DESIGN AND IMPLEMENTATION OF AN OFF-GRID PHOTOVOLTAIC SYSTEM FOR OPTIMAL UTILIZATION IN RURAL AREAS

BY

FAVOUR OGAGAOGHENE OGHENEKOWHO	**ENG1804772**
ATARHE JUDE OGHENEMEGA	**ENG1810277**
ADEBUDO DIVINE JESULUNAHME	**ENG1805598**
INEGBEDION ODIANOSEN LAWRENCE	**ENG1805079**
OLA NOSAKHARE DESTINY	**ENG1604183**
UGBENI EMMANUEL OSEMUDIAME	**ENG1809291**
SADOH JOSEPH OYIAREKHUA	**ENG1810685**
EHIS SAMUEL AMIENGHEMEN	**ENG1707796**

DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING
UNIVERSITY OF BENIN
BENIN CITY

APRIL, 2024

DESIGN AND IMPLEMENTATION OF AN OFF-GRID PHOTOVOLTAIC SYSTEM FOR OPTIMAL UTILIZATION IN RURAL AREAS

BY

FAVOUR OGAGAOGHENE OGHENEKOWHO	**ENG1804772**
ATARHE JUDE OGHENEMEGA	**ENG1810277**
ADEBUDO DIVINE JESULUNAHME	**ENG1805598**
INEGBEDION ODIANOSEN LAWRENCE	**ENG1805079**
OLA NOSAKHARE DESTINY	**ENG1604183**
UGBENI EMMANUEL OSEMUDIAME	**ENG1809291**
SADOH JOSEPH OYIAREKHUA	**ENG1810685**
EHIS SAMUEL AMIENGHEMEN	**ENG1707796**

A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN IN PARTIAL FULFILLMENT FOR THE REQUIREMENT OF THE AWARD OF THE BACHELOR OF ENGINEERING (BENG) DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING.

APRIL, 2024

CERTIFICATION

This is to certify that the project titled "Design and implementation of an off-grid system for optimal utilization in rural areas" submitted in partial fulfilment of the requirements for the award of degree Bachelor of Engineering from the department of Electrical and Electronic Engineering, was performed by **FAVOUR OGAGAOGHENE OGHENEKOWHO, ADEBUDO DIVINE JESULUNAHME, INEGBEDION ODIANOSEN LAWRENCE, OLA NOSAKHARE DESTINY, UGBENI EMMANUEL OSEMUDIAME, SADOH JOSEPH OYIAREKHUA, AMIENGHEMEN EHIS SAMUEL,** and **ATARHE JUDE OGHENEMEGA** has been read and approved for meeting part of the requirement and regulations governing the award of Bachelors of Engineering degree in University of Benin, Benin City, Edo State, Nigeria.

PROF. S.O. IGBINOVIA **PROJECT SUPERVISOR**	**DATE**
ENGR. E.I. IBHADODE **CO. SUPERVISOR**	**DATE**
PROF. K.O. OGBEIDE **HEAD OF DEPARTMENT**	**DATE**

DEDICATION

This project is dedicated to God Almighty for His grace, provision, and blessing of good health throughout the duration of the work.

ACKNOWLEDGEMENT

We extend our deepest gratitude to Prof. S.O. Igbinovia and Engr. E.I. Ibhadode for their steadfast support and encouragement throughout the project. Their invaluable insights, recommendations, and guidance have been indispensable, and we attribute our success confidently to their contributions. Additionally, we would like to express our heartfelt appreciation to our parents, whose unwavering belief in our abilities as individuals has inspired us to unite as a team, collaborate, and achieve remarkable heights. Their guidance and financial support have served as a constant source of encouragement, and we are truly grateful for their unwavering backing.

ABSTRACT

Access to reliable and sustainable electricity remains a significant challenge in many rural areas worldwide. In addressing this issue, off-grid photovoltaic (PV) systems have emerged as a promising solution due to their environmental friendliness, scalability, and decreasing costs. This paper presents the design and implementation of an off-grid PV system tailored for optimal utilization in rural areas. With the aim of addressing the energy needs of a modern 2-bedroom apartment located in a rural community, this study emphasizes the development of a self-sustaining PV system capable of providing reliable electricity access independent of the traditional grid infrastructure.

The design process begins with a comprehensive assessment of the energy needs and resource availability of the target rural community and in this case a 2-bedroom apartment. This assessment includes factors such as household electricity consumption patterns, local climate conditions, solar irradiance data, and geographical characteristics. Utilizing this data, the system's components are sized appropriately to meet the community's energy demands reliably. Since, our system will be independent of the traditional grid infrastructure, we made sure that our system will be able to sustain the energy requirement of the two-bedroom residential for an average of 19 hours, this led us to the following system requirement of 15,975W solar panel capacity, 915.2Ah battery capacity and a 4KVA inverter capacity, this translates to using 32 solar panels with each rated 500W, 16 batteries each 12V. The core components of the PV system include photovoltaic panels, charge controllers, batteries, inverters, and distribution systems. Each component is carefully selected based on efficiency, durability, and compatibility to ensure maximum system performance and longevity in rural settings. Furthermore, the implementation phase involves the installation and integration of the PV system into the 2-bedroom apartment. Monitoring and evaluation mechanisms were established to track the performance and impact of the PV system over time.

In line with our study, we came to discover that the optimal tilt angle of solar panel in the University of Benin, Ugbowo campus (test location) was 20° which is in line with the reference angle of 0° to 42°. A DC load test was carried out on the implemented PV system, resulting in a short circuit current of 1.45A and an open circuit voltage of 13.75V. Additionally, a charging test revealed that it took 6.86 hours to charge a 100Ah, 12V battery using a 200W solar panel operating at a voltage of 13.72V. Simulation of the proposed PV system was obtained using the PVSYST simulation software, from the simulation we discovered that the system produces an annual energy of 14,341kWh/year with a performance ratio of 0.515, the daily input/output graph also show variability which is connected to the irradiance and seasonal variations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

In recent years, addressing energy poverty and promoting sustainable electrification in rural areas has emerged as a critical global concern as the world move to sustainable energy generation. The lack of access to reliable electricity significantly impacts the lives of millions, hindering socio-economic development, education, healthcare, and overall quality of life in these regions. As a response to this challenge, the implementation of fully fled off-grid solar systems have garnered significant attention as a feasible solution to provide reliable and sustainable power in rural communities.

Renewable energy systems, such as solar power systems, offer a promising avenue for electrification in areas without access to centralized grid infrastructure. These systems consist of solar panels that convert sunlight into electricity, energy storage solutions such as batteries, and necessary power electronics to regulate and distribute the generated electricity for local use. Implementing such systems requires a comprehensive understanding of the unique requirements and constraints of rural areas, including factors such as energy demand patterns, climatic conditions, local infrastructure, and socio-economic dynamics.

The implementation of an optimised off-grid PV (photovoltaic) system tailored specifically for rural areas involve several critical aspects. These include selecting appropriate photovoltaic technologies and components, sizing the system based on energy demand and available solar resources, optimising the system for cost-effectiveness and reliability, integrating energy storage solutions for uninterrupted power supply, and considering community engagement and capacity building for sustainable operation and maintenance.

This study aims to investigate the design and implementation intricacies of an off-grid PV system customised for optimal utilisation in rural areas. It seeks to explore the technical, economic, and social aspects involved in deploying such systems effectively. By assessing real-world case studies, conducting feasibility analyses, and incorporating community needs and feedback, this research endeavours to provide insights and recommendations for designing an off-grid PV systems that maximise energy access, promote socio-economic development, and contribute to sustainable livelihoods in rural communities.

1.2 PROBLEM STATEMENT

Access to electrical power has consistently played a crucial role in advancing progress across all sectors of society. However, despite its importance, approximately 1.3 billion people worldwide continue to lack access to electricity (Mandelli et al., 2016). In developed nations, the conventional model of energy distribution involves several major power stations responsible for generating the entire nation's energy requirements. Subsequently, this electricity is transmitted across the country through power lines, distributed according to varying demands in different regions. While this approach works well in developed nations, there are regions where this method may not be viable due to various factors, including geographical remoteness, economic constraints, or the destruction of essential infrastructure caused by conflicts or natural calamities (Facchin, et al., 2016). The lack of centralized grid infrastructure leaves rural regions underserved, causing socio-economic constraints. This research aims to provide reliable power in these areas by designing an optimized off-grid solar photovoltaic system, reducing the need for centralized electrical infrastructure. It addresses the untapped demand for affordable, decentralized energy solutions tailored to small-scale needs, focusing on overcoming technical barriers and achieving sustainability for rural communities.

1.3 AIM

The aim of this research is to design and implement an off-grid photovoltaic system for optimal utilization in rural areas.

1.4 OBJECTIVES

The specific objectives of this project work are as follows:

1. Develop a comprehensive electrical plan for a two-bedroom residential building for a proposed PV system.
2. Determine the load requirement of the two-bedroom residential building for a proposed PV system.
3. Sizing of the photovoltaic (PV) system such as the panel sizing, battery sizing, inverter sizing and cable sizing for a proposed PV system.
4. Perform on-field test to determine the optimal tilt angle for maximum energy conversion for the implemented PV system.
5. Implementation of a PV system with DC load and acquisition of voltage and current readings at various time intervals

vi. Simulation of the proposed PV System to determine the system daily input/output graph, array temperature vs effective irradiance graph and performance ratio vs solar fraction graph.

1.6 METHODOLOGY

The methodologies employed in this research study are as follows:

i. EdrawMax was used to carry out a comprehensive electrical plan for the residential building for the proposed PV system.

ii. Thorough load assessment was made on the two-bedroom residential building to calculate the load requirement and also relevant mathematical equations was used to calculate the inverter sizing, panel sizing and battery sizing for the proposed PV system.

iii. Physical on-field test was performed to determine the optimal tilt angle for the implemented PV system.

iv. Assembly of the PV array, charge controller and battery to give a PV system whose voltage and current readings for full-load, half-load and no-load was acquired at various time intervals were carried out.

v. The proposed PV system was simulated and analysed using PVSYST software to determine the system daily input/output graph, array temperature vs effective irradiance graph and performance ratio vs solar fraction.

1.5 SCOPE OF THE PROJECT

The scope of this project covers the following components, 48V Battery System, 4KVA Inverter System, 500Watt Solar Panel, 200A MPPT charge controller.

1.7 SIGNIFICANCE OF STUDY

This research work contributes to alleviating energy poverty by offering a sustainable and reliable electricity solution for rural communities lacking access to centralized grids. This work supports global sustainability goals by reducing fossil fuel dependence, mitigating environmental impacts, and promoting clean, renewable energy. It helps combat climate change and fosters technological advancements and innovation, leading to more efficient and cost-effective solutions beneficial for both rural and urban areas. This work can also inform policy makers, stakeholders and governments about the feasibility, challenges, and benefits of deploying off-grid PV systems in rural communities where it is needed. This can influence policy decisions, funding allocations, and initiatives aimed at promoting renewable energy adoption in remote areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW OF OTHER RELATED WORKS

The research study by (Ajao, et al., 2009) shows that Nigeria can obtain about 2.54×10^6 MWh of electrical energy from the sun which is equivalent to 4.66 million barrels of oil, this proves that solar energy is sufficient to sustain off-grid rural electrification. The authors also emphasize that distributed energy generation significantly reduce the amount of energy lost during transmission.

(Kaundinya, et al., 2009) tells us that distributed or standalone energy system are more suitable for remotest locations like rural areas where transmission grid cannot penetrate and no other source of energy other than renewable sources are available. The author further stated that Stand-alone systems are the preferred choice when accessibility is a primary concern, making them well-suited for supplying electricity to hilly regions and remote villages. In addition to considerations of accessibility and climate change benefits, the choice between Grid-connected systems or Stand-alone systems is influenced by economic feasibility and load factors. The authors further compared the economics of grid electricity to stand-alone solar pond, wind energy and biomass from the perceptive of total cost of generation per kWh, transmission and distribution losses and load factors, They emphasis the decentralized option for successful electrification of rural areas.

Similarly, (Afsharzade, et al., 2016) also delve into the connection between renewable energy and sustainable rural development, exploring various challenges encountered in rural electrification in Iran, including aspects related to infrastructure, management, socio-cultural factors, and economic considerations. And how renewable Energy development is essential due to the lack of access to conventional energy resources and the consequential adverse impacts.

(Ghafoor & Munir, 2015) stated that renewable energy sources are one of viable option to reduce electricity crises and went further to investigate the economic evaluation of an off-grid system in a single residential household in Pakistan, the result shows that the unit cost of electricity produced using an off-grid system was significantly lower than that produced using conventional energy generation methods. It was concluded that off-grid photovoltaic (PV) electricity is both technically and economically feasible for electrifying residential applications.

We have established the fact that off-grid energy system is more feasible than centralized energy system for rural areas, However, (Byrne, et al., 1998) stated that for rural renewable energy systems to thrive, they must contend with the presence of small-scale generator sets powered by gasoline or diesel, which have frequently served as the primary sources of electricity for remote households. It is also important to note that there has been a significant rise in fuel pump price over the years and many institutions have adjusted policies relating to the use of fossil to significantly reduce carbon footprint, thus, incentivizing the use of renewable sources.

2.2. ON-GRID PHOTOVOLTAIC SYSTEM

An on-grid photovoltaic (PV) system is a sustainable energy solution that harnesses solar energy through photovoltaic panels, which convert sunlight into usable electricity for residential or commercial buildings. These systems are different from off-grid solar systems, which are independent and operate without connection to the electrical grid. On-grid systems, on the other hand, are connected to the utility grid and can feed excess energy back into it, allowing users to earn credits and reduce their reliance on non-renewable sources of power. As energy needs increase and fossil resources decrease, the development of grid-connected photovoltaic energy is becoming an important part of the energy mix in the majority of countries (Nasreddine Attou, 2020).

What is an On-Grid system?

A grid-tied or grid-connected solar system, commonly referred to as an on-grid photovoltaic (PV) system, involves connecting solar panels directly to the electrical grid. This setup enables the solar energy generated to power the electrical loads within a building or home, with any surplus electricity typically returned to the grid. The most economical and straightforward solar energy setup is a grid-connected PV system that doesn't use batteries. Compared to stand-alone systems, it requires less maintenance and reinvestment, making it more cost-effective. It's worth noting that this type of solar energy system feeds excess energy directly back into the grid, ensuring that any surplus power generated on sunny days is immediately reintroduced based on current electricity demand and insolation conditions.

2.2.1. OPERATION OF AN ONGRID PHOTOVOLTAIC SYSTEM

The photovoltaic system functions by converting incident light energy into electricity, a process that is consistent across both off-grid and on-grid photovoltaic systems. When the photovoltaic module receives sufficient light energy to produce electrons, direct current (DC) power is produced at the output terminals of the PV array. This DC power is then directed to power converters, facilitating the conversion from DC to alternating current (AC). The AC energy generated can either be utilized directly by electrical loads or be transmitted to the utility grid through net metering. If the electricity generated is used for various load applications at the generation site, it is classified as a standalone PV system. Conversely, if the energy produced is continuously supplied to the utility grid, it is referred to as an on-grid photovoltaic system. In general, solar peak generation is between 9:00 AM to 3:00 PM and is typically called the solar window. However, based on the type of system installed, surroundings, shadow, and all other design specifications, generation can be anywhere between 7:00 AM and 5:00 PM (ECOSOCH, 2024). Once solar generation starts, the generated energy is first consumed by the loads. Once the load requirement is satisfied, the remaining energy will be exported to the grid. Grid by itself acts as a virtual battery taking in all the excess energy that has been exported. After the commencement of solar generation, the energy produced is initially utilized to meet the demands of the loads. Once the load requirement is fulfilled, any surplus energy is then transmitted to the grid. The grid functions as a virtual battery, accumulating all the excess energy that has been exported. This process is commonly referred to as energy banking. During nighttime, when solar generation is absent, the loads can draw upon the banked energy. Similarly, in instances where solar generation is reduced due to cloudy weather conditions, the required energy is obtained from the grid. After each billing cycle, the amount of energy exported and imported is calculated, and this net value is determined with the assistance of a Bi-directional meter. Now a bidirectional meter is an instrument that performs the multiple function of recording 3 readings, the total amount of energy exported in KWh, the total amount of energy imported and also the Net energy difference between the export and import.

2.2.2. COMPONENTS OF A GRID-CONNECTED PV SYSTEM

i. **Solar Panels:** Solar panels absorb energy from the sunlight and promptly convert it into a DC supply. That DC power is sent to a solar inverter.

ii. **Solar Inverter:** The inverter is an essential component in the grid-connected PV system. It converts the DC power it receives from the panels into AC power. The inverter then sends the AC supply to the house so that all the connected devices can run on solar electricity. If the system generates more power than the consumer’s requirement during the day, it is sent through the net meter and stored in the grid.

iii. **Net meter (bidirectional meter):** The net meter withdraws (imports) the exported units from the grid at night. It keeps all the appliances running. This power exchange is known as net metering. The Government of India has approved and mandated this facility in every State and Union territory.

iv. **Grid:** Grid is the quintessential part of a grid-connected PV system. It’s more of a sort of battery since that’s where excess power is sent and then taken back when needed. So, it’s a sort of power backup.

v. **Mounting structures:** Mounting structures or mounting stands are structures where the solar panels are mounted. They have to be strong enough since solar panels have weight. Some other miscellaneous components that are equally important parts of a grid-connected PV system include AC cables, DC cables, AC combiner box, DC combiner box, earthing strips and cables, and MC4 connectors.

2.2.3 TYPES OF ONGRID SOLAR PV SYSTEM

Solar technology within the rooftop industry has experienced significant advancements in recent years, effectively meeting the increasing needs of consumers seeking sustainable energy solutions. Various types of rooftops exist, each presenting unique conditions such as diverse roof structures, orientations, and potential shading concerns. In the realm of on-grid solar photovoltaic (PV) systems, three primary system variations can be identified.

i. String Inverter
ii. Micro Inverter
iii. Power Optimizers

2.2.3.1 STRING INVERTER

When connecting a group of solar panels in series as shown in Figure 2.1, a string inverter is commonly employed to gather the combined DC power and transform it into grid-compatible AC power. Despite the overall reliability of these inverters because of their simplicity, it is important to recognize that the output of the entire array can be affected by the lowest-producing module in the series. This is particularly evident in situations where shading problems or underperforming modules hinder the energy flow. Nevertheless, this setup remains a viable option for rooftops unaffected by shading issues caused by trees, nearby buildings, and other obstructions**.**

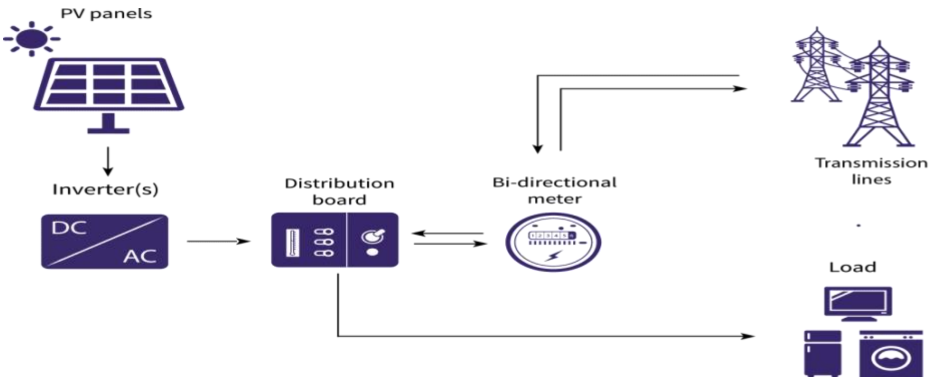


Figure 2.1: **A string inverter type on-grid system** (ECOSOCH, 2024)

2.2.3.2 MICRO INVERTER

Micro-inverters provide a practical alternative to string inverters. In this particular system, each module is connected to an inverter positioned beneath it as shown in Figure 2.2, enabling independent power generation for every panel. This configuration proves to be highly advantageous in areas where certain modules are affected by shadows or in situations where roofs have varying orientations. One of the key advantages of micro-inverters is their ability to facilitate module-level monitoring, simplifying system maintenance. Furthermore, in the event of a module or inverter failure, the rest of the system remains unaffected. In summary, the utilization of micro inverters presents a solution that enhances energy production efficiency, ensuring greater reliability and simplified maintenance. Consequently, it is a favorable choice for a wide range of settings.

