DESIGN AND IMPLEMENTATION OF A SOLAR MINI GRID SYSTEM FOR RURAL COMMUNITY EMPOWERMENT

BY

IGBINOVIA Benard Osamudiamen (ENG1805067)

SULEMAN Hadi (ENG1905394)

OSARENKHOE Aisosa Ekpenede (ENG1805682)

IJEVIE Jeremiah Arerosuoghene (ENG1805069)

THE DEPARTMENT OF ELECTRICAL/ ELECTRONIC ENGINEERING,

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN, BENIN CITY, EDO STATE.

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A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL/ELECTRONIC ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, IN PARTIAL FUFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN ELECTRICAL AND ELECTRONIC ENGINEERING

APRIL, 2024

CERTIFICATION

This is to certify that this project work was carried out by the aforementioned students stated in the previous page (II) in partial fulfilment of the requirement for the award of Bachelor of Engineering in the Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State.

Engr. E.O. Edegbe **Date**

(Project Supervisor)

Engr. Prof. K.O. Ogbiede **Date**

(Head of Department)

DEDICATION

This research work is faithfully dedicated to God Almighty for his favour, his unmerited love, grace, provision, and kindness that made this project a success.

ACKNOWLEDGEMENT

To God alone be the glory who made it possible for this project to see the light of the day.

Our intellectual debts goes to those authors and engineers whose work and materials were consulted in writing this project.

Grateful acknowledgement to our supervisor Engr. E.O Edegbe, our Head of Department Engr. Prof. K.O. Ogbiede and lecturers of Electrical/Electronic Engineering Department in the University of Benin for providing us with the necessary resources, academic guidance throughout our academic journey.

To our beloved parents, we say a very big thanks for been there as sources of encouragement and patience as we dedicated our time and energy to this project. Your unwavering support has been a source of motivation throughout this journey, we are truly grateful.

TABLE OF CONTENTS

CONTENTS

TABLE OF FIGURES

LIST OF TABLES

ABSTRACT

In rural areas, access to sustainable and dependable power is essential for advancing healthcare, education, and socioeconomic development. This project work presents the design and implementation of a solar mini grid aimed at providing electrification for a rural community. The project focuses on providing a load dispensary using solar mini grid as a clean and renewable source via a pure sine wave inverter to address the energy poverty occurring in remote areas.

The design methodology contains a thorough assessment of the energy needs of the target community, considering factors such as population density, existing infrastructure, and the specific load requirement for the dispensary. The selected photovoltaic panels, charge controllers, designed inverters, and battery storage systems are optimized for efficiency, durability, and cost-effectiveness.

Finally, the conclusion was drawn from the final results and observations in the course of the project. The project's conclusions offer significant new information to the field of renewable energy planning, with practical applications for engineers and other professionals who strive to provide rural communities with sustainable and equitable access to energy.

CHAPTER ONE

1.1 BACKGROUND OF THE STUDY

A grid is a system or network of wires and cables by which sources of power, such as electricity, are distributed throughout a country or area. When most people talk about the power "grid," they're referring to the transmission system for electricity. The electrical grid is an electrical power system network which consist of the generating plant, the transmission lines, the substation, transformers, the distribution lines and the consumer.

A mini grid constitutes a collection of small-scale electricity generators and, potentially, energy storage systems connected to a distribution network supplying electricity to a localized group of customers. It functions independently of the national transmission grid and varies in size from a few kilowatts to 10 megawatts. Smaller mini-grids may be denoted as "micro-grids" or "nano-grids" (referenced from "Design and Implementation of Solar Mini-Grids for Rural Electrification" by C. Venkateswarlu et al).

The popularity of solar mini grid projects has surged in recent years, especially for providing electricity to remote and off-grid communities. These projects yield positive impacts, encompassing social, economic, and environmental benefits. Enhanced access to electricity, a primary social benefit, significantly improves the quality of life in remote communities. The International Energy Agency's study indicates positive impacts on health, education, and economic development attributable to improved access to electricity (IEA, 2017). Communities gain the ability to power medical clinics, schools, and businesses, thereby enhancing essential services and creating economic opportunities. A study in Kenya discovered that solar mini grids led to improved health outcomes, increased school attendance, and higher incomes (Power for All, 2018).

Economically, solar mini grid projects deliver advantages by diminishing reliance on costly and unreliable diesel generators, resulting in cost savings for the community. According to the International Renewable Energy Agency, solar mini grids can offer electricity at a lower cost compared to diesel generators in many off-grid areas (IRENA, 2018). Additionally, these projects contribute to job creation in installation, operation, and maintenance. Studies in India and Nigeria underscored job creation, increased income for local technicians, and reduced carbon emissions (Power for All, 2018; Africa Progress Panel, 2015). Moreover, solar mini grids mitigate environmental impact associated with traditional energy sources, such as air pollution and water contamination.

However, challenges exist in planning, implementing, and operating these projects. The substantial initial capital cost stands out as a primary challenge, with studies indicating costs up to four times higher than diesel generator-based systems (Jaiswal et al., 2020). Financing mechanisms like grants, loans, and partnerships are crucial to alleviating the financial burden on communities (Gakuru et al., 2021). Another obstacle is the lack of technical expertise within communities, hindering proper maintenance and repair. Addressing this requires training and education programs to build local capacity and ensure project sustainability (Jaiswal et al., 2020).

The remoteness of installation sites poses logistical challenges, impacting transportation and project timelines. Creative solutions, like utilizing local resources and labor, can alleviate these challenges (Jaiswal et al., 2020). Lastly, policy and regulatory frameworks may not favor solar mini grids, making permit acquisition difficult. Advocacy and engagement with policymakers become crucial for developing supportive policies and regulations (Gakuru et al., 2021). In Nigeria, the demand for electricity in rural areas has been largely neglected by the government due to the high cost of connecting these areas to the main grid. This neglect has resulted in significant developmental disparities between rural and urban areas. Recognizing electricity as a fundamental factor in development, there is a need to explore clean energy solutions for rural areas.

The background of the study for creating a solar mini grid in a rural community is grounded in several factors. Firstly, many rural communities in developing countries, including Nigeria, lack access to electricity, limiting economic development and impeding the improvement of people's quality of life.

Also, traditional energy sources like kerosene, diesel, and biomass are often unreliable, expensive, and detrimental to health and the environment. In this context, solar energy emerges as a renewable, clean, and abundant source that can offer a sustainable solution to meet the energy needs of rural communities.

Mini-grid technology, specifically solar mini-grids, is designed to provide small-scale, decentralized, and clean energy to communities not connected to the main grid. These mini-grids prove cost-effective and scalable, offering reliable and affordable energy to rural areas. Beyond the economic considerations, providing rural communities with access to clean energy can stimulate local economic development, improve health and education, and promote gender equality and empowerment.

These factors underscore the importance and relevance of the study for creating a solar mini grid in a rural community. The study aims to offer a tailored solution to meet the specific energy needs of these communities, aligning with the principles of sustainability and development.

In conclusion, while solar mini grid projects hold promise for providing clean and reliable electricity to remote communities, overcoming challenges in their implementation and operation is imperative for their success.

1.2 STATEMENT OF PROBLEM

Even with major developments in renewable energy sources, dependable electricity is still unavailable in many isolated and off-grid settlements. In order to meet their energy needs, localized solutions like solar mini-grids must be developed in the absence of a centralized power grid. These mini-grid systems' design and optimization present a number of difficulties that need for careful thought and creative solutions.

This study helps to provide solutions to the problem that may arise as a result of; system component selection, resource assessment, load profiling, grid stability and reliability and many others.

1.3 AIM

The aim of this project is to design, implement and simulate a solar mini grid system for a rural community. The specific objectives are:

1.4 OBJECTIVES

a. Develop a comprehensive methodology for solar resource assessment and load profiling in remote communities.

b. Examine and evaluate the solar energy generation technologies.

c. Create a simulation-based effective energy computation by defining the system, selecting suitable software, modeling the components, confirming the model, executing simulations, evaluating the outcomes, and optimizing the system..

d. Develop a mini grid system for a remote community.

e. Analyze the remote community's mini grid system powered by solar energy, evaluating factors like load analysis, energy generation, energy storage, system efficiency, and cost analysis.

1.5 METHODOLOGY

This research utilized various methods:

1. Literature Review: A thorough assessment of the literature offered insights into the status of knowledge and technology in solar mini grids today, guiding design and pointing out potential obstacles and opportunities.

2. Resource Assessment: Identifying the location and determining the geographical location of the mini-grid site was carried or. Also, conducting a thorough assessment of solar irradiance levels in the area using historical data or on-site measurements was carried out.

3. Simulation and Modeling: Simulation and modeling were employed to analyze the performance and efficiency of the solar mini grid under different conditions, identifying potential challenges and opportunities for improvement.

4. Data Analysis: Data analysis was employed to develop a remote community with a mini grid, involving the gathering and analysis of relevant data to make informed decisions, optimize system design, and ensure project sustainability.

5. System Components Selection: Electronic components and devices such as solar panels, charge controllers, battery bank, inverters will be selected to accurately produce efficient power source needed for the design

6. Power Demand Assessment: The design of the solar mini grid was guided by the information obtained from a power demand assessment of the community's overall energy demands, appliance types used, and patterns of energy usage.

1.6 SIGNIFICANCE OF THE PROJECT

Designing a solar mini-grid holds significant importance in various contexts, especially in regions where access to reliable electricity is limited. The following are some salient features emphasizing the importance of this kind of project:

Energy Access: Communities in many isolated or rural places do not have access to centralized electrical grids. These towns benefit from a solar mini-grid's consistent and sustainable electricity supply, which raises living standards, powers vital institutions like hospitals and schools, and promotes economic growth.

Transition to Renewable Energy: Solar mini-grids are essential to the shift to renewable energy sources. These initiatives help to lessen reliance on fossil fuels, mitigate climate change, and promote environmental sustainability by utilizing solar power.

Dependability and Adaptability: Mini-grids, especially solar-powered ones, provide a more reliable and resilient energy source compared to traditional diesel generators or unreliable grid connections. They are less susceptible to disruptions caused by fuel shortages, extreme weather events, or technical failures.

Cost-Effectiveness: Over time, solar mini-grids may prove to be a financially advantageous installation. Since sunshine is free and abundant, solar mini-grids require less ongoing operating costs than traditional grid expansions, despite the higher initial setup costs. Over time, this can result in significant savings, particularly in isolated locations where it would be prohibitively expensive to extend the main grid.

Empowerment and Community Development: Building local capacity and involving the community are frequent components of implementing solar mini-grids. In addition to encouraging business options (such mini-grid maintenance and operation), this gives communities the power to take control of their energy resources and advances socioeconomic development in general.

