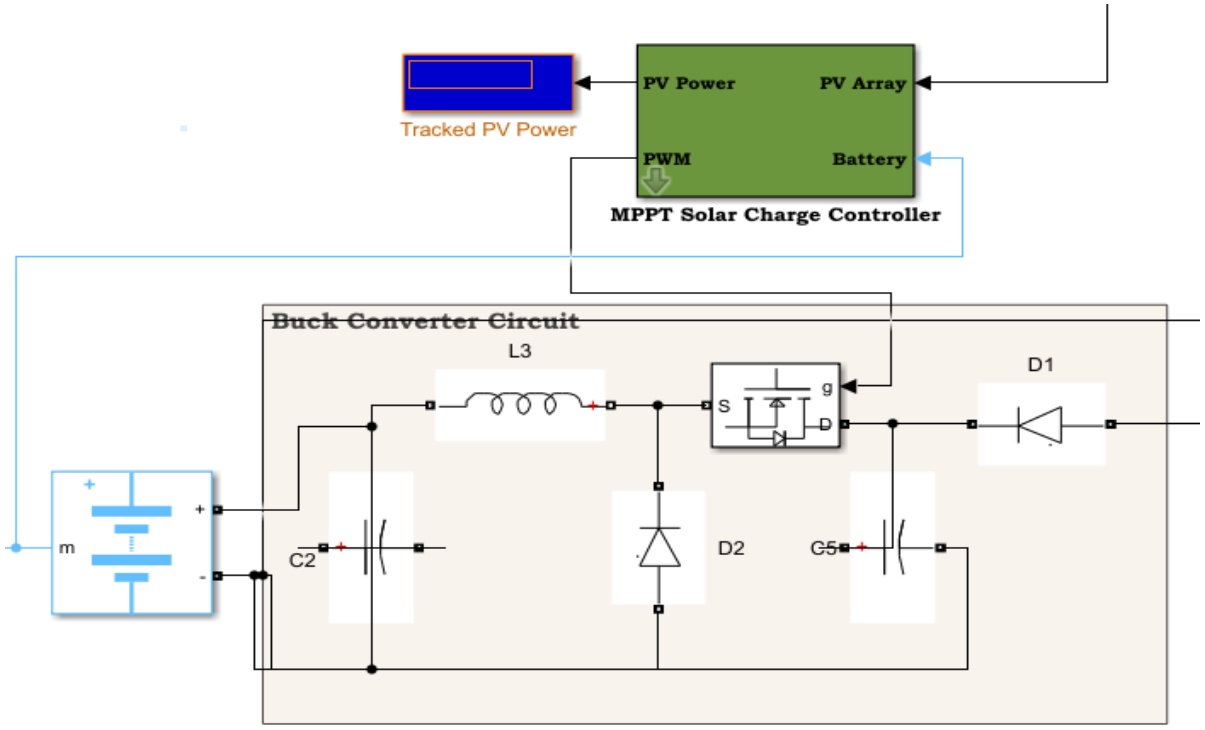

Figure 3.14 Battery Energy Storage System Integration

Battery Energy Storage System Integration is a critical aspect of solar PV systems that involves the seamless incorporation and optimization of battery energy storage. It enables efficient energy management, grid support, and self-consumption optimization. By designing, controlling, and managing battery systems, the overall performance and reliability of solar PV systems can be significantly enhanced.