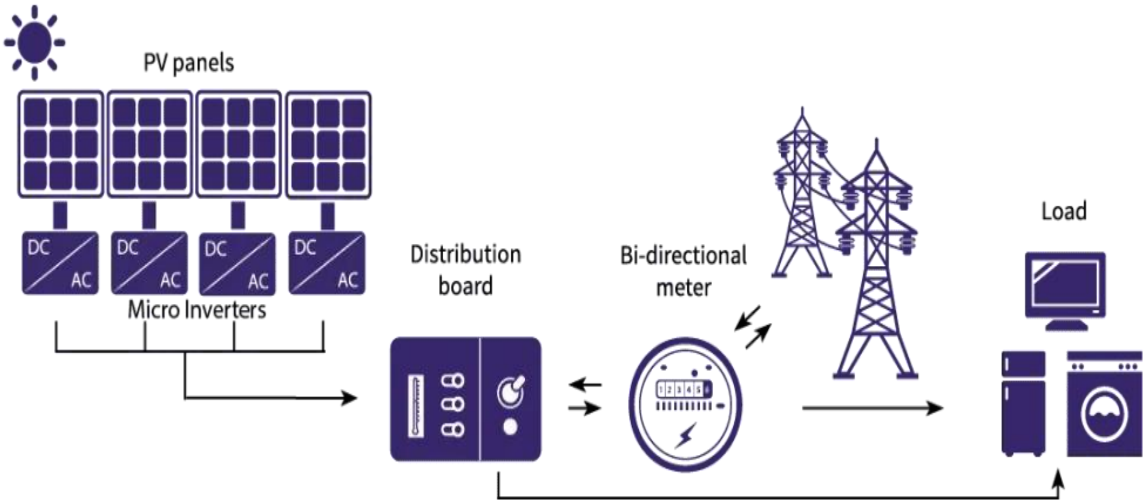


Figure 2.2: A micro inverter type on-grid system (ECOSOCH, 2024)

2.2.3.3 POWER OPTIMIZERS

Power optimizers and micro inverters are both commonly used solutions in solar panel systems. While micro-inverters convert DC electricity from each panel into AC electricity individually, power optimizers operate differently. In a power optimizer system (Figure 2.3), each solar panel is linked to a power optimizer, with some cases involving a pair of panels connected to one optimizer. These optimizers are specifically designed to monitor the maximum power point (MPP) at lower voltages, enabling power generation even in low light and heavy shadow conditions. They optimize the output of each module separately before transmitting the DC output to the string inverter at the end.

One key benefit of power optimizers is the reduction of electronic components on the rooftop, simplifying installation and lowering the risk of equipment malfunction. Furthermore, optimizers can be set up to connect one optimizer to one module or two modules, potentially reducing the overall system cost. In summary, power optimizers provide a dependable and effective solution for solar panel systems.

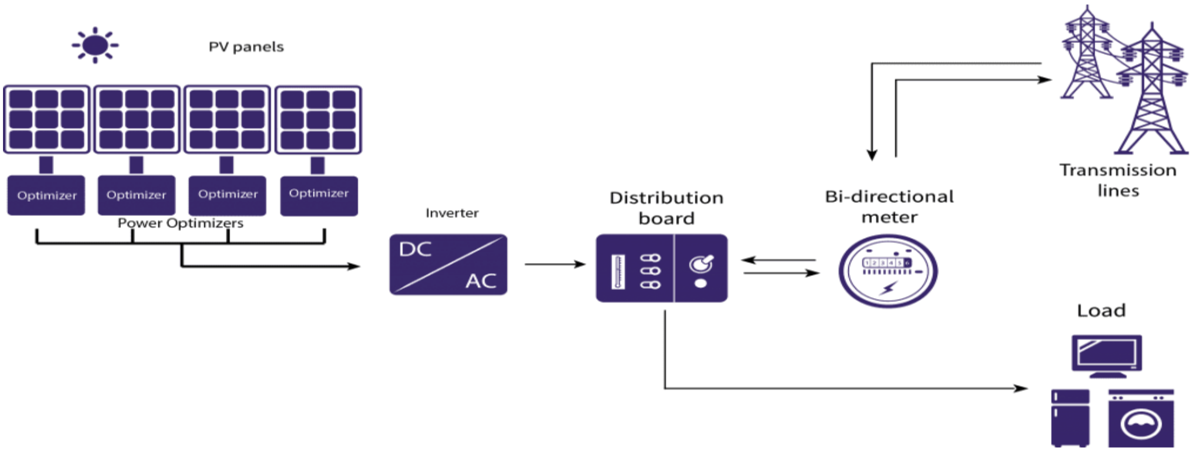


Figure 2.3: A power optimizer type on-grid system (ECOSOCH, 2024)

2.2.4 ADVANTAGES OF USING A GRID-CONNECTED PV SYSTEM

i. It comes with low maintenance costs. It contributes to lower electricity usage by harnessing energy from sunlight. Installation is a breeze.

ii. The gestation period for a grid-connected PV system is short. It operates without releasing harmful carbon emissions.

iii. Most grid-connected PV systems don't need extra batteries, making them more cost-effective than other solar system types.

iv. You can easily install a grid-connected PV solar system on unused roof space without additional land. It's highly dependable.

v. Besides powering homes, this system can also be used as the primary energy source in commercial, industrial, and educational settings.

2.2.5 DISADVANTAGES OF A GRID-CONNECTED PV SYSTEM

i. It cannot function without a grid. If the grid fails, the system will stop working.

ii. The initial installation cost is high.

iii. The models without a battery backup cannot provide electricity during power outages.

2.3 OFF-GRID SOLAR PV SYSTEMS

Off-grid solar photovoltaic (PV) systems are a brilliant example of sustainable energy solutions in today's world, where environmental challenges are getting more pressing and the need for energy is expanding. Operating independently of the centralized power grids, these systems provide a promising path toward energy independence, particularly in isolated areas where the conventional grid configuration is unreliable or unavailable.

The rising cost of energy, fuel, food, and other essentials has led to an increase in the popularity of living "off the grid." Due to rising electricity prices over the past ten years, more people are searching for alternate sources of energy for their homes. Solar energy is a sustainable form of green energy that can power your home independently from the electrical grid. (Ritchie, 2022)

An off-grid solar PV system is a self-contained power generation device that uses solar energy to generate electricity in remote locations without connection to the main power grid as shown in Figure 2.4. For your house or land, it functions as a miniature power plant. The off-grid solar PV system is very important has it plays a vital role in utilizing and generating electricity. The off-grid solar PV consists of different sections or units that makes production of light possible. The Solar Panel, Battery, Charge Controller and the Inverter make up the solar photovoltaic system.

An off-grid or Stand-Alone PV System is made up of a number of individual photovoltaic modules (or panels) usually of 12 volts with power outputs of between 50 and 100+ watts each. These PV modules are then combined into a single array to give the desired power output.

A basic off-grid photovoltaic system (PV system) is an automated solar energy system that generates electricity during the day to charge battery banks for usage at night when solar energy is not available. The electrical energy produced by a PV panel or array is stored in rechargeable batteries in a standalone small-scale PV system.

In situations, where using other power sources to operate appliances, lights, and other devices is either impractical or not possible, stand-alone photovoltaic systems are the best option for isolated rural locations. Installing a single standalone PV system in these situations is more economical than paying the local energy provider to run power lines and cables directly to the house as part of a grid-connected PV system.

An array of one or more photovoltaic (PV) modules, wires, electrical components, and one or more loads make up a stand-alone PV system. However, for residential use, a small-scale off-grid solar system does not need to be fixed to a building or roof. Off grid solar systems are widely used to power boats, tents, campers, RVs, campers, and other isolated locations.

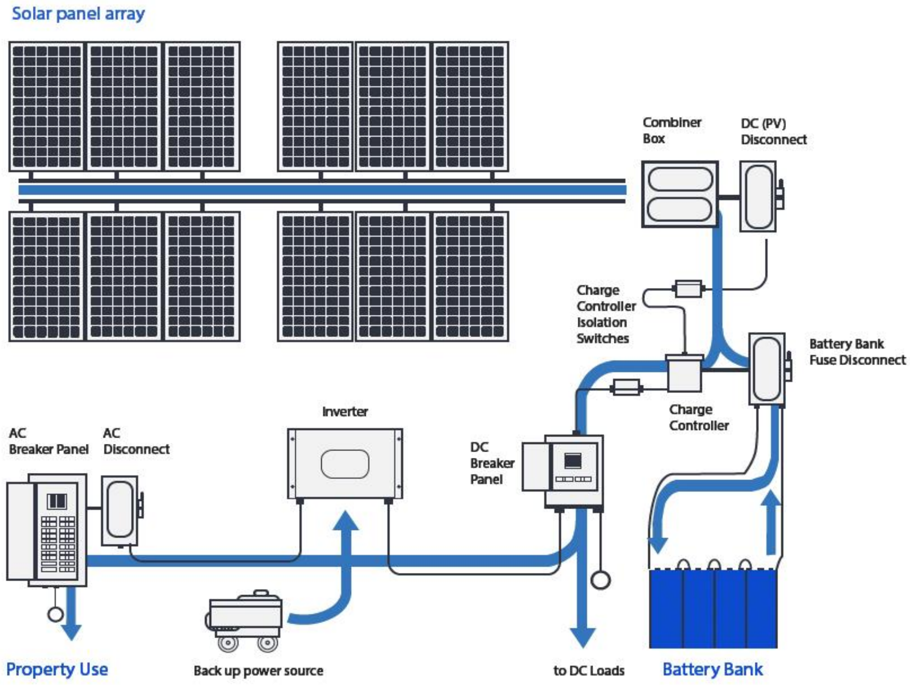


Figure 2.4: Schematics of an off-grid solar PV

2.3.1 COMPONENTS OF OFF-GRID SOLAR PV

Solar Panels: Also referred to as photovoltaic modules, solar panels are the essential component of any off-grid solar PV system. These solar panels use the photovoltaic effect to directly turn sunlight into electricity through a network of interconnected solar cells.

Charge Controllers: Crucial parts that control how much power is sent from the solar panels to the battery bank are charge controllers. Their main purpose is to keep batteries from being overcharged or undercharged, which maximizes battery life and system efficiency.

Battery Bank: Energy storage, which enables the storing of excess electricity produced during peak solar hours for use at a later time during low or no sunshine, is a crucial component of off-grid systems. DC electricity is often stored using deep-cycle batteries, such as lead-acid or lithium-ion batteries.

Inverters: Inverters are essential components of off-grid systems because they transform direct current (DC) electricity from solar panels and batteries into alternating current (AC) electricity, which is suitable for the majority of electrical loads and home appliances.

The combination of these components makes up the Off-grid solar PV system as shown in Figure 2.5.

2.3.2 FUNCTIONALITY AND OPERATION

The basic idea behind off-grid solar PV systems is to use the sun's energy during the day, store any extra electricity in batteries, and use that stored energy to power electrical loads at night or when there isn't any sunshine. First, sunlight is captured by solar panels, which transform it into DC electricity that is fed into the charge controller. In order to guarantee that the battery bank is charged effectively and without going overboard, the charge controller controls both voltage and current. Any extra power that is not used right away is kept in the battery bank for subsequent use. When power is required, the inverter transforms DC electricity from the batteries into AC electricity, which powers electrical appliances and other equipment in the home.

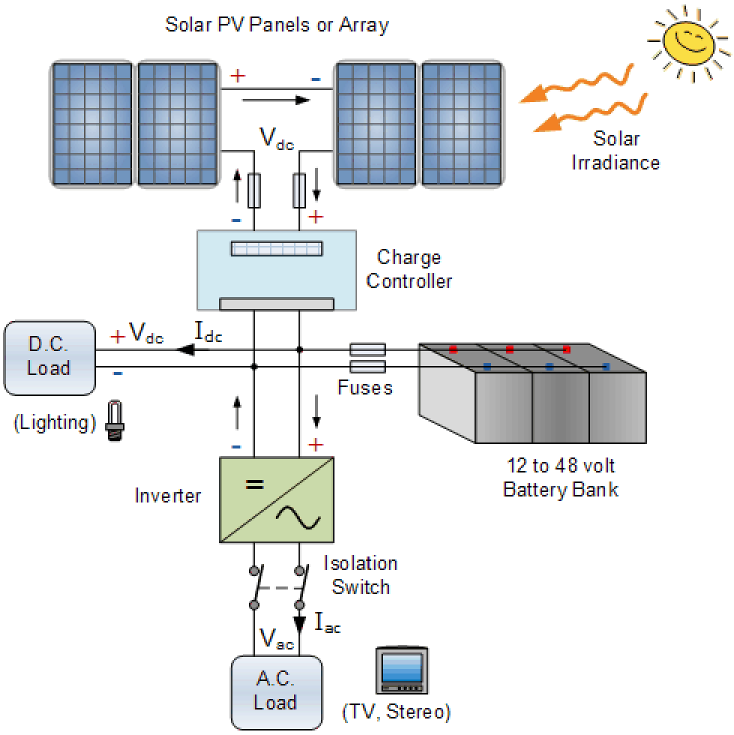


Figure 2.5: A simplified off-grid solar PV system

2.4 ADVANTAGES OF OFF-GRID OVER ON-GRID ELECTRIFICATION

A report in 2018 showed that about 789 million people lack lacked access to electricity which excluded those that households that had unsustainable and expensive electrification in many countries of the world. (Ortega-Arriaga, et al., 2021). When the On-grid uses the conventional fossil full, the off-grid rely mainly on solar PV and batteries.

There has been a persistent gap of 1-2 billion people without access to electricity since the late 1800s as a result of global population increase outpacing grid expansion. Furthermore, the supply of energy is erratic and inadequate even in nations with substantial access to it. For instance, Mexico, where 99% of households are connected to the grid, is ranked 72nd out of 137 countries in the World Bank's "Quality of electricity supply" indicator, which compares voltage fluctuations and interruptions across nations to evaluate supply reliability.

Moreover, grid electrification which uses the extensive mechanical burning of fossil fuel are the major causes of climate change that exhumes the greenhouse gases. Over the years, this has caused air pollution which is hazardous to the health of the masses and the community as a whole. Putting this into consideration grid system is not cost-effective.

Although, grid electrification has thrived and the existing need to sustain off-grid electrification can be traced back to the late nineties or early twenties. This is as a result of how off grid could meet high power demand in both offices, household for powering power draining appliances that are essential to live a technology driven home with ease and industries where high-power consuming power machines are used. Nevertheless, the pollution and health threats cannot be overlooked.

Consistent study has shown that grid connection to rural areas either experiences inadequacies which could be in the form of diminished quality or reduced quantity, sometimes as a result of the poverty prevalent in the rural areas that makes the unable to afford the general price which urban population can afford. (Palit & Chaurey, 2011).

The off-grid solar PV system cost of maintenance is not as much as that of the grid system. In the genesis, before a grid system can exist a large mass area or location has to be discovered due to the large machines that re used to turn the turbines, also a grid system does not just exist without proper planning. Right now, in Nigeria the semi urban areas that are connected to the grid to not have sustainable power supply, it is then inadvisable for the rural areas to be connected to such streams. Therefore, if the rural area will benefit for electricity, they will have to be connected to a newly connected grid, which is not feasible. Hence, going for off-grid in rural areas will be more effective. This postulate is clear since, the electrical need for rural area is minimal, and construction a grid system independently for the will be cost ineffective.

Additionally, the grid power generation is now owned by private individuals who are more interested in the in making money. The returns for the sales of electricity in rural areas will not yield sufficient income.

Off-grid PV electrification will be of greater benefit compare to its counterpart grid for small scale businesses such as dress makers, vendors etc. and this level of business is common in the developing countries especially rural areas. The off-grid system will ensure that they use power enough for their essentials and avoid outrageous bill paid by urban customers connected to the grid electricity supply. Paying such bills of the grid system way prey on the little income they get from their menial establishment.

2.5 COMPARISON BETWEEN GRID CONNECTED SYSTEM AND OFF-GRID SYSTEM

A detailed comparison is made between a grid connected system and an off-grid system as shown in Table 2.1

Table 2.1: Comparison between grid connected system and off-grid system

Aspect	Off-Grid PV System	On-Grid PV System
Energy Independence	Energy generated can be stored locally, offering independence from the grid.	Reliance on the grid for electricity supply; no energy independence.
Resilience and Reliability	Provides greater resilience during grid outages or disasters, ensuring uninterrupted power supply.	Vulnerable to grid outages; the power supply relies on the stability of the grid.
Location Flexibility	Suitable for remote areas or off-grid properties without access to utility lines.	Requires grid connection, limiting installation options to areas with grid access.
Environmental Sustainability	Reduces reliance on fossil fuels, mitigating greenhouse gas emissions and promoting sustainability.	It contributes to reducing fossil fuel consumption but remains connected to centralized power generation.
Cost Savings in the Long Run	Higher initial investment but leads to long-term cost savings by avoiding recurring electricity bills.	Lower initial investment but entails ongoing electricity bills; may not offer the same level of cost savings over time.
Customization and Scalability	Offers flexibility in system design and scalability to meet specific energy needs and usage patterns.	System design is standard leading to limited flexibility and scalability compared to off-grid systems.

2.6 HISTORY OF PHOTOVOLTAIC TECHNOLOGY

Photovoltaic (PV) technology harnesses the power of sunlight to generate electricity, offering a sustainable and renewable energy solution. This technology revolves around the use of solar cells, typically made from semiconductor materials like silicon, that convert sunlight directly into electrical energy through the photovoltaic effect.

According to (Marques, et al., 2022), In 1839, a young French physicist named Alexandre Edmond Becquerel first observed the photovoltaic effect. While conducting electrochemical experiments, he observed the manifestation of this effect on silver and platinum electrodes that were exposed to sunlight. In 1876, English physicist William Grylls Adams and his student Richard Evans Day made the discovery that light striking selenium generates electrical energy.

In 1883, the initial solar cells crafted from selenium were created by American inventor Charles Fritts. While Fritts aspired for his solar cells to rival Edison's coal-fired power plants, they proved to be less than one percent efficient in converting sunlight to electricity, rendering them impractical for widespread use. Research on selenium photovoltaics persisted for several decades, leading to the discovery of a few applications. However, these applications did not see widespread use.

In 1905, Albert Einstein introduced the photoelectric theory, incorporating certain concepts put forth earlier by Max Planck. This theory explains the connection between light waves and photons, the fundamental quanta of light, as well as the correlation between the energy of photons and their frequency. This led to Einstein winning the Nobel Prize in physics in 1921. Einstein explained that "light consists of quanta—packets with fixed energies corresponding to certain frequencies. One such light quantum, a photon, must have a certain minimum frequency before it can liberate an electron." (The Nobel Prize in Physics, 1921).

