UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

Project Title: "**Design of PV Microgrid For Rural Areas in Rwanda": Case Study of Gitwa Village.**

A Thesis submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD)

In partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN ELECTRICAL POWER SYSTEM

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Kigali-Rwanda

Declaration

I, the undersigned, declare that this Project proposal is my original work, and has not been presented for a degree at the University of Rwanda or any other universities. All sources of materials that will be used for the thesis work will have been fully acknowledged.

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APPROVAL

Date of Submission: **2nd October 2025**

This Thesis proposal has been submitted for examination with my approval as a university advisor.

Associate. Prof Kizito Nkurikiyeyezu Signature

Dedication

This work is truly dedicated to my beloved Friends and Families

Acknowledgments

I would like to express my heartfelt gratitude to all those who contributed to the successful completion of this project. My sincere appreciation goes to my supervisor, Associate Prof. Kizito Nkurikiyeyezu, for his invaluable guidance, insightful feedback, and continuous support throughout the research process. I extend my thanks to the African Center of Excellence in Energy for Sustainable Development (ACE-ESD) for providing the academic platform and resources necessary for this study. I am also grateful to my colleagues, friends, and family for their encouragement and unwavering belief in my capabilities. Lastly, I acknowledge the people of Gitwa Village for their cooperation and willingness to share valuable insights, which played a crucial role in shaping this project.

Abstract

Access to reliable and affordable electricity remains a significant challenge for rural communities in Rwanda. Extending the national grid to remote areas is often impractical due to high infrastructure costs, challenging terrain, and low population density. To address this issue, photovoltaic (PV) microgrids offer a sustainable and cost-effective alternative, harnessing the abundant solar energy available in the country. This study focuses on designing an optimized PV microgrid system for Gitwa Village, which currently lacks access to electricity.

The project involves an in-depth analysis of the village's energy demand, the assessment of solar energy potential, and the design of a scalable standalone PV microgrid system. A systematic methodology was employed, including data collection on household energy consumption, solar irradiation analysis, and the selection of appropriate system components such as PV panels, inverters, and battery storage. To ensure efficiency and reliability, the system was simulated using HOMER software, which provided insights into energy production, cost-effectiveness, and performance under various scenarios.

The results of the study indicate that Gitwa Village requires approximately 324 kWh/day to meet its daily electricity needs. The optimized PV microgrid design consists of an 81.25 kW PV array, a 32KW inverter, and a battery bank with 148 batteries to ensure stable power supply. Simulation results show that the system is capable of providing reliable electricity at a competitive Levelized Cost of Energy (LCOE) of $0.07469/kWh, making it an economically viable solution for rural electrification.

This research highlights the potential of PV microgrids in bridging the energy access gap in Rwanda, providing not only electricity but also fostering socio-economic development. The study also emphasizes the importance of government support, financial incentives, and local capacity building to ensure the long-term sustainability of such systems. The findings serve as a valuable reference for policymakers, energy developers, and researchers working towards scalable off-grid electrification solutions in Rwanda and beyond.

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List of Acronyms

ACEESD: African Center of Excellence in Energy for Sustainable Development

DoA: Days of Autonomy

DoD: Depth of Discharge

REG: Rwanda Energy Group

EUCL: Energy Utility Corporation Limited

PSH: Peak Sun Hours

PV: Photo Voltaic

RE: Renewable Energy

UR: University of Rwanda

AC: Alternating Current

DC: Direct current

HOMER: Hybrid Optimization of Multiple Energy Resources

RUEAP: Programs such as the Rwanda Universal Energy Access Program

IEA: International Energy Agency

LCO: lithium cobalt oxide

LFP: lithium iron phosphate

LCOE: Levelized Cost of Energy

NPC: Net present cost

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CHAPTER 1: INTRODUCTION

1.1.Background

Rwanda has made significant progress in expanding electricity access, with the government actively working towards universal electrification. As of 2024, the country's energy access rate has improved considerably, thanks to a mix of on-grid and off-grid solutions that contribute to national development. However, rural areas still face major challenges in electrification. Extending the national grid to remote villages is often impractical due to high infrastructure costs, difficult terrain, and the scattered nature of rural settlements. The financial burden of grid expansion is particularly high because these communities have low energy consumption, making the per capita cost of electricity distribution/Transmission unsustainable[1].

As a result, many rural households and businesses continue to rely on costly and inefficient energy sources like kerosene lamps, diesel generators, and firewood for lighting and cooking. These alternatives not only increase household energy expenses but also pose serious health and environmental risks, such as indoor air pollution and carbon emissions[2]. Additionally, reliance on fossil fuels like diesel creates economic instability, as fuel prices fluctuate and supply chains in remote areas remain unreliable[3].

Standalone photovoltaic (PV) microgrids offer a practical and sustainable solution to address these rural electrification challenges. Unlike large-scale grid expansion, PV microgrids require lower capital investment, can be deployed in phases, and are well-suited for remote areas with strong solar potential[4]. Rwanda's solar energy resources, averaging about 5 kWh/m² per day, provide an excellent opportunity to generate clean, reliable, and cost-effective electricity for off-grid villages[5].

One such village is Gitwa, located in Nyanza District, Southern Province. Gitwa is home to around 350 people living in 112 households and currently lacks access to reliable electricity. This power shortage limits economic development and restricts essential services. Given its characteristics, Gitwa has been selected as a reference model for this study, with the aim of designing an optimized PV microgrids that can serve as a scalable and replicable solution for similar rural communities across Rwanda.

A well-designed PV microgrids can bring transformative benefits to rural communities. Households will gain access to affordable and reliable electricity, small businesses can grow, and some essential services will function more effectively. Schools, for instance, can integrate digital learning tools. Additionally, access to electricity can stimulate local economic activities by enabling small enterprises, supporting agricultural processing, and reducing dependence on expensive fossil fuels[6].

Given these advantages, PV microgrids are increasingly being recognized as a key part of Rwanda's rural electrification strategy. The government, in collaboration with development partners and private sector stakeholders, has launched various initiatives to expand access to decentralized renewable energy. RUEAP and partnerships with companies like BBOXX and Ignite Power have played a role in deploying off-grid solar systems and mini-grids throughout the country[7]. However, challenges remain in ensuring the long-term sustainability, affordability, and scalability of these solutions. Addressing barriers such as financing constraints, technical expertise, and policy support will be critical to successfully integrating PV microgrids into Rwanda's energy framework.

By leveraging its abundant solar resources and embracing innovative energy models, Rwanda can bridge the rural electricity gap through PV microgrids. This approach aligns with the country's Vision 2050 goals and its commitment to achieving universal access to modern, sustainable, and affordable electricity[8].

1.2. Problem Statement

The lack of access to affordable and stable electricity in Gitwa Village negatively affects the community's economic activities, education, and healthcare services. Traditional electrification approaches, such as extending the national grid, are not financially viable due to high infrastructure costs and low population density. Existing solar home systems provide limited energy, failing to support larger power needs such as small businesses. A PV microgrids offers a decentralized and cost-effective solution to these challenges. However, there is a need for an optimized design that ensures reliable energy distribution and economic sustainability.

1.3. Objectives

1.3.1 General Objective

To design a photovoltaic (PV) microgrids for Gitwa Village that ensures reliable and sustainable rural electrification.

1.3.2 Specific Objectives

- Assess the daily energy demand of Gitwa Village.
- Analyze the solar energy potential of the region.
- Design a scalable PV microgrids that meets the energy needs of the village.
- Evaluate system performance through HOMER simulation.

1.4 Scope of the Study

This study focuses on the design and simulation of a standalone PV microgrids tailored to the energy needs of Gitwa Village. The research involves a detailed assessment of the village's electricity demand, an analysis of the available solar energy potential, and the selection of appropriate system components to ensure efficiency and reliability. The performance of the proposed microgrid is evaluated using HOMER software to optimize system design and assess its technical and economic feasibility. While this study does not include physical implementation, it aims to provide valuable insights and practical recommendations for future real-world deployment, contributing to sustainable rural electrification efforts.

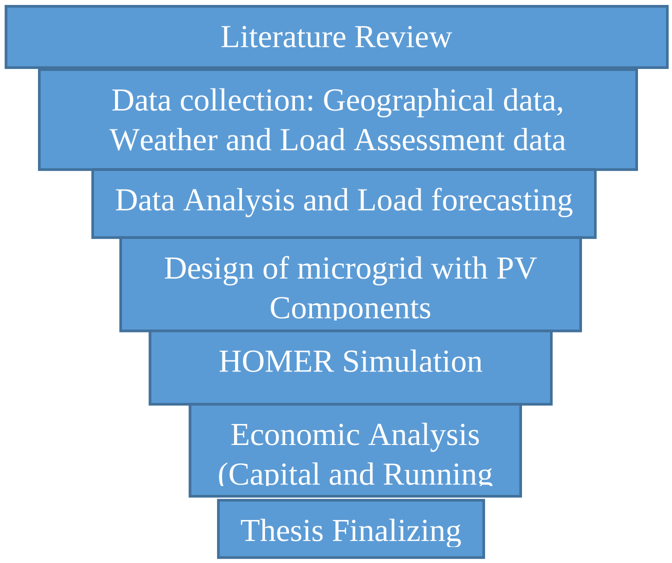


Figure 1 Thesis Structure

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Access to reliable electricity remains a significant challenge in many developing nations, particularly across Africa. Rural communities often struggle with limited or no access to power, hindering economic growth, education, healthcare, and overall quality of life. One of the primary barriers to rural electrification is the high cost and logistical difficulty of extending national grids to remote areas. Factors such as rugged terrain, sparse populations, and the substantial investment required make traditional grid expansion financially unfeasible in many cases[9].