3.6.1.5 Grid Connection and Stability Analysis

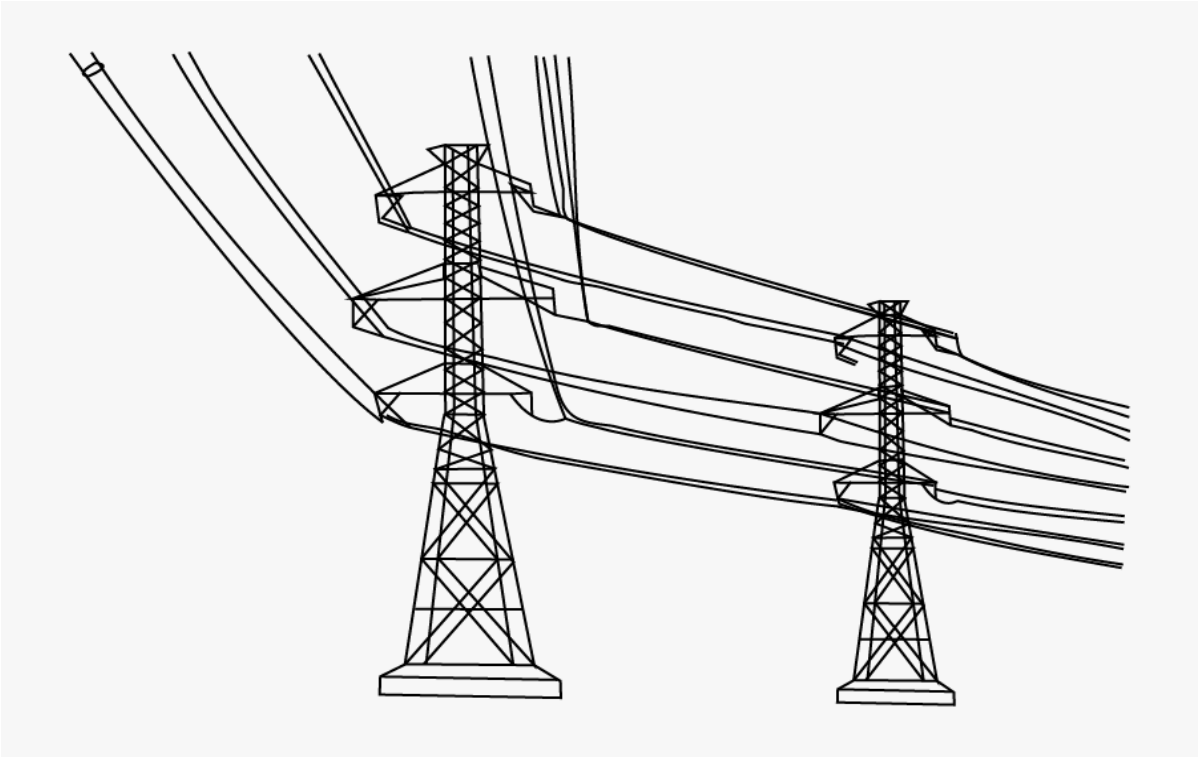

Figure 3.15 Electrical Power Grid

Grid Connection and Stability Analysis refer to the process of integrating a solar photovoltaic (PV) system with the electrical grid and evaluating the system's impact on grid stability. It involves assessing the behaviour and performance of the PV system in relation to the grid, ensuring compliance with grid requirements, and analysing the system's response to various grid conditions.

Grid Connection and Stability Analysis involve the seamless integration of a solar PV system with the electrical grid while evaluating the system's influence on grid stability. It encompasses the evaluation of the system's behaviour and performance in relation to the grid, ensuring adherence to grid standards, and analysing the system's response to diverse grid conditions.

Stability analysis focuses on assessing the dynamic behaviour and interaction between the solar PV system and the grid. It involves evaluating parameters such as voltage, frequency, power factor, and transient response to disturbances. This analysis aims to ensure that the PV system operates within acceptable limits and does not compromise the stability and quality of the grid.

To conduct grid stability analysis, engineers utilize simulation tools, such as MATLAB Simulink, to model the electrical characteristics of the PV system and the grid. The model includes representations of the PV panels, power electronics, control systems, and grid interfaces. By simulating various operating scenarios, such as changes in solar irradiance, load variations, or grid faults, engineers can analyse the system's performance, voltage and current profiles, power flow control, and grid synchronization.

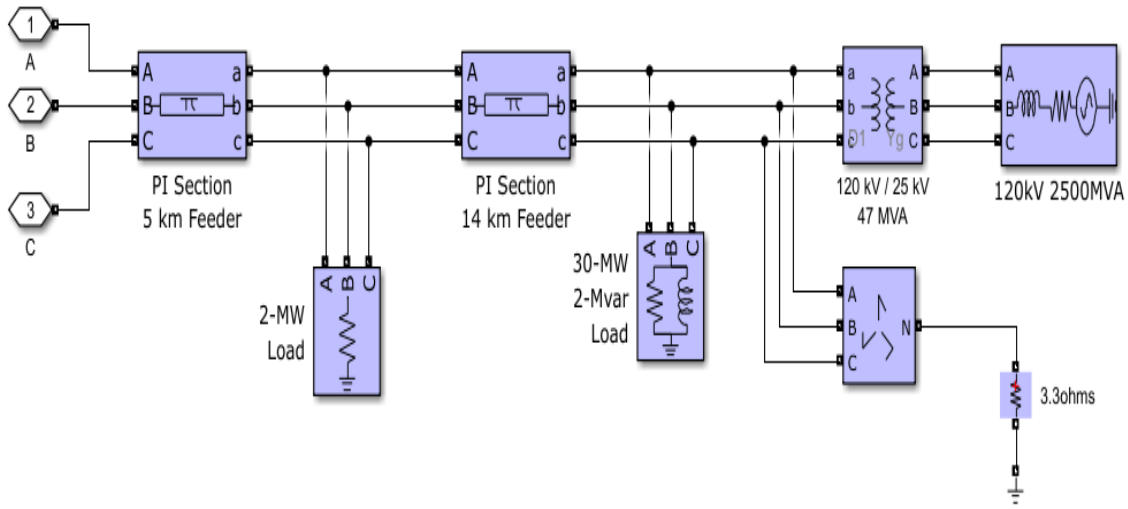

Figure 3.16 Block diagram of Grid Connection and Stability Analysis

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

This chapter discusses the results obtained from the simulation using MATLAB Simulink. The result is mainly focused on the power generated by the solar panels to power up the system and its relationship to the solar irradiance. There are three parts of the result which will be discussed. The first part in when the solar irradiance begins to decline and its effect on the power generated by the solar panel. The second part is when the switching between battery to electric grid happens after the solar irradiance begin to decline more. The third and the last part will demonstrate the aftermath of the system when the switching is completed. The discussion on the functionality and sustainability of the hybrid solar PV system will be reviewed further in this chapter.

4.2 Experimental Results

4.2.1 The Value of Solar Irradiance

Solar irradiance refers to the amount of solar power received per unit area on a surface perpendicular to the Sun's rays. It is a critical parameter in understanding the intensity of solar energy and plays a fundamental role in various applications, including solar power generation, meteorology, and climate studies. In this comprehensive explanation, we will delve into the concept of solar irradiance, its measurement, factors affecting it, and its significance in different fields.