The next major advancement in Photovoltaic technology was reported in 1940, when Russell Shoemaker Ohl, a semiconductor researcher at Bell Labs, achieved a significant breakthrough in solar cell technology. While examining silicon samples, he discovered an unexpected phenomenon in a sample with a crack. When exposed to light, current flowed through this particular sample. The crack, likely formed during the sample's creation, delineated regions with varying impurity levels, resulting in one side being positively doped and the other side negatively doped. Unintentionally, Ohl had created a p-n junction, the foundational component of a solar cell. This junction led to the accumulation of excess positive charge on one side and excess negative charge on the other, generating an electric field. When connected in a circuit, incoming photons could impart energy to electrons, initiating a flow of current. Ohl patented his solar cell, boasting an efficiency of approximately one percent. Thirteen years later, a group of scientists collaborated at Bell Labs to develop the first functional silicon solar cell. However, these solar were being used as sensors due to its low efficiency, Nevertheless, it was not until 1954 that Calvin Fuller, a chemist at Bell Labs, pioneered a method for silicon doping, which resulted in an astonishing efficiency of 6%, for dopants of boron and arsenic. Additional enhancements were made to the design, they connected multiple solar cells to form what they referred to as a "solar battery".

Bell Labs announced the invention on April 25, 1954 in Murray Hill, New Jersey. They demonstrated their solar panel by using it to power a small toy Ferris wheel and a solar powered radio transmitter.

Solar cells currently find utility in a wide range of devices, spanning from handheld calculators to rooftop solar panels. Enhanced designs and the utilization of advanced materials have enabled the construction of solar cells achieving efficiencies exceeding 40%. Ongoing research and development aim to reduce costs and enhance efficiency further, with the ultimate objective of making solar power more competitive with traditional fossil fuels.

2.7 COMPONENTS IN SOLAR PV SYSTEM

2.7.1 SOLAR INVERTERS

Population growth and economic development lead to an increase the global energy consumption from (60) million barrels per day in 1980 to (96.5) million barrels per day in 2021 and consumption is expected to increase and reach (104.1) million barrels per day in 2026. Fossil fuel causes the emission of greenhouse gases such as carbon dioxide and methane which are causes of global warming and are expected to be exhausted within (40-60) years. Solar energy does not emit any pollutants and it is permanent as the sun is always shining, so it is necessary to develop the solar energy sector to reduce the risk of climate change and to make the air we breathe safer, also to produce energy locally and reduce dependence on foreign sources of energy. A solar inverter is one of the most important elements of the solar electric power system. It converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into alternating 220V current (AC). This AC electricity then can be fed into your home to operate your appliances. Long-lasting solar power systems require a high-quality inverter with a robust convection cooling system. Low-quality inverters have failed in generating the required power. (Shukir, 2021).

The solar inverter is an essential part of a solar power system as it converts the direct current (DC) electricity produced by solar panels into alternating current (AC) electricity that can be utilized to power household appliances and feed into the electrical grid. Essentially, it changes the energy gathered by solar panels into a form compatible with standard electrical outlets and appliances. Some advanced inverters also provide features such as maximum power point tracking (MPPT) to optimize energy production and monitoring capabilities to keep track of system performance.

2.7.1.2 WORKING PRINCIPLES OF A SOLAR INVERTER

A solar inverter works by taking in the variable direct current, or 'DC' output, from your solar panels and transforming it into alternating 120V/240V current, or 'AC' output. The appliances in your home run on AC, not DC, which is why the solar inverter must change the DC output that is collected by your solar panels.

To be a little more technical, the sun shines down on your solar panels (Figure 2.6), which are made of semiconductor layers of crystalline silicon or gallium arsenide. These layers are a combo of both positive and negative layers, which are connected by a junction. When the sun shines, the semiconductor layers absorb the light and send the energy to the PV cell. This energy runs around and bumps electrons lose, and they move between the positive and negative layers, producing an electric current known as direct current (DC). Once this energy is produced, it is either stored in a battery for later use or sent directly to an inverter (this depends on the type of system you have).

When the energy gets sent to the inverter, it is in DC format but your home requires AC. The inverter grabs the energy and runs it through a transformer, which then spits out an AC output. The inverter, in essence, 'tricks' the transformer into thinking that the DC is AC, by forcing it to act in a way like AC – the inverter runs the DC through two or more transistors that turn on and off super-fast and feed two varying sides of the transformer.

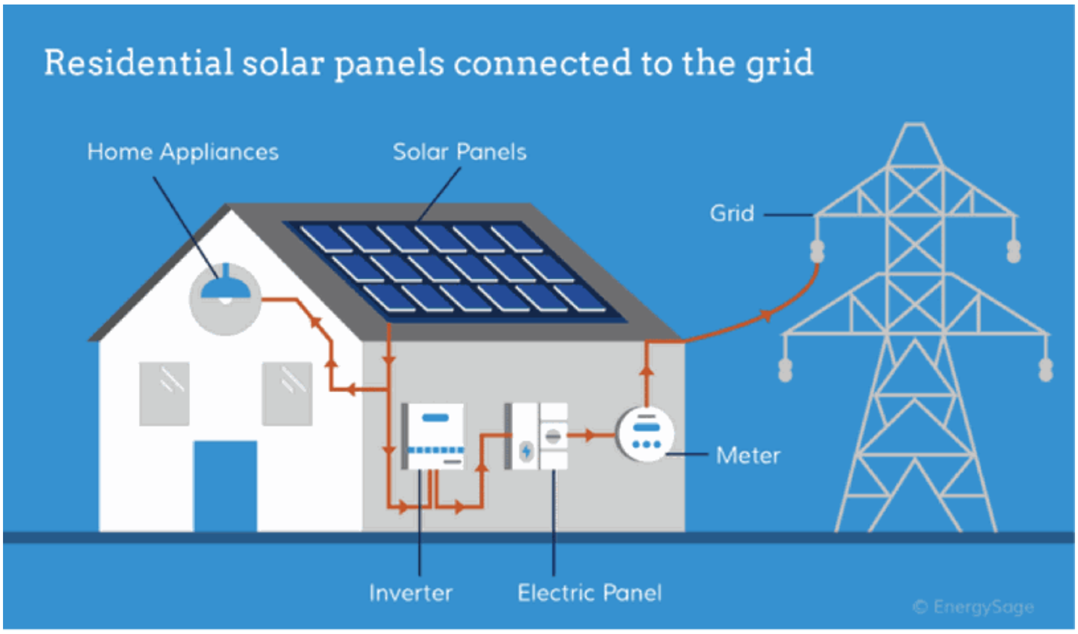


Figure 2.6: Residential Building Making Use of Solar Inverter

2.7.1.3 BENEFITS OF A SOLAR INVERTER

Your solar PV inverter does more than just convert sunlight into usable energy. It has the ability to optimize energy production, monitor output, communicate with the utility grid, and identify potential faults that could harm your solar power system.

Maximizing Energy Production

Solar inverters optimize the voltage of your solar array to generate the maximum amount of clean energy possible. For grid-tied home solar inverters, the output is a pure sine wave that ensures the seamless and efficient operation of delicate appliances, in contrast to low-cost inverters that produce a modified sine wave.

Monitoring System Output

It's truly exciting to witness a solar power system generating thousands of watts on a sunny day. Naturally, homeowners want to keep tabs on the performance of their investment. Luckily, most solar panel inverters provide a way to view real-time energy production, and some even offer the convenience of tracking performance via a mobile app or website. If any issues arise, some home inverters have an automatic performance checking feature that will alert you if any component is not functioning correctly. Additionally, you can use the inverter's performance tracking to periodically check your system's components and ensure that it's generating the correct amount of electricity.

Communicating With the Utility Grid

During a temporary power outage, solar inverters prevent your panels from transmitting electricity to the external power lines. This measure ensures that line workers, who may be examining or repairing the grid, remain safe from harm. Additionally, if you have a complete solar battery bank or your household does not require all of the electricity being generated, you can still benefit from solar energy

Fault Detection

If you don't keep your electrical wiring and solar equipment well-maintained, they may start to deteriorate over time. This could cause dangerous electrical issues like ground faults or arcs. If this happens, the solar power inverter will detect the problem and shut down quickly. This will protect the rest of your system and warn you that you need to get it serviced before anything else happens.

2.8 SOLAR PANELS

2.8.1 CLASSIFICATIONS OF SOLAR PANELS

Solar panel technology can be categorized into three generations, with this classification being determined by the materials used and the efficiency of the solar cells.

2.8.2 FIRST GENERATION

The first generation of solar cells were wafer-based, indicating that their fabrication techniques primarily drew upon methods already utilized in integrated circuit manufacturing at that time. This enabled them to leverage the extensive expertise in the field of silicon wafer production. The silicon wafer-based technology is further categorized into two subgroups:

- Monocrystalline solar panels
- Polycrystalline solar panels

2.8.2.1 MONOCRYSTALLINE SOLAR PANELS (MONO-SI)

The monocrystalline solar cell as shown in Figure 2.7, as its name implies, is produced from single crystals of silicon through a method known as the Czochralski process. In the manufacturing process, Si crystals are cut from large-sized ingots. The production of these large single crystals demands meticulous processing, as the "recrystallization" of the cells is a more costly and multi-step procedure. The efficiency of monocrystalline silicon solar cells typically ranges between 17% and 20% (Sharma, et al., 2015).

They are the purest type of solar panel you can find; they are easily identifiable by their consistent dark appearance and rounded edges.

Figure 2.7: Monocrystalline solar panel

Monocrystalline panels have higher power output, making them a preferred choice for those seeking efficient energy generation. Additionally, their ability to occupy less space is a valuable feature, especially in installations where space is a premium. These panels are recognized for their durability, often outlasting other types of solar panels. However, it's worth noting that the premium performance and longevity come at a higher cost, making monocrystalline panels the more expensive option among solar technologies.

Monocrystalline panels exhibit a resilience to high temperatures, a characteristic that enhances their performance in diverse environmental conditions. This heat resistance can contribute to a more consistent and reliable energy production, even in regions with elevated temperatures. This attribute positions monocrystalline panels as a reliable and efficient solution for those prioritizing durability and performance in their solar energy systems.

2.8.2.2 POLYCRYSTALLINE SOLAR PANELS (POLY-SI)

Polycrystalline solar panels (Figure 2.8) typically consist of numerous different crystals fused together in a single cell. The manufacturing process of polycrystalline Si solar cells is more cost-effective, involving the cooling of a graphite mold filled with molten silicon. Currently, polycrystalline Si solar cells enjoy widespread popularity and are estimated to constitute up to 48% of global solar cell production as of 2008.

As the molten silicon solidifies, various crystal structures are formed. While these panels are somewhat more economical to produce compared to monocrystalline silicon solar panels, they exhibit a lower efficiency, typically ranging from 12% to 14% (Sharma, et al., 2015).

These panels are easily identifiable by their distinctive features, including square shapes, uncut angles, and a speckled blue appearance. The lower price of these panels comes at a cost of reduced efficiency and shorter lifespan since they are affected by hot temperatures to a greater degree. However, the distinctions between monocrystalline and polycrystalline solar panels are not overly substantial, and your decision should primarily hinge on individual circumstances. While the former provides slightly better space efficiency at a marginally higher cost, the power outputs of both options are essentially equivalent.

Figure 2.8: Polycrystalline solar panel

2.8.3 SECOND GENERATION

The development of second-generation cells aimed to decrease the costs of the preceding generation while enhancing their features (Marques, et al., 2022). Hence, most of the Thin-film second generation solar cells. Regular silicon-wafer cells feature light-absorbing layers with a thickness of up to 350µm, whereas thin-film solar cells typically have extremely thin light-absorbing layers, usually around 1µm in thickness. Thin-film solar cells are classified as:

- Amorphous-silicon (a-SI)
- Cadmium Telluride (CdTe)
- Copper Indium Gallium Di-Selenide (CIGS)

2.8.3.1 AMORPHOUS-SILICON THIN FILM SOLAR CELLS (A-SI)

Amorphous (a-Si) solar cells as shown in Figure 2.9 can be produced at a low processing temperature, allowing the utilization of various affordable polymer and flexible substrates. These substrates demand less energy during processing. Hence, the a-Si amorphous solar cell is relatively more cost-effective and readily accessible. The term "amorphous" in the context of solar cells indicates that the silicon material in the cell lacks a defined arrangement of atoms in the lattice, possessing a non-crystalline or less highly structured structure. These cells are created by applying doped silicon material to the backside of the substrate or glass plate. Typically, these solar cells appear dark brown on the reflecting side and silverish on the conducting side.

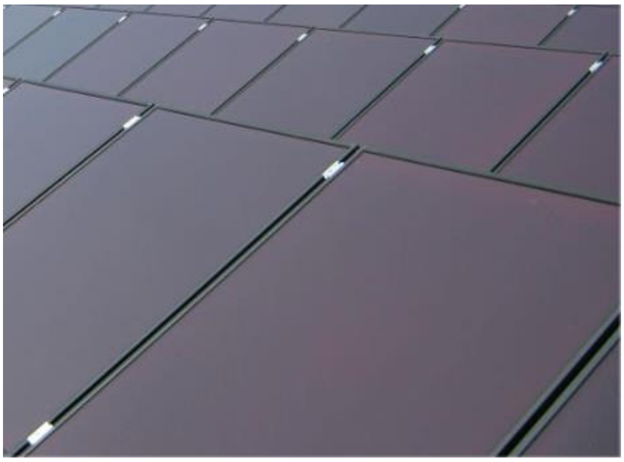


Figure 2.9: **Amorphous solar panel**

The primary challenge with a-Si solar cells lies in their low and relatively unstable efficiency, which diminishes further at the PV module level. Presently, commercial PV modules exhibit efficiencies ranging from 4% to 8%. However, they can effectively operate at higher temperatures, making them suitable for variable climatic conditions where sunlight is available for only a limited duration.

2.8.3.2 CADMIUM TELLURIDE (CdTe) THIN FILM SOLAR CELL

Cadmium Telluride Thin Film solar cell as shown in Figure 2.10 is a superior direct band gap crystalline compound semiconductor that increases efficiency and facilitates light absorption. A p-n junction diode is often created by sandwiching between layers of cadmium sulphide.

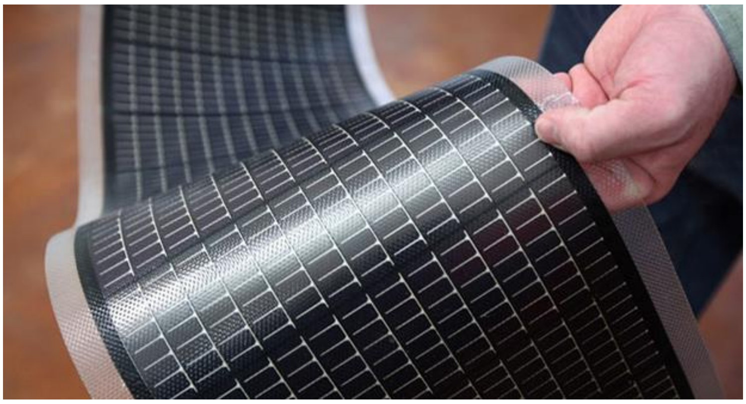


Figure 2.10: Cadmium Telluride (CdTe) solar panel

These solar cells are made from a thin layer of cadmium telluride, a compound semiconductor material, deposited onto a substrate, typically glass or a flexible material like plastic. CdTe thin film solar cells have gained attention for their potential cost- effectiveness and high efficiency in converting sunlight into electricity.

The manufacturing process comprises three main steps. Initially, CdTe-based solar cells are synthesized from polycrystalline materials, with glass selected as the substrate. The second step involves deposition, wherein multiple layers of CdTe solar cells are coated onto the substrate using various cost-effective methods. It has been noted that CdTe possesses an optimum direct band gap (~1.45 eV) with a high absorption coefficient exceeding 5 × 10^15/cm.

Consequently, its efficiency typically falls within the range of 9% to 11%. CdTe solar cells can also be produced on polymer substrates, rendering them flexible. However, concerns arise regarding environmental issues associated with the cadmium component of these solar cells. Cadmium is classified as a heavy metal and a potential toxic substance capable of accumulating in humans, animals, and plants. The disposal of the toxic Cd based materials as well as their recycling can be highly expensive and damaging too to our environment and society. Therefore, a limited supply of cadmium and environmental hazard associated with its use are the main issues with this CdTe technology (Sharma, et al., 2015).

2.8.3.3 COPPER INDIUM GALLIUM DI-SELENIDE (CIGS) SOLAR PANEL

CIGS (Copper Indium Gallium Di-Selenide) as shown in Figure 2.11 is a quaternary compound semiconductor composed of four elements: Copper, Indium, Gallium, and Selenium. These materials are direct band gap semiconductors. In comparison to CdTe thin film solar cells, CIGS exhibits higher efficiency, typically ranging from 10% to 12%. Because of their notably high efficiency and cost-effectiveness, CIGS-based solar cell technology is among the most promising thin film technologies. The processing of CIGS involves several techniques, including sputtering, evaporation, electrochemical coating, printing, and electron beam deposition (Sharma, et al., 2015).

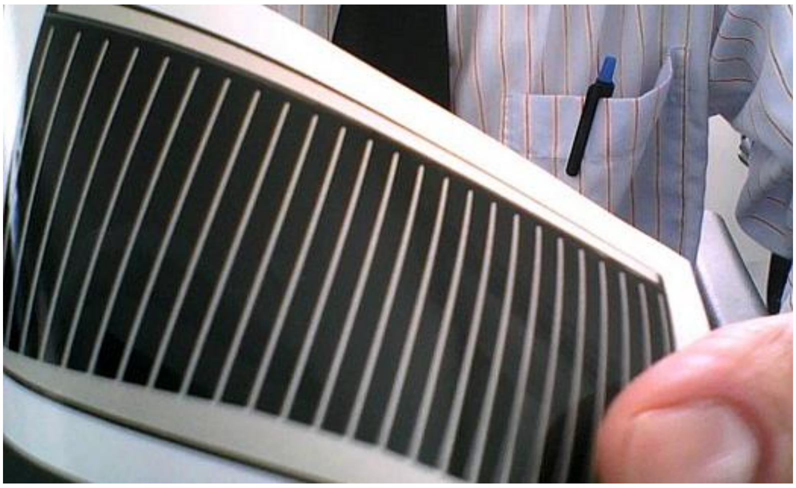


Figure 2.11: Copper Induim Gallium Di-selenide (CIGS) solar panel

2.9 THE BATTERY

A battery as shown in Figure 2.12 is a component that is used to convert chemical energy into electrical energy by a chemical reaction. Usually, the chemicals are kept inside the battery. It is used in a circuit to power other components. A battery produces direct current (DC) electricity. A battery is a combination of multiple cell that are coupled together. Over the years, battery has served as a sure means to preserve energy and convert it into electricity, although a battery has a duration to which it can withhold energy stored in it. In Solar PV system, Batteries are usually called inverter batteries.

Figure 2.12: A Solar Battery

2.9.1 THE SOLAR BATTERY TRADITIONAL CONSTRUCTION AND RECENT INNOVATION

Over the traditional battery that is used to store the light energy from the solar cells is much more different from what it used to be this is as a result of continuous need for improvement.

The conventional PV battery-charging technique operates the PV and battery as two separate components that are electrically connected by wires. This is known as a discrete or isolated design. These systems are typically more costly, large, and rigid, requiring more room and packaging, and undergoing energy loss via external cables. An integrated design is produced when energy production and storage are combined into a single unit. The integrated design of PV and batteries will function as a self-sufficient energy source, resolving the issues with solar cell energy storage and battery energy density.

2.9.2 TYPES OF SOLAR BATTERY USED IN PV SYSTEM

Four different kinds of battery are available that can be used to store solar energy which are lead-acid, lithium-ion, flow batteries, and nickel cadmium and these different batteries will be discussed in this section.