Scalability and Adaptability: Whether a community is tiny or large, solar mini-grid installations can be tailored to meet the unique requirements of various settings. Additionally, they are expandable, enabling future growth in response to rising demand or technological advancements. Mini-grids can also be connected with additional energy sources, like diesel generators for backup or batteries for energy storage, to increase their flexibility and dependability.

Reducing Energy Poverty: One of the most important ways to reduce poverty is by providing access to power. By offering clean, inexpensive, and sustainable electricity to areas that would otherwise be underserved or shut out of the energy grid, solar mini-grids contribute to the fight against energy poverty.

All things considered, the planning and execution of solar mini-grid projects represent important strides toward attaining universal energy access, encouraging sustainable growth, and halting climate change both locally and globally.

1.7 LIMITATIONS OF THE PROJECT

While building a solar mini grid offers a sustainable energy source to rural communities, it is not without limitations:

1. **High Initial Costs**: The substantial initial costs can be a barrier for communities with limited resources, impacting affordability and implementation.

2. Technical Challenges: Designing, installing, and commissioning a solar mini grid can pose technical challenges, especially in rural areas with limited access to skilled technicians and resources.

3. **Maintenance and Repair**: Ensuring regular maintenance and repair can be challenging in rural areas where access to spare parts and specialized services is limited.

4. **Grid Interconnection**: Interconnecting a solar mini grid to the main grid may require significant investment and technical challenges, particularly in areas with limited grid access.

5. **Financial Sustainability**: Ensuring the financial sustainability of a solar mini grid can be challenging, especially in rural areas with limited access to finance.

Despite these limitations, successful implementations of solar mini grids demonstrate their potential to provide sustainable energy to rural areas. Addressing these challenges is essential to create successful and sustainable solutions benefiting local communities and the environment.

CHAPTER TWO

2.0 INTRODUCTION

This chapter looks at the pertinent research that is associated with the topic of study. This review, however, will help us determine the justification of this project study.

2.1 LITERATURE REVIEW OF OTHER RELATED WORKS

Real-world solar mini grid projects have been put into place all over the world, with the goal of providing impoverished and rural communities with inexpensive, dependable electricity. We will look at a few of these projects in this overview along with their difficulties and successes.

The Nigerian Rural Electrification Agency Electrification project in Rokota community, Niger state:

The Nigerian Rural Electrification Agency (REA) is Implementing Agency of the Federal Government of Nigeria (FGN) tasked with the electrification of unserved and underserved communities. The Federal Government of Nigeria, through its Implementing Agency - REA, facilitated the commissioning of a solar hybrid mini grid power plant in Rokota Community, Edati Local Government Area, Niger State. The project is the first to be commissioned under the World Bank supported Nigeria Electrification Project (NEP). Three thousand (3000) residents in the town are projected to benefit from the project's clean, safe, and dependable power.

The transformative project under the management of the REA delivered the solar hybrid mini grid power plant within 2 months, a record time. The mini grid, with a total solar capacity of 64KW and 360KWh of battery storage, was delivered based on international best practice and standards while also using local labour, and provides sufficient power for about 3,000 people**.**

The REA is committed to using renewable energy in the reduction of annual greenhouse carbon emissions by 25,0000 metric tons. This is in adherence to Nigeria’s commitment to the Paris Agreement on Climate Change. World Bank Nigeria Country Director, Mr. Shubham Chaudhuri, in his goodwill message reiterated the World Bank’s commitment to promoting universal access to electricity. He noted that “the World Bank is committed to reducing the consumption and use of fossil fuels in energy production through renewable energy investments. Through various renewable energy projects across the world, the Bank ensures that there is an increase in universal access to electricity especially in underserved and unserved communities.”

Rokota Community is the first beneficiary of renewable off grid electricity under the Nigeria Electrification Project Mini Grids component. The component aims to provide clean, safe, reliable and affordable electricity to 300,000 homes and 30,000 local businesses in Nigeria.

The Melinda Foundation’s Solar Mini-Grid project in Mozambique:

Another effective example of a solar micro grid that offers dependable and reasonably priced electricity to an off-grid community is the Melinda Foundation's Solar micro Grid Project in Mozambique. The project was carried out in the 3,000-person village of Namaacha, which was situated in a remote and rural region of Mozambique.

The project included setting up a distribution network, 208 kWh of battery storage, and 27 kWp of solar panels. To guarantee effective electricity distribution, the battery storage was positioned in a central location in the neighborhood, and the solar panels were mounted on the rooftops of nearby buildings. Training local professionals to install and maintain the system was another aspect of the project.

With an annual energy output of 96,000 kWh, the project effectively supplied the community with dependable electricity, this is according to a report by the International Renewable Energy Agency (IRENA). This made it possible for the neighborhood to have access to basic electrical services like lights, phone charging, and small appliance power. In addition, the initiative had favorable social and economic effects, including better lighting, higher output, and the potential to create jobs. For example, local firms were able to enhance productivity and revenue generation by extending their working hours. This project took into account a number of factors, including feasibility, cost analysis, and energy calculation.

PowerGen Solar Mini-Grid Project in Tanzania:

PowerGen is a company that specializes in developing and operating mini-grids across Africa, and one of its successful projects is the Solar Mini Grid Project in Tanzania. The project was carried out in the isolated, steep Tanzanian village of Mwenga, which was not connected to the national grid.

The project involved the installation of a 16 kWp solar array, 30 kWh of battery storage, and a distribution network. The solar panels were installed on the roofs of local buildings, and the battery storage was placed in a central location to ensure efficient distribution of the electricity. The project also involved the training of local technicians to install and maintain the system.

According to a case study by the Clean Energy Solutions Center, the project successfully provided reliable electricity to the village, with a total energy output of 82,000 kWh per year. This enabled the community to access basic electricity services, such as lighting, phone charging, and powering small appliances. The project also had positive social and economic impacts, such as improved health, safety, and educational outcomes. For instance, the availability of electricity allowed for the use of medical equipment, improved safety at night, and access to educational resources.

2.2 ANALYSIS OF A REMOTE COMMUNITY WITH A MINI-GRID SYSTEM POWERED BY USING SOLAR ENERGY

2.2.0 OVERVIEW OF MINI-GRID SYSTEMS

A mini-grid system is a small-scale electrical grid that can provide electricity to a community or a group of buildings. Solar, wind, hydro, and biomass energy are just a few of the renewable energy sources that can power these systems. The use of mini grids as a means of supplying electricity to isolated villages cut off from the main electrical grid is growing in favor. A mini-grid system typically consists of a generation source (such as solar panels), energy storage (such as batteries), a distribution network, and load centers.

Analysis of a Remote Community with a Mini-Grid System Powered by Solar Energy: Numerous research projects have examined the viability and efficiency of utilizing solar-powered mini-grid systems to supply isolated settlements with electricity. In a study conducted by Kemafo et al. (2021), a remote community in Cameroon was analyzed for the potential of a mini-grid system powered by solar energy. According to the analysis, a mini-grid system with a 7-years payback period would be both practical and affordable. The study also found that the mini-grid system would significantly reduce the community's reliance on fossil fuels for power.

Benefits of Mini-Grid Systems Powered by Solar Energy:

Solar-powered mini-grid systems provide isolated communities a number of advantages. First of all, they give villages without access to the main electrical grid dependable, reasonably priced electricity. This can lead to major social and economic advantages to this, as well as better communication, healthcare, and educational opportunities. Furthermore, solar-powered mini-grid systems can lessen the community's dependency on fossil fuels for electricity while also being environmentally benign. Significant environmental advantages could result from this, such as a decrease in greenhouse gas emissions and an improvement in air quality. Lastly, the community can profit financially from mini-grid systems running on solar energy, particularly through the creation of jobs and an increase in economic activity.

2.2.1 LOAD ANALYSIS

Load analysis is the process of determining the electrical load requirements of a building. It entails determining a building's energy demand, which is computed by adding up the power usage of all the appliances and electrical equipment the structure has.

2.2.1.1 TYPES OF LOADS

AC Loads: These are the alternating current (AC) electrical loads that are frequently seen in residences and commercial buildings. A solar mini grid may be used to power common AC loads like fans, air conditioners, lights, refrigerators, and televisions.

DC Loads: These are direct current (DC) electrical loads, which are frequently seen in off-grid solar systems. Common DC loads that can be connected to a solar mini grid are DC water pumps, LED lights, and cell phone chargers.

Some other factors that need to be considered when running a load analysis in a solar mini grid includes:

Load Demand: The term "load demand" describes the quantity of energy or power that users need at any given moment. Power is commonly expressed in kilowatts (kW) or kilovolt-amperes (kVA), whereas energy is expressed in megawatt-hours (MWh) or kilowatt-hours (kWh). Load demand can vary depending on factors such as time of day, season, weather conditions, and specific consumer behaviours.

Load Profile: In order to analyze load demand, load profiles which show how load demand varies over time are frequently created. These profiles can be created using prediction models, simulations, or historical data. Load profiles give utilities useful information about the trends in power usage, which they can use to better plan and allocate their resources. Solar panels are sized appropriately to generate enough energy to meet the peak load.

Load Efficiency: This is the efficiency of the load in converting electrical energy into useful work. It is important to choose efficient appliances and devices to minimize energy waste and reduce the size of the solar panels and battery bank required to meet the energy needs of the users.

By considering these factors, a load analysis can help to determine the size of the solar panels, battery bank, and other components required to build an efficient and cost-effective solar mini grid.

2.2.1.2 EFFICIENCY OF SOLAR PANELS

Another important factor in load analysis is a solar panel's efficiency. Finding the most economical solution for the project might be aided by understanding how to calculate a solar panel's efficiency. The percentage of sunlight that is converted to electrical energy is known as a solar panel's efficiency. Stated differently, it represents the degree of effectiveness with which the solar panel generates power from sunshine. Numerous investigations into the efficiency of solar panels in diverse settings have been carried out.

Numerous factors, such as the kind of solar cell technology employed, the caliber of the materials, and the panel's design, affect how efficient solar panels perform.. The most commonly used solar cell technology is silicon-based, with monocrystalline and polycrystalline silicon being the most popular. Knowing how to calculate a solar panel's efficiency can help you determine the most cost-effective option for your project. Efficiency accounts for your system's performance and will help you decide whether a larger or smaller system is more cost-effective for your needs.

The efficiency of a solar panel is measured in watts per unit of input power. For example, a solar panel that generates 0.5 watts per unit of input power is 50% efficient. To calculate your PV system's efficiency, use the following formula below:

$$\boldsymbol{Efficiency}\,(\%) \;=\; \frac{\boldsymbol{P_{max}}}{(\boldsymbol{Area\;x\;1000W/m^2})}\;\boldsymbol{x\;100}$$

At Standard Test Condition (STC) = Irradiance $1000W/m^2$

Pmax = Maximum panel power (W)

Area = panel area (m^2)

For example, if a solar panel has a maximum power output of 500 watts and a surface area of 2.2 square meters, the efficiency of the panel can be calculated as follows:

$$\boldsymbol{Efficiency}\,(\%) \;=\; \frac{\mathbf{500}}{(\mathbf{2.2}\;\boldsymbol{x}\;\mathbf{1000}\boldsymbol{W/m^2})}\;\boldsymbol{x}\;\mathbf{100} \;=\; \mathbf{22.7}\%$$

Therefore, the efficiency of the solar panel in this example is 22.7%.