As a result, decentralized energy solutions have emerged as a promising alternative, with photovoltaic (PV) microgrids standing out as one of the most viable and sustainable options. These microgrids, which generate and distribute electricity locally using solar power, offer an efficient way to electrify off-grid communities. By leveraging renewable energy, PV microgrids not only reduce dependence on fossil fuels but also provide a cost-effective and environmentally friendly solution to energy poverty[8].

2.2 The Energy Access Gap in Africa

Sub-Saharan Africa remains one of the most energy-deprived regions globally, with more than 600 million people lacking access to electricity[10]. The disparity between urban and rural electrification rates is significant, as rural areas often receive less government investment in grid expansion due to cost constraints and low population density. Research has shown that limited energy access has adverse effects on healthcare services, agricultural productivity, and overall economic development[11]. As a result, alternative electrification strategies are required to bridge this gap effectively.

According to the IEA, electrification rates in Africa have improved in recent years, but the progress remains slow, particularly in remote communities. In response, governments and international organizations are focusing on decentralized renewable energy solutions as a more viable approach to rural electrification[12].

2.3 Decentralized Energy Solutions and the Role of PV Microgrids

Decentralized energy solutions, including stand-alone solar home systems and community-based microgrids, have gained traction as an alternative to traditional grid extension. Among these, PV microgrids are particularly well-suited for rural electrification due to their scalability, affordability, and reliability. These systems consist of distributed solar panels, energy storage, and local distribution networks, providing a community-based solution to electricity access[12].

The advantages of PV microgrids include reduced transmission losses, lower costs compared to long-distance grid expansion, and the ability to integrate with emerging smart grid technologies. Moreover, PV microgrids align with sustainable development goals by reducing greenhouse gas emissions and minimizing reliance on fossil fuels[13].

2.5 Case Studies of PV Microgrid Deployment in Africa and Rwanda

Several African countries have successfully implemented PV microgrids to address energy poverty, demonstrating the potential of decentralized solar energy solutions across different regions. In *Tanzania*, Mwenga microgrid supplies electricity to over 4,500 rural households, supporting local businesses and improving healthcare access. *Kenya*, A solar mini-grid in Kitonyoni has provided reliable electricity to a rural village, fostering economic growth through enhanced trade and education. *Nigeria*, Off-grid solar mini-grids have been deployed in several states, improving access to electricity for thousands of households while reducing reliance on diesel generators[14].

Rwanda has been a pioneer in deploying off-grid solar solutions as part of its national electrification strategy. The Rwandan government, in collaboration with private investors, has implemented several PV microgrid projects, particularly in remote areas where grid extension is not feasible. Two recently notable projects are *RENERG* In Nyamasheke District and *NESELTECK* in kirehe district also known as Rushonga Solar Mini-Grid both minigrid systems produce 30KW, which used to provide electricity to rural businesses, schools, and healthcare centers, significantly improving local livelihoods[14].

Rwanda's approach to public-private partnerships and supportive regulatory frameworks has contributed to the success of its off-grid electrification initiatives.

Figure 2 : NESELTECK Located in Kirehe District with a capacity to generate 30KW

Figure 3: RENERG located in Nyamasheke District with a capacity to generate 30KW

These case studies demonstrate that PV microgrids are more than just an alternative energy source—they are a catalyst for economic and social transformation. By providing clean, reliable electricity, these systems help bridge the energy divide in rural Rwanda, improving living standards, supporting small businesses, and enabling better educational opportunities.

Rwanda has made significant progress in off-grid solar electrification, driven by innovative companies such as BBOXX and Ignite Power. These organizations have deployed thousands of PV microgrids and standalone solar home systems, replacing traditional energy sources like kerosene lamps and firewood[14]. This transition has brought numerous benefits, including improved air quality, reduced household energy costs, and enhanced productivity in rural enterprises. Furthermore, access to electricity has enabled the use of essential technologies, such as mobile phone charging and irrigation systems, fostering economic.

However, despite these achievements, several challenges persist. The high upfront costs of PV microgrid installations remain a significant barrier, particularly for low-income households. Limited financing options also hinder widespread adoption, as many rural communities struggle to afford the initial investment without subsidies or flexible payment models[1]. Additionally, energy limitations remain a key challenge. Many of the solar home systems and microgrids deployed by BBOXX and Ignite Power provide only basic electricity, sufficient for lighting, phone charging, and small appliances, but insufficient for high-energy applications like refrigeration, agricultural processing, or large-scale industrial activities [2]. This restricts the long-term economic impact of these systems, as businesses and households still face constraints in scaling their activities.

Figure 4:Ignite Power Solar panel

Moreover, the sustainability of these systems depends on regular maintenance, which can be difficult due to a shortage of trained technicians and the availability of spare parts. Energy storage remains another challenge, as battery degradation over time reduces system efficiency and increases replacement costs[15] Addressing these limitations requires collaborative efforts from governments, private sector players, and development organizations to develop innovative financing solutions, invest in battery technology, improve energy storage capacity, and create policies that support the integration of higher-capacity solar systems[11]

2.6 Understanding PV Microgrids

PV microgrids are decentralized energy systems that generate electricity using solar panels and distribute it to local consumers. Unlike centralized grid systems, they provide a localized, scalable, and modular solution for rural electrification.

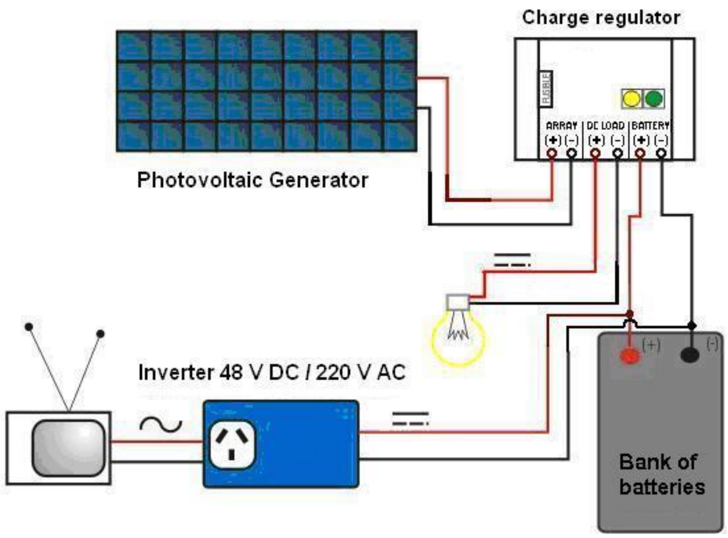


Figure 5: A block diagram of a typical PV microgrid setup

2.6.1 Key Components of a PV Microgrid

SOLAR PHOTOVOLTAIC PANEL

Photovoltaic (PV) technology, a term derived from two words—**photo**, meaning light, and **voltaic**, referring to voltage—represents a groundbreaking way to harness the sun's energy. At the heart of PV systems are solar cells, made from semiconductors, which directly convert sunlight into electricity. Among the various materials used, crystalline silicon has emerged as the most widely adopted semiconductor due to its numerous advantages. These solar cells are quiet, reliable, highly durable, and, most importantly, they don't require fuel to generate power, making them a clean and sustainable energy solution.

A solar cell is essentially built using two types of semiconductors: **P-type** and **N-type**, which are joined together at a boundary known as the **p-n junction**. This junction is where the magic happens—it enables the conversion of sunlight into electrical energy. The journey of photovoltaic research began many decades ago, with early breakthroughs paving the way for modern solar technology. One of the pioneers in this field was Charles Fritts, a scientist who first experimented with selenium as a material capable of generating electricity from sunlight. His work laid the foundation for the solar technology we rely on today.

At its core, a solar cell is a small but powerful unit designed to produce a specific amount of electrical power. These cells can be made from a variety of materials, each with its own unique properties, but they all share the same purpose: to transform the sun's abundant energy into usable electricity. Imagine a tiny device, no larger than the palm of your hand, quietly and efficiently converting sunlight into the energy that powers homes, schools, and businesses. It's a testament to human ingenuity and our ability to harness nature's resources in innovative ways.

The story of PV technology is not just about science and engineering—it's about people. It's about families in rural areas who now have access to clean, reliable energy for the first time. It's about children who can study after sunset, farmers who can irrigate their fields more efficiently, and communities that can thrive without relying on harmful fuels like kerosene or firewood. Solar cells may be small, but their impact is enormous, lighting up lives and powering progress in ways that were once unimaginable.