2.9.2.1 LEAD ACID BATTERY

The most traditional kind of solar battery. Its lengthy history has allowed it to be developed in tandem with renewable energy sources. There are two varieties of lead-acid solar batteries, Sealed and Flooded lead acid batteries. The construction of sealed lead acid batteries minimizes the emission of harmful gases into the atmosphere while they are being charged.

Flooded lead acid batteries are the second kind of lead-acid battery. This is comparable to a conventional automobile battery on a larger scale.

Lead-acid solar batteries are characterized by a lower depth of discharge and a generally shorter lifespan when compared to alternative storage choices. They also need to be maintained on a regular basis. Lead-acid batteries are regarded as the least expensive of the four because of this.

2.9.2.2 LITHIUM ION BATTERY

In contrast to lead-acid batteries, which have a far longer history, we can refer to this type as "the new kid on the block." It has been enhanced in recent years in tandem with advancements in battery technology necessary for electric vehicles.

Residential property owners are fond of lithium-ion solar batteries. This is due to three factors: They live longer, they do not require close routine upkeep compared to the lead-acid battery and they are of reduced size compared to same capacity of that of lead-acid battery. These batteries have a higher usable capacity in addition to being able to withstand heavy discharges of 80% or more with ease (M., 2023).

That being said, a significant disadvantage of lithium-ion batteries is their potential for thermal runaway, which means that improper installation could result in a fire.

2.9.2.3 FLOW BATTERY

The flow battery essentially comprises two key elements: the cell stacks, where chemical energy is converted into electricity in a reversible process, and the tanks of electrolytes, where energy is stored. Although this battery is still in its development stage, it has been able to establish remarkable advantages for himself. The flow battery has a depth discharge of 100% which makes it to be able to completely exhaust all the energy it has stored in it. Also, compared to Nickel Cadmium which will be discussed subsequently, Flow battery uses a non-toxic chemical substance for its energy reaction which is water based.

Nevertheless, there was need for more innovation due to its problem of consuming excess space as compared to other types of batteries, meaning for the same capacity, a Flow battery will consume more space compared to other batteries. Also, in a developing economy where we need to cut cost, Flow battery is too expensive.

2.9.2.4 NICKEL CADMIUM

Nickel cadmium batteries, sometimes referred to as "nickel batteries" or "Ni-Cd," are another well-researched option that has been around for a long in the battery technology arena. They are renowned for their capacity to function in extremely hot environments without the need of intricate battery management systems. They are therefore more common in initiatives of a commercial nature.

It's crucial to remember that nickel batteries are a somewhat ancient technology. Many nations have prohibited them due to their high level of toxicity.

2.10 THE CHARGE CONTROLLER

A charge controller, also known as a charge regulator, functions as a voltage and/or current regulator within the context of solar energy systems, serving to prevent batteries from experiencing overcharging. Its primary role involves the regulation of both voltage and current levels originating from solar panels, thereby managing the flow of energy directed towards the battery bank. (Osaretin & Edeko , 2015). In a charge controller, there are two switches serving distinct purposes. The initial switch facilitates the connection or disconnection between the photovoltaic (PV) array and the battery, while the subsequent switch manages the connection or disconnection between the battery and the load. Activation of the first switch initiates the charging process of the battery, whereas engagement of the second switch triggers battery discharge. Concurrent activation of both switches indicates a state of simultaneous charging and discharging within the system. To mitigate issues such as overcharge and over discharge arising from potential oscillations, hysteresis control mechanisms have been integrated into the circuitry. These mechanisms ensure that the PV array does not reconnect to the batteries until a certain level of discharge has been attained, or that the load does not reconnect until a specified voltage threshold within the batteries is met. (Rahaman, et al., 2015)

There are charge controllers that work with relays. These charge controllers also have poor current flow capabilities and seldom satisfy the precise specifications needed by PV systems. (Rahaman, et al., 2015)

2.10.1 TYPES OF CHARGE CONTROLLERS

The realm of charge controllers encompasses a diverse array of solutions tailored to managing the flow of energy within solar power systems. These controllers vary in their mechanisms and functionalities, each offering distinct advantages suited to specific operational requirements and environmental conditions. These types of charge controllers include:

1. Pulse width modulation (PWM)
2. Maximum power point tracking (MPPT)

2.10.1.1 PULSE WIDTH MODULATION (PWM)

The utilization of Pulse Width Modulation (PWM) as shown in Figure 2.13 charge controller stands out as a highly efficient approach in achieving consistent voltage battery charging through the modulation of the duty cycle of MOSFET switches. Within the PWM charge controller framework, the current sourced from the solar panel diminishes in accordance with the battery's state and its recharging requisites. Upon the battery voltage attaining the predetermined regulation threshold, the PWM algorithm systematically diminishes the charging current, thereby mitigating the risk of battery overheating and excessive gassing, while ensuring the continued delivery of maximum energy to the battery within an optimal timeframe. Consequently, the voltage of the solar panel array is drawn down to approximate parity with that of the battery. (KUMAR, et al., 2021).

Figure 2.13: Pulse Width Modulation (PWM)

The Pulse Width Modulation (PWM) mechanism regulates the duty cycle of switches in response to input variations, thereby maintaining a consistent output voltage. This process entails the conversion of DC voltage into a square-wave signal that oscillates between full activation and complete deactivation. PWM serves as a means of digitally representing analog signal intensities, while concurrently governing the charging current directed towards the battery, including trickle charging functionalities. Specifically, the voltage mode PWM controller encompasses essential attributes requisite for fundamental voltage mode functionality. Moreover, this PWM controller is tailored to facilitate efficient operation in high-frequency primary side control scenarios. (Ikeh & Uzor, 2017).

In the realm of power management, it is imperative to discern that a Pulse Width Modulation (PWM) controller operates distinctively from a DC-to-DC transformer. Unlike the latter, the PWM controller functions as a switch, facilitating the connection between the solar panel and the battery, thereby regulating power flow through modulation of the switch's duty cycle. (Kumar , et al., 2021)

2.10.1.2 MAXIMUM POWER POINT TRACKING (MPPT)

MPPT as shown in Figure 2.14 is an advanced strategy utilized in solar energy systems to improve the effectiveness of converting sunlight into electricity. Its core principle involves dynamically modifying the electrical characteristics of solar panels, like voltage and current, to optimize power extraction from the available solar irradiance at any particular time.

In the realm of power management, it's crucial to distinguish that a PWM controller does not function as a direct DC-to-DC transformer. Instead, the PWM controller operates as a pivotal switch, facilitating the connection between the solar panel and the battery within the system. (Kumar , et al., 2021).

The MPPT revolves around a synchronous buck converter configuration. This setup reduces the elevated voltage generated by the solar panel to match the charging voltage necessary for the battery.

Figure 2.14: Maximum power point tracking (MPPT)

It dynamically regulates its input voltage to capture the utmost power from the solar panel and subsequently converts this power to meet the fluctuating voltage demands of both the battery and the load. (Kumar , et al., 2021).

In conclusion, Maximum Power Point Tracking (MPPT) stands as a critical technique in enhancing the efficiency and performance of renewable energy systems, particularly those employing solar photovoltaic technology. Through its sophisticated algorithms and real-time adjustments, MPPT algorithms enable the extraction of maximum available power from solar panels under varying environmental conditions. As the demand for clean energy solutions continues to rise, MPPT remains a cornerstone in optimizing energy conversion processes, fostering sustainability, and advancing the integration of renewable resources into the global energy landscape. Continued research and development in MPPT methodologies promise further enhancements in energy harvesting efficiency, contributing to the realization of a more sustainable and resilient energy future.

CHAPTER THREE

3.0 DESIGN METHODOLOGY OF PROPOSED PV SYSTEM

Designing an off-grid photovoltaic system for a residential building, specifically a two-bedroom apartment in this case, demands a comprehensive approach. This approach is essential to ensure efficiency, safety, optimal performance, and, most importantly, enhanced system longevity.

In this section, we will take a structured approach to designing such a system. We will begin by assessing the energy needs of the building, conducting site evaluations, sizing the system (including inverter and load sizing), performing financial analysis, selecting components, overseeing installation, and establishing monitoring and maintenance procedures.

3.1 ELECTRICAL PLAN OF THE BUILDING

Electricity exists in a form that is useful to exploit, however, it will also be important to install electricity as efficiently as possible, and design of the power distribution system should be convenient so as to minimize power losses. We would be using a two-bedroom flat as a base for the installation of the off-grid photo-voltaic system. The purpose of this work is to present a suitable approach to electrical services design based on the provision of the Institution of Electrical Engineers (IEE) Regulations, which includes lighting, power, distribution boards schematics. The results of the whole analysis and design was illustrated with EdrawMax application. This work gives a direct approach from design of the electrical services to the installation stage. The results of the calculations in the design helps the designer to make vital decisions such as types of luminaries, sizes of cables and nominal ratings of protective devices required by each circuit and by the entire installation in line with appropriate standards and regulations.

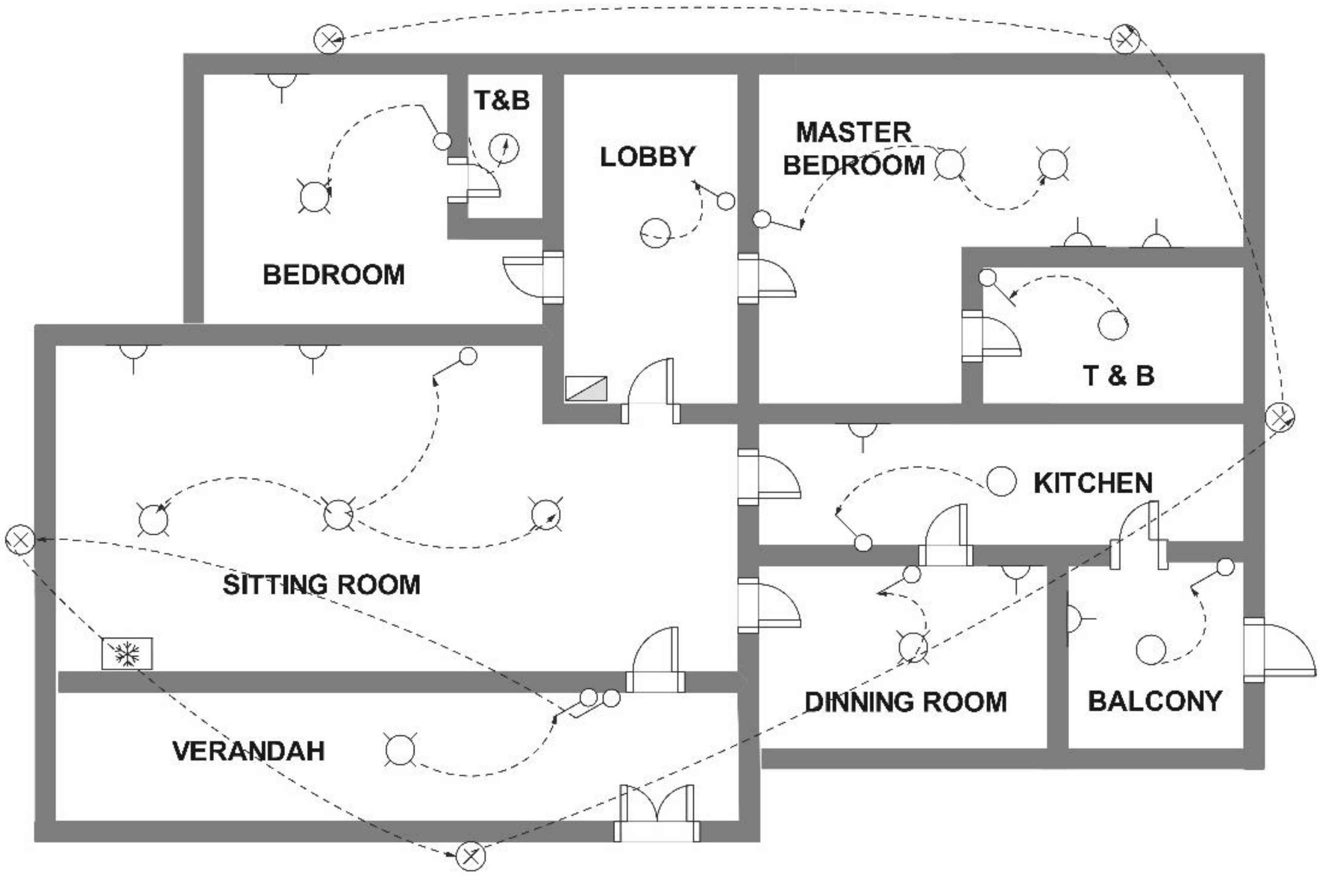


Figure 3.1: Building Plan Showing Loads

3.2 LOAD ASSESSMENT OF PROPOSED PV SYSTEM

Before designing the Off-grid system for a given residential apartment, it is very important we do a load assessment or audit, to evaluate every load component the Photovoltaic system will be power, this is to ensure optimal performance and efficiency while taking into account cost because our resources are limited, it is also important we give load allowance in our system for future load addition by our client. The Table 3.1 shows the Electrical load requirement of the two-bedroom flat. The information presented in Table 3.2 offers a comprehensive overview of the total energy demand, highlighting the total power and the amount of time utilized while Table 3.3 shows the load table and the respective socket outlet for the various load. This data serves as a critical reference point for understanding the overall energy requirements within the context studied. Together, these tables contribute significantly to our understanding of energy utilization and load management within the specified residential setting.

3.3 LOAD REQUIREMENT

Table 3.1: Load Requirement for the Two-Bedroom Apartment

S/N	Location	Load	Qty	Current Ratings (A)	Voltage Ratings (V)	Rated Power (W)	Total Power (Qty x Rated power)	Total hour per day	Total Energy Demand (W)
1.	Sitting Room	Television	1	0.33	151	50	50	12	600
		Decoder	1	0.14	71	10	10	12	120
		Air conditioner	1	8.33	168	1400	1400	12	16,800
		Electric Fan	1	0.31	225	70	70	12	840
		LED Bulb	3	0.45	110	50	150	12	1800
		Spare load	1	0.23	220	50	50	12	600
2.	Master Bedroom	Electric fan	1	0.31	225	70	70	12	840
		LED bulb	2	0.45	110	50	100	12	1200
		Television	1	0.33	151	50	50	12	600
		Spare load	1	0.23	220	50	50	12	600
3.	Bedroom	Electric Fan	1	0.31	225	70	70	12	840
		LED Bulb	1	0.45	110	50	50	12	600
		Decoder	1	0.14	71	10	10	12	120
		Spare load	1	0.23	220	50	50	12	600
4.	Dining Room	LED Bulb	1	0.45	110	50	50	12	600
		Water Dispenser	1	0.34	220	75	75	19	1425

5.	Kitchen	LED Bulb	1	0.45	110	50	50	12	600
		Inverter Refrigerator	1	1.14	220	250	250	19	4750
6.	Verandah	LED Bulb	1	0.45	110	50	50	12	600
7.	Balcony	LED Bulb	1	0.45	110	50	50	12	600
8.	Lobby	LED Bulb	1	0.45	110	50	50	12	600
9.	Master Bedroom Toilet	LED Bulb	1	0.45	110	50	50	12	600
10.	Toilet	LED Bulb	1	0.45	110	50	50	12	600
11	Outside	LED Bulb	5	0.45	110	50	250	12	3,000
	TOTAL						**3,105**		**39,535**

NB: All loads are operating at a frequency of 50Hz

3.3.1 SUMMARY OF THE LOAD AND ENERGY DEMAND

Table 3.2: Summary of Energy Demand

Load	**Quantity**	**Total Power (Watts)**	**Total Hours per Day**	**Total Energy Demand (Watt -Hour)**
Television	2	100	12	1,200
Decoder	2	20	12	240
Air Conditioner	1	1400	12	16,800
Electric Fan	3	210	12	2,520
LED Bulb	18	900	12	10,800

Water Dispenser	1	75	19	1,425
Inverter Refrigerator	1	250	19	4,750
Spare	3	150	12	1,800
Total		**3,105**		**39,535**

Table 3.3: Load Table

S/N	DESCRIPTION	SINGLE PHASE (W)
1	Lighting point A1 (LED Bulbs)	900
2	13A SSO AS1 (Television)	100
3	13A SSO AS2 (Decoder)	20
4	13A SSO AS3 (Electric Fan)	210
5	13A SSO AS4 (Water Dispenser)	75
6	13A SS0 AS5 (Refrigerator)	250
7	15A SSO AS6 (AC)	1400
8	Spare	150
	TOTAL LOAD CONNECTED	**3,105**

3.4 CABLE SIZING

$$P = IV\cos\theta$$

$$I = \frac{P}{V \times \cos\theta}$$

Using a power factor of 0.9

$$I = \frac{3105}{240 \times 0.9}$$

$$I = 14.375A$$

For a current of 14.375A, we used a cable with current carrying capacity of 17A. From the cable rating in table 3.4, the voltage drop per ampere per metre will be 28mV

Therefore, **Cable Size = 1.5mm^2**

3.5 DISTRIBUTION BOARD PROTECTIVE DEVICE RATING

Rating of protective device $= I \times 1.45 = 14.375 \times 1.45$

Rating of DB $= 20.84A$

The range for DB ratings are 5A, 10A, 15A, 30A, 45A, 60A, 63A, 100A, 125A…

Therefore**, DB rating = 30A**

3.6 CIRCUIT BREAKER RATING

$P = IV$

$I = \frac{P}{V}$

$I = \frac{3105}{240}$

$I_{(new)} = current \times safety\ factor$

$I_{(new)} = 12.94 \times 1.25$

$I_{(new)} = 16.18A$

The range for CB ratings is 5A, 10A, 15A, 20A, 25A, 30A, 40A, 45A, 60A, 100A, 125A…

Therefore, **CB rating = 20A**

3.7 LOAD ANALYSIS OF PROPOSED PV SYSTEM

The observation in Table 3.1, reveals that the overall load of 3,105W requires several cascaded deep cycle batteries rated along with cascaded solar panels, charge controller and an inverter. To appropriately design the off-grid photovoltaic system, it's essential to convert the real power to an estimated apparent power, which involves selecting a suitable power factor value, assume we are using 0.9 as our Power factor, the estimated apparent power is given as;

Apparent Power (KVA) = Real Power (KW) / Power Factor

Apparent Power (KVA) = $\frac{3105W}{0.9}$ = 3.45KVA

Apparent Power = 3.45KVA

3.7.1 INVERTER SIZING

Solar inverters come in various capacities and they are produced by different companies, so we have to select the appropriate inverter system to power our load, we also have to give a load allowance as discussed earlier to accommodate transient voltages or surges. There are inverters of 1KVA, 2.5KVA, 4KVA etc.

However, based on our calculation of apparent power we are going to be working with a **4KVA** inverter system to power the Two-bedroom apartment, this means we are going to have an allowance of **0.55KVA**.

Minimum Usage Operating time

The minimum usage time refers to an estimated duration representing the expected lifespan of the batteries when the inverter system operates at maximum load capacity. Despite the system rarely being utilized under such extreme conditions in practice, an assumption is made based on user requirements, stipulating that the inverter system should endure for a minimum of 17 hours at full load.

3.8 SYSTEM SIZING OF PROPOSED PV SYSTEM

We are going to determine the appropriate capacity for various components of the system to meet our specific load requirement of 4KVA. First, we have to calculate the appropriate battery capacity to power a 4KVA load.

3.8.1 BATTERY SIZING

Converting our load from KVA to Watts,

Watts = KVA × Power Factor

Recall, we are working with a power factor of 0.9

Watts = 4KVA × 0.9 = 3.6KW

3.8.2 BATTERY CABLE SIZING

Inverter designers always supply these to meet their design specifications. These specifications are shown below in the Table.