2.2.1.3 ENERGY GENERATION

The energy generation of a solar mini grid depends on various factors such as the size and capacity of the solar panels, the amount of sunlight received, the efficiency of the system components, and the energy demand of the connected loads.

To calculate the energy generation of a solar mini grid, we need to determine the total capacity of the installed solar panels and the amount of sunlight received in the area. The energy generation can be calculated using the following formula:

Energy Generation (kWh) = Total Capacity of Solar Panels (kW) x Solar Radiation (kWh/kW/day) x System Efficiency (%) x System Availability (%)

Total Capacity of Solar Panels is the combined capacity of all the solar panels in the mini grid, usually measured in kilowatts (kW).

Solar Radiation is the average amount of solar energy received per kilowatt of installed capacity per day, usually measured in kilowatt-hours (kWh).

System Efficiency is the overall efficiency of the solar mini grid system, including solar panels, batteries, inverters, and other components, usually expressed as a percentage.

System Availability is the percentage of time that the system is available and operating efficiently, considering factors such as maintenance and downtime due to weather conditions or other factors.

For example, if a solar mini grid has a total capacity of 50 kW, a solar radiation of 5 kWh/kW/day, a system efficiency of 80%, and a system availability of 90%, the energy generation of the solar mini grid can be calculated as follows:

Energy Generation (kWh) = 50 kW x 5 kWh/kW/day x 80% x 90% = 1,800 kWh/day

Therefore, the solar mini grid in this example would generate 1,800 kilowatt-hours of energy per day.

2.2.1.4 ENERGY STORAGE

Energy storage is a part of solar energy generation, enabling solar power to be used when sunlight is not available. which makes solar power usable even in the absence of sunlight. An overview of the research on solar energy storage, including the various kinds of energy storage systems and their efficacy, can be found in the literature review that follows.

Energy storage is an essential component of a solar mini grid, as it enables the system to provide power even when there is little or no sunlight. The energy storage in a solar mini grid is typically provided by batteries, which store excess energy generated during the day and discharge it when needed. In order for a solar mini grid to function even in the absence of direct sunlight, energy storage is a necessary component. Batteries are commonly utilized as energy storage in solar micro grids to store extra energy produced throughout the day and release it when required.

There are several types of batteries that can be used for energy storage in a solar mini grid, including lead-acid batteries, lithium-ion batteries, flow batteries, and others. Lithium-ion batteries are increasingly popular due to their high energy density, longer lifespan, and faster charging times compared to other types of batteries.

The size and capacity of the battery bank in a solar mini grid depend on the energy demand of the connected loads and the amount of solar energy available. A larger battery bank can provide more energy storage capacity, which can help to meet higher energy demands or provide power for longer periods of time.

When there is less sunlight or more demand for electricity than the solar panels can provide, the energy stored in the battery bank can be used to power the associated loads. When there are emergencies or grid disruptions, the battery bank can also be used as a backup power source.

2.2.1.5 SYSTEM EFFICIENCY

The system efficiency of a solar mini grid is a measure of how effectively the system converts solar energy into usable electricity. It entails the efficiency of the solar panels, the efficiency of the power electronics (such as the charge controller and inverter), and the efficiency of the energy storage system.

The overall system efficiency is typically expressed as a percentage, and it varies depending on the specific components used in the system and the operating conditions.

2.3 SOLAR GENERATION TECHNOLOGY

Light, sometimes referred to as electromagnetic radiation, is what the sun emits and is called solar radiation. By using solar technologies, this radiation can be captured and converted into energy that is useful. Solar technologies generate electrical energy from sunshine. There are two main types of solar technologies; **photovoltaic panels** and **concentrating solar-thermal power**.

2.3.0 PHOTOVOLTAICS PANELS

Photovoltaic (PV) panels, often referred to simply as solar panels, are at the heart of solar energy systems, including solar mini-grids.

Photovoltaic panels are made up of semiconductor materials, typically silicon, that convert sunlight directly into electricity through the photovoltaic effect. When sunlight strikes the surface of the solar cells within the panels, it excites electrons, creating an electric current. This direct conversion of sunlight into electricity makes PV panels a clean and renewable energy source.

A single PV device is known as a cell, an individual PV cell is usually small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, they are connected in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays are then connected to the electrical grid as part of a complete PV system.

2.3.1 TYPES OF PHOTOVOLTAICS PANELS

PV panels come in various types, including monocrystalline, polycrystalline, and thin-film. Each type has its own characteristics in terms of efficiency, cost, and performance under different conditions. Most of the solar panels on the market today for residential solar energy system can be categorized into;

- Monocrystalline.
- Polycrystalline.
- Thin film.

2.3.1.1 MONOCRYSTALLINE

Monocrystalline panels are the oldest most developed type of Solar panels. They are known for their high efficiencies and sleek appearance. As the name implies, monocrystalline solar panels are made from single crystal silicon solar cells. Because monocrystalline solar cells are made from a single crystal of silicon, electrons can flow easier through the cell, which makes the PV cell efficiency higher than other types of solar panels. The higher efficiency of monocrystalline solar panels means that they require less space to reach a given power capacity. So, monocrystalline solar panels will usually have a higher power output rating than either polycrystalline or thin-film modules.

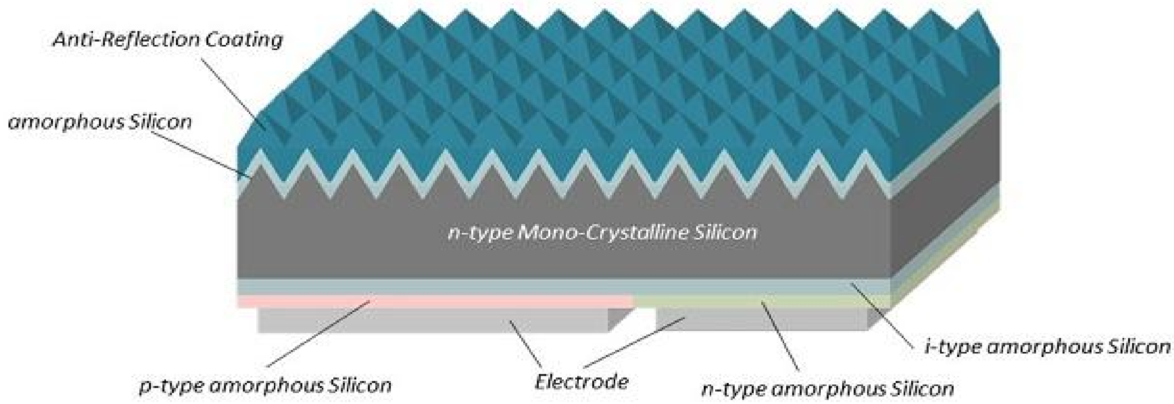


Figure 2. 1: n-type Mono-Crystalline Silicon

Figure 2. 2 Monocrystalline solar panel

When it comes to making a choice as regards modern black solar panels, monocrystalline cells are the best option because they are more expensive but also have higher efficiency, a longer lifespan, and a uniform black finish. The monocrystalline cells absorb solar radiation and use a complex process to create an electric field which comprises voltage and current and produces power which is governed by the equation P = I x V. This power can be used directly through controllers to power devices that run on direct current (DC) or it can also be converted to alternating current (AC) using an inverter.

2.3.1.2 POLYCRYSTALLINE SOLAR PANEL

Polycrystalline is often considered the mid-range panel. Although less efficient, Polycrystalline Solar panels are the more affordable option.

Just like monocrystalline solar panels, polycrystalline cells are made from silicon. However, as the name implies, Polycrystalline solar panels are made from silicon cells that are composed of multiple silicon crystals.

One of the key characteristics of polycrystalline solar panels is their blue color, resulting from the reflective properties of the silicon crystals. This color is a distinguishing feature that sets them apart from monocrystalline solar panels, which typically have a uniform black color.

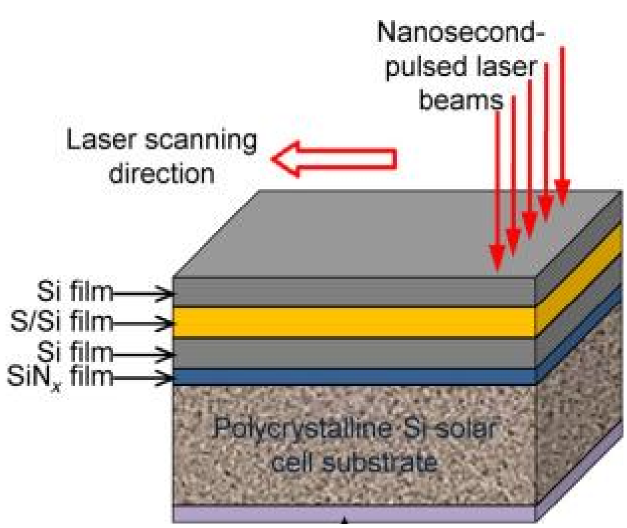


Figure 2. 3: Polycrystalline Solar Cell

Compared to monocrystalline solar panels, polycrystalline solar panels are known for their cost-effectiveness because their fabrication uses less energy and a less complex procedure. Because of this, they are a well-liked option for large-scale solar projects where minimizing costs is essential. Polycrystalline solar panels have a shorter lifespan and less efficiency. In other words, they don't use the sun to produce as much power for as long as monocrystalline panels do. This is because each cell contains a large number of crystals, which limits the electrons' freedom of motion.

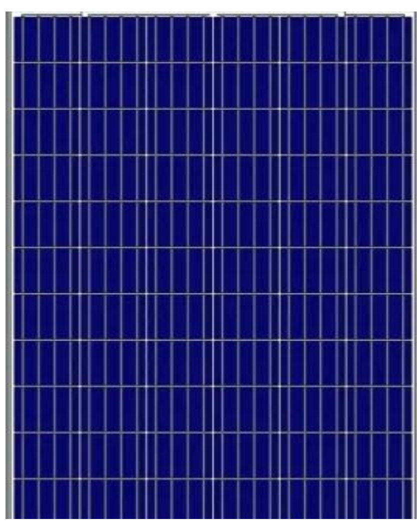


Figure 2. 4: Polycrystalline Solar Array

2.3.1.3 THIN-FILM SOLAR PANELS

Thin-film solar panels represent a significant advancement in photovoltaic technology, offering distinct advantages over traditional crystalline silicon panels.