Solar irradiance is measured in watts per square meter (W/m^2) and represents the instantaneous power of solar radiation at a specific location on Earth's surface. Various factors influence solar irradiance, including geographical location, time of day, time of year, atmospheric conditions, and solar zenith angle. Geographical location plays a

significant role as areas closer to the equator receive higher solar irradiance due to the more direct path of the Sun's rays. The time of day affects solar irradiance due to the changing solar zenith angle, which is the angle between the Sun and a line perpendicular to the Earth's surface. Solar irradiance is highest around solar noon when the Sun is at its highest point in the sky.

The time of year also affects solar irradiance due to the Earth's axial tilt, resulting in variations in the Sun's angle relative to different regions. During summer in the Northern Hemisphere, for example, the Sun is higher in the sky, leading to increased solar irradiance. Atmospheric conditions play a crucial role as well. Cloud cover, air pollution, and the presence of aerosols in the atmosphere can scatter or absorb sunlight, reducing solar irradiance. Water vapor and other greenhouse gases in the atmosphere can also impact solar irradiance by absorbing specific wavelengths of sunlight.

In Malaysia, solar irradiance varies across different regions and seasons due to factors such as geographical location, weather patterns, and atmospheric conditions. Analysing the maximum, average, and minimum solar irradiance in Malaysia provides valuable insights into the solar energy potential of the country.

The maximum solar irradiance in Malaysia typically occurs during the dry season, which generally spans from March to September. This period is characterized by longer hours of sunshine and fewer cloud cover. Regions closer to the equator, such as Perlis, Kedah, and Penang, tend to experience higher solar irradiance compared to regions further away from the equator. In these areas, the maximum solar irradiance can reach values of around 1,000 to 1,200 watts per square meter (W/m^2) or higher. These high levels of solar irradiance make these regions favourable for solar energy projects and installations.

The average solar irradiance in Malaysia is influenced by both the dry and wet seasons. Malaysia experiences a monsoonal climate, with two distinct monsoon seasons: the Southwest Monsoon (May to September) and the Northeast Monsoon (November to March). During the wet seasons, cloud cover and precipitation increase, resulting in reduced solar irradiance. However, due to Malaysia's proximity to the equator, the average solar irradiance remains relatively high throughout the year. On average, solar irradiance levels in Malaysia range from approximately 800 to 1,000 W/m².

The minimum solar irradiance in Malaysia typically occurs during the wet monsoon seasons when cloud cover is more prevalent. The Northeast Monsoon, which affects the eastern coast of Peninsular Malaysia and parts of Borneo, brings heavier rainfall and increased cloudiness, resulting in lower solar irradiance levels. During this period, solar irradiance values can drop to around 400 to 600 W/m² or lower in some areas. However, it is important to note that even during the wet monsoon seasons, there are still days with clearer skies and relatively higher solar irradiance.

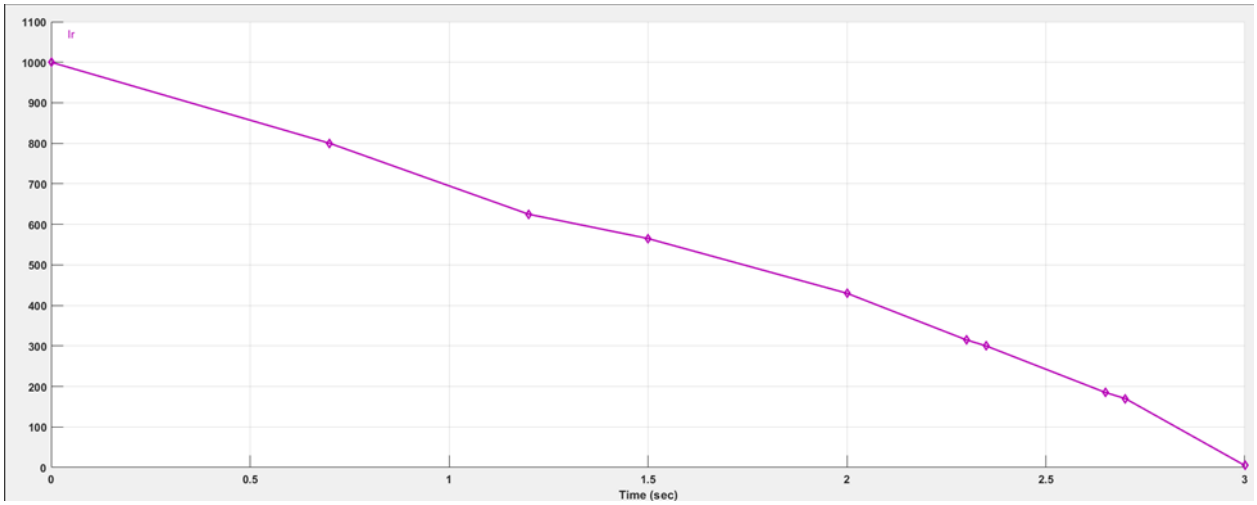

Figure 4.1 Manipulated Values of Solar Irradiance (W/m^2)

The values of solar irradiance are manipulated from 1000 W/m^2 to 0 W/m^2 in order to illustrate the various condition that will affect the solar energy gained from the solar panel as mentioned before. The value of solar irradiance is set up as so to simulate the power generated by solar panels, battery capacity and voltage produced in the circuit throughout the maximum, average and minimum value of solar irradiation. Power generated by solar panels, battery capacity and voltage produced in the circuit is relatively.