Table 3.4: Cable Rating Table

CABLE RATING TABLE				
Cable Cross Sectional Area	One twin cable, with or without protective conductor, single phase AC or DC		One three-core cable, with or without protective conductor, or one four-cable, three phase	
	Current carrying capacity	Volt drop per ampere per meter	Current carrying capacity	Volt drop per ampere per meter
mm^2	A	mV	A	mV
1.0	14	42	12	37
1.5	17	28	16	24
2.5	24	17	21	15

4	32	11	29	9.2
6	40	7.1	36	6.2
10	53	4.2	49	3.7
16	70	2.7	62	2.3
25	79	1.8	70	1.6
35	98	1.3	86	1.1

3.8.3 TIME ESTIMATION

Next, we have to determine how long the battery is going to last, considering the fact we are working on an off-grid system, we have to design a system that will be able to sustain the resident for a reasonable amount of time throughout the day and night. Let's consider that our photovoltaic system will operate from 5 am to 12 pm during the day. It will then recharge from 12 pm to 4 pm, followed by operation from 4 pm to 4 am during the night/morning, which corresponds to our peak consumption period.

In summary;

5am – 12 noon ------------------ Consumption (7hrs)
12noon – 4pm ------------------- Charge time without usage (4hrs)
4pm – 4am ----------------------- Consumption (12hrs)
4am – 5am------------------------ Idle Time (1hr)

Total consumption time: 7hrs + 12hrs = 19hrs

Runtime: 19hrs

3.8.4 ENERGY REQUIREMENT

We can deduce the Energy requirement from the load requirement as seen in Table 3.2.

Total Energy Required (Wh) = 1,200 + 240 + 16,800 + 2,520 + 10,800 + 1,425+4,750 +1,800 = 39,535 Wh

Total Energy Required (Wh) = 39,535 Wh

3.8.5 BATTERY EFFICIENCY

Batteries are not 100% efficient, so we need to account for the efficiency of the battery system. Let’s assume a battery efficiency of **90%**

Battery Voltage:

Our battery bank voltage must match the inverter voltage; Hence, our battery bank voltage will be **48V**

Battery Capacity:

$$\text{Battery Capacity (Ah)} = \frac{Total\ Energy\ Required\ (Wh)}{Battery\ Voltage\ (V) \times Battery\ Efficiency\ (\%)}$$

$$\text{Battery Capacity (Ah)} = \frac{39{,}535Wh}{48V \times 90\,\%}$$

$$\text{Battery Capacity (Ah)} = \frac{39{,}535Wh}{48V \times 0.9} \approx \ 915.2\text{Ah}$$

Battery Capacity = 915.2Ah

So, to power the two-bedroom apartment with a 12V batteries at 90% efficiency, we would need approximately 915.2 ampere-hours of battery capacity. Keep in mind that this is a simplified calculation, and actual requirements may vary based on factors such as battery chemistry, temperature, and discharge rate.

3.8.6 PANEL SIZING

Now, we are required to calculate the total power rating that can conveniently charge our 915.2Ah battery under 4hrs.

Energy (Wh) = Battery Capacity (Ah) × Battery Voltage (V)

Energy (Wh) = 915.2Ah × 48V

Energy (Wh) = 43,930Wh

Solar panels do not operate at 100% efficiency, so we need to factor in an efficiency value. A typical solar panel convert about 15% to 30% of sunlight incident on it to useable energy, let’s assume our panels have an efficiency value of 25%

$$\text{Therefore, Solar Power rating} = \frac{Energy\ Required\ (Wh)}{Charging\ Efficiency(\,\%\,) \times Charge\ Time(hrs)}$$

NB: It is important to note from our time estimation calculation that from 7am – 12noon and 4pm – 6pm, the Photovoltaic system will be in usage while also charging, this time interval is 7hrs. This means we would have two charge time efficiency, 7hrs with usage and 4hrs without usage.

Without consumption = 25% $\times$ 4hrs = 1hr

With Consumption = 25% $\times$ 7hrs = 1.75hr

Total Charge Time Efficiency = 1 + 1.75 = 2.75

Solar Power Rating (W) = $\frac{43{,}930Wh}{2.75} \approx$ 15,975W

Solar Power Rating (W) $\approx$ 15,975W

Table 3.5: System Sizing

S/N	Inverter Capacity	Solar Panel Capacity	Battery Capacity
1	4KVA	15,975W	915.2Ah

3.9 NUMBER OF COMPONENTS REQUIRED OF PROPOSED PV SYSTEM

We can calculate the number of batteries, solar panels and the type of inverter to achieve the above system size.

3.9.1 NUMBER OF SOLAR PANELS

The number of solar panels required to deliver 15975W can be gotten by the formula below:

Number of Panels = $\frac{Solar\ Power\ Rating}{Panel\ Capacity}$

To achieve the solar power rating without having an enormous number of panels, we choose a panel capacity of 500W, therefore;

Panel Capacity = 500W

Number of Panels = $\frac{15{,}975W}{500W}$ = 31.95 Units

Number of Panels $\approx$ 32 Panels

3.9.1.2 PANELS CONNECTIONS

Each panel possesses a rating of 500W at 24V. However, given our utilization of a 48V inverter system, we must interconnect 32 panels to attain the desired 48V while also fulfilling the 16,000W requirement. This necessitates employing a series-parallel connection, which combines both series and parallel configurations. Initially, we link 2 panels in series to achieve 48V (24V + 24V) while maintaining a consistent current, resulting in a total of 1000W as shown in Figure 3.2. This series connection is replicated for all 16 pairs of panels, generating 16 series strings. Subsequently, each string is connected in parallel, maintaining the voltage constant while increasing the current to achieve a total rating of 16,000W. It is important to note that we had to use 16,000W instead of the 15,971W as gotten from the above result, this is because we scaled up our value due to decimal value.

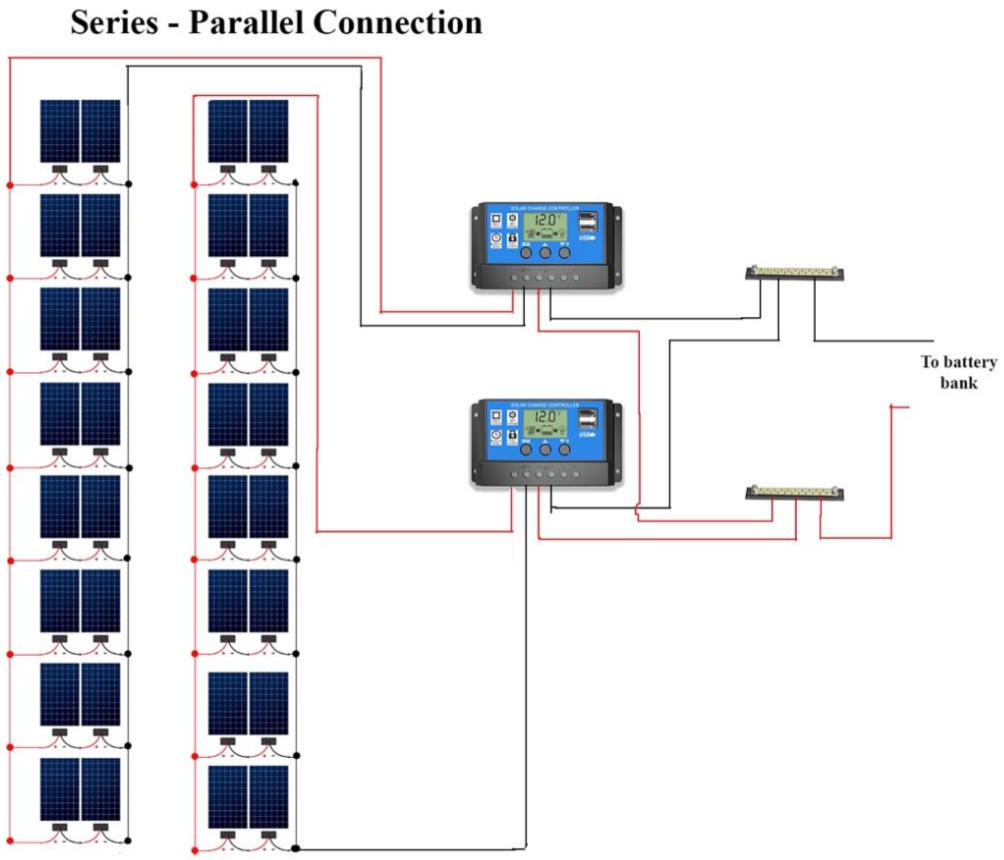


Figure 3.2: Solar Panel Array connections

3.9.2 NUMBER OF BATTERIES

The number of batteries can be gotten by dividing the total desired capacity by the individual battery capacity.

$$\text{Number of Batteries connected in series} = \frac{Total\ Desired\ Capacity}{Battery\ Capacity}$$

$$\text{Number of Batteries connected in series} = \frac{915.2Ah}{300Ah} \approx 4$$

But since we have to connect 4 Batteries in series to achieve 48V, the Total number of batteries is $4 \times 4 = 16$ Batteries.

It is important to note this configuration will give us a battery capacity of 1200Ah instead of the normal 915.2Ah, this is due to approximation to whole number.

Number of Batteries = 16 Batteries

3.9.2.1 BATTERIES CONNECTIONS

Each battery rated 12V 300Ah, to reach the desired output voltage of 48 volts (Inverter voltage), we'll need to connect the batteries in series-parallel connection as shown in Figure 3.3, which is a combination of both series and parallel. When batteries are connected in series, their voltages add up but if the batteries are connected in parallel the battery capacity(amp-hour) add up, hence to achieve a battery capacity of 48V and 915.2Ah, we have to utilize the combination of the two connections.

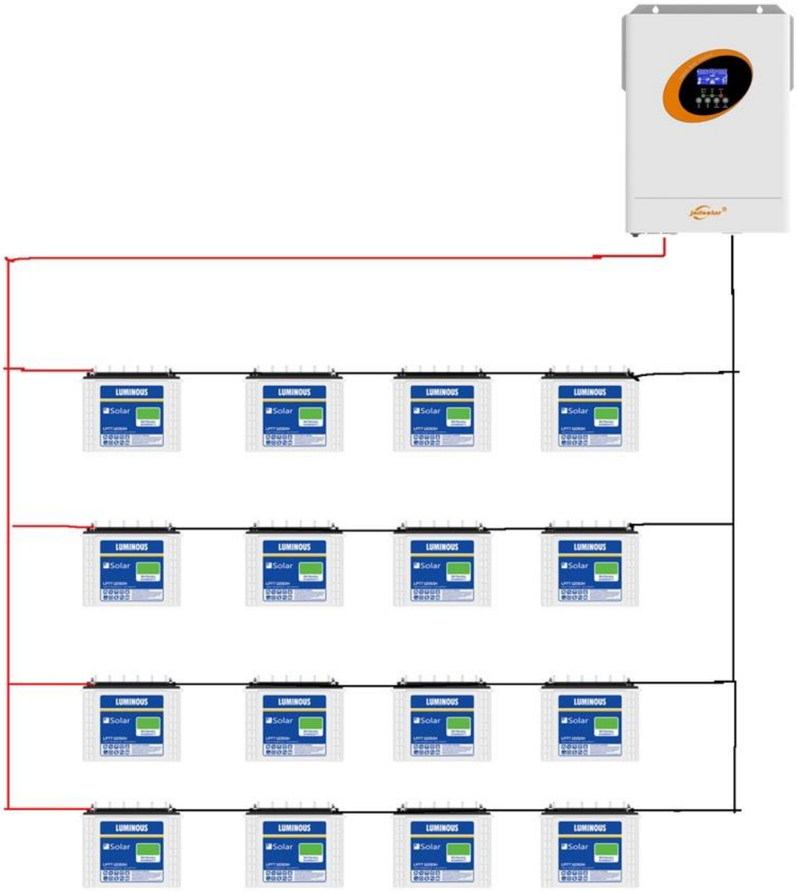


Figure 3.3: Battery Bank connections

3.9.3 CHARGE-CONTROLLER SIZING

Power of the solar array (Watts) = 16,000W

Voltage of solar array (Volts) = 48V

$$\text{Current (Amps)} = \frac{\text{Power (Watts)}}{\text{Voltage (Volts)}}$$

$$\text{Current (Amps)} = \frac{16{,}000}{48}$$

Current of the solar array (Amps) = 333.33A

Assuming a safety margin of 20%,

Safety Margin Current = Current × Safety Margin

Safety Margin Current = 333.33A × 0.20

Safety Margin Current = 66.67 A

Adjusted Current = Current + Safety Margin Current

Adjusted Current = 333.33A + 66.67A

Adjusted Current = 400 A

We would need a charge controller rated at 400 A. However, such a 400A charge controller cannot be found as a single unit, therefore, we would utilize two 200A charge controllers. This way the charge controller will meet our required safety margin for the solar array. A simulated charge controller is shown in Figure 3.4.

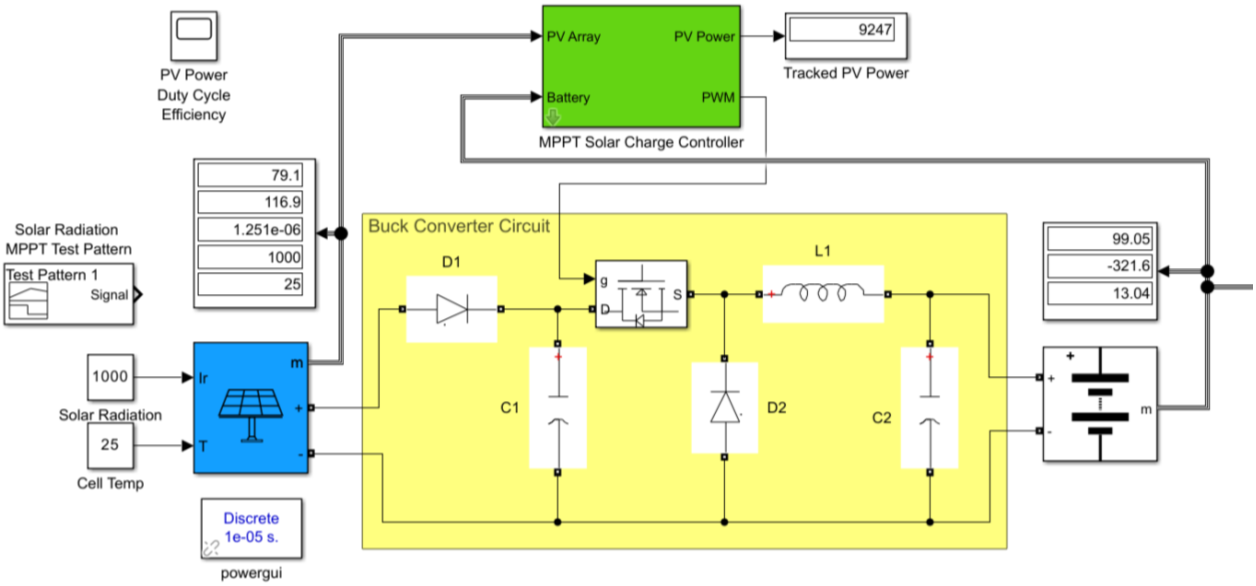


Figure 3.4: **Simulation of the Internal circuitry of the MPPT charge controller using MATLAB**

3.9.4 INVERTER DESIGN

In designing and building a solar power system, selecting an inverter that efficiently converts captured sunlight into usable electricity is paramount. From our system sizing we see that we need a 48V, 4KVA inverter system (Figure 3.6) that can conveniently handle our load. Understanding the functions of each component is crucial for selecting the most appropriate inverter for a specific solar project. This knowledge will guide in ensuring the inverter seamlessly integrates with the system design, efficiently converting solar energy into reliable backup power. The block diagram of the inverter circuit is shown in Figure 3.5.

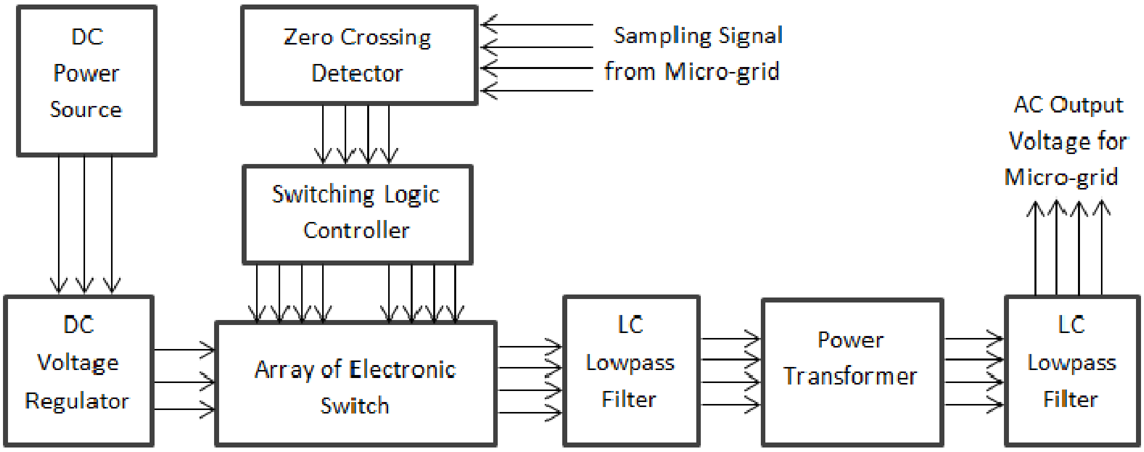


Figure 3.5: **The Inverter Block diagram**

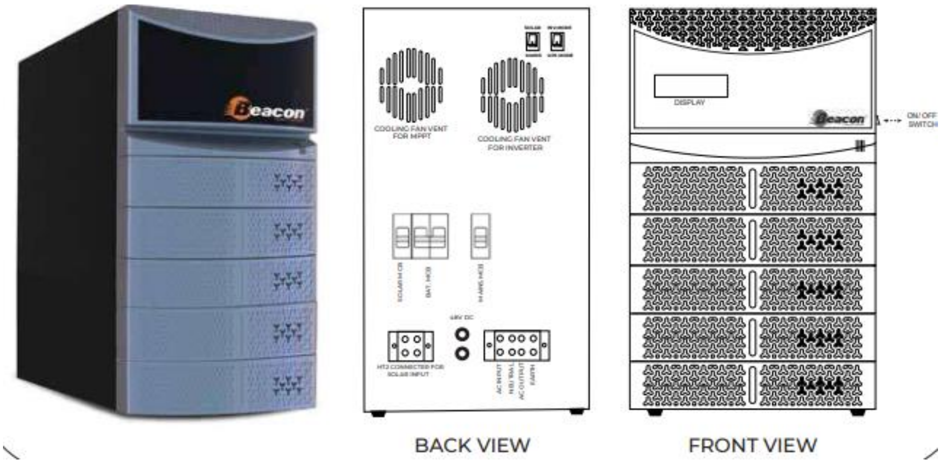


Figure 3.6: Diagram of a 48V, 4KVA MPPT Inverter

(Source: https://www.beaconpowersys.com)

3.10 OVERVIEW OF PV SYSTEM

We've finished designing all the parts of our solar power system. Now, it's time to bring everything together as shown in Figure 3.7 to make our off-grid system a reality.