Thin-film solar panels are made using thin layers of semiconductor materials such as cadmium telluride (CdTe), amorphous silicon (a-Si), or copper indium gallium selenide (CIGS) deposited on a substrate like glass, plastic, or metal. Unlike crystalline silicon panels, which use thick wafers of silicon, thin-film panels require much less material, making them lighter, more flexible, and potentially cheaper to produce.

However, thin-film solar panels typically have lower efficiency compared to crystalline silicon panels, meaning they require more surface area to generate the same amount of electricity. This can be a limiting factor in space-constrained installations. Additionally, thin-film panels may degrade more rapidly over time compared to crystalline silicon panels, although advancements in technology have improved their longevity and performance.

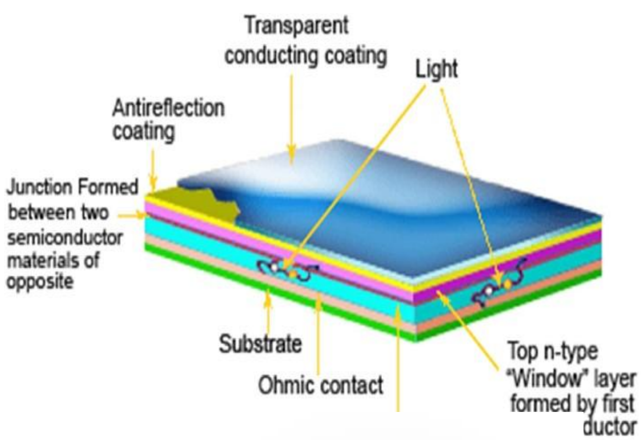


Figure 2. 5: Thin Film Solar Cell

2.4.0 INVERTER

Inverters are essential in solar mini-grid systems, because they transform the direct current (DC) power produced by solar panels into alternating current (AC) electricity that can be used in homes and businesses.

The output of a PV panel is direct current or DC. DC is the unidirectional flow of electric charge. For solar power to be more useful in the electrical grid, it must be transformed to an AC form. An inverter, which changes a DC electrical signal into an AC electrical signal, is used to do this. Inverters are categorized based on their modes of operation, output, and kinds of loads.

2.4.1 CLASSIFICATION BASED ON MODE OF OPERATION

- Grid-connected inverter.
- Stand-alone inverter.
- Hybrid inverter.

2.4.1.1 GRID-CONNECTED INVERTER

Grid-connected inverters are a type of inverter used in solar photovoltaic (PV) systems that are connected to the main electrical grid. They are also referred to as grid-tied inverters or grid-interfacing inverters. The integration of solar energy into the current grid infrastructure is made possible in large part by these inverters.

The purpose of a grid-connected inverter is to support grid-connected applications without the need for a battery backup solution. Grid-connected inverters provide the bidirectional transfer of power between the grid and photovoltaic solar systems. Excess electricity can be sent to the grid to balance utility use during times of high solar generation. On the other hand, power can be taken from the grid to satisfy demand in situations where solar generation is insufficient.

2.4.4.2 STAND-ALONE INVERTER

Off-grid or stand-alone inverters are inverters made specifically for use in off-grid photovoltaic installations. Stand-alone inverters are not linked to the main electrical grid, in contrast to grid-connected inverters. Rather, they are employed in systems that produce power from solar panels and store it in batteries for use at a later time, all without requiring a grid connection. Depending on your needs, stand-alone inverters come in a range of sizes and output waveforms. It takes a pure sine inverter to provide the greatest output. It is appropriate for rural electrification, village electrification, and solar residential systems in isolated locations without access to the utility grid.

2.4.4.3 HYBRID INVERTER

A hybrid inverter combines stand-alone and grid-connected solar power systems. A hybrid inverter combines the functions of a battery inverter and a solar inverter into one unit. A grid-connected solar system handles power from your solar panels, utility grid, and solar batteries all at once, so you don't need a separate battery inverter. This inverter can charge your solar batteries, feed excess electricity into the grid, and supply power to your home by converting DC power from solar panels to AC power. Inverters that are hybrids can function as grid-tied or standalone inverters. In order to deliver consistent, dependable power in remote areas, it is appropriate for electrifying rural villages or islands.

2.4.2 CLASSIFICATION BASED ON OUTPUT CHARACTERISTICS

- Square Wave Inverter
- Sine Wave Inverter
- Modified Sine Wave Inverter

2.4.2.1 SQUARE WAVE INVERTER

The voltage output waveform of this inverter is a square wave. This kind of inverter is the least common among all the other kinds because all appliances are made to run on sine waves; if we supply square waves to appliances that run on sine waves, they could be damaged or experience very high losses. This kind of inverter is extremely inexpensive, but it is only used in very specific applications, such as basic tools that have universal motors.

2.4.2.2 MODIFIED SINE WAVE

A power inverter that creates an output waveform that resembles a sine wave but is not quite as smooth or ideal is called a modified sine wave inverter. This inverter produces an output that is neither square wave nor pure sine wave. An inverter of this type produces two square waves added together as output. The term "modified sine wave" refers to the waveform, which is made up of a sequence of stepped voltage levels that resemble a sine wave.

2.5.0 BATTERY

Batteries chemically store electrical energy in renewable energy systems. Although they are available at a number of voltages, 6 and 12 volts are the most popular. They provide you more alternatives for how to power your home and assist in storing extra electricity that you can utilize when your solar panels aren't producing enough energy. Utilizing as much of the solar energy you generate as possible is the goal of a solar battery.

1. Lead-acid: The three types of lead acid batteries that are most common to renewable energy system are:

i. Flooded Lead-Acid Batteries: they are the most cost-effective variety. They require maintenance that involves monitoring voltage, adding water, and occasional overcharge
ii. Sealed Absorbed Glass Mat Batteries (AGM): AGM batteries cost more and are more sensitive to overcharging than FLAs
iii. Sealed Gel Cell Batteries: Gel cell batteries are similar to AGMs in that they are also sealed and therefore require low maintenance, but tend to be the most expensive of the three types

2. Lithium-ion: Lithium-ion (Li-ion) batteries are a type of rechargeable battery commonly used in a wide range of electronic devices, electric vehicles, and energy storage systems. In comparison to other forms of rechargeable batteries, they are renowned for their high energy density, extended cycle life, and comparatively lightweight design. Several salient traits and attributes of lithium-ion batteries includes:

- High energy density
- Longer life span
- Fast charging
- Low self-discharge rate

3. Flow batteries: Unlike conventional solid-state batteries, flow batteries store energy in liquid electrolytes contained in external tanks.

- As said before, its technology is still in the development stage, yet it is more expensive than the other options.
- It occupies more space due to low storage capacity.
- Flow batteries help reduce peak demand charges by discharging stored energy during periods of high electricity demand, thereby reducing the need to draw power from the grid at expensive rates.
- They have long cycle life and can be cycled a thousand times

4. Nickel cadmium: Nickel-cadmium (Ni-Cd) batteries are a type of rechargeable battery that uses nickel oxide hydroxide and metallic cadmium as electrodes. Nickel-cadmium (Ni-Cd) batteries have a limited cycle life, a high charge/discharge efficiency, and a high power and energy density. The main drawback of Ni-Cd batteries is their comparatively high cost, which results from an expensive production process.

2.6.0 CHARGE CONTROLLER

By monitoring and controlling the output from the solar PV array, a solar charge controller not only charges the battery but also guards against overcharging it. Hydrogen and oxygen gasses are released from the electrolyte when a battery is overcharged, potentially leading to an explosion or failure. The battery's charge will be depleted if an excessive current discharge is permitted. As a result, the battery's lifespan will be shortened and it may eventually fail.

2.6.1 TYPES OF CHARGE CONTROLLERS

There are two types of solar charge controllers:

- The maximum power point tracker (MPPT)
- Pulse width modulation (PWM).

The MPPT controller is considered a better solar charge controller as compared to the PWM controller. Photovoltaic (PV) systems use MPPT (Maximum Power Point Tracking) solar charge controllers, which are advanced electrical devices that maximize solar energy harvesting efficiency. Their main job is to control how quickly solar panels charge batteries by continuously altering the panels' operating point to maximum power output. This offers high efficiency over a wide range of operating points. MPPT controllers are more efficient due some of its features stated below.

- Flexiblity and scalibilty
- Monitoring and protection
- Compatibility

- Efficient Battery charging regulation
- Output power optimization

PWM charge controllers use a technique called pulse width modulation to regulate the charging current supplied to the battery. This involves rapidly switching the solar panel's output on and off, effectively controlling the amount of power transferred to the battery. PWM charge controllers typically operate in three stages: bulk charging, absorption charging, and float charging. During bulk charging, the controller delivers maximum current to rapidly charge the battery. In the absorption stage, the controller maintains a constant voltage to ensure the battery is fully charged. Finally, during float charging, the controller maintains the battery at a lower voltage to prevent overcharging.

CHAPTER THREE

3.0 DESIGN METHODOLOGY

The technique for designing a solar micro grid is extensive and iterative, considering the community's unique demands and limits, as well as the available solar resources and technologies mentioned in this chapter.

3.1 BLOCK DIAGRAM

Figure 3.1 below shows a block diagram describing the interaction between various subsystems making up the solar mini grid.

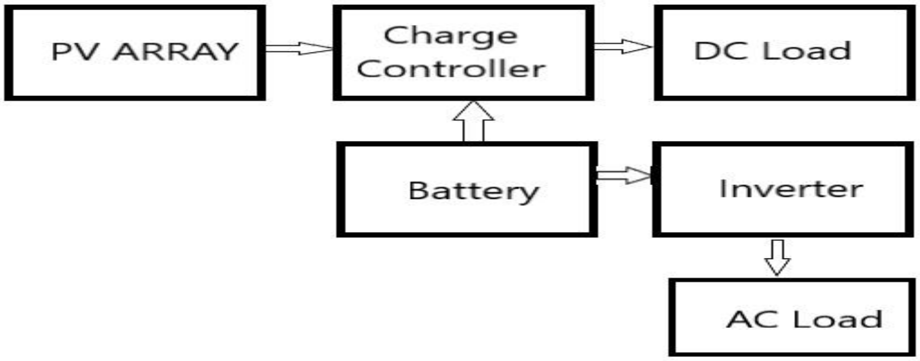


Figure 3. 1: Block Diagram

3.2 DESIGN CONSIDERATIONS

Figure 3.1 depicts the project design, which contains the charge controller block, the DC load block, the battery block, the inverter block, and the AC load outlet block. Each of the blocks presented is a step-by-step approach for the creation of this project.

3.2.1 THE CHARGE CONTROLLER BLOCK

The block diagram below shows the subsystems making up the charge controller block.