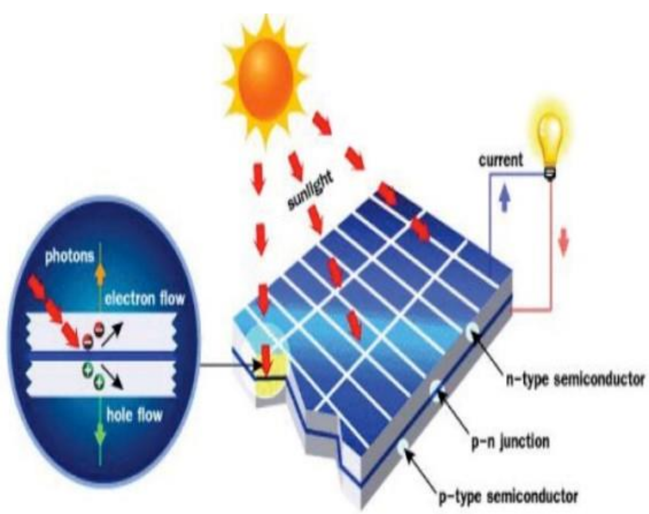


Figure 6: Photovoltaic effect

To power everyday devices that need specific voltage or current, solar cells are combined into a **solar panel,** also known as a **PV module.** These modules, often called the "heart" of the system, act as power generators. For large-scale solar plants, multiple PV modules are connected to form a **PV array.** Alongside the modules, other essential components include wiring for connections and mounting structures to secure the panels in place.

Solar panels have **positive (+) and negative (-) terminals**, much like a battery. When panels are wired **in series**—connecting the negative terminal of one panel to the positive terminal of the next—the voltages add up. On the other hand, wiring panels **in parallel** increases the current while keeping the voltage constant. This flexibility allows solar systems to be tailored to meet specific energy needs, whether for a small home or a massive power plant. In essence, these interconnected panels work together to turn sunlight into reliable, usable energy, lighting up lives and powering progress. Output of solar module = One solar cell voltage × Number of solar cells

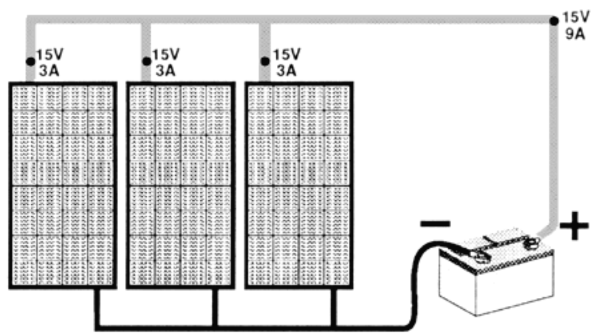


Figure 7: Parallel connection of three solar cells

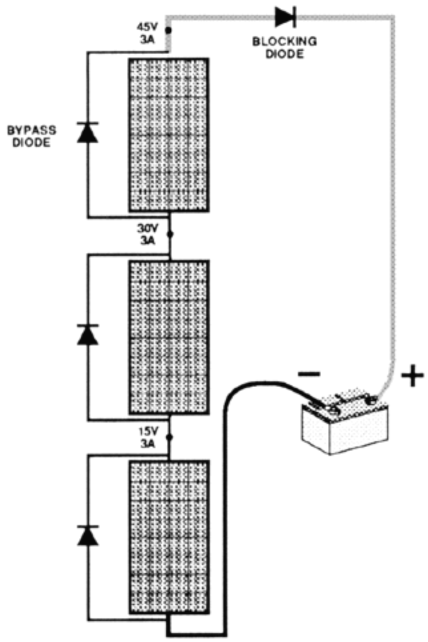


Figure 8: Series connection of three solar cells

PV modules harness sunlight and convert it directly into electricity through the photovoltaic effect, a process that is both silent and environmentally friendly. Today, there are numerous PV technologies available, and researchers worldwide are working tirelessly to discover new materials and designs to enhance the efficiency and performance of solar cells. Solar cells come in various types, each with its unique characteristics. In this discussion, we'll focus on the three main types of solar cells that dominate the market: crystalline silicon and thin-film technologies. These innovations are at the forefront of the solar energy revolution, helping to power homes, businesses, and communities in a sustainable way.

Types of PV Cells

Solar photovoltaic (PV) cells are broadly categorized into three main types, each with its unique characteristics and applications. Silicon is the primary material used in manufacturing these cells, and the technology behind them continues to evolve. Here's a closer look at the three classes of PV cells:

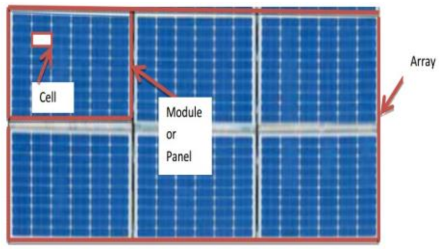


Figure 9: PV cell, PV module and PV array

1. Monocrystalline Silicon Panels

Monocrystalline silicon panels are the most widely used type of PV cells due to their exceptional efficiency and durability. These panels are made from a single, pure crystal structure, which allows them to achieve an impressive efficiency rate of around 20%. They require less space for installation compared to other types, making them ideal for areas with limited room. Additionally, monocrystalline panels have a long lifespan, often exceeding 25 years, and they generate significantly more DC power than thin-film cells of the same size under similar weather conditions. While they tend to be more expensive, their high performance and reliability make them a popular choice for both residential and commercial applications.

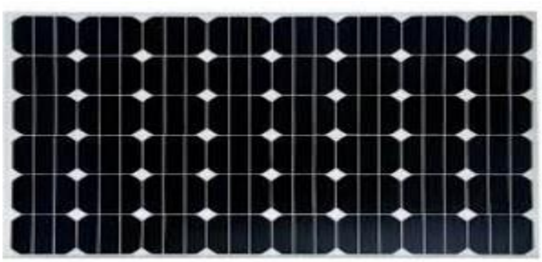
2. Polycrystalline Silicon Panels

Polycrystalline silicon panels, also known as poly-Si, multicrystalline, or simply "poly," are another common type of PV cell. These panels are made from multiple silicon crystals, which makes them less efficient than monocrystalline panels, with efficiency rates typically ranging between 13% and 16%. However, they are more affordable to produce, making them a cost-effective option for many users. One drawback is that they require more space for installation to achieve the same power output as monocrystalline panels. Their lifespan is slightly shorter, usually between 20 and 25 years, but they remain a reliable and widely used technology in the solar industry.

3. Thin-Film Silicon Panels

Thin-film silicon panels represent the next generation of PV technology. These cells are made from non-crystalline silicon and require significantly less material and energy to produce, making them more economical and environmentally friendly. However, they have lower conversion efficiency, typically below 12%, which makes them less effective in terms of power output. Despite this, thin-film panels perform well in low-light conditions, which is one of their standout qualities. They are also lightweight and flexible, making them suitable for a variety of applications where traditional rigid panels may not be practical. While they may not match the efficiency of crystalline silicon panels, their affordability and adaptability make them a promising option for certain use cases.

Table 1: Strengths and weakness of different photovoltaic technologies

PV Technology	Strengths	Weaknesses
Monocrystalline Silicon (mono-Si) 	-Efficiency: 15-20 % (21.5 % as current maximum) -Long-life up to 25 years - Occupy less space	-Expensive -Sensitivity to ambient temperature -Sensitivity to shading issues, snow and dirt -Wasteful manufacturing process
Polycrystalline Silicon (p-Si or m-Si) 	-Simple, cost-efficient and not wasteful manufacturing process -Insignificant intolerance to high ambient temperature	-Impurities and efficiency of 1316 % -Low space efficient -Energy extensive manufacturing process`

Thin-film (TFSC) - Amorphous silicon (a-Si) - Cadmium telluride (CdTe) - Copper indium gallium selenide (CIS/CIGS) 	-Cost-efficient and simple manufacturing process -Flexible configurations -Tolerance to shading issues and ambient temperature variation	-low efficiency: 9-12% -Big space required -High degradation rate

BATTERY STORAGE

Battery storage plays a vital role in modern energy systems, especially in microgrids and renewable energy setups, by storing excess electricity generated during peak production times—like sunny or windy periods—for use when energy generation is low, such as at night or on cloudy days. These systems help **shift energy** from times of surplus to times of need, ensuring a steady power supply. They also enhance **grid stability** by providing backup power during outages and balancing supply and demand to prevent blackouts. Additionally, battery storage supports the integration of renewable energy by smoothing out the intermittent nature of sources like solar and wind, making them more reliable. Beyond reliability, they offer **cost savings** by storing energy when it's inexpensive (e.g., during off-peak hours) and using it when electricity prices are high. In essence, battery storage is a cornerstone of sustainable energy systems, empowering communities with reliable, affordable, and clean power.

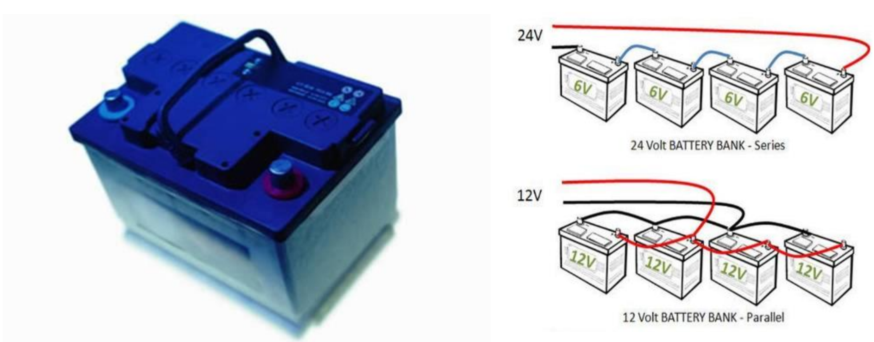


Figure 10: Battery storage and connection configuration

Types of Battery Storage

The two most common types of batteries used in energy storage systems are lead-acid and lithium-ion. *Lead-Acid Batteries:* One of the oldest and most established battery technologies consists of lead dioxide (positive electrode), sponge lead (negative electrode), and sulfuric acid (electrolyte) and *Lithium-Ion Batteries*, a newer and more advanced battery technology widely used in electronics, electric vehicles, and renewable energy systems typically uses lithium cobalt oxide (LCO), lithium iron phosphate (LFP), or other lithium-based chemistries.