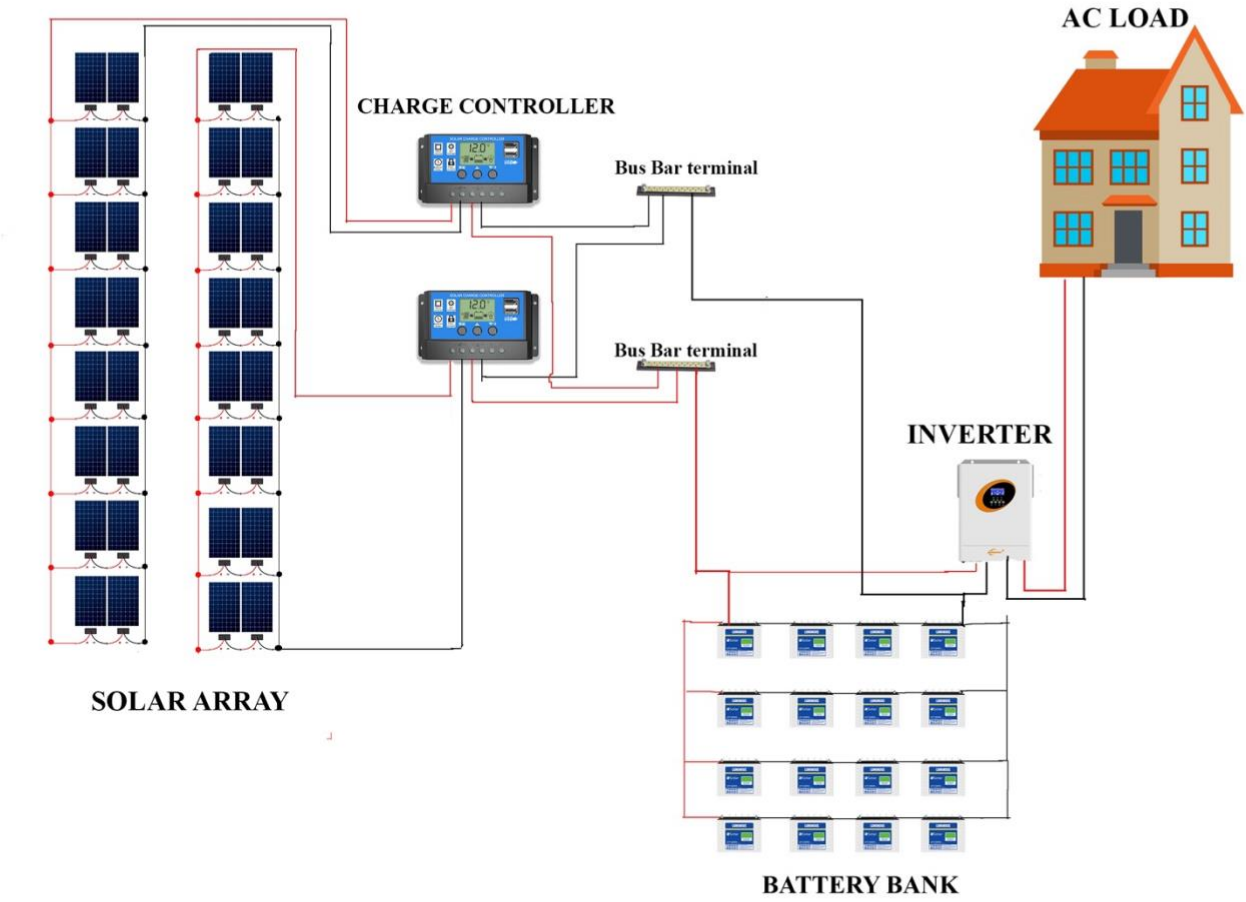


Figure 3.7: General Overview of a proposed Off-grid PV system.

3.11 IMPLEMENTED PV SYSTEM

Due to financial constraints, a DC PV system was used, consisting of a photo-voltaic solar panel, a charge controller, a battery and a DC load. The system was connected as shown in Figure 3.8. The system is designed to power DC loads directly. These DC loads include various appliances and devices that operate on DC electricity, such as lights, pumps, communication equipment, and other low-voltage devices. By directly powering DC loads, the system minimizes energy losses that can occur during the DC to AC conversion process, thereby maximizing overall efficiency.

Despite its simplicity compared to grid-tied systems with inverters, this DC PV system is robust and efficient, offering reliable electricity supply especially in off-grid or remote locations where access to the electrical grid is limited or costly. Figure 3.9 shows the contrasted PV system on site.

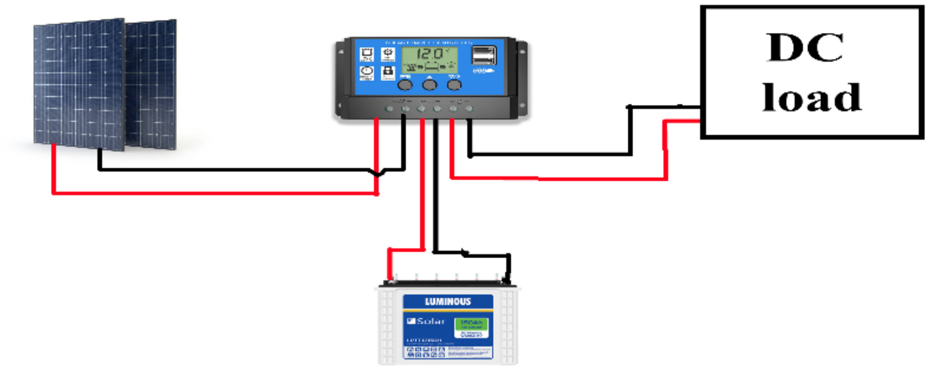


Figure 3.8: General Overview of implemented PV system supplying only DC Load

Figure 3.9: Physical Implementation of the PV system

CHAPTER FOUR

INSTALLATION, TESTING AND RESULT

4.1 INSTALLATION PROCESS OF PROPOSED PV SYSTEM

The installation of the 4KVA Photovoltaic system was carried out using the following steps to ensure safe and efficient operation of system.

4.1.1 SITE ASSESSMENT

Site assessment was a crucial step in the installation process of the solar photovoltaic (PV) system. It involves evaluating the location where the solar panels will be installed to ensure optimal performance and efficiency. The following was considered during site assessment process:

1. **Sunlight Availability:** The availability of sunlight in our rural location was a very important factor we considered. However, this wasn’t a problem because our site was located in the equator. Through thorough analysis we concluded that the sun rises by 6am in the morning and run till 6pm in evening with an average of temperature of 32˚C - 34 ˚C, we also checked for other important factors such as the orientation of the site, shading from nearby buildings or trees etc. Assessing the amount of sunlight, the site receives throughout the day and year helps determine the potential energy production of the solar PV system.
2. **Type of Mounting System:** We thought about what kind of mounting system to use, and we decided on a ground mounting system instead of mounting the panels on the roof. This is because we need about 32 panels to make our system robust and completely off-grid. Putting these panels on the roof might be too much for the structure to handle. whereas, there's sufficient space on the ground, so ground mounting was the best choice.
3. **Tilt Angle:** The orientation and tilt angle of the roof play a significant role in maximizing energy production from solar panels. We experimented on the different tilt angles to get the optimal production of energy; these results we be discussed later in this project.
4. **Budget and Financing:** We also made financial considerations associated with the installation of the solar PV system.

4.1.2 DESIGN

Based on the site assessment and energy requirements, a detailed design for the solar PV system was created as discussed in chapter Three. This includes determining the optimal system sizing, number of inverters, panels and type of charge controllers required to make our system function optimally.

4.1.3 PROCUREMENT OF EQUIPMENT

The necessary equipment for the solar PV system is procured as shown in Figure 4.1, including solar panels, inverters, mounting hardware, wiring, and other electrical components. The procurement cost will be reflected in our Bill of Engineering Measurement Evaluation (BEME) on Table 5.1.

Figure 4.1: Procurement of solar panels

4.1.4 MOUNTING STRUCTURES

Mounting structures such as ground mounts as shown in Figure 4.2 are installed to support the solar panels. These structures are securely attached to the ground using bolts and anchors. These mounts are made up of galvanized steel or aluminum support. The support structures are anchored to the ground using foundations made up of driven piles, helical piles, ground screws, concrete footings, concrete ballast, or a combination of these elements, this is essential to make the structure withstand heavy wind.

Figure 4.2: Solar panel mounting structure

4.1.5 THE BATTERY BANK

The installation of the battery bank (Figure 4.3) is carried out using a series-parallel configuration, this configuration involves connecting the 4 batteries in series to achieve a voltage of 48V, then connecting 4 strings of those 4 Batteries in parallel to achieve our desired 1200Ah battery capacity as illustrated in **Fig 3.3.**

Figure 4.3: Installation of Battery Bank

4.1.6 INSTALLATION OF INVERTER

A Pure sine wave 48V 4KVA inverter system as shown in Figure 4.4 is installed to enable our PV system convert the DC energy generated by our solar panel to useable AC that can power our load. The Installation process is as follows:

1. Unpacking the inverter from its carton.
2. The inverter is placed on a platform few meters above the ground.
3. The inverter is screwed to the platform.
4. Confirm if the inverter is firmly placed.

Figure 4.4: 4KVA 48V Inverter system

4.1.7 ELECTRICAL WIRING

Various electrical wiring is carried out to link the Solar PV system to Load in the house, Knife switch, electrical wires and distribution board as shown in Figure 4.5 is majorly used to achieve this.

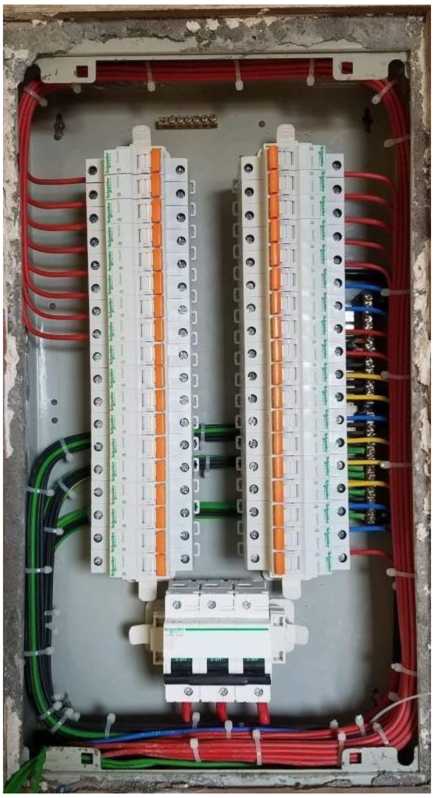


Figure 4.5: Distribution Board

4.2 TESTING OF IMPLEMENTED PV SYSTEM

4.2.1 OPTIMAL TILT ANGLE TEST OF IMPLEMENTED PV SYSTEM

The optimal tilt angle test (Figure 4.6) for solar panels involves determining the angle at which the panels can capture the maximum amount of sunlight throughout the year, thereby maximizing energy production. The following are the steps involves in conducting this test;

1. **Initial Assessment:** Before conducting the test, it's essential to consider factors such as the latitude of the installation site, the seasonality of sunlight, and any obstructions that may affect sunlight exposure, for this test the University of Benin, Ugbowo campus was used as the test location .
2. **Tilt Angle Range Selection:** Based on the initial assessment, a range of tilt angles is selected for testing, for this test we chose a range of 0˚ to 45˚.
3. **Installation of tilt Mechanism:** A tilt mechanism is installed for the solar panels to allow for adjustment of the tilt angle. This mechanism uses adjustable tilt racks powered by a motor system.

Figure 4.6: Tilt Mechanism

4. **Adjustment of Tilt Angle:** The tilt mechanism is adjusted periodically depending on the specific requirements of the installation site to find the Optimal tilt angle.
5. **Monitoring and Data collection:** Once the tilt mechanism is installed, the solar panels are set to different tilt angles within the selected range. A data logging system is used to monitor the energy output of the panels at each tilt angle over a specified period, typically spanning several weeks or months to capture seasonal variations.
6. **Analysis of Result:** After collecting sufficient data, the energy output of the panels at each tilt angle is analyzed to determine which angle provides the highest energy yield throughout the year. This analysis takes into account factors such as daily and seasonal variations in sunlight intensity and angle.

4.2.1.1 TILT ANGLE RESULT OF IMPLEMENTED PV SYSTEM

Table 4.1: Data Obtained on Week 1

Angle	**Voltage(V) Day 1**	**Voltage(V) Day 2**	**Voltage(V) Day 3**	**Voltage(V) Day 4**	**Voltage(V) Day 5**
45°	21.5V	20.9V	18.8V	20.5V	20.0V
40°	22.1V	21.5V	18.9V	20.2V	19.3V
35°	20.9V	21.2V	19.7V	20.2V	19.3V
30°	23.1V	21.2V	21.2V	20.2V	20.1V
25°	20.8V	21.5V	21.2V	20.4V	19.9V
20°	23.8V	23.1V	22.8V	20.7V	20.8V
15°	20.8V	22.6V	23.1V	20.9V	19.8V
10°	23.4V	22.9V	23.1V	20.1V	19.9V
0°	24V	23.5V	23.2V	21.0V	20.1V

Table 4.2: Data Obtained on Week 2

Angle	**Voltage(V) Day 1**	**Voltage(V) Day 2**	**Voltage(V) Day 3**
45°	20.6V	20.3V	19.3V
40°	20.7V	20.1V	19.3V
35°	20.7V	19.5V	19.3V
30°	20.9V	21.0V	19.2V
25°	20.7V	21.2V	19.2V
20°	22.8V	21.6V	19.9V
15°	21.9V	22.5V	19.3V

10°	21.7V	22.4V	19.3V
0°	22.3V	22.0V	19.5V

We can therefore evaluate the average voltage obtained on each tilt angle

Table 4.3: Average Voltage on each tilt angle

Angle	Average Voltage (V) Week 1	Average Voltage (V) Week 2	Total Average (V)
45°	20.34	20.06	20.20
40°	20.40	20.03	20.21
35°	20.26	19.83	20.04
30°	21.16	20.37	20.76
25°	20.76	20.36	20.56
20°	22.24	21.43	21.84
15°	21.44	21.23	21.34
10°	21.88	21.13	21.51
0°	22.36	21.26	21.81

The result depicted in Table 4.3 shows that the maximum average voltage generated was 21.84V which corresponds to an inclination angle of 20° (Figure 4.7). It can therefore be concluded that 20° is the optimal tilt angle for solar panels in this specific geographical location as determined by this experiment.

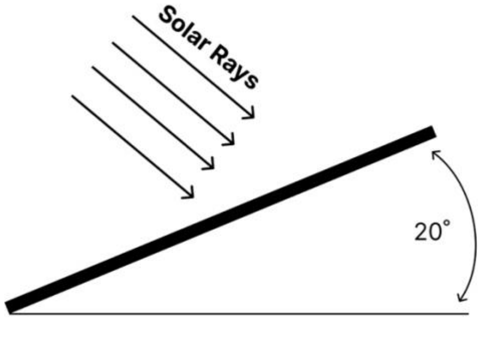


Figure 4.7: Tilt Angle

4.2.2 DC LOAD TEST OF IMPLEMENTED PV SYSTEM

Testing was carried out based on the connection of the PV system based on the use of a DC load, readings were taken at intervals of 30 mins ranging from a time period of 11:00 am to 4:00 pm. The values obtained for the voltage and current at full load, half load and no load is giving in Table 4.4 and Table 4.5 respectively;

Short circuit Current = **1.45 A**

Open circuit Voltage = **13.75 V**

Table 4.4: Voltage at full-load, half-load and at no-load

Time of day	**Voltage of DC load (at full load)**	**Voltage of DC load (at half-load)**	**Voltage of DC load (at no load)**
11:00 AM	12.78 V	13.11 V	13.65 V
11:30 AM	12.65 V	13.09 V	13.62 V
12:00 PM	12.72 V	13.14 V	13.65 V
12:30 PM	12.73 V	13.12 V	13.69 V
1:00 PM	12.79 V	13.11 V	13.75 V
1:30 PM	12.80 V	13.19 V	13.79 V
2:00 PM	12.75 V	13.13 V	13.73 V
2:30 PM	12.69 V	13.18 V	13.72 V
3:00 PM	12.66 V	13.08 V	13.70 V
3:30 PM	12.55 V	13.04 V	13.65 V
4:00 PM	12.47 V	13.02 V	13.61 V

Table 4.5: Current at full-load, half-load and at no-load

Time of day	**Current of DC load (at full load)**	**Current of DC load (at half-load)**	**Current of DC load (at no load)**
11:00 AM	2.18 A	1.43 A	0
11:30 AM	2.16 A	1.41 A	0
12:00 PM	2.17 A	1.41 A	0

12:30 PM	2.18 A	1.42 A	0
1:00 PM	2.18 A	1.42 A	0
1:30 PM	2.17 A	1.41 A	0
2:00 PM	2.16 A	1.41 A	0
2:30 PM	2.17 A	1.41 A	0
3:00 PM	2.18 A	1.43 A	0
3:30 PM	2.18 A	1.42 A	0
4:00 PM	2.17 A	1.41 A	0

The DC load test results provide crucial insights into the performance and efficiency of the power supply system under various loading conditions over time. The test, conducted at full load, half load, and no-load intervals, with observations taken at different times, allows for a comprehensive analysis of the system's behavior and stability.

1. **Voltage Stability**:

- **Full Load**: At full load, the voltage remained within acceptable limits, indicating that the power supply can handle maximum demand without significant voltage drops.
- **Half Load**: The voltage at half load showed less variation compared to full load, demonstrating the power supply's ability to maintain stability with moderate demand.
- **No Load**: At no load, the voltage was the highest and most stable, reflecting the system's baseline performance without any external demand.

2. **Current Draw**:

- **Full Load**: The current draw at full load was consistent with the expected maximum current, confirming that the power supply can deliver the required current without overloading.
- **Half Load**: The current at half load was approximately half of the full load current, showing a linear relationship between load and current draw, which is characteristic of a well-functioning power supply.
- **No Load**: The current at no load was minimal, as expected, indicating no significant leakage or idle current draw.

The DC load test results indicate that the power supply system is highly reliable and stable across different load conditions and over extended periods. It maintains voltage stability and consistent current draw under full, half, and no-load scenarios.

4.2.2.1 Charge Time of the Battery

The charge time of a battery is significantly influenced by its capacity and the charging current. Battery capacity, measured in ampere-hours (Ah) or milliampere-hours (mAh), determines how much energy a battery can store; larger capacities generally require more time to charge fully. The charging current, expressed in amperes (A), determines the rate at which energy is supplied to the battery. A higher charging current can reduce the overall charging time, although it must be managed carefully to avoid damaging the battery. Together, these factors play a crucial role in determining how quickly a battery can be recharged.