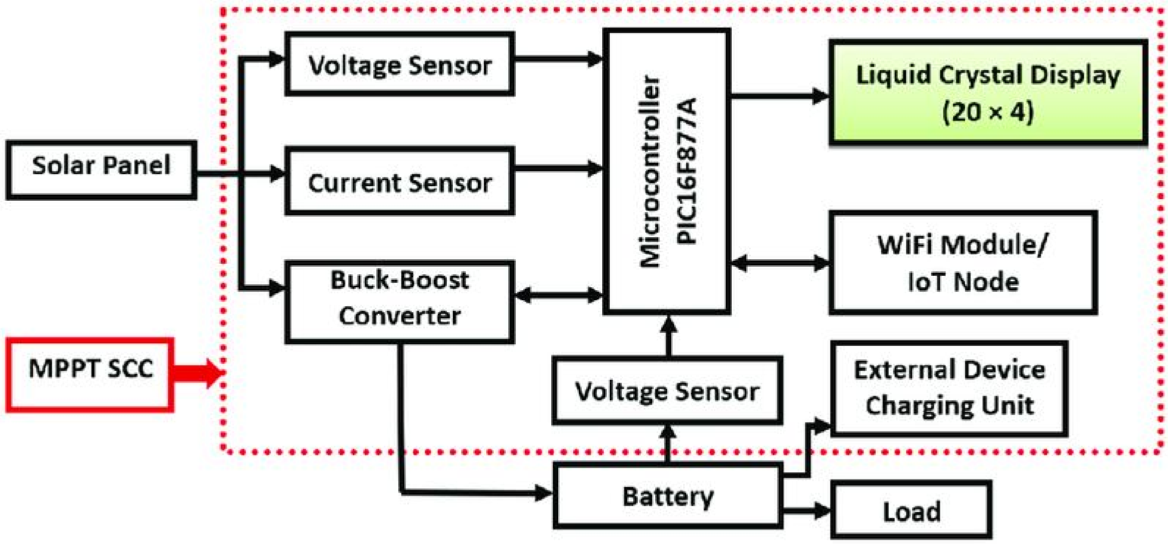


Figure 3. 2 : Charge controller block diagram

This charge controller block is made up of the following sub systems.

- Voltage Sensor
- Current Sensor
- Buck-Boost Converter
- Microcontroller
- L.C.D

3.2.1.1 VOLTAGE SENSOR

This provides a more accurate battery charging voltage to the controller, which allows for more precise charging stage regulation and increases overall battery life performance.

3.2.1.2 CURRENT SENSOR

The current sensor is necessary for controlling the charging current and ensuring that the battery bank charges safely and effectively. By monitoring current flow, the charge controller can limit the output voltage and protect the batteries from overcharging, hence boosting the battery bank's longevity and performance.

3.2.1.3 BUCK-BOOST CONVERTER

A buck-boost converter provides a controlled DC output voltage that can be greater or lower than the input voltage while maintaining high efficiency and a broad input voltage range. It is a flexible component that may be applied to a wide range of applications requiring voltage control and power efficiency.

3.2.1.4 PIC16F877A MICROCONTROLLER

The PIC16F877A microcontroller in a charge controller provides the control, monitoring, and safety capabilities required to charge the battery safely and effectively. It is an essential component of a solar power system that extends battery life and improves overall system performance.

3.2.1.5 L.C.D DISPLAY

An LCD in a charge controller displays crucial information regarding the charging process and system condition. It is a valuable component that contributes to the overall performance and dependability of the system.

3.2.2 INVERTER BLOCK

An inverter involves converting direct current (DC) into alternating current (AC) using switching devices such as field-effect transistors (FETs) or insulated-gate bipolar transistors (IGBTs). The input DC power is divided into a series of pulse signals, which are filtered and adjusted to produce AC power with the same frequency, amplitude, and waveform as the desired output.

Inverters are composed of two main parts: the control circuit and the power circuit. The control circuit implements signal conditioning and control of the inverter, including controlling the switching state of the thyristor or FET, generating high-frequency drive pulse signals, and providing protection. The power circuit converts DC power into AC output, including rectifier circuit, filter circuit, and inverter output circuit.

3.2.3 INVERTER SIZING

Using a hybrid inverter of 3.5KVA, 24V, it is designed to work with both solar panels and batteries, allowing for a more flexible and efficient energy system.

Total wattage of the system (KW)= Power factor × Required VA of the system (KVA)

Assuming a power factor of 0.9

P= 3.5 × 0.9= 3.15KW

With the inverter size calculated, the maximum load selected should have a safety margin of 25% to avoid the risk of overloading.

Maximum Connected Load = 3150 × (1-0.25) = 2362.5 watts.

We can thus use a maximum load of approximately 2400 watts.

Figure 3. 3: Coupling the Inverter

3.2.4 BATTERY BANK SIZING

Battery rating = 12V, 220Ah

Since the inverter is a 24V system, we need two 12V,220Ah connected in series.

Therefore, total battery rating in Watt-hour

= 24V × 220Ah = 5280 Wh

To determine the number of hours the system will last, while the battery is connected to a maximum connected load of 2300 watts.

$T = \frac{5280\,Wh}{2400} = 2.2\text{hrs}$

Assuming a system uptime of 6 hours

Total Energy demand per day (Wh) = 6hrs × 2400 = 14400Wh

For a 24V system battery size becomes $\frac{14{,}400Wh}{24V}$ = 600Ah

Thus, a 24V battery (12V each connected in series) and three battery systems of 220Ah rating to give a total of 660Ah and 6 batteries to give an operating time of over 6 hours.

3.2.5 PV ARRAY BLOCK

The PV array block is an essential part of any solar mini-grid system. It absorbs solar energy and turns it into electrical energy that may be used to power the entire system. To guarantee efficient and effective operation, the PV array block must be appropriately designed and installed.

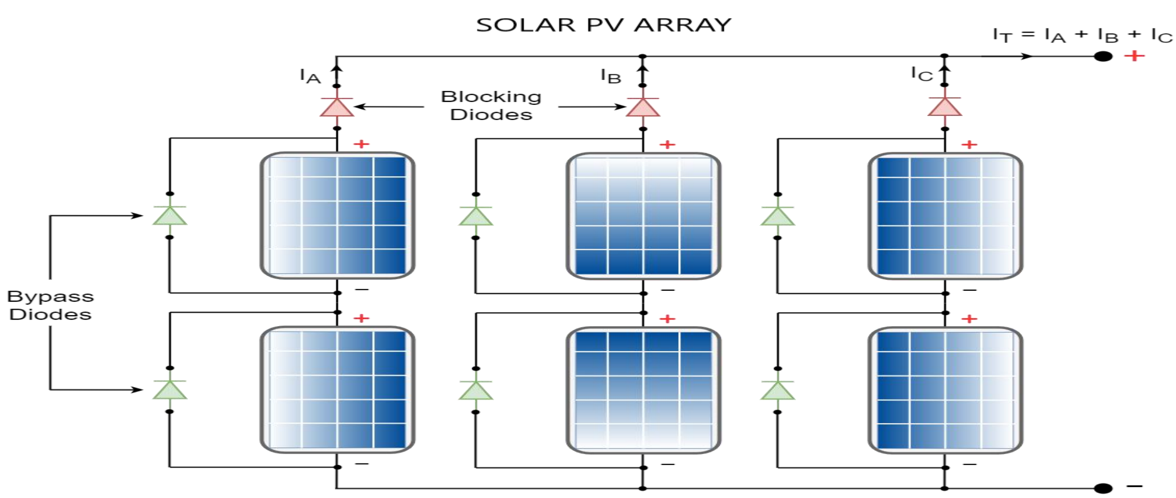


Figure 3. 4: SOLAR PV ARRAY

The solar PV array consists of the following components:

- Solar cells
- Bypass Diodes
- Blocking Diodes

3.2.5.1 SOLAR CELLS

Solar cells are electronic devices that directly convert sunlight into electricity through the photovoltaic effect. The voltage produced by a single solar cell normally ranges from 0.5 to 0.6 Volts (DC). The voltage produced by a solar cell depends on the construction and configuration of the solar cell. However, the magnitude of the current produced upon connection of load depends majorly on the photons striking on the surface of the solar panel. Normally, the voltage is nearly constant whereas the current is considered to be directly proportional to the size of the cell and the intensity of light falling on it.

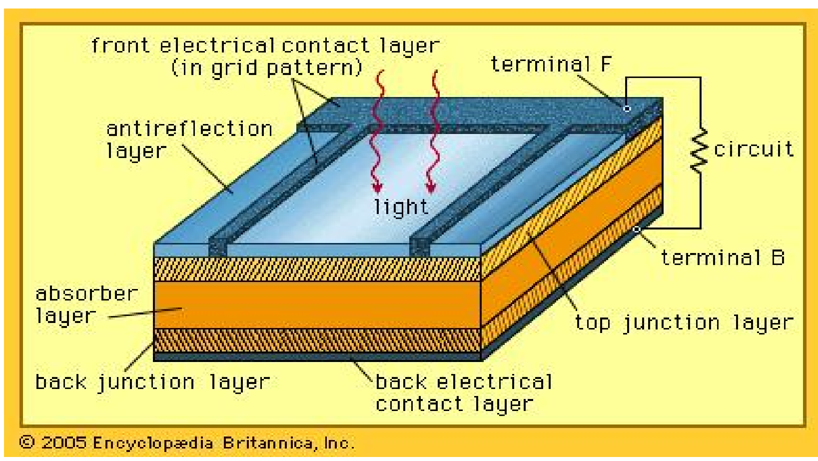


Figure 3. 5: SOLAR CELL

3.2.5.2 BYPASS DIODES

A bypass diode is an electronic component that is mounted on a solar panel to protect the panel from damage due to high forward bias. It is connected in parallel with a solar cell, but with opposite polarity. Under normal operation, each solar cell will be forward biased, and the bypass diode will be reverse biased, effectively acting as an open circuit. However, if a solar cell is reverse biased due to a mismatch in short-circuit current between several series-connected cells, then the bypass diode conducts, thereby allowing the current from the good solar cells to flow in the external circuit rather than forward biasing each good cell. This prevents hot-spot heating, which can damage the solar panel.

3.2.5.3 BLOCKING DIODES

Blocking diodes are electronic components that are installed in series with a solar panel to prevent current from flowing back from the battery to the solar panel, thus preventing the battery from discharging.

3.2.6 PV ARRAY SIZING

Solar Panel size is given by $\frac{Total\,Wattage\ Per\ day}{Sunshine\ hours}$

Where Total wattage per day = Daily Watt hour × Expected duration of use (hours)

Thus, Total wattage per day = 2400 × 6 =14,400

Note: When sizing the solar panel, the least possible peak sun hour for a given location is used which will be taken as 4 hours.

Solar Panel size is given by $\frac{14400}{4} \;\; = \; 3600watts$

To compensate for the degradation of the solar panel and its output over time, a factor of 1.2 is used to increase the panel size.

PV Array Size = 3600 × 1.2 =4320watts.