4.2.2 The Values of Power Generated by Solar Panels to the System

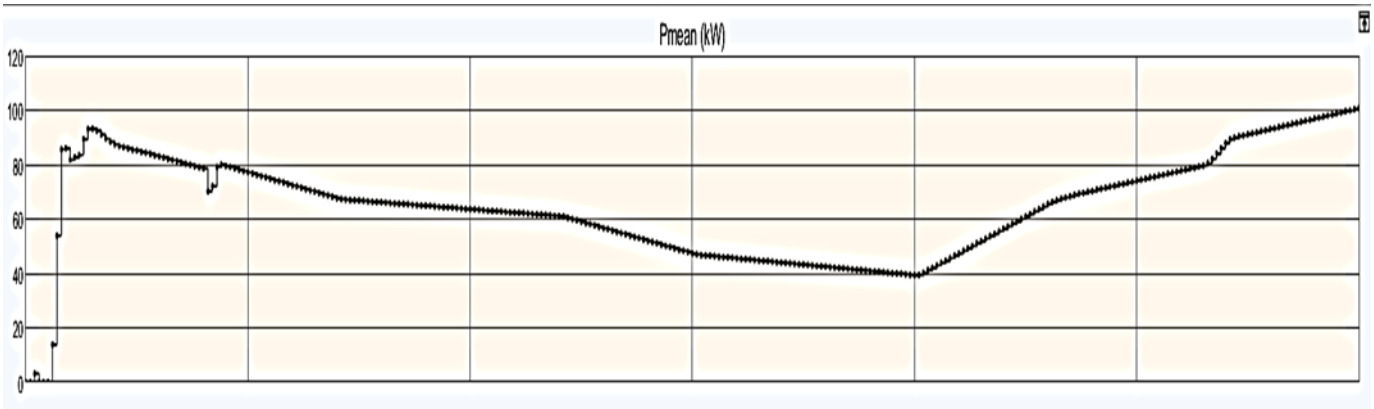

Figure 4.2 The Values of Power Generated by the Solar Panels to the System

In the MATLAB Simulink simulation, a clear relationship between solar irradiation and the power generated by solar panels was observed. The solar irradiation values were varied during the 3-second runtime to examine the corresponding changes in the power generated.

Throughout the simulation, a distinct pattern in the solar irradiation values is observed, directly impacting the power output of the solar panels. As the solar irradiance input is manipulated from 1000W/m^2, noticeable variations in the power generation are taken account to, indicating a strong correlation between these two variables. Experimenting with different levels of solar irradiation provided valuable insights into how the solar panels responded to varying irradiation levels. This allowed for a better understanding of the behaviour of the solar panels in generating power.

In general view, the power generation in the system declines to the lowest point at 40 kW/h before it increases to 100 kW/h in the end. This occurred due to the switching of electrical supply from battery to the electric grid. When a solar PV system transitions from relying on a battery as its primary source of electricity to drawing power from the electric grid, several changes occur in the power generation dynamics. Initially, the solar panels generate power by converting sunlight into electricity through the photovoltaic effect. This power is primarily used to fulfil the immediate demand of the system, with any excess energy being stored in the battery for later use.