Charge Time of the Battery = $\frac{Battery\ Capacity(Ah)}{Charging\ Current(A)}$

Rating of the Battery Capacity = 100Ah

Charging current = $\frac{Panel\ Capacity}{Open\ Circuit\ Voltage} = \frac{200\text{watts}}{13.72volts}$

= 14.57A

Where 13.72V is the open Circuit voltage

Therefore;

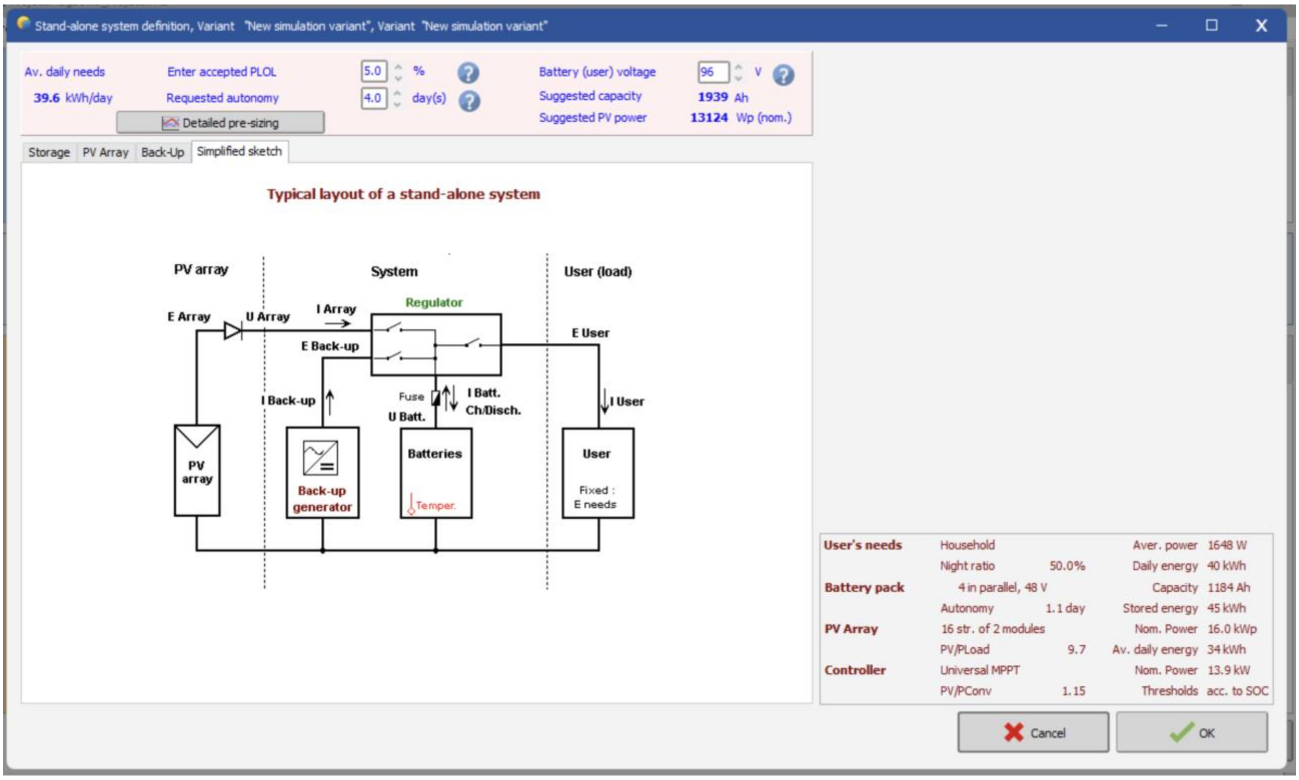
Charge Time of the Battery = $\frac{\mathbf{100Ah}}{\mathbf{14.57A}}$

Charge Time of the Battery = 6.86hrs

4.3 RESULT OF PROPOSED PV SYSTEM

4.3.1 PYSYST LAYOUT OF THE PV SYSTEM

To get an optimal result for our PV system, a simulation of the system was carried out using PVSYST software as seen in Figure 4.8;


Stand-alone system definition, Variant "New simulation variant", Variant "New simulation variant"

Av. daily needs 39.6 kWh/day

Enter accepted PLOL 5.0 %

Requested autonomy 4.0 day(s)

Battery (user) voltage 96 V

Suggested capacity 1939 Ah

Suggested PV power 13124 Wp (nom.)

User's needs	Household		Aver. power	1648 W
	Night ratio	50.0%	Daily energy	40 kWh
Battery pack	4 in parallel, 48 V		Capacity	1184 Ah
	Autonomy	1.1 day	Stored energy	45 kWh
PV Array	16 str. of 2 modules		Nom. Power	16.0 kWp
	PV/PLoad	9.7	Av. daily energy	34 kWh
Controller	Universal MPPT		Nom. Power	13.9 kW
	PV/PConv	1.15	Thresholds	acc. to SOC

Figure 4.8: PYSYST layout of the PV system

Figure 4.8 shows a typical layout of the plan of the stand-alone system. The PVSYST software provides us with a comprehensive schematic of the circuit layout. The diagram displayed is sectioned into three; the PV array, the system circuitry and the user which represent the output or load.

The PV array section details the interaction between the solar panels and sunlight. The system illustrates how components such as batteries, inverters, and regulators are interconnected to produce the desired output. The final section pertains to the load.

The proposed project was simulated using the PVSYST software and the results obtained are described by the graphs below:

4.3.2 DAILY INPUT/OUTPUT GRAPH

The daily input vs output graph shows the energy incident on the solar array in comparison with the energy output by the solar array.

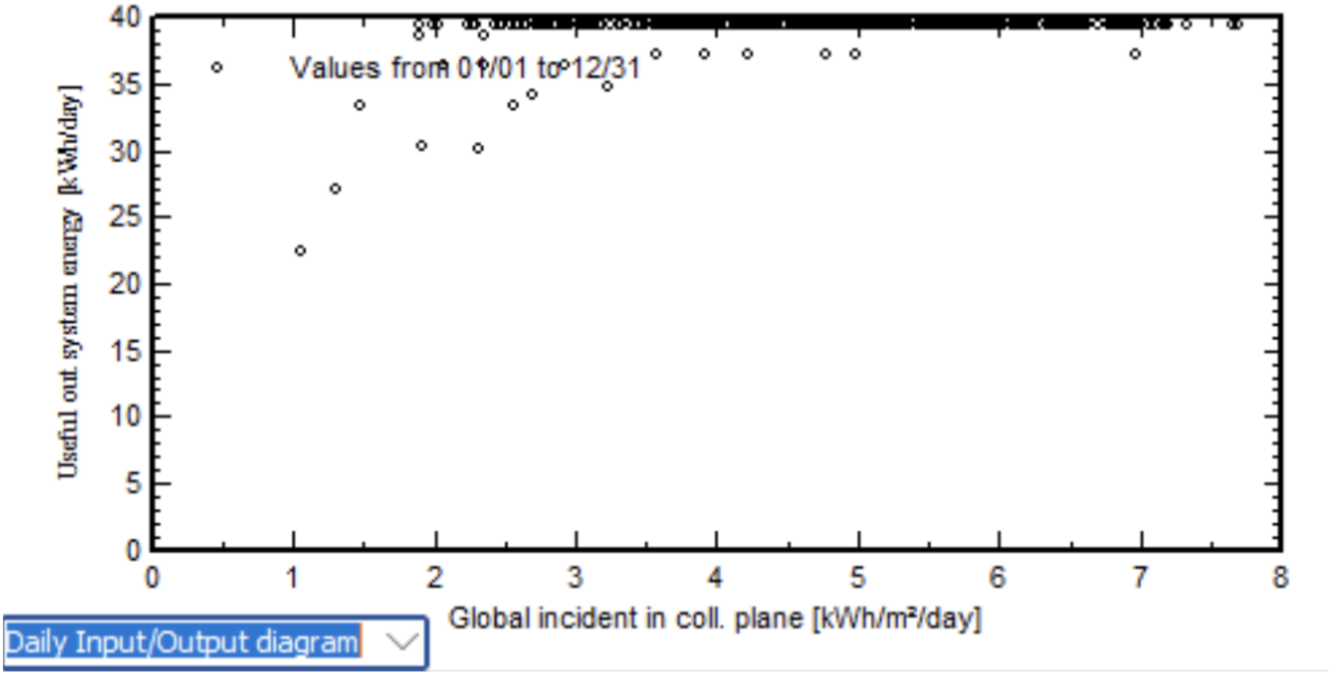


Figure 4.9: Daily output vs input graph

It is observed that the daily input and output plot of the solar array is represented by a scattered plot, this is because the intensity of the sun rays varies round the clock. Also, we noticed in the scatter plot that as the global incident increases the useful output energy also increases. This means that the amount of sun rays' incident on the horizontal plane is directly proportional to the output energy. If a line of best fit is drawn the slope given by that line will be positive.

The Global Incident in Coll. Plane representing the horizontal axis of the graph is the result of the transposition of the irradiance from the horizontal to the plane of the array. It is a measure of the deviation from Global Horizontal Irradiance (GHI). It is unit is in Kilowatt-hour

Global Horizontal Irradiance is the sum of all the short waves received by a surface which is parallel to the earth's surface or horizontally inclined to the earth.

The GHI is a function of the Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF). The global irradiance on a tilted plane; Gt, whose tilt is β degrees from the horizontal could be calculated from the equation:

$$G_t = G_{dn} \cos\theta + G_d R_d + \rho G_h R_t$$

where G_{dn} is the direct normal irradiance (DNI)

G_d is the diffuse horizontal irradiance (DHI),

G_h is the global horizontal irradiance (GHI),

θ is the angle of incidence of the sun rays on the tilted plane

R_d is the diffuse transposition factor,

ρ is the foreground's albedo

and R_t is the transposition factor for ground reflection.

The global horizontal irradiance (GHI) could be calculated as follows:

$$G_h = G_{dn} \cos\theta_z + G_d$$

where θ_z is the sun's zenith angle at any instant.

The method of deriving the tilted component of DNI is completely geometric unlike the ground reflected diffuse irradiance which is dependent on the factor R_t.

$$R_t = (1 - \cos\beta)/2$$

4.3.3 PERFORMANCE RATIO AND SOLAR FRACTION RESULT

The performance ratio reflects the performance throughout the year and provides insights on how the overall system losses affect the rated output. These losses comprise factors such as PV module efficiency, tilt angle, dust, shading, and module temperature. Analysis with monocrystalline silicon PV modules reveals varying system performance over the course of 2 weeks, with a rising trend observed in the solar fraction during the initial week as shown in Figure 4.9.

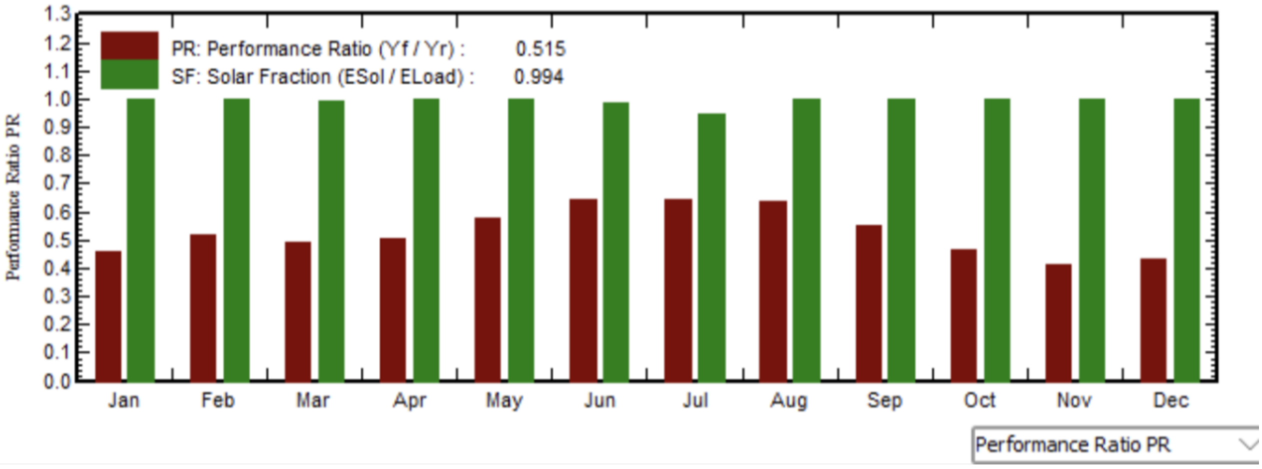


Figure 4.10: Graph of performance ratio to solar fraction

The parameters from the graph in Figure 4.10 are the solar fraction (SF) and the performance ratio (PR). The Solar Fraction can be defined as the ratio of the energy consumed by the user using the solar PV system to the overall power usage of the consumer. It is denoted by SF.

The performance ratio is the actual energy output from the PV system to the theoretical output predictions assuming there were no losses. These parameters are very useful to determine how efficient the system will be and if the system is capable of accommodating the load available.

$$PR = \frac{Y_f}{Y_r}$$

Where PR is the performance ratio

Y_f is the actual energy output per year

Y_r is the theoretical energy per year

With this we may conclude that higher the performance ratio the more efficient the system and the ideal solar PV system has a PR of 1.

Solar fraction is given by the formula:

$$SF = \frac{E_{sol}}{E_{load}}$$

Where SF is the Solar Fraction

E_{sol} is the energy output of the solar PV system

E_{load} is the total energy consumed by the load

Hence, these two parameters determine the efficiency of solar PV system.

In the graph, the PR is quite low compared to the SF, this is usually the case because at most 40% of the sun rays that are incident on the panel are converted to electricity, so, the actual energy produced is low compared to the theological energy expected.

Nevertheless, the system is good enough because the high SF shows that the solar PV stand-alone can power majority of the load on its own.

4.3.4 ARRAY TEMPERATURE VS EFFECTIVE IRRADIANCE

The array temperature to the effective irradiance on the solar photovoltaic system can be seen in figure 4.10

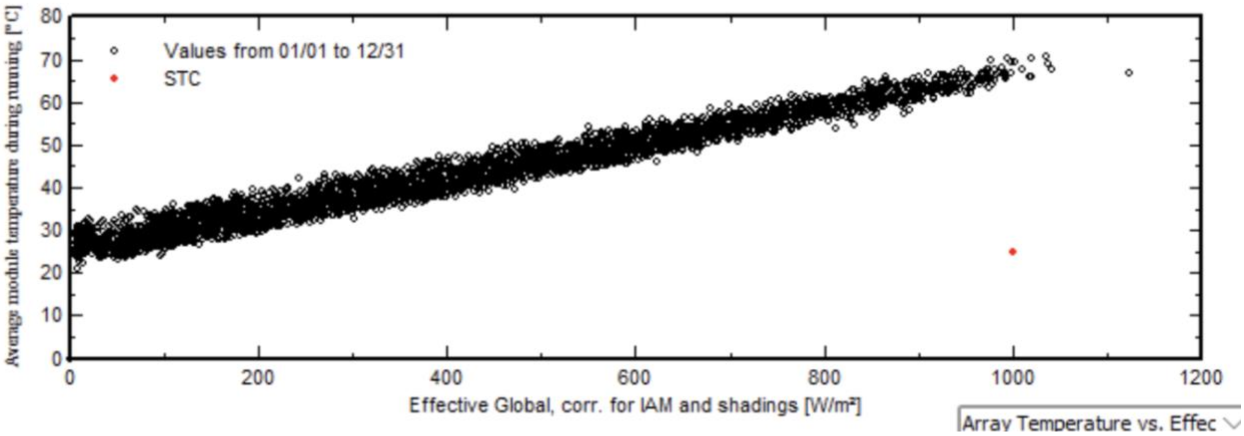


Figure 4.11: Array temperature vs Effective irradiance

The average module temperature during running versus the effective global correction (for AM times and shadings) irradiance is the plot shown in Figure 4.11.

It can be seen that the temperature of the solar array increases as the irradiance increases, and this should be the case. Notice that the plot does not start from the origin, that is because it has been corrected from the certain times where there is no sufficient sunlight as well as total shading, hence, the result.

This will ensure that at every point in time while the system is running, it is actually accumulating some sort of energy, in other words, there will be no idle time. The system will be turned off completely when it cannot receive sufficient energy from the sun.

4.3.5 ARRAY POWER DISTRIBUTION

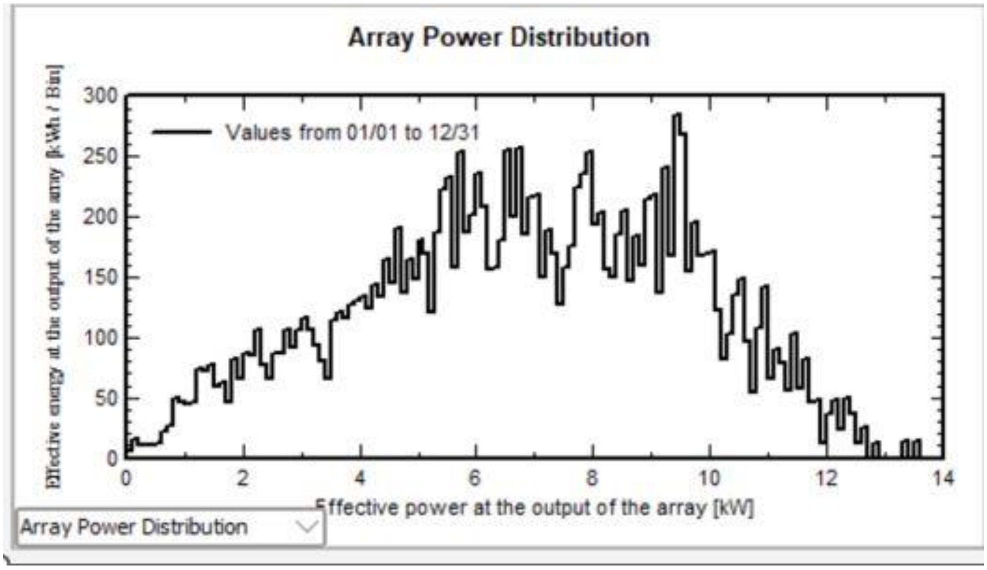
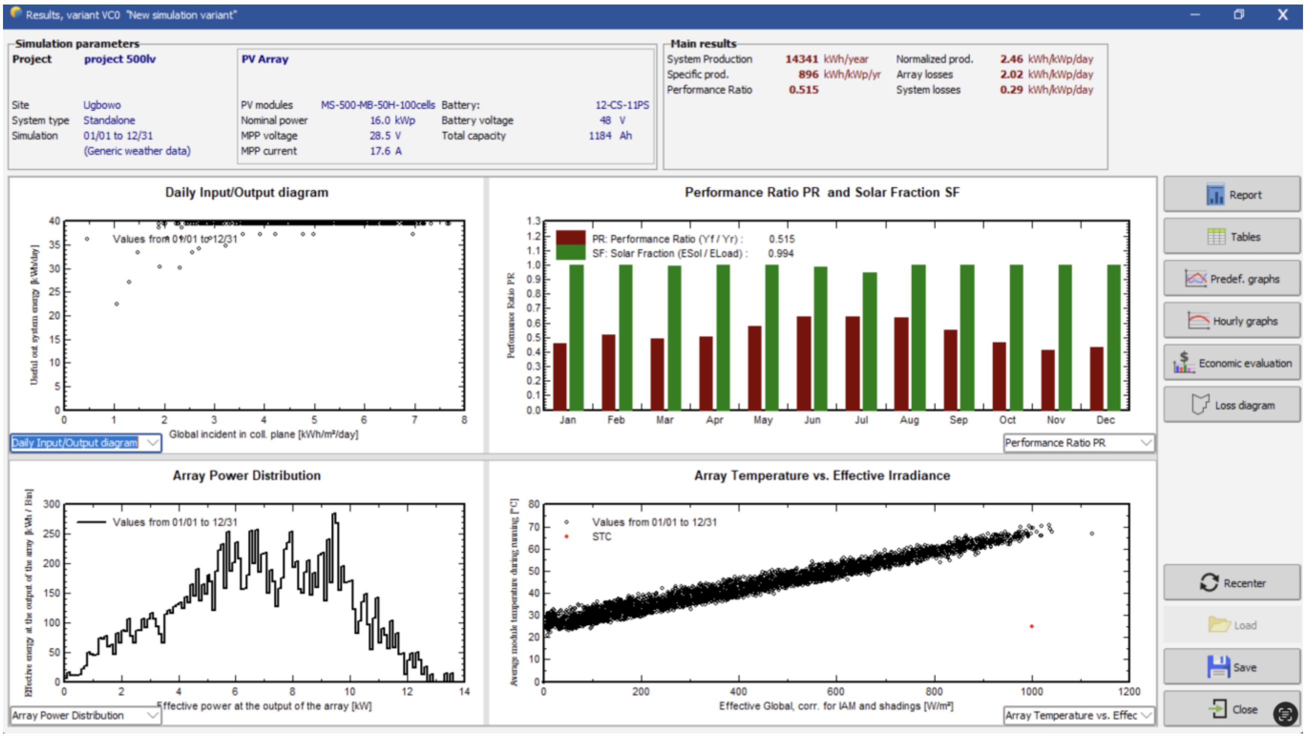