INVERTERS

Inverters are critical components in solar power systems and other renewable energy setups, as they convert DC (Direct Current) electricity generated by solar panels or stored in batteries into AC (Alternating Current) electricity, which is the standard form of electricity used by most household appliances. Inverters perform the DC to AC Conversion where Solar panels and batteries produce DC electricity, but most household appliances, industrial equipment, and the power grid operate on AC electricity

Figure 11: Inverter

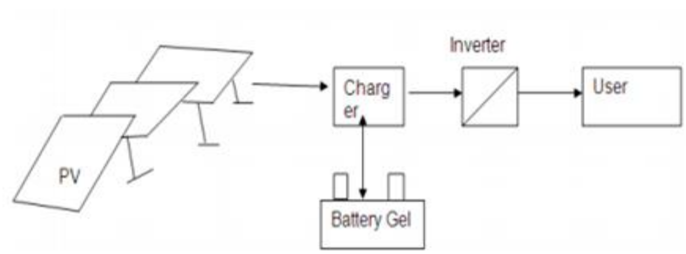


Figure 12: Photovoltaic system Block

CHAPTER 3: METHODOLOGY

With the specific objectives of providing reliable electricity to Gitwa Village, optimizing energy access, and demonstrating the feasibility of PV microgrids in remote areas, the methodology for this study has been carefully designed and executed. This chapter outlines the step-by-step approach used to achieve these objectives, including site selection, data collection, system design, and simulation. The methodology ensures that the proposed PV microgrid is both technically sound and tailored to the unique needs of the community.

3.1 Site Selection and Data Collection

3.1.1 Selection of Gitwa Village

Gitwa Village was chosen as the case study due to its remote location and lack of access to reliable electricity. The village represents a typical off-grid community where traditional energy sources, such as kerosene and firewood, are the primary means of meeting daily energy needs. By focusing on Gitwa Village, this study aims to demonstrate how PV microgrids can transform energy access in similar underserved areas.

3.1.2 Data Collection Process

To design a system that meets the specific needs of the community, a comprehensive data collection process was undertaken. This included:

HOUSEHOLD AND COMMUNITY SURVEYS

Surveys were conducted to assess the energy needs of households and community facilities, such as schools, health centers, and small businesses.

Key data points included the types of appliances used, daily energy consumption patterns, and the willingness of residents to adopt solar energy solutions.

The surveys also gathered information on the economic capacity of households to pay for electricity, ensuring the system is financially sustainable.

SOLAR IRRADIANCE ANALYSIS

Solar irradiance data was obtained from meteorological sources to determine the amount of sunlight available in Gitwa Village throughout the year.

This data was critical for sizing the PV system and estimating its energy generation potential.

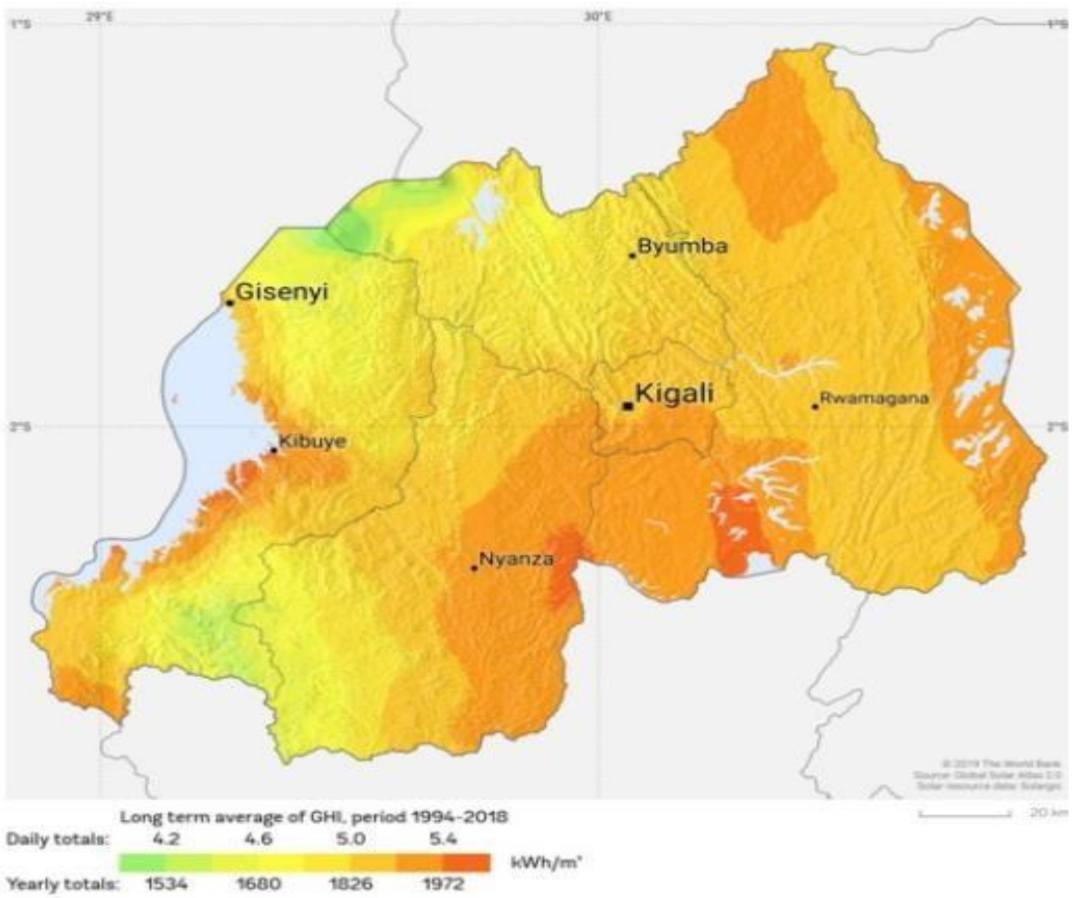


Figure 13: Global Horizontal Irradiation (GHI) and Gitwa located in Nyanza district

3.2 PV Microgrid Design and Simulation

3.2.1 System Design Considerations

The design of the PV microgrid was guided by the data collected during the site selection phase. Key considerations included:

LOAD DEMAND CALCULATIONS

The total energy demand of the village was calculated based on the load profiles and survey data.

This included both daily energy consumption and peak power requirements.

COMPONENT SELECTION

PV Panels: The type and number of panels were selected based on the solar irradiance data and energy demand. Monocrystalline panels were chosen for their high efficiency and durability.

Inverters: Inverters were sized to match the peak load and ensure efficient conversion of DC power from the panels to AC power for household use.

Batteries: Lithium-ion batteries were selected for their longer lifespan, higher efficiency, and ability to store excess energy for use during periods of low sunlight.

SYSTEM CONFIGURATION

The PV panels were configured in a combination of series and parallel connections to optimize voltage and current output.

The battery bank was designed to provide sufficient storage capacity to meet the community’s energy needs during nighttime and cloudy days.

3.2.2 Simulation Using HOMER Software

To evaluate the performance of the proposed PV microgrid system, the HOMER (Hybrid Optimization of Multiple Energy Resources) software was used. HOMER is a powerful modeling tool designed to simulate and optimize renewable energy systems, making it ideal for assessing the feasibility and performance of hybrid energy solutions like the one proposed for Gitwa Village. Below is an explanation of how HOMER works, its key features, and how it aids in the simulation process.

WHAT IS HOMER?

HOMER is a widely used software tool developed by the National Renewable Energy Laboratory (NREL) in the United States. It is specifically designed to model and optimize off-grid and grid-connected energy systems that incorporate renewable energy sources, such as solar, wind, and hydropower, along with conventional generators and energy storage systems. HOMER helps users evaluate the technical and economic viability of different system configurations, making it an essential tool for designing sustainable energy solutions.

HOW HOMER WORKS

HOMER operates by simulating the performance of an energy system over a specified period (typically one year) using hourly data. It considers various inputs, such as energy demand, resource availability (e.g., solar irradiance), and system component specifications, to model how the system will perform under different conditions. The software then evaluates thousands of possible system configurations to identify the most cost-effective and reliable solution.

KEY FEATURES OF HOMER

System Modeling:

- HOMER allows users to model complex energy systems by combining multiple energy sources (e.g., solar PV, batteries, diesel generators) and loads.
- It simulates the interaction between these components to determine how well the system meets the energy demand.

Optimization:

- The software evaluates different system configurations to find the one that meets the energy demand at the lowest cost.
- It considers factors such as component sizing, energy storage capacity, and fuel consumption (if applicable).