4.2.3 The First Part of the Simulation

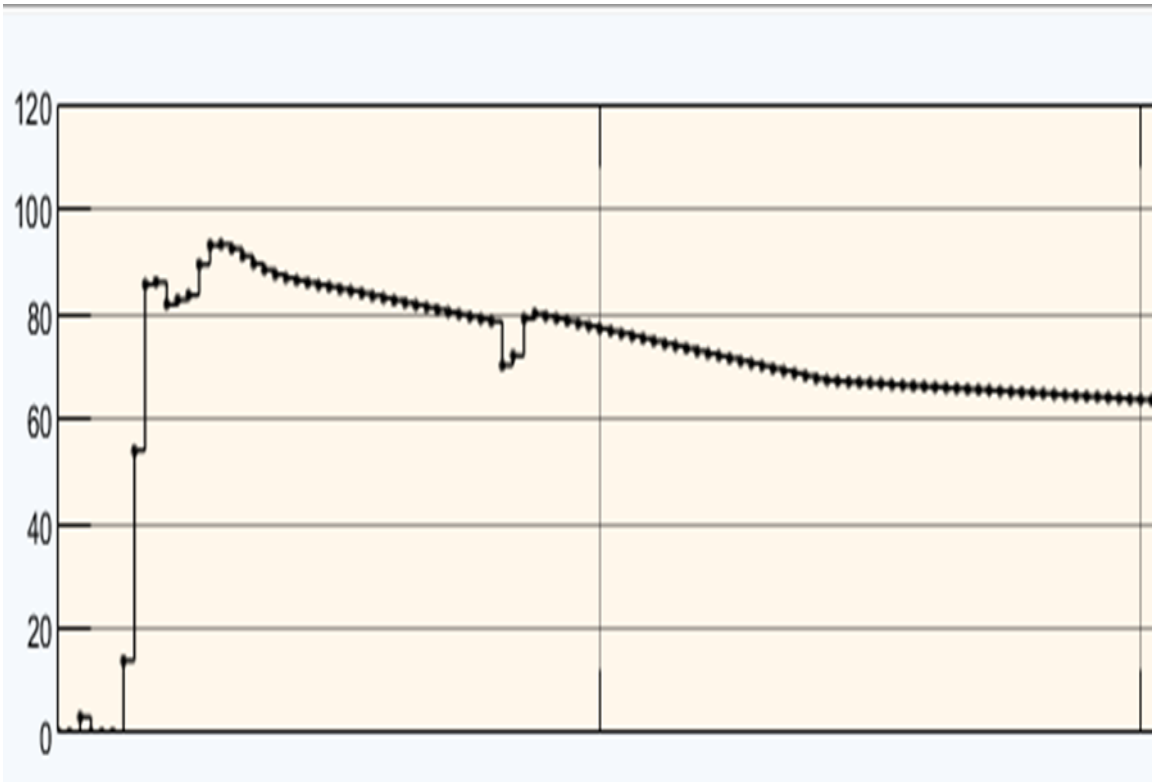

Figure 4.3 Graph of the First Part of the Simulation

The first part of the simulation shows that the power generated by the solar panels decreases as the solar irradiance. During this period, the energy gained by the solar panels is not enough to maintain the power needed to generate electrical energy for the system. The early stage of the graph shows the power generated is 0 kW/h before it rises to 95 kW/h. The solar power generated by the solar panels charges the battery as the battery is the main supply of electricity to the system. As time goes by, the power generated started to decrease as the solar irradiance decreases. The battery does not have enough energy to supply the system which results in the power generated dropping to 60 kW/h.

During this period of simulation, the value of power generated decreases as the solar irradiance decreases. The area exposed to the sunlight, or solar irradiance, directly affects the amount of energy available for conversion into electricity. When solar irradiance decreases, there is a reduction in the intensity of sunlight reaching the solar panels.

Solar panels operate by converting sunlight into electricity through the photovoltaic effect. Photons from sunlight strike the solar cells, exciting electrons within the semiconductor material and creating an electric current. However, with lower solar irradiance, fewer photons reach the solar panels, resulting in a decrease in the number of excited electrons and subsequently a lower electric current output.

In normal sunlight conditions, with higher solar irradiance, there is a greater number of photons available to interact with the solar cells. This means more electrons within the semiconductor material can be excited and enter a higher energy state. As a result, a larger number of excited electrons are available for the creation of an electric current, leading to higher power generation.

However, when solar irradiance decreases, the number of photons striking the solar panels also decreases. With a reduced number of photons, fewer electrons within the semiconductor material are excited, resulting in a lower electric current being generated. The power output of the solar panels is directly proportional to the number of excited electrons and the corresponding electric current.

4.2.4 The Second Part of the Simulation

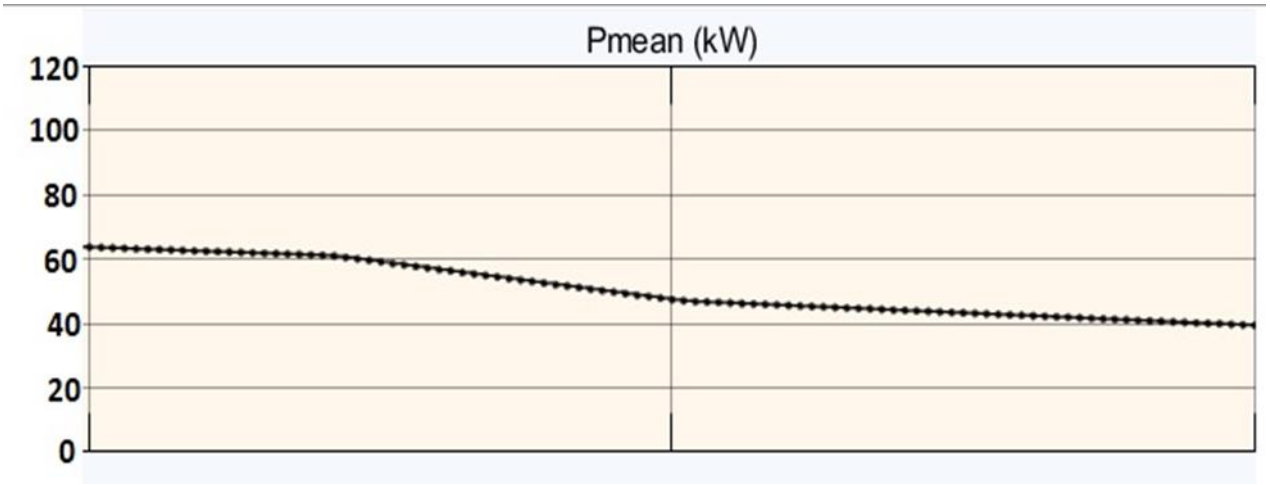

Figure 4.4 Graph of the Second Part of the Simulation

For the second part of the simulation, the graph 4.2.2.2 shows the dramatic decrease of power generated when the solar irradiance is around 500 W/m2. The power generated at this point is 40 kW/h. During this period, the battery started to switch to the electric grid to supply electricity to the system as the battery does not have enough energy to support the system.