Assuming a PV array of 300W,

Number of solar panel array is given by $\frac{4320}{300} \; \sim 14\ panels$

3.2.7 SIZING THE CHARGE CONTROLLER

Battery bank charging current is:

Charging Current (I_{batt}) = $\frac{1}{10}$ $of\ battery\ Ah$

= $\frac{1}{10}$ $of\ 660Ah\ = 66A$

For efficient charging a 70A controller is used.

3.2.8 AC LOAD BLOCK

A solar micro grid's AC load is the number of electrical devices or appliances powered by the solar energy system. The AC load can be classified as essential or non-essential based on its value to the system's users.

Description of item	**Number of equipment**	**Capacity of equipment (watts)**	**Installed capacity (watts)**	**Duration (hours)**	**Total wattage per day (watt-hour)**
Socket stations (Lower rated)	24	60	1440	6	8640
Socket stations (Higher rated)	6	200	1200	6	7200
Lamps	5	15	75	6	450
Fans	2	70	140	6	840

Table 3. 1 AC LOAD PROFILE

3.3 PRINCIPLE OF OPERATION

The principle of operation of the solar microgrid system involves several subsystems working together to convert and manage solar energy for various loads. The primary components include the PV array block, charge controller block, battery block, inverter block, and AC load block.

PV Array Block: The PV array block consists of solar cells, bypass diodes, and blocking diodes. Solar cells convert sunlight into electrical energy through the photovoltaic effect. Bypass diodes protect the panel from damage due to high forward bias, while blocking diodes prevent current from flowing back from the battery to the solar panel. The solar panel size is calculated based on the total wattage per day and the least possible peak sun hours.

Charge Controller Block: The charge controller block is responsible for managing the charging process of the battery bank. It includes a voltage sensor, current sensor, buck-boost converter, microcontroller, and LCD display. The voltage sensor provides accurate battery charging voltage, while the current sensor controls the charging current. The buck-boost converter offers a controlled DC output voltage, and the microcontroller provides control, monitoring, and safety capabilities. The LCD display shows crucial information regarding the charging process and system condition.

Battery Block: The battery block stores the electrical energy produced by the PV array. The battery rating and size are determined based on the total charge demand per day and the system's operating time.

Inverter Block: The inverter block converts direct current (DC) into alternating current (AC) using switching devices such as field-effect transistors (FETs) or insulated-gate bipolar transistors (IGBTs). The inverter is designed to work with both solar panels and batteries, allowing for a more flexible and efficient energy system.

AC Load Block: The AC load block consists of electrical devices or appliances powered by the solar energy system. The AC load can be classified as essential or non-essential based on its value to the system's users.

In summary, the solar microgrid system operates by converting solar energy into electrical energy through the PV array block, managing and storing the electrical energy using the charge controller and battery blocks, and converting the stored energy into usable AC power through the inverter block. The system is designed to optimize energy production, storage, and consumption, ensuring a reliable and efficient solar power solution.

CHAPTER FOUR

DATA PRESENTATION/ANALYSIS OF RESULT

4.0 INTRODUCTION

This chapter carefully describes the experimental implementation of this project as well as discusses the results obtain from the experiment on the basis of solar panel efficiency. Hence, this chapter will also present a comparative tabular and graph representation of output voltage, charging current and output power.

4.1 EXPERIMENTAL IMPLEMENTATION

The set up consists of two monocrystalline solar panels, a two 12V battery (220Ah) and a 3.5KVA inverter. The system was compared to another simulated system which was modelled using PVSYST with similar parameters, A digital multimeter for manually measuring the currents and voltages from the panel. the solar panels were installed properly where all parameters to be investigated were evident.

The system was set at Faculty of Engineering close to LT1 and LT2 the comparison was carried out for two days. A digital multimeter was used to take measurement readings of current, voltages and power was calculated.

Figure 4. 1: Connecting the Solar Mini Grid

4.2 CIRCUIT TESTING OF SOLAR PANEL

Testing solar panels is crucial to ensure they are performing efficiently and generating the expected amount of electricity. The readings of current, voltages and power were calculated for 4 days, from the 5th of April till the 8th of April.

Figure 4. 2: Taking Readings from The Solar Grid

TIME	VOLTAGE	CURRENT	POWER
4/5/24 12:00 AM	34.25105669	0.5	0.171255283
4/5/24 1:00 AM	36.96022783	0.55	0.203281253
4/5/24 2:00 AM	34.65301914	0.34	0.117820265
4/5/24 4:00 AM	35.24197689	2.012	0.709068575
4/5/24 5:00 AM	37.39709879	2.455	0.918098775
4/5/24 6:00 AM	38.17224905	3.503	1.337173884
4/5/24 8:00 AM	33.594274	3.102	1.042094379
4/5/24 9:00 AM	35.70653841	5.432	1.939579166
4/5/24 10:00 AM	37.77276096	4.565	1.724326538
4/5/24 11:00 AM	35.21382309	6.893	2.427288826
4/5/24 12:00 PM	34.24012757	7.342	2.513910166
4/5/24 1:00 PM	37.03579124	7.592	2.811757271
4/5/24 2:00 PM	36.21786084	8.012	2.90177501
4/5/24 3:00 PM	36.27360371	7.845	2.845664211
4/5/24 5:00 PM	36.68805845	5.673	2.081313556
4/5/24 6:00 PM	34.57528882	4.656	1.609825447
4/5/24 7:00 PM	37.28329333	4.212	1.570372315
4/5/24 8:00 PM	36.52864851	2.123	0.775503208
4/5/24 9:00 PM	38.01369499	1.555	0.591112957
4/5/24 10:00 PM	37.36830193	0.333	0.124436445
4/5/24 11:00 PM	38.13972494	0.45	0.171628762
4/6/24 12:00 AM	36.71911773	0.211	0.077477338

Table 4. 1: Readings of Open circuit Voltage, Current and Power (KWh*)*

4/6/24 1:00 AM	**34.88271507**	**0.503**	**0.175460057**
4/6/24 2:00 AM	34.60390751	0.539	0.186515061
4/6/24 3:00 AM	36.59327634	0.314	0.114902888
4/6/24 4:00 AM	34.00496948	0.732	0.248916377
4/6/24 5:00 AM	34.89217945	2.012	0.702030651
4/6/24 6:00 AM	36.1713032	2.455	0.888005494
4/6/24 7:00 AM	35.95137442	3.503	1.259376646
4/6/24 8:00 AM	33.95153267	3.541	1.202223772
4/6/24 9:00 AM	33.8457253	3.102	1.049894399
4/6/24 10:00 AM	33.76206037	5.432	1.833955119
4/6/24 11:00 AM	35.35934737	4.565	1.614154207
4/6/24 12:00 PM	36.18737169	6.893	2.494395531
4/6/24 1:00 PM	38.24835934	7.342	2.808194543
4/6/24 2:00 PM	37.97430041	7.892	2.996931788
4/6/24 3:00 PM	36.61500954	8.012	2.933594564
4/6/24 4:00 PM	37.87250725	6.845	2.592373121
4/6/24 5:00 PM	36.47670466	6.012	2.192979484
4/6/24 6:00 PM	33.81012987	5.673	1.918048668
4/6/24 7:00 PM	38.25688356	4.656	1.781240499
4/6/24 8:00 PM	35.18599486	4.102	1.443329509
4/6/24 9:00 PM	33.84004974	2.123	0.718424256
4/6/24 10:00 PM	35.81502929	1.555	0.556923705
4/6/24 11:00 PM	34.81506786	0.333	0.115934176
4/7/24 12:00 AM	37.76014354	0.45	0.169920646

4/7/24 1:00 AM	35.97044214	0.211	0.075897633
4/7/24 2:00 AM	35.90128805	0.5	0.17950644
4/7/24 3:00 AM	37.38329884	0.55	0.205608144
4/7/24 4:00 AM	33.97974459	0.34	0.115531132
4/7/24 5:00 AM	35.72609195	0.832	0.297241085
4/7/24 6:00 AM	37.58220116	2.012	0.756153887
4/7/24 7:00 AM	35.52430786	2.455	0.872121758
4/7/24 8:00 AM	35.17214053	3.503	1.232080083
4/7/24 9:00 AM	35.59103745	3.541	1.260278636
4/7/24 10:00 AM	34.35949172	3.102	1.065831433
4/7/24 11:00 AM	34.24651133	5.432	1.860270495
4/7/24 12:00 PM	36.94343186	4.565	1.686467665
4/7/24 1:00 PM	37.04018635	6.893	2.553180045
4/7/24 2:00 PM	36.01833574	7.342	2.64446621
4/7/24 3:00 PM	34.28244439	7.892	2.705570511
4/7/24 4:00 PM	33.84205366	8.012	2.711425339
4/7/24 5:00 PM	37.81232352	7.845	2.96637678
4/7/24 6:00 PM	35.45364347	6.012	2.131473045
4/7/24 7:00 PM	34.49483542	5.673	1.956892013
4/7/24 8:00 PM	36.53101912	4.656	1.70088425
4/7/24 9:00 PM	34.8254363	4.212	1.466847377
4/7/24 10:00 PM	34.59555015	2.123	0.73446353
4/7/24 11:00 PM	34.23548969	1.555	0.532361865
4/8/24 12:00 AM	37.79953531	0.333	0.125872453

4/8/24 1:00 AM	37.89978156	0.45	0.170549017
4/8/24 2:00 AM	35.79094165	0.211	0.075518887
4/8/24 3:00 AM	35.26348841	0.5	0.176317442
4/8/24 4:00 AM	35.24624934	0.55	0.193854371
4/8/24 5:00 AM	37.88340137	0.34	0.128803565
4/8/24 6:00 AM	37.0408881	0.832	0.308180189
4/8/24 7:00 AM	35.69678983	2.012	0.718219411
4/8/24 8:00 AM	35.33033527	2.455	0.867359731
4/8/24 9:00 AM	35.15077528	3.503	1.231331658
4/8/24 10:00 AM	36.42781229	3.541	1.289908833
4/8/24 11:00 AM	35.0772107	3.102	1.088095076
4/8/24 12:00 PM	34.5856442	5.432	1.878692193
4/8/24 1:00 PM	36.04664823	4.565	1.645529492
4/8/24 2:00 PM	35.88719444	6.893	2.473704313
4/8/24 3:00 PM	33.8020186	7.342	2.481744205
4/8/24 4:00 PM	37.29595082	7.892	2.943396439
4/8/24 5:00 PM	35.01849134	4.012	1.404941872
4/8/24 6:00 PM	34.27299514	5.4345	1.862565921
4/8/24 7:00 PM	36.29664572	3.012	1.093254969
4/8/24 8:00 PM	38.26223399	2.673	1.022749514
4/8/24 9:00 PM	37.15955493	1.343	0.499052823
4/8/24 10:00 PM	38.19928472	0.9212	0.351891811
4/8/24 11:00 PM	37.01832133	0.123	0.045532535