Sensitivity Analysis:

- HOMER can analyze how changes in key parameters (e.g., solar irradiance, fuel prices, or load demand) affect system performance and costs.
- This helps in understanding the robustness of the system under varying conditions.

Economic Analysis:

- The software calculates key financial metrics, such as the Levelized Cost of Energy (LCOE), net present cost (NPC), to assess the economic feasibility of the system.

Performance Metrics:

- HOMER provides detailed performance metrics, including energy generation, storage utilization, and system reliability, to help users evaluate the technical viability of the system.

HOW HOMER HELPS IN SIMULATION

Input Parameters:

- Solar Irradiance Data: Hourly solar radiation data for Gitwa Village was input to estimate the energy generation potential of the PV panels.

- Load Profiles: The energy demand patterns of the village, based on surveys and load profiling, were input to ensure the system meets the community's needs.
- Component Specifications: Details of the PV panels, batteries, inverters, and other components were input to model their performance.
- Economic Data: Costs of components, maintenance constraints were included to evaluate the financial feasibility of the system.

System Optimization:

- HOMER evaluated different configurations of the PV microgrid, such as varying the number of PV panels, battery capacity, and inverter size, to identify the most cost-effective and reliable setup.
- It ensured that the system could meet the village's energy demand while minimizing costs and maximizing efficiency.

Performance Evaluation:

- The software simulated the system's performance over a year, providing insights into key metrics such as:
  - Energy Generation: How much electricity the PV panels would produce under local solar conditions.
  - Storage Utilization: How effectively the batteries store and release energy to meet demand during periods of low sunlight.
  - System Reliability: The system's ability to provide uninterrupted power, even during peak demand or adverse weather conditions.

Sensitivity Analysis:

- HOMER assessed how changes in factors like solar irradiance, load growth, or component costs could impact the system's performance and costs.

- This helped in designing a system that is resilient to uncertainties and future changes.

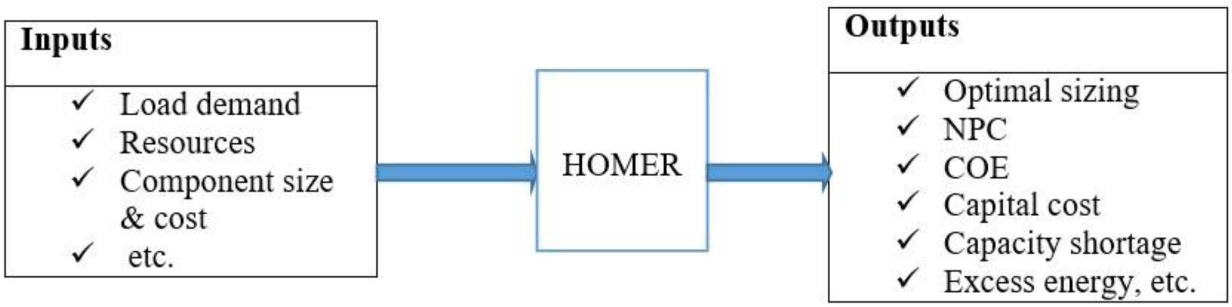


Figure 14: Inputs and outputs of the simulation software (Homer)

CHAPTER 4: DESIGN

To design an effective and scalable PV microgrid system for Gitwa Village, a decentralized approach was adopted. Instead of constructing a single large plant to supply all 112 households at once, the energy demand was divided into smaller, independent subsystems. This approach not only reduces energy losses associated with long-distance distribution but also ensures flexibility and scalability for future expansion. The design process involved assessing solar potential, land feasibility, and energy consumption patterns, followed by the creation of a reference submicrogrid that can be replicated across the village.

4.1 Data Collection and Analysis

4.1.1 Solar Energy Potential

The first step in the design process was to assess the solar energy potential in Gitwa Village. According to METEO RWANDA, the region receives an average solar irradiation of 5.488 kWh/m² per day, with peak sun hours averaging 5 hours per day. This data confirmed that Gitwa Village is well-suited for harnessing solar energy, making PV microgrids a viable solution for the community.

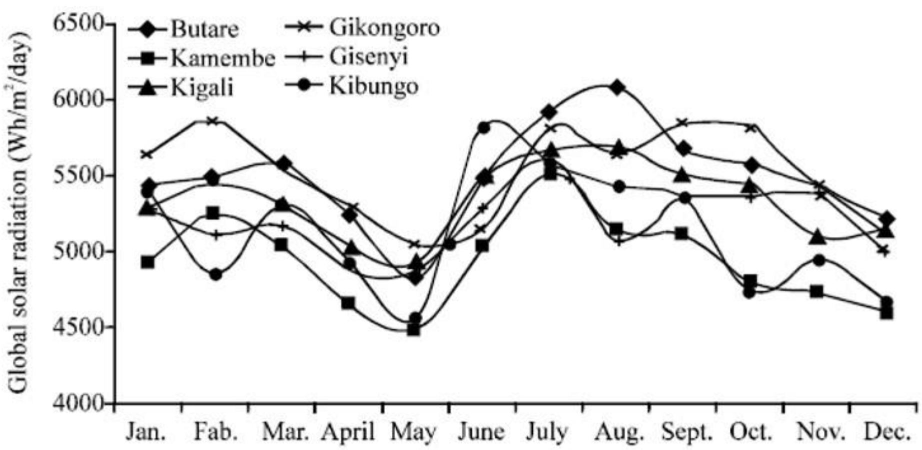


Figure 15: Monthly average of estimated global solar radiation on the sites of Rwanda

4.1.2 Land Feasibility

The second aspect considered was land availability for installing the PV systems. An on-site evaluation confirmed that suitable land is accessible for small-scale installations. Environmental factors, such as shading and terrain, were considered to ensure optimal performance. Additionally, since land costs in rural areas are relatively low, this aspect of the project remained financially feasible.

4.1.3 Energy Consumption Patterns

The third and most critical part of the data collection process focused on understanding the village's electricity consumption needs. A household survey was conducted by visiting homes in Gitwa. It was observed that many villagers currently rely on small solar panels provided by various companies in Rwanda, primarily using them to power basic devices such as radios, lamps, and mobile phones. When asked about their energy aspirations, the majority expressed a desire to own televisions to stay informed through news broadcasts.

To estimate potential electricity demand, the survey was extended to other villages within the same district that already have grid access. By analyzing their daily consumption patterns, it was observed that energy usage varied between 0.5 kWh to 2 kWh per household per day, depending on the number of connected devices and usage duration. To ensure a reliable design, the upper limit of 2 kWh per household per day was adopted as a reference value.

Given that Gitwa has approximately 112 households with a total population of 350 people, the total daily energy demand for the village was estimated at 224 kWh per day (112 households × 2 kWh/household).

4.2.2 Future Expansion Plan

Future Expansion Considerations

To ensure the long-term sustainability of the PV microgrid, it is crucial to account for future growth in energy demand. As communities develop and living standards improve, electricity consumption is expected to rise due to the adoption of additional household appliances, increased business activities, and the expansion of community infrastructure.

A comprehensive survey was conducted to assess the projected growth of the village. The findings indicate that, on average, two new houses are built each year. Given the 25-year lifespan of the project, this translates to an additional 50 households over the next 25 years. This projected growth represents approximately 45% of the current number of households (112).

To accommodate this expected increase in demand, a 45% margin was added to the estimated daily energy consumption.

4.2. PV SIZING

Proper sizing of the PV system is essential to ensure it meets the community's current and future energy demands efficiently. The system must be designed to generate sufficient power while considering factors such as daily consumption, energy storage, and seasonal variations in solar availability. This section outlines the key calculations and considerations for determining the optimal PV capacity.

Notable formulas:

4.2.1. PV PANELS

i. Power

$$PA = \frac{\text{Total Daily Energy Demand}}{\text{Average sun hour per day xKFX}\eta\text{bat}} \quad \ldots\ldots[1]$$

PA: PV Array Power
KF: Operating factor in this condition it is assumed as 1
ηbat: Battery efficiency

ii. Number and Connections of PV module

$$N_P=\frac{PA}{Pp} \quad \ldots\ldots[2]$$

N_P: Number of modules or panels
PA: Array Power
Pp: Power of panel

$$Ns=\frac{Vs}{Vp} \quad \ldots\ldots[3]$$

$$Nparallel=\frac{Np}{Ns} \quad \ldots\ldots[4]$$

Ns: Number of modules in series
Vs: system voltage
Vp: voltage of module
Nparallel: Number of modules connected in parallel or strings

4.2.2. BATTERY BANK

$$B_{capacity} = \frac{\text{Total Daily Energy Demand x DOA}}{Vbx\ \text{DODx}\eta\text{bat}} \quad \ldots\ldots[5]$$

$B_{capacity}$: Capacity of the battery bank to store the energy required
DOA: Days of Autonomy (Days where battery bank can supply energy in absence of PV power in this case it is 2 days)
Vb: Battery voltage
DOD: Depth of discharge

$N_{Batteries} = \frac{\text{Bcapacity}}{Capacity\ of\ single\ battery}$……………………………………………[6]

$N_{batteries\_Series} = \frac{Vs}{Vb}$……………………………………………………………[7]

$N_{Batteries}$: Number of batteries for the whole system
$N_{batteries\_Series}$: Number of batteries connected in series
Vb: Battery voltage
Vs: system voltage

$N_{batteries\_Parallel} = \frac{\text{NBatteries}}{\text{Nbatteries\_Series}}$………………………………………………..[8]

4.2.3. INVERTER

Inverter capacity= $\frac{\text{Maximum Demand}}{safety\ factor\ x\ Inverter\ Efficiency}$ …………………………..[9]

4.2.4. CHARGE CONTROLLER

Charge controller current = $short\ circuit\ current\ of\ panel\ x\ number\ of\ panels\ in\ string\ X\ safety$ factor………………………………………………………[10]

4.3. CALCULATIONS

From the 112 households and 2kwh/day as assumed consumption of one household we will get the total daily consumption of the village.