Batteries in a solar PV system are charged during periods of excess solar generation, typically during the day when the sunlight is abundant. They store this excess energy for later use. When the battery charge level drops below a certain threshold, it indicates that the stored energy is running low. To ensure a continuous power supply, the system switches to the electric grid as a backup power source.

The presence of energy imbalance in the hybrid solar PV systems has generated electricity from sunlight, which is intermittent and varies throughout the day. During periods of low sunlight or at night, the solar panels produce less or no electricity. If the energy demand exceeds the amount being generated by the solar panels, the battery takes over to supply the additional power required.

Due to the stated reason, battery capacity is insufficient to meet the peak demand. As a result, the system switches to the grid to fulfil the additional power requirements. The automatic switching between battery power and the electric grid is typically managed by a solar inverter or a hybrid inverter, which monitors the system's parameters and controls the flow of electricity. The goal is to optimize self-consumption of solar energy and minimize reliance on the grid while ensuring a reliable power supply at all times.

4.2.5 The Third Part of the Simulation

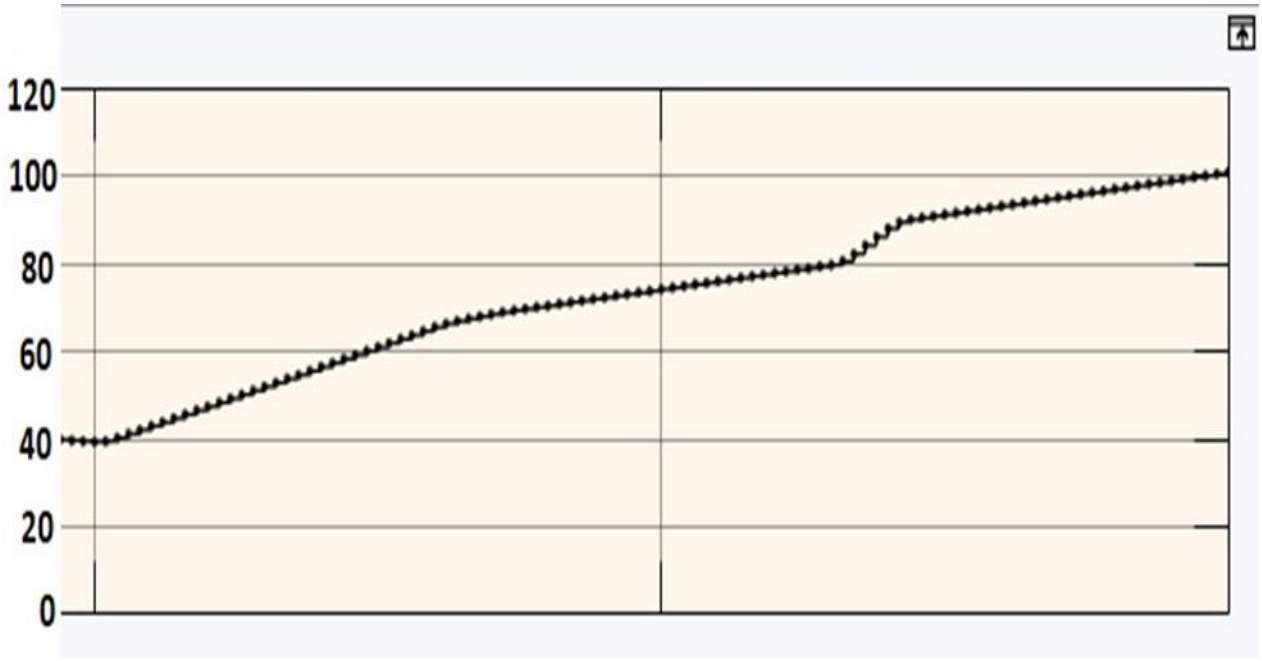

Figure 4.5 Graph of the Third Part of the Simulation

The third part of the simulation shows the moment when the battery switches to the electricity grid. By referring to graph in 4.2.1, during this period, the solar irradiance drops from 400 W/m2 to 0 W/m2. The system manages to gain electrical energy to power up the system due to the electric supply from the grid. The power generated in the system rises from 40 kW/h to 100 kW/h in order to maintain the electrical supply to the system.

Switching from battery power to the electric grid is a crucial aspect of solar PV systems with battery storage. This transition occurs when the solar irradiance drops significantly, rendering solar panels incapable of generating sufficient electricity to meet the energy demand of the system. During this phase, the system relies on the electric supply from the grid to power up the electrical loads and maintain a continuous power supply. Let's explore this process in detail.

In a solar PV system with battery storage, the inverter or hybrid inverter plays a pivotal role in managing the system's operation. It continuously monitors the battery charge level, ensuring it remains above a predefined threshold set to optimize the battery's longevity. When the inverter detects that the battery charge has fallen below this threshold, it sends a signal to deactivate the battery.

The deactivation process involves disconnecting the battery from the system's electrical circuit. By isolating the battery, it is effectively prevented from supplying power to the system. At this point, the system transitions from relying on battery power to drawing electricity from the electric grid.