Table 4. 2: Readings of Open circuit Voltage, Current and Power (KWh*)*

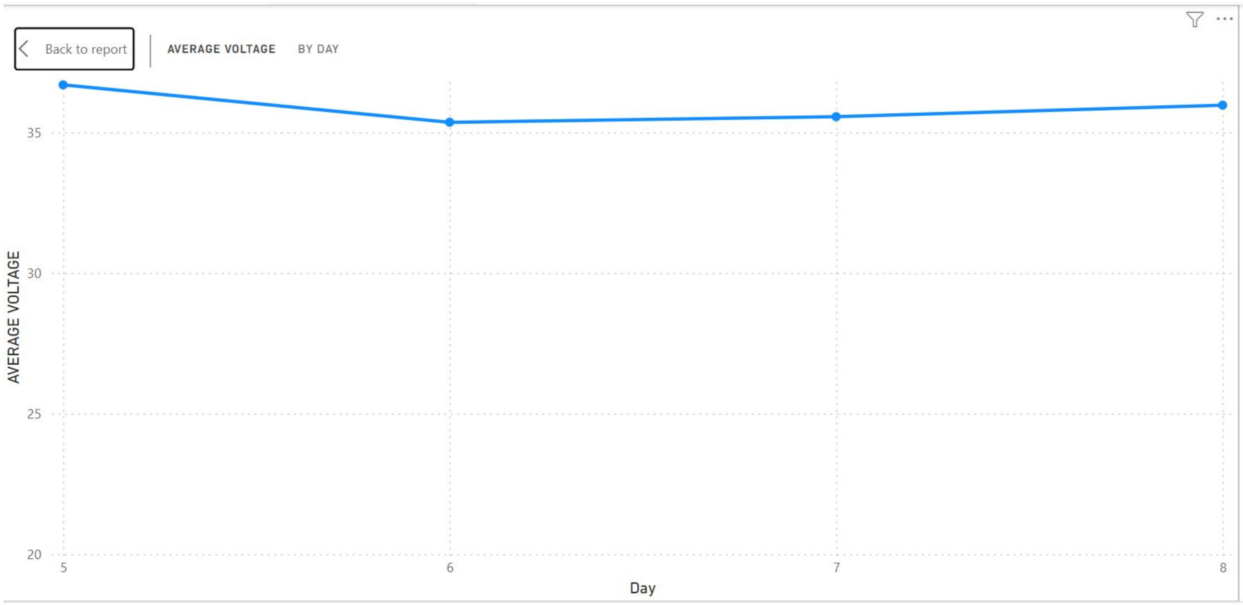


Figure 4. 3: Average voltage per day

The open circuit voltage maintains a near constant voltage that is approximately the rated open circuit voltage.

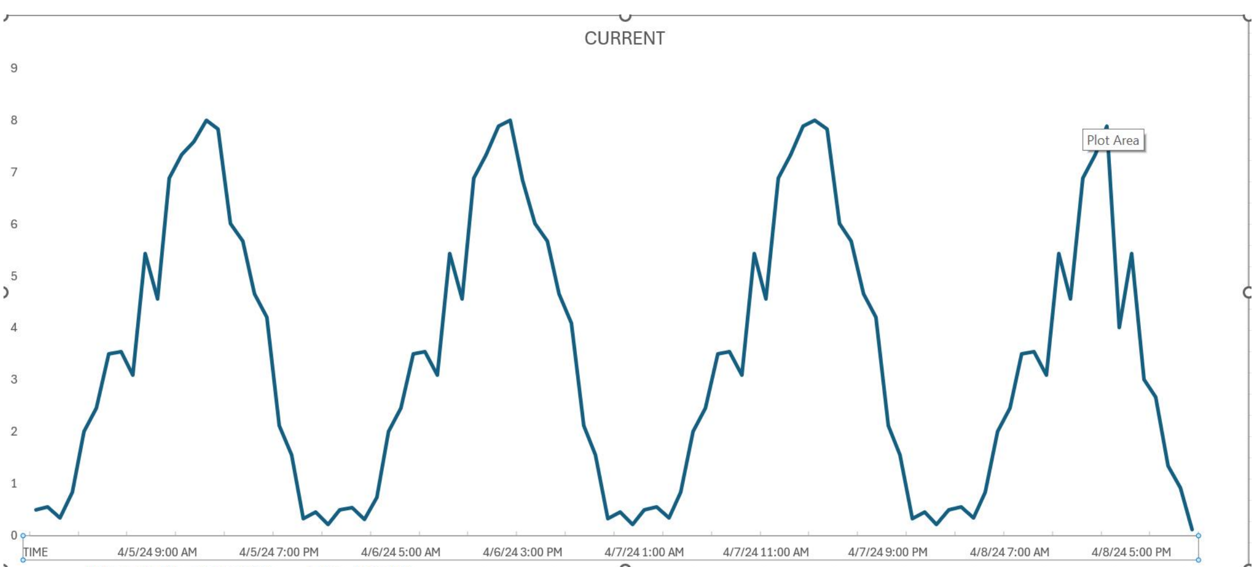


Figure 4. 4 Current readings per hour

The current measured follows a normal distribution that follow the rising and falling temperatures of the days measured.

4.3 PVsyst SIMULATION FOR SOLAR MINI GRID IN COMPARISON TO EXPERIMENTAL INSTRUMENTATION

Project summary

Geographical Site		Situation		Project settings	
Uwelu		Latitude	6.38 °N	Albedo	0.20
Nigeria		Longitude	5.58 °E		
		Altitude	108 m		
		Time zone	UTC+1		

Weather data
Uwelu
PVGIS api TMY

System summary

Standalone system

Standalone system with batteries

PV Field Orientation		User's needs	
Fixed plane		Daily household consumers	
Tilt/Azimuth	10.7 / 2.5 °	Constant over the year	
		Average	13.2 kWh/Day

System information

PV Array		Battery pack	
Nb. of modules	14 units	Technology	Lead-acid, sealed, Gel
Pnom total	4200 Wp	Nb. of units	312 units
		Voltage	24 V
		Capacity	2600 Ah

Results summary

Useful energy from solar	4715.18 kWh/year	Specific production	1123 kWh/kWp/year	Perf. Ratio PR	60.38 %
Missing Energy	91.87 kWh/year	Available solar energy	6282.23 kWh/year	Solar Fraction SF	98.10 %
Excess (unused)	1032.08 kWh/year				

Table of contents

Figure 4. 5 : High level Simulation of Simulation

This image shows some high-level summaries of the project, systems and results of this simulation variant. The geographical site and data properties are fully defined here. They will not appear elsewhere in the report.

General parameters

Standalone system — **Standalone system with batteries**

PV Field Orientation

Orientation		**Sheds configuration**	**Models used**	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	10.7 / 2.5 °		Diffuse	Imported
			Circumsolar	separate

User's needs

Daily household consumers

Constant over the year

Average 13.2 kWh/Day

PV Array Characteristics

PV module		**Battery**	
Manufacturer	Generic	Manufacturer	Generic
Model	Mono 300 Wp 60 cells	Model	Adjustable Lead-acid
(Original PVsyst database)		Technology	Lead-acid, sealed, Gel
Unit Nom. Power	300 Wp	Nb. of units	26 in parallel x 12 in series
Number of PV modules	14 units	Discharging min. SOC	20.0 %
Nominal (STC)	4200 Wp	Stored energy	49.9 kWh
Modules	14 string x 1 In series	**Battery Pack Characteristics**	
At operating cond. (50°C)		Voltage	24 V
Pmpp	3780 Wp	Nominal Capacity	2600 Ah (C10)
U mpp	28 V	Temperature	Fixed 20 °C
I mpp	133 A		
Controller		**Battery Management control**	
Universal controller		Threshold commands as	SOC calculation
Technology	MPPT converter	Charging	SOC = 0.90 / 0.75
Temp coeff.	-5.0 mV/°C/Elem.	approx.	26.9 / 25.1 V
Converter		Discharging	SOC = 0.20 / 0.45
Maxi and EURO efficiencies	97.0 / 95.0 %	approx.	23.3 / 24.4 V
Total PV power			
Nominal (STC)	4.20 kWp		
Total	14 modules		
Module area	22.8 m²		
Cell area	19.9 m²		

Array losses

Thermal Loss factor		**DC wiring losses**		**Serie Diode Loss**	
Module temperature according to irradiance		Global array res.	3.6 mΩ	Voltage drop	0.7 V
Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC	Loss Fraction	2.2 % at STC
Uv (wind)	0.0 W/m²K/m/s				
Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.8 %	Loss Fraction	0.0 % at MPP	Loss Fraction	0.2 %

IAM loss factor

Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Figure 4. 6: General Parameters, PV Array Characteristics, Array Losses

This page shows all the parameters, characteristics and losses of the simulation. Which are

1. **THE GENERAL PARAMETERS:** The general parameters include the systems kind, PV field orientation and the shading configuration used.

2. **THE PV ARRAY CHARACTERISTICS:** The PV array characteristics tells us everything about the PV system. This includes the modules and their arrangement in the array and the inverters as well

3. **ARRAY LOSSES:** The array losses give an overview of all the settings involved in the calculation of the losses during the simulation.

4.3.1 COMPARISON

The power output of the solar panels in comparison to the simulated values are below.