Total average daily consumption=112 x 2= 224Kwh/day

With the future plan of the growth in load consumption of the community we will get the total average energy consumption to be design on.

Average energy to refer when designing = $\frac{224x45}{100}$ + 224= 324.8kwh/day~ 325kwh/day

1. **PV Data Sheet of PV panel:**

Some Specification of PV Panel: Maximum Power Rating STC: 325 Watt

Number of Cells per Module: 72

Maximum Power Voltage (Vmp): 24 V

Short Circuit Current (Isc): 9.34 A

Efficiency: 19.1%

Module Dimension: 1956x991x40 mm

Weight: 22.5 kg

Manufacturer: Canadian Solar Manpower

System voltage: 48V

2. **PV PANELS DESIGN**

PA= $\frac{325KWH/day}{\frac{5h}{day}x\ 0.8}$= 81.25KW

Np= 81.25KW/325W=250panels

Number of modules in series= 48/24V=2

Number of panels in parallel=250/2=125 panels

3. **Battery Bank**

Technical data sheet of Battery

Battery capacity= 327Ah; Battery Voltage= 24V; Battery efficiency=0.8; DOD=0.7; DOA of autonomy= 2days.

Total Batteries Capacity= 325000*2/ (24*0.8*0.7)= 48363Ah

Total number of batteries to be used= 48363 Ah /327Ah=148 Batteries

Batteries in series= 48/24= 2 batteries; Batteries in Parallel= 148/2= 74 batteries

4. INVERTER SIZING

Simultaneity factor has been considered to be different to 1 and assumed that consumption do not connect at the same time hence Maximum demand will be different to total load.

Maximum demand calculated with assumed daily load distribution through HOMER is

Inverter capacity= 28.95*1.2*0.9= 32KW

5. CHARGE CONTROLLER

Charge controller current= 9.34*125*1.2=**1400 A**

In the design of this system, a total of 408 panels are required. Each panel has an area of 1956 mm x 991mm (1.93 m^2), therefore more than the 484.5 m^2 (250 x 1.93 m^2) land area is required for this SPV Power Plant.

Table 2: Results of the sized system

Item	Description	Results
Electrical Load	Per day consumption of the AC load	325 kwh/day
PV Array	Name: **CanadianSolar MaxPower CS6X-325P** Abbreviation: **CS6X-325P** Panel Type: **Flat plate** Rated Capacity (kW): **0.325** Temperature Coefficient: **-0.41** Operating Temperature (°C): **45.00** Efficiency (%): **16.94** Manufacturer: **Canadian Solar**	
	Capacity	81.25 kW
	Modules to be connected in series	2 PV Modules
	Modules to be connected in parallel	125 PV Modules
	Total number of modules	250 PV Modules
Battery Bank	Capacity of total Batteries	48363Ah
	Kinetic Battery Model Nominal Voltage (V): 24 Nominal Capacity (kWh): 7.85 Maximum Capacity (Ah): 327 Capacity Ratio: 0.266 Rate Constant (1/hr): 2.63 Roundtrip efficiency (%): 95 Maximum Charge Current (A): 138 Maximum Discharge Current (A): 672 Maximum Charge Rate (A/Ah): 1	

	Batteries connected in series	2 Batteries
	Batteries connected in parallel	74 Batteries
	Total Number batteries	148 Batteries
Inverter	Capacity	32KW
	32KW pure sine wave off-grid inverter	32KW
	Total Number of Inverters	1 inverters
Charger Controller	Capacity	1400A
	Total number of controller	1Controller
Land area	250 x 1.93 m^2	484.5 m^2

CHAPTER 5: SIMULATION, RESULTS AND DISCUSSION

5.1. SIMULATION OF THE DESIGN

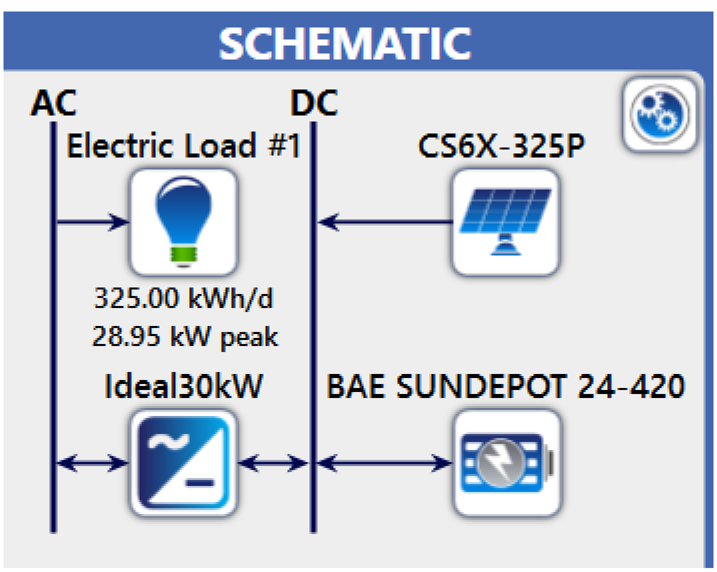
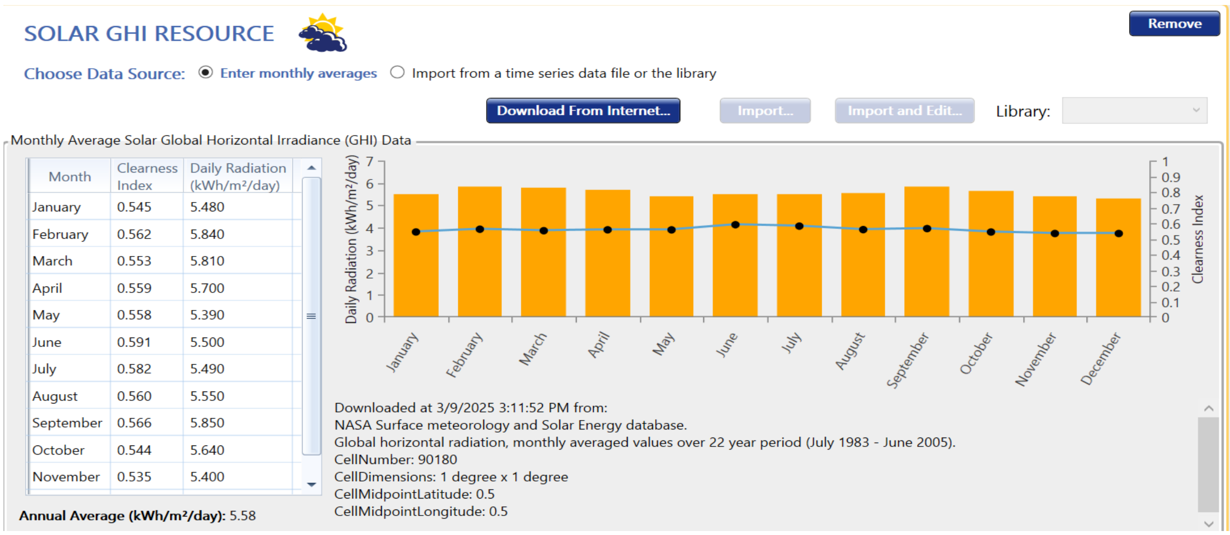


Figure 16: PV microgrid with battery backup to power the Gitwa village

5.1.1. Solar Energy Potential of the Region

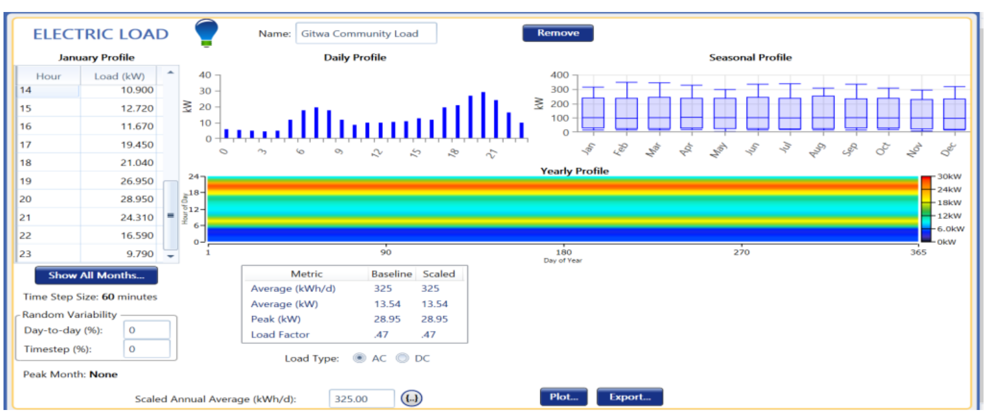


Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.545	5.480
February	0.562	5.840
March	0.553	5.810
April	0.559	5.700
May	0.558	5.390
June	0.591	5.500
July	0.582	5.490
August	0.560	5.550
September	0.566	5.850
October	0.544	5.640
November	0.535	5.400

Table 3: Solar Energy potential of Gitwa

5.1.2. Load Input

The daily electricity consumption of Gitwa village was analyzed to design a cost-effective PV system with battery backup, ensuring reliable power for the entire community. The hourly energy usage was estimated based on reasonable assumptions to create an efficient and practical distribution plan.