Simultaneously, the inverter facilitates the charging of the battery whenever there is an opportunity to do so. This occurs when excess solar energy becomes available or during periods of low energy consumption. When the solar panels generate more electricity than the immediate demand of the building, the surplus energy is directed to a separate charging circuit that replenishes the battery's charge level. This charging process is essential for storing energy and ensuring the availability of power during subsequent periods of low solar irradiance.

After the battery is deactivated, the power electronics system automatically initiates a switch in the power source. This switch occurs seamlessly and without noticeable interruption to the electrical loads. The solar PV system, which previously relied on battery power, now starts drawing electrical energy directly from the electric grid to meet the energy demand of the household or facility.

The electrical loads in the building, including lights, appliances, and other devices, continue to receive power during this transition. However, the power now originates from the grid instead of the battery. The grid supply serves as a reliable backup power source, ensuring uninterrupted electricity supply when solar energy production is insufficient, or the battery charge level is low.

Switching to the electric grid signifies a temporary reliance on grid power as the primary energy source. It enables the solar PV system to bridge the gap between solar generation and energy demand, ensuring continuous power supply. This grid dependency is particularly important during periods of low solar irradiance, such as at night or during cloudy weather.

By seamlessly switching to the electric grid, the solar PV system with battery storage ensures a reliable power supply. It mitigates the limitations associated with solar energy intermittency and battery charge depletion. This integration of grid power as a backup source enhances the overall reliability of the system, providing users with a consistent supply of electricity regardless of fluctuations in solar generation.

In summary, when the battery charge level drops below a predefined threshold, the solar PV system with battery storage switches to the electric grid. The battery is deactivated and disconnected from the system's electrical circuit, preventing it from supplying power. The system seamlessly transitions to drawing electrical energy from the grid to power the electrical loads. Meanwhile, the inverter takes advantage of opportunities to recharge the battery whenever excess solar energy is available or during periods of low energy consumption. This integration of grid power as a backup source ensures a continuous power supply, enhances system reliability, and provides uninterrupted electricity even when solar energy production is insufficient, or the battery charge level is low.

4.3 Limitation of the Project

MATLAB Simulink provides a valuable platform for system modelling and analysis, it has inherent constraints that may hinder the accuracy and real-world representation of hardware-based implementations. The limitations of using MATLAB Simulink compared to building the hardware are as follow:

i. Hardware Representation:

MATLAB Simulink simulations employ mathematical models to approximate the behaviour of hardware components. However, these models may not fully capture the intricacies and variations found in real-world hardware. Components such as solar panels, batteries, and power electronics possess unique characteristics and performance variations that can significantly impact the overall system behaviour. MATLAB Simulink models often simplify these complexities, resulting in a less accurate representation of the actual hardware.

ii. System Dynamics:

Accurate representation of system dynamics is essential for reliable simulation results. However, MATLAB Simulink simulations rely on pre-defined mathematical models and idealized assumptions about the system dynamics. In reality, solar PV systems are influenced by various factors, including solar irradiance, ambient temperature, load variations, and grid conditions. These factors introduce non-linearities and time-varying behaviour that may not be adequately captured by the simplified models used in MATLAB Simulink simulations. As a result, the simulation results may deviate from the actual system performance. To mitigate this limitation, it is important to refine the mathematical models used in MATLAB Simulink to better capture the complexities of system dynamics and validate the simulation results against real-world data.

iii. Control Algorithms:

Efficient control algorithms play a crucial role in optimizing the performance of solar PV systems with battery storage and grid connection. MATLAB Simulink provides a platform for implementing and testing control strategies. However, the effectiveness of these algorithms in real-world scenarios cannot be solely determined through simulations. Control algorithms developed and tested in MATLAB Simulink may require further refinement and validation on hardware platforms to ensure their robustness and effectiveness. Factors such as component interactions, system dynamics, and environmental conditions can affect the performance of control algorithms, and these aspects are not always accurately captured in MATLAB Simulink simulations.

iv. Environmental Factors:

Solar PV systems are highly dependent on environmental factors such as temperature, humidity, and shading. These factors can significantly impact the performance of the system. However, MATLAB Simulink simulations often rely on fixed or average values for environmental conditions, which may not reflect the real-world variations. The assumptions made in the simulations can lead to discrepancies between the simulated results and the actual system performance. To address this limitation, it is important to consider the variability of environmental factors and incorporate realistic models or data in MATLAB Simulink simulations. Validation against real-world measurements under varying environmental conditions is necessary to ensure accurate representation and reliable performance predictions.

CHAPTER 5

CONCLUSION

5.1 General Conclusion

Solar photovoltaic (PV) systems, harnessing the power of the sun to generate clean electricity, have emerged as a leading solution in the global energy landscape. The integration of battery storage and grid connectivity with solar PV systems has gained significant attention. One of the significant advantages of this technology combination is its contribution to renewable energy generation and reduced carbon footprint. By harnessing solar energy, these systems reduce reliance on fossil fuels and lower greenhouse gas emissions, making a substantial positive impact on the environment. The ability to store excess solar energy in batteries also enhances energy independence and resilience, allowing users to rely less on the grid and ensuring a reliable energy supply during grid outages or emergencies.