Figure 4.12: Array Power Distribution

Figure 4.12 shows the graph of Effective Energy at the output of the array (kwh/Bin) against Effective Power at the output of the array (kw)

4.4 SUMMARY OF RESULTS

The graph below shows that our PV system performance is optimal, the general result of the simulation is shown below in Figure 4.13


Results, variant VC0 "New simulation variant"

Simulation parameters

Project project 500lv

Site Ugbowo
System type Standalone
Simulation 01/01 to 12/31
(Generic weather data)

PV Array

PV modules MS-500-MB-50H-100cells
Nominal power 16.0 kWp
MPP voltage 28.5 V
MPP current 17.6 A
Battery: 12-CS-11PS
Battery voltage 48 V
Total capacity 1184 Ah

Main results

System Production 14341 kWh/year
Specific prod. 896 kWh/kWp/yr
Performance Ratio 0.515
Normalized prod. 2.46 kWh/kWp/day
Array losses 2.02 kWh/kWp/day
System losses 0.29 kWh/kWp/day

PR: Performance Ratio (Yf / Yr) : 0.515
SF: Solar Fraction (ESol / ELoad) : 0.994

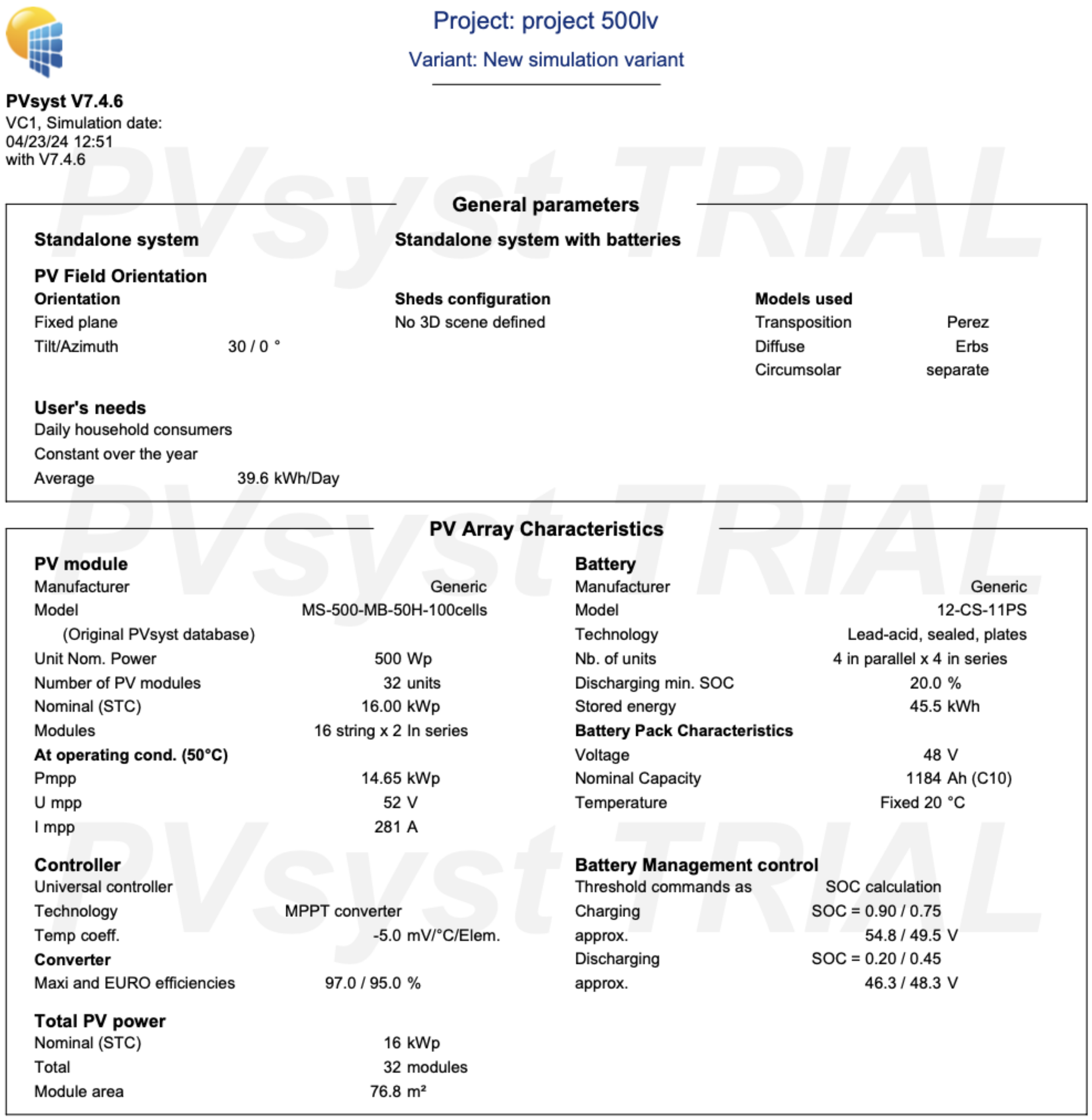
Figure 4.13: Summary simulation result

Figure 4.13 presents the summary of the PV system simulation by combining the various graph obtained during the simulation. Key parameters and results are displayed, providing insights into the system's performance over a year. The data is presented in various diagrams and charts to offer a comprehensive view. Main results obtained are the following;

1. System Production: 14,341 kWh/year
2. Specific production: 896 kWh/kWp/year
3. Performance Ratio (PR): 0.515
4. System losses: 2,024 kWh/year
5. Normalized production: 2.46 kWh/kWp/day
6. Array losses: 2.02 kWh/kWp/day
7. System losses: 0.29 kWh/kWp/day

We can therefore infer the following from this result;

1. The system produces a substantial amount of energy annually (14,341 kWh/year) but has a moderate performance ratio of 0.515, indicating there might be room for efficiency improvements.
2. The daily input/output diagram shows that energy production is closely linked to irradiance, with some variability.
3. The performance ratio and solar fraction chart indicate seasonal variations in efficiency and solar contribution, likely due to changes in sunlight availability and weather conditions.
4. The array power distribution histogram helps understand the typical operating conditions of the array.
5. The temperature vs. irradiance plot highlights the impact of irradiance on array temperature, which can affect performance.



Project: project 500lv

Variant: New simulation variant

PVsyst V7.4.6
VC1, Simulation date:
04/23/24 12:51
with V7.4.6

General parameters

Standalone system **Standalone system with batteries**

PV Field Orientation

Orientation	
Fixed plane	
Tilt/Azimuth	30 / 0 °

Sheds configuration
No 3D scene defined

Models used	
Transposition	Perez
Diffuse	Erbs
Circumsolar	separate

User's needs

Daily household consumers	
Constant over the year	
Average	39.6 kWh/Day

PV Array Characteristics

PV module	
Manufacturer	Generic
Model	MS-500-MB-50H-100cells
(Original PVsyst database)	
Unit Nom. Power	500 Wp
Number of PV modules	32 units
Nominal (STC)	16.00 kWp
Modules	16 string x 2 In series
At operating cond. (50°C)	
Pmpp	14.65 kWp
U mpp	52 V
I mpp	281 A

Controller	
Universal controller	
Technology	MPPT converter
Temp coeff.	-5.0 mV/°C/Elem.
Converter	
Maxi and EURO efficiencies	97.0 / 95.0 %

Total PV power	
Nominal (STC)	16 kWp
Total	32 modules
Module area	76.8 m²

Battery	
Manufacturer	Generic
Model	12-CS-11PS
Technology	Lead-acid, sealed, plates
Nb. of units	4 in parallel x 4 in series
Discharging min. SOC	20.0 %
Stored energy	45.5 kWh
Battery Pack Characteristics	
Voltage	48 V
Nominal Capacity	1184 Ah (C10)
Temperature	Fixed 20 °C

Battery Management control	
Threshold commands as	SOC calculation
Charging	SOC = 0.90 / 0.75
approx.	54.8 / 49.5 V
Discharging	SOC = 0.20 / 0.45
approx.	46.3 / 48.3 V

Figure 4.14: General simulation results

Figure 4.14 shows the general parameters for the system simulation which includes the General Parameter and the PV Array Characteristics. The General Parameter displays the system type which is a Standalone System in this case, the PV Field Orientation in degrees and the User's needs in kW/Day. The PV Array Characteristic includes the PV Module, Controllers, Battery and Battery Management. The Figure gives both qualitative and quantitative description of the system. The Total Power is represented in this section as well. For more complex systems, this Figure will be elaborate and more parameters may apply.

4.4 BILL OF ENGINEERING MEASURMENT EVALUATION

This bill of engineering measurement and evaluation provided in Table 4.7 and Table 4.8 encompasses all associated costs involved in the installation and commissioning of the proposed photovoltaic (PV) system. It is imperative to acknowledge that the financial estimates provided herein are subject to fluctuations influenced by various factors. These factors include but are not limited to regional economic conditions, local market dynamics, and geographical considerations.

The economic landscape can significantly impact the prices of materials, labor, and ancillary services required for the successful deployment of the PV system. Additionally, geographical factors such as the availability of resources, transportation logistics, and local regulatory frameworks can also contribute to cost variability.

Therefore, while the provided estimates aim to be as accurate and comprehensive as possible, stakeholders should be aware of the potential for price variations. Continuous monitoring of market conditions and strategic planning are recommended to mitigate financial risks and ensure the project's feasibility and sustainability.

Table 4.7: Bill of engineering measurements and evaluation for the proposed PV system

S/N	Items Required	Description	Unit	Price Per Unit (N)	Amount Required	Price Per Amount (N)
1.	Inverter	4KVA, 48V	Piece	400,000	1	400,000
2.	Deep Cycle Battery	12V, 300Ah	Pieces	220,000	16	3,520,000
3.	Solar Panels	500Watt	Panels	60,000	32	1,920,000
4.	MPPT Charge controller	200Amp	Pieces	163,400	2	326,800
5.	Solar Wire	15mm^2	Yards	800	20	18,000
6.	Circuit Breaker	200Amp	Piece	6,000	1	8,000

7.	Distribution Board	6-way Distribution Board	Pieces	50,000	1	50,000
8.	Aluminium Angle Bar	30 Feet	Bar	10,500	2	21,000
9.	Knife Switch	200Amp	Piece	10,000	1	10,000
10.	Single Core* Wire	$1.5mm^2$	Yards	200	20	4000
11.	Nails	2 inches	Packet	500	1	500
12.	Screws	1 inch	Packet	500	1	500
13.	**Cost Of Materials**	**-**	**-**	**-**	**-**	**6,278,800**
14.	Logistics And Transportation of Materials	-	-	-	-	50,000
15.						
16.	**GROSS TOTAL**	**-**	**-**	**-**	**-**	**6,328,800**

Table 4.8: Bill of engineering measurements and evaluation for implemented PV system

S/N	ITEMS REQUIRED	DESCRIPTION	UNITS	PRICE PER UNIT	QUANTITY REQUIRED	COST OF ITEMS (₦)
1	Solar panels	200 watts	Pieces	78,000	2	156,000
2	Cables	1.5mm	Yards	400	9	3,600
3	Screws	Fastening screw, medium size	pieces	50	16	2,400
4	Multimeter	Digital multimeter calibrated in ampere, voltage and watt	pieces	9,500	1	9,500
5	Charge Controller	Maximum Power Point Tracking,	Pieces	13,500	1	13,500
7	Screw Driver	Star and flat shape, small size	Pieces	1,500	1	1,500
8	Extension Board	Wood	Pieces	400	1	400
9	Bulbs	Dc bulbs, 9 watts	Pieces	1,400	6	8,400
10	Lamp holders	Pin and screw in type two in one lamp holders	Pieces	300	6	1,800
11	Black tape	To serve as insulator for exposed conductors	Pieces	300	1	300
12	COST OF MATERIALS	-	-	-	-	**197,400**
13	Logistics and transportation	-	-	-	-	5,000
14	**GROSS TOTAL**	-	-	-	-	**202,400**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This thesis is exclusively dedicated to the design and implementation of an off-grid solar photovoltaic system for optimal utilization within a residential building situated in a rural area, while taking into consideration the optimal tilt angle and effective way of generating the maximum power when mounting the solar panel, simulation was also carried out with PYSYST simulation software for proposed PV system.

An extensive electrical layout of the building, proper load analysis and energy demand coupled with suitable sizing for the Solar panels, Inverter, Charge controller and batteries were also carried out. The simulation of the proposed PV system using PVSYST photovoltaic software indicated optimal performance, as shown in Figure 4.13. An optimal tilt angle of 20° was obtained from the implemented system. Additionally, a short circuit current of 1.45A and open circuit voltage of 13.75V were measured during the test.

The angle at which a solar panel is tilted, the weather, and the panel's orientation all affect how much electricity it generates. All of these factors can lead to variations in the performance of the PV system. Solar panels should be angled at their ideal tilt angle for maximum energy gain. Seasonal panel adjustments can result in a significant increase in the amount of power obtained from solar radiation.

These results suggest that the power supply is well-suited for applications requiring consistent and reliable power delivery, capable of handling various load demands while maintaining performance integrity over time.

5.2 RECOMMENDATION

When installing solar systems, one common issue is positioning the panels to receive the most amount of sunshine. In order to maximize the energy generated by solar panels during solar radiation, engineers need to understand the optimal placement and positioning of these devices. When the Sun's rays strike a solar panel's surface perpendicularly, the panel will capture the greatest energy (Foster, 2010). Generally speaking, solar panels erected in the northern hemisphere (and in the southern, true north) should face true south. Since solar panels would receive direct sunlight all day, this is typically the optimum orientation. A solar compass can be used to accomplish this with ease. Using the angle of the shadow produced by the Sun in conjunction with a compass card, a flat disk bearing points and degrees of direction, it determines the direction.

The tilt or angle of a solar panel is another crucial consideration. The angle at which a solar panel should be installed to produce the maximum amount of energy in a given year depends on the geographic latitude. Generally speaking, aligning the tilt angle of the solar panels with the latitude of the location produces the most energy per year. (Gevorkian, 2008)

For instance, if the location of the solar array is at 50˚ latitude, the optimal tilt angle is also 50˚. In general, a solar panel should be pointed straight up the closer it is to the equator. The panels should lean further toward the equator the closer they are to the poles.

In addition, it is recommended to always split the inverter's KVA value into smaller KVA values and connect them in parallel in case of unanticipated future events. If one of the inverters fails, the remaining ones can function as a backup until a more permanent fix is implemented. Giving the inverter system a lot of allowance during design is also recommended. If additional appliances are added to the system, you should be able to have a design that can accommodate such unanticipated events.

One drawback that should be mentioned is that the solar system's effectiveness decreases during the wet seasons. Because PV cells need sunlight radiation to work, solar panels in overcast weather usually produce a little less energy than they do on bright days. On cloudy days, the solar panel output is influenced by the density of the cloud cover. As a result, the power produced by the PV system may not be consistent.

One common electrical choice that gets neglected a lot, is installing thunder arrestors at the top of the roof where the panels are going to be mounted. Installing a thunder arrestor by the engineer is crucial in order to prevent lightning strikes from damaging the PV system's solar panels as well as multiple other components.

Lastly, it is important to remember that minimizing significant losses like dust formation will help the PV system operate at peak efficiency throughout the duration of its life. Because of the abundance of sunlight in the dry season is ideal for photovoltaic generation; yet, the buildup of dust particles during this time might negatively impact the system's performance. Therefore, additional labor might be required during this time to clean the panels.

REFERENCES

1. Mandelli, S., Barbieri, J., Mereu, R. & Colombo, 2016. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review.. May.58(Renewable and Sustainable Energy Reviews).

2. Facchin, C., Waterworth, A. & Weston, W., 2016. Decentralised, Sustainable Energy Solutions for Remote Areas. Renewable Energy and Power Quality Journal, May.p. 178–184.

3. Ajao, K. R., Ajimotokan, H. A. & Popoola, O. T., 2009. Electric Energy Supply in Nigeria, Decentralized Energy Approach. Cogeneration & Distributed Generation Journal, October, Issue 24(4), p. 34–50.

4. Kaundinya, D. P., Balachandra, P. & Ravindranath, N., 2009. Grid-connected versus stand-alone energy systems for decentralized power—A review of literature. Renewable and Sustainable Energy Reviews, October, Issue 13(8), p. 2041–2050.

5. Afsharzade, N. et al., 2016. Renewable energy development in rural areas of Iran. Renewable and Sustainable Energy Reviews, November, Issue 65, p. 743–755.

6. Ghafoor, A. & Munir, A., 2015. Design and economics analysis of an off-grid PV system for household electrification. Renewable and Sustainable Energy Reviews, February, Issue 42, pp. 496-502.

7. Byrne, J., Shen, B. & Wallace, W., 1998. The economics of sustainable energy for rural development: A study of renewable energy in rural China. Energy Policy, January, Issue 26, pp. 45-54.

8. Marques, L. et al., 2022. A Photovoltaic Technology Review: History, Fundamentals and Applications. Energies, 1 March.Issue 15(5).

9. The Nobel Prize in Physics, 1921. The Nobel Prize in Physics 1921. (n.d.). NobelPrize.org.. [Online] Available at: https://www.nobelprize.org/prizes/physics/1921/einstein/facts/ [Accessed 26 January 2024].

10. Sharma, S., Jain, K. & Sharma, A., 2015. Solar Cells: In Research and Applications. A Review. Materials Sciences and Applications, 1 January.

11. Foster, R., 2010. Solar Energy. 1st ed. Boca Raton, USA: s.n.
Gevorkian, P., 2008. Array tilt angle loss. In: 1. edition, ed. Solar Power in Building Design. United States of America: McGraw-Hill, p. chapter 4/page 109.

12. Gevorkian, P., 2008. Array tilt angle loss. Solar Power in Building Design, p. 109.

Nallapaneni Manoj Kumar, M. S., 2018. On-Grid Solar Photovoltaic System: Components, DesignConsiderations, and Case Study. Issue 617.
13. Nasreddine Attou, 2020. Grid-connected Photovoltaic System. solar square, 18 Feburaury.Issue 101.

14.ECOSOCH,2024. ecosoch.com. [Online] Available at: https://ecosoch.com/grid-solar-pv-system/

15. Ritchie, C., 2022. SaveOnEnergy. [Online]

16. Available at: https://www.saveonenergy.com/solar-energy/what-is-off-grid-solar-system/ [Accessed 05 June 2022].

17. Ortega-Arriaga, P., Babacan, O., Nelson, J. & Gam, 2021. Grid versus off-grid electricity access options: A review on the economic and environmental impacts.. 01 June .

18. Palit, D. & Chaurey, A., 2011. Off-grid rural electrification experiences from South Asia: Status and best practices. Energy for Sustainable Development, 01 September.
M., 2023. Roofit.Solar. [Online]

19. Available at: https://roofit.solar/everything-you-need-to-know-about-solar-batteries/ [Accessed 10 February 2024].

20. Rahaman, M. A., Matin, M., Sarker, A. & Uddin, 2015. A cost effective solar charge controller. International Journal of Research in Engineering and Technology.

21. Osaretin, C. & Edeko , F., 2015. Design and implemantation a solar charge controller. Journal of Electrical and Electronic Engineering.

22. Ikeh, C. & Uzor, C., 2017. Design of a Pulse Width Modulation(PWM) Or Standard Charge Controller For a Photovoltaic system in Akwa, Nigeria. European Journal of Engineering and Technology, Issue 5.

23. Kumar , I., Alexander, S. & Rajendran, M., 2021. Power electronic converters for solar photovoltaic systems. Brian Romer.