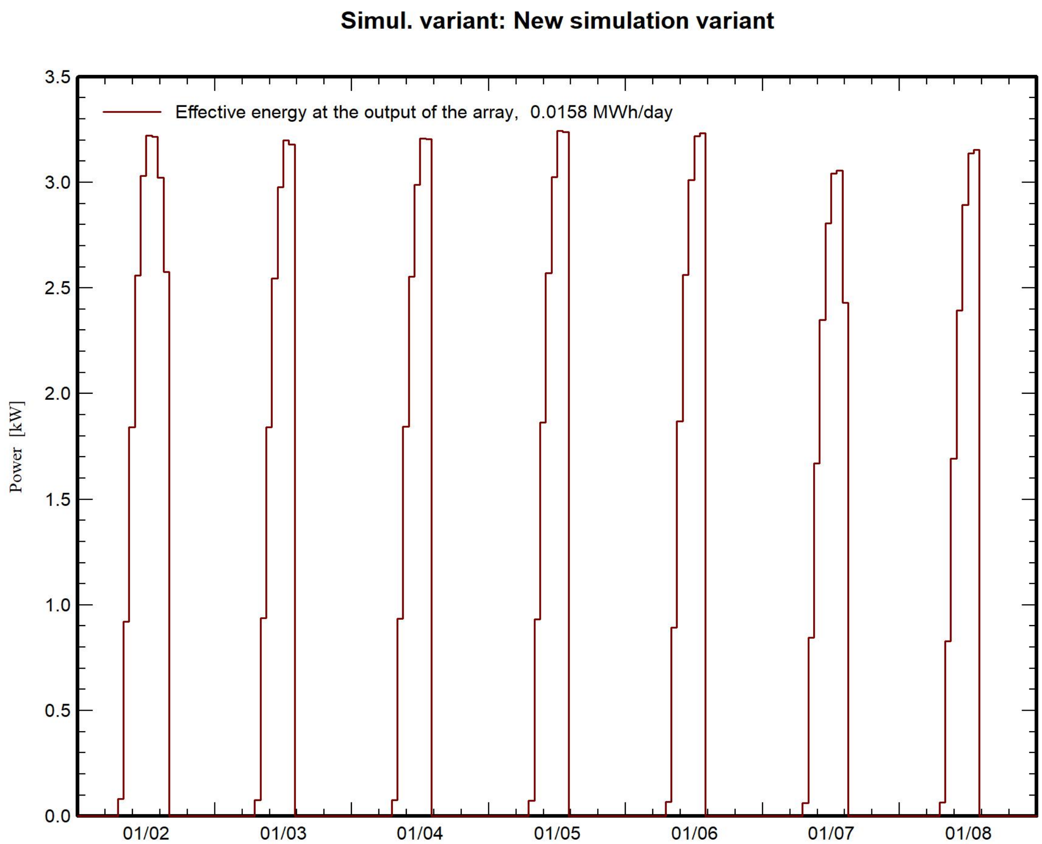


Figure 4. 7: Power readings from simulated version

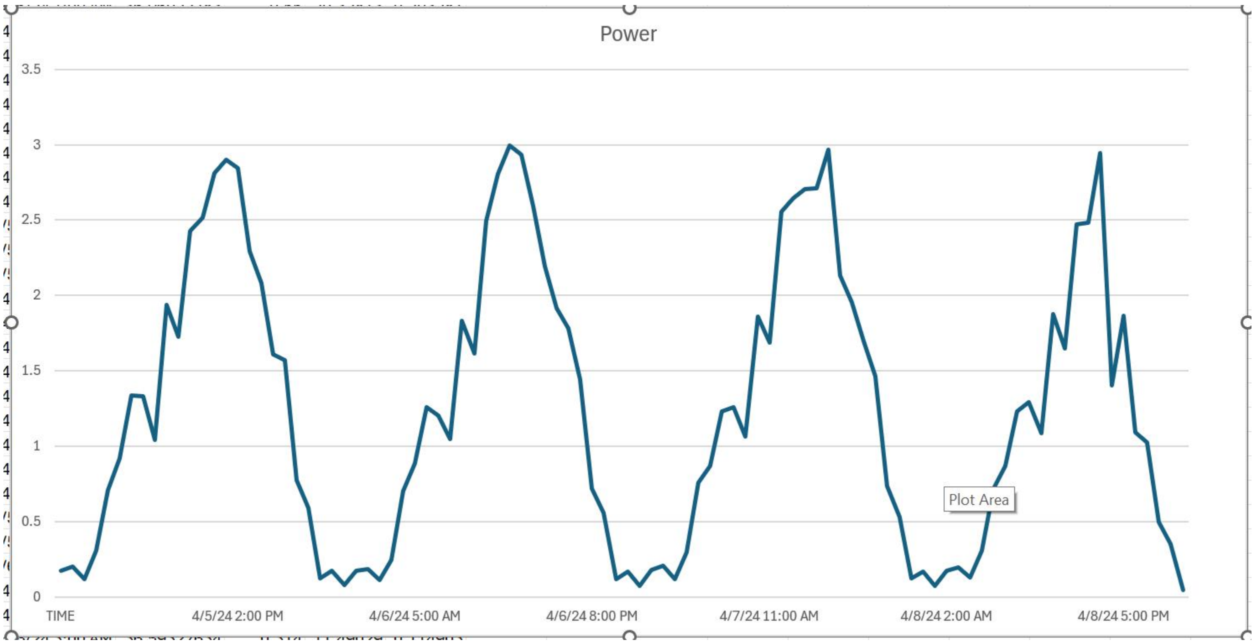


Figure 4. 8 : Actual readings of Power

The simulated energy values reached a peak power of approximately 3.35Kwh, compared to the peak value of 3Kwh for the actual values.

4.3.2 OBSERVATION

A mini-grid system provides flexibility for future growth. If the rural settlement experiences population growth or increased energy demand, the mini grid can be expanded or upgraded to accommodate the growing needs. This scalability allows for a seamless transition to a full grid-connected system when required, without significant disruptions or infrastructure changes

4.4 FINDINGS

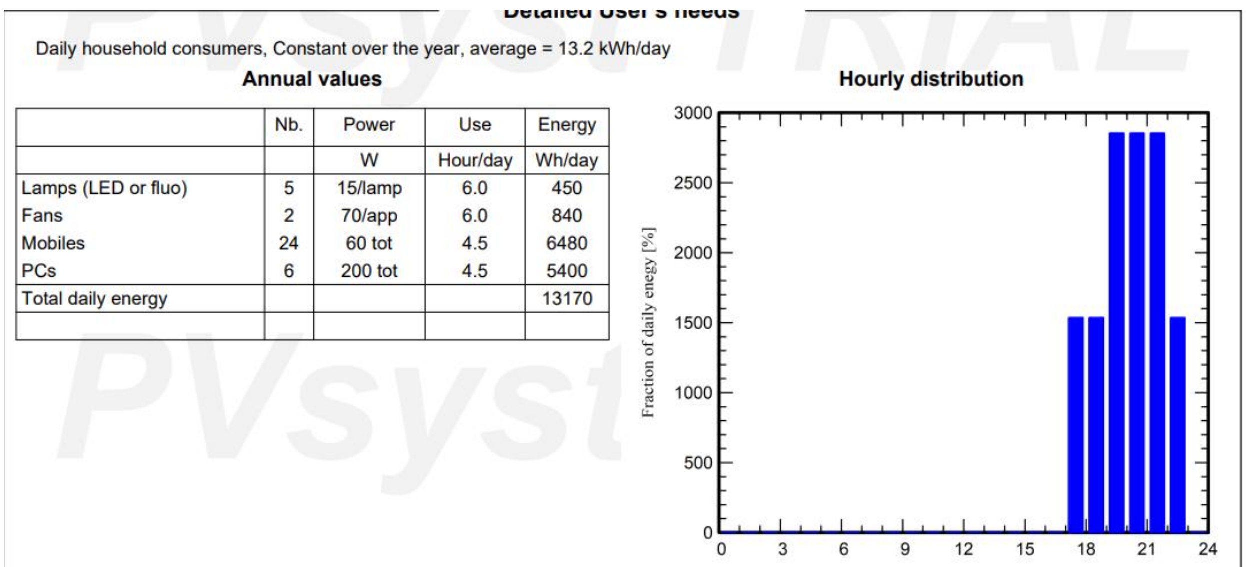
Using simulation in the design of a solar mini-grid can provide valuable insights and help optimize the system's performance. These are some key findings associated with in the design process:

1. Energy Production:

With simulations, energy production can accurately matched the expected energy production of the mini-grid under varying weather conditions, allowing for more accurate sizing of the solar array and battery storage capacity.

2. Load Profiling:

Accounting for Energy consumption patterns of the community helped in designing an appropriately sized system to meet peak and average demand, leading to cost-effective solutions.



	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	5	15/lamp	6.0	450
Fans	2	70/app	6.0	840
Mobiles	24	60 tot	4.5	6480
PCs	6	200 tot	4.5	5400
Total daily energy				13170

Figure 4. 9: Hourly Load Distribution

3. Battery Sizing and Dispatch: The size of the batteries was not adequate due to financial restraints as the PVSyst determined the optimal size and discharge strategies for energy storage, ensuring reliable power during non-solar hours.

Figure 4. 10: Mounting the Solar Mini Grid

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 SUMMARY

The solar mini-grid project aims to provide a localized electricity distribution center powered by solar energy in a rural community. The project begins by evaluating technical, economic, and social factors. Detailed design and engineering plans were also developed, considering solar resource availability, load requirements, and system components. Infrastructure installation involves procuring and constructing solar panels, batteries and inverters adhering to safety standards. Energy storage through batteries ensures a continuous power supply. A distribution network is established to supply electricity to households, businesses, and public facilities. The use of simulation software with a good algorithm to run the simulation of the micro grid showing the output, losses, runtime, peak output and low output, solar radiation intensity and its variations, battery charging time and drain, which then helps us to factor and analyze howthis project would work in a real rural location.

5.1 CONCLUSION

After conducting a thorough research on the solar mini-grid project, the following are the key findings which emerged:

1. **Feasibility**: The research confirmed the technical, economic, and social viability of implementing a solar mini grid in the target rural community. The solar resource availability was found to be sufficient, and the community's energy demand could be met effectively through the mini-grid system.

2. **Reliability and Energy Access**: The research revealed that a solar mini-grid system could provide reliable and uninterrupted electricity access to the community. By incorporating battery storage, the system was able to overcome intermittent issues, ensuring a consistent power supply even during periods of low solar generation.

3. **Environmental Sustainability**: The research emphasized the environmental benefits of a solar mini grid. By utilizing renewable solar energy, the project significantly reduced carbon emissions and minimized the community's reliance on fossil fuel- based energy sources. This aspect aligns with the global push for sustainable energy solutions and contributes to the overall environmental well-being.

4. Scalability and Adaptability: The study found that the solar mini-grid project was designed with scalability in mind, allowing for future expansion and adaptation to changing energy needs. The system could be easily upgraded to accommodate population growth or increased energy demands, and it had the potential for integrating other renewable energy sources or grid connections if required.

5.2 RECOMMENDATION

The following are recommendations for further studies and related research areas:

1. **Technical Optimization**: Conduct a study on the optimization of solar mini-grid systems, exploring advanced technologies, such as energy management systems, smart grid integration, and advanced control algorithms. Investigate how these technologies can improve system efficiency, reliability, and energy dispatch strategies.

2. **Energy Storage Technologies**: Explore different energy storage technologies, such as

advanced battery chemistries, flow batteries, compressed air energy systems to assess their suitability and cost-effectiveness for solar mini-grid applications. Investigate the performance, lifespan, and scalability of these technologies to enhance the energy storage capabilities of mini-grid systems.

3. **Grid Integration**: Explore the potential for grid integration of solar mini-grid systems. Assess the feasibility and benefits of connecting mini grids to the centralized grid, allowing for energy exchange, grid support services, and surplus energy sales. Analyze the technical, economic, and regulatory aspects of grid integration.

4. **Long-Term Performance and Maintenance**: Study the long-term performance and maintenance requirements of solar mini-grid systems. Assess the degradation rates of solar panels, battery lifespan, and the cost-effectiveness of maintenance strategies. Develop predictive models and maintenance protocols for optimal system performance and durability.

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