Peak shaving and load shifting are additional benefits offered by solar PV systems with battery storage and grid connection. Battery storage enables the reduction of electricity demand during peak load periods, helping to alleviate strain on the grid and mitigate costly peak-hour rates. Furthermore, load shifting allows users to consume stored energy during high electricity rate periods, resulting in significant cost savings. These financial benefits, combined with potential income from excess energy exports, provide a compelling economic case for adopting solar PV systems with battery storage.

Moreover, solar PV systems with battery storage can provide ancillary services to the grid, improving grid stability and reliability. These services include frequency regulation, voltage support, and grid balancing, which contribute to the efficient operation of the overall electricity network. By actively participating in grid operations, solar PV systems with battery storage enhance the integration of renewable energy into existing grids and support the transition to a more sustainable and resilient energy system.

5.2 Limitations

While solar PV systems with battery storage offer significant advantages, they also present challenges that need to be addressed for their widespread adoption. One primary concern is the cost associated with batteries. Currently, batteries contribute a significant portion to the overall system cost. However, with advancements in technology and increasing economies of scale, the cost of batteries is expected to decline, making these systems more affordable in the future.

Another challenge is the environmental impact of battery production and disposal. Battery manufacturing involves the extraction of raw materials, which can have environmental consequences if not managed sustainably. Additionally, battery disposal at the end of their lifecycle requires proper recycling to avoid environmental pollution. Continued research and development efforts are necessary to improve battery efficiency, lifespan, and sustainability.

Integration with the existing grid infrastructure also poses challenges. Grid regulations and policies need to be updated to accommodate the integration of solar PV systems with battery storage. Clear guidelines on net metering, feed-in tariffs, and grid connection standards are required to ensure fair compensation for excess electricity generation and a seamless integration process.

Another limitation of the hybrid solar PV system is intermittency: Solar PV systems rely on sunlight for electricity generation. Therefore, their output is subject to fluctuations due to weather conditions, such as cloud cover and seasonal variations. This intermittency can impact the reliability and predictability of solar energy generation.

There are researches have been carried on in order to improve the efficiency and performance. As mentioned before, Solar PV systems have certain efficiency limitations. Factors such as panel degradation over time, shading effects, and variations in temperature can affect system performance. Additionally, battery efficiency can be influenced by factors like energy conversion losses and self-discharge rates.

Addressing these limitations requires ongoing research and development efforts, technological advancements, supportive policies, and improved infrastructure. By mitigating these challenges, hybrid solar PV systems with battery storage and grid connection can play a more significant role in achieving a sustainable and renewable energy future.

5.3 Future Scope

The potential impact of solar PV systems with battery storage on grid infrastructure should not be overlooked. By decentralizing power generation and storage, these systems reduce strain on the grid, enhance grid stability, and contribute to load balancing. Moreover, when combined with smart grid technologies, solar PV systems with battery storage can enable demand response programs, optimizing energy consumption and reducing peak demand.

Solar PV systems with battery storage present several opportunities for the future. As battery technology advances, the storage capacity and efficiency of batteries will increase, allowing for longer durations of energy storage. This will further enhance the viability of renewable energy sources and contribute to the transition toward a cleaner and more sustainable energy future.

Moreover, solar PV systems with battery storage can foster energy independence and resilience at the individual and community levels. In the event of natural disasters or grid failures, these systems can provide critical backup power, improving emergency preparedness and response capabilities.

The integration of solar PV systems, battery storage, and grid connectivity with advanced digital technologies is another key aspect of the future. Smart grids will enable real-time monitoring, intelligent control, and optimized energy flows, ensuring grid stability and supporting demand response programs. This integration will enable the seamless integration of diverse energy sources and facilitate the transition to a more decentralized energy ecosystem. Moreover, the rise of microgrid and community applications will allow for localized energy generation, storage, and distribution. This approach enhances energy independence, resilience, and fosters energy-sharing models within communities, reducing reliance on traditional grid infrastructure.

The electrification of transportation presents another avenue for the future of solar PV systems with battery storage and grid connection. Electric vehicles (EVs) can serve as mobile energy storage units, allowing for vehicle-to-grid (V2G) integration. By utilizing EV batteries to store and supply energy to the grid, V2G technology enhances grid stability and provides additional revenue streams for EV owners. This synergy between solar PV systems, battery storage, and EVs contributes to a more sustainable and integrated energy ecosystem.

Advanced energy management systems will play a crucial role in optimizing the performance of solar PV systems with battery storage. Leveraging artificial intelligence, machine learning, and predictive analytics, these systems will intelligently manage energy flows based on weather conditions, consumption patterns, and electricity rates. This optimization will maximize self-consumption, minimize grid dependence, and further enhance the efficiency and effectiveness of these systems.

Market growth and policy support are also key drivers for the future of solar PV systems with battery storage and grid connection. The solar PV industry is experiencing significant growth due to declining costs, increasing environmental awareness, and supportive government policies. Favourable regulations, financial incentives, and feed-in tariffs encourage the adoption of these systems, promoting their widespread deployment and market viability.

In conclusion, the future of solar PV systems with battery storage and grid connection is characterized by technological advancements, enhanced energy management systems, integration with smart grids and EVs, microgrid applications, and supportive policies. These developments will contribute to increased energy generation, improved efficiency, reduced costs, enhanced grid stability, and greater renewable energy integration, paving the way for a sustainable and decentralized energy future.

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