Hour	Load (kW)
14	10.900
15	12.720
16	11.670
17	19.450
18	21.040
19	26.950
20	28.950
21	24.310
22	16.590
23	9.790

Metric	Baseline	Scaled
Average (kWh/d)	325	325
Average (kW)	13.54	13.54
Peak (kW)	28.95	28.95
Load Factor	.47	.47

Table 4: Load profile inputs window in HOMER

5.1.3. System component inputs.

Solar PV Panel inputs.

The solar PV capacity (kW) is set according to the designed size. HOMER Optimizer was selected for the optimal PV size, derating factors, efficiency and operating temperature to be predefined parameters depending on the manufacture, capital, replacement, Operation and Maintenances (O&M) cost that have been inputted in HOMER software.

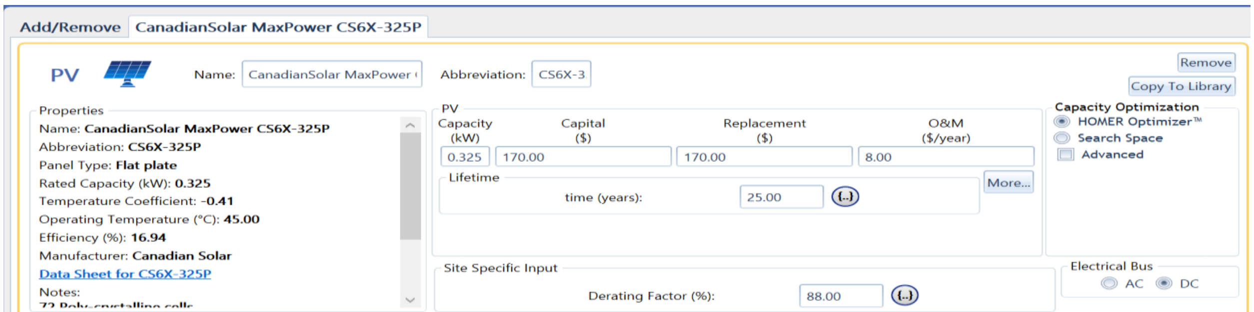


Table 5: Solar PV panel input window in HOMER.

Battery Storage

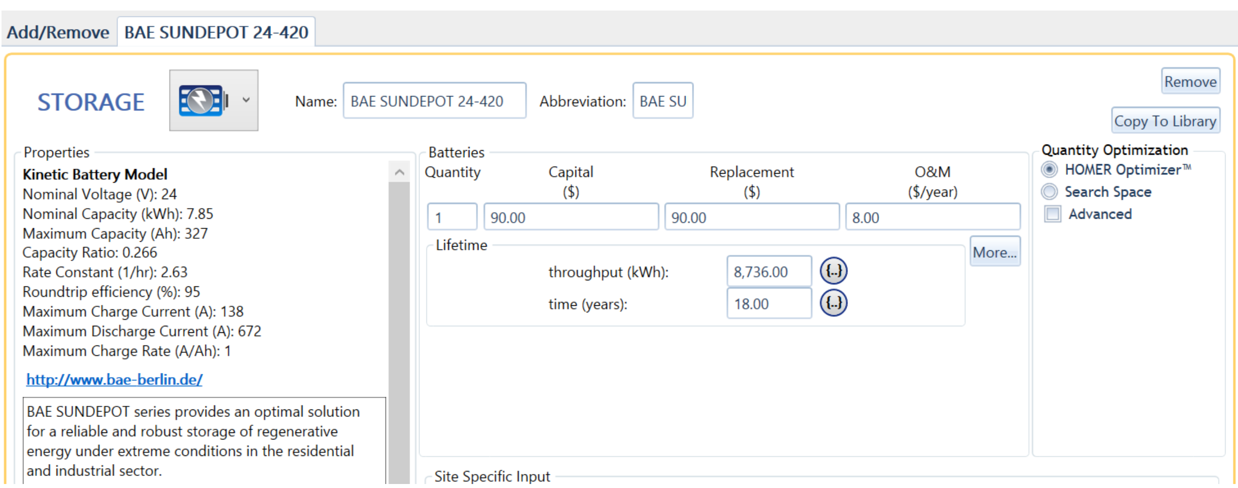


Table 6: Battery storage input window in HOMER

Inverter

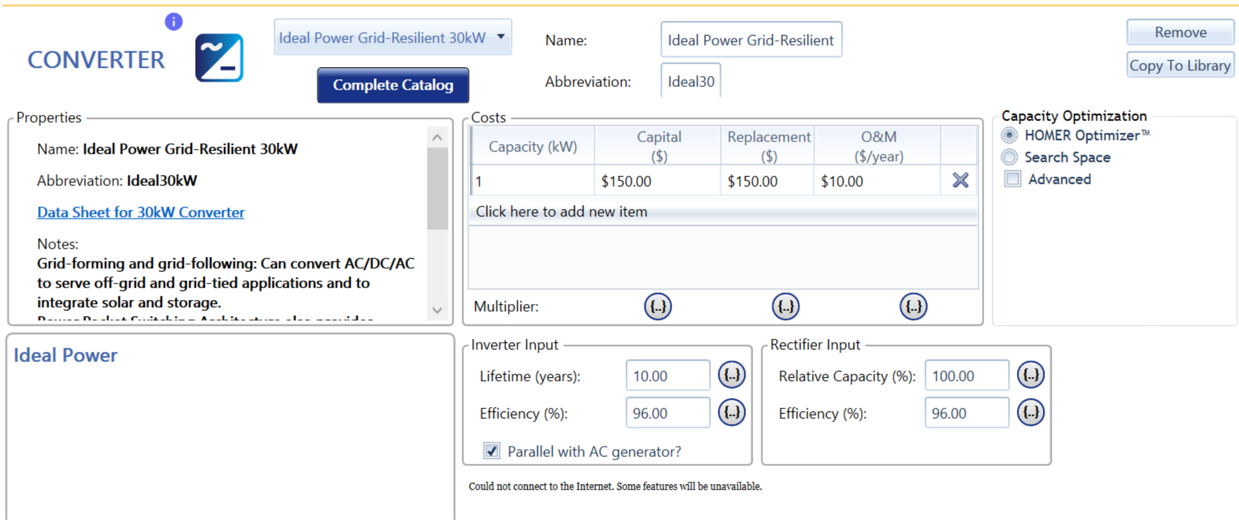
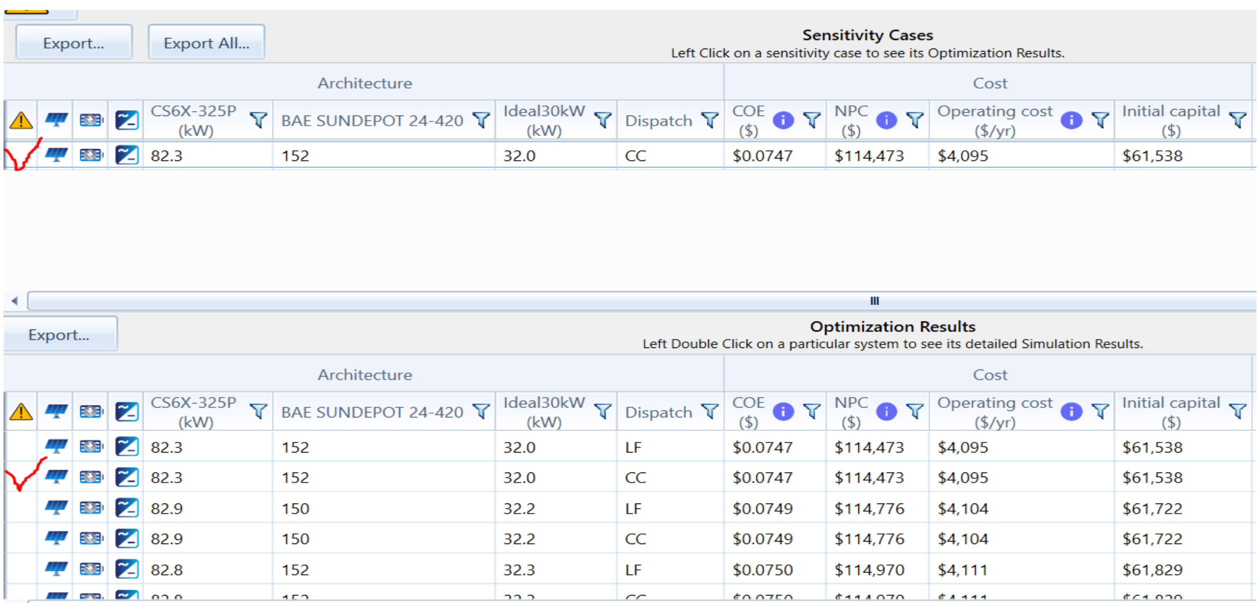


Table 7: DC TO AC inverter inputs window in HOME



Sensitivity Cases — Left Click on a sensitivity case to see its Optimization Results.

CS6X-325P (kW)	BAE SUNDEPOT 24-420	Ideal30kW (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)
82.3	152	32.0	CC	$0.0747	$114,473	$4,095	$61,538

Optimization Results — Left Double Click on a particular system to see its detailed Simulation Results.

CS6X-325P (kW)	BAE SUNDEPOT 24-420	Ideal30kW (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)
82.3	152	32.0	LF	$0.0747	$114,473	$4,095	$61,538
82.3	152	32.0	CC	$0.0747	$114,473	$4,095	$61,538
82.9	150	32.2	LF	$0.0749	$114,776	$4,104	$61,722
82.9	150	32.2	CC	$0.0749	$114,776	$4,104	$61,722
82.8	152	32.3	LF	$0.0750	$114,970	$4,111	$61,829

Table 8: optimum size of proposed PV system.

5.2.RESULTS AND DISCUSSION

By following the specific objectives result has been found solar radiation of the village was found to be enough to get the desired energy consumption which has been estimated according to the survey made in the village HOMER with its HOMER optimizer enabled supported to Optimize the system.

Optimized results:

Ideal Power Grid-Resilient 30kW Emissions
Cost Summary Cash Flow Compare Economics Electrical Renewable Penetration BAE SUNDEPOT 24-420 CanadianSolar MaxPower CS6X-325P

Quantity	Value	Units
Batteries	152	qty.
String Size	2.00	batteries
Strings in Parallel	76.0	strings
Bus Voltage	48.0	V

Quantity	Value	Units
Autonomy	70.5	hr
Storage Wear Cost	0.0106	$/kWh
Nominal Capacity	1,193	kWh
Usable Nominal Capacity	955	kWh
Lifetime Throughput	1,327,872	kWh
Expected Life	17.4	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	77,970	kWh/yr
Energy Out	74,360	kWh/yr
Storage Depletion	296	kWh/yr
Losses	3,906	kWh/yr
Annual Throughput	76,291	kWh/yr

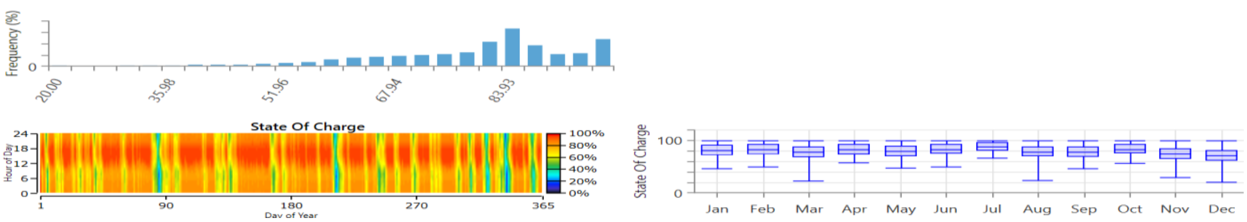


Table 9: Optimized battery sizing

Cost Summary Cash Flow Compare Economics Electrical Renewable Penetration BAE SUNDEPOT 24-420 CanadianSolar MaxPower CS6X-325P

Quantity	Value	Units
Rated Capacity	82.3	kW
Mean Output	16.4	kW
Mean Output	394	kWh/d
Capacity Factor	20.0	%
Total Production	143,909	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	79.4	kW
PV Penetration	121	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.0372	$/kWh

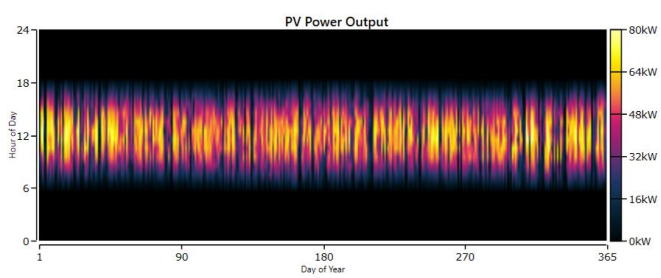


Table 10: Optimized PV sizing

Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | BAE SUNDEPOT 24-420 | CanadianSolar MaxPower CS6X-325P | Ideal Power Grid-Resilient 30kW | Emissions

Quantity	Inverter	Rectifier	Units
Capacity	32.0	32.0	kW
Mean Output	13.5	0	kW
Minimum Output	0	0	kW
Maximum Output	29.0	0	kW
Capacity Factor	42.2	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	118,556	0	kWh/yr
Energy In	123,496	0	kWh/yr
Losses	4,940	0	kWh/yr

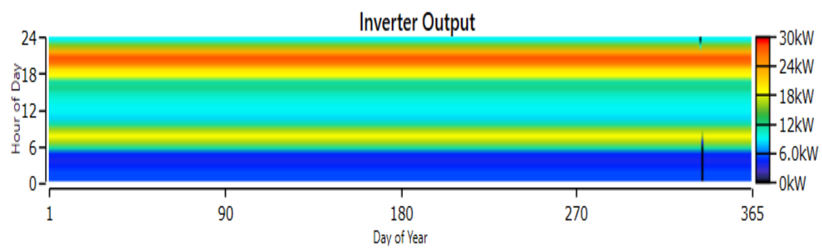


Table 11: Optimized Inverter Sizing

Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | BAE SUNDEPOT 24-420 | CanadianSolar MaxPower CS6X-325P

Production	kWh/yr	%
CanadianSolar MaxPower CS6X-325P	143,909	100
Total	143,909	100

Consumption	kWh/yr	%
AC Primary Load	118,556	100
DC Primary Load	0	0
Total	118,556	100

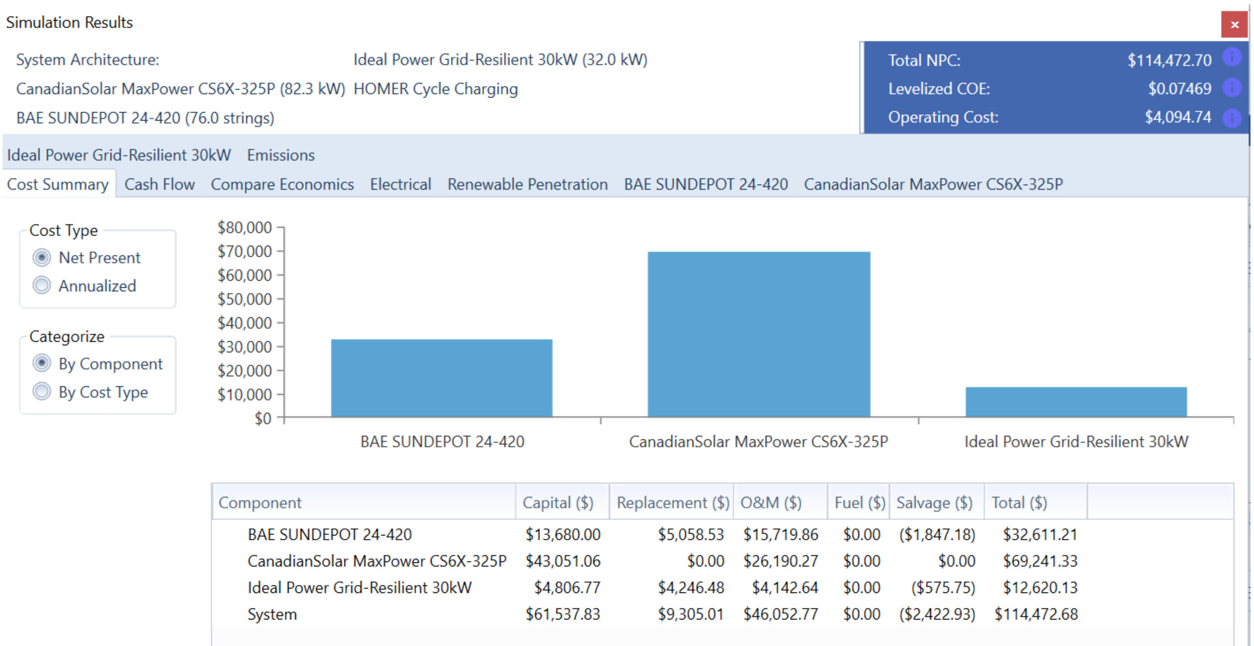
Quantity	kWh/yr	%
Excess Electricity	16,803	11.7
Unmet Electric Load	68.9	0.0581
Capacity Shortage	109	0.0919

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	877

Table 12: Reliability Metrics

SYSTEM OVERALL COST

Following the simulation of the designed schematic architecture, which included all load inputs, the capital costs of components, replacement costs, operation and maintenance expenses, component lifetimes, and the operating power range, the results were analyzed.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE SUNDEPOT 24-420	$13,680.00	$5,058.53	$15,719.86	$0.00	($1,847.18)	$32,611.21
CanadianSolar MaxPower CS6X-325P	$43,051.06	$0.00	$26,190.27	$0.00	$0.00	$69,241.33
Ideal Power Grid-Resilient 30kW	$4,806.77	$4,246.48	$4,142.64	$0.00	($575.75)	$12,620.13
System	$61,537.83	$9,305.01	$46,052.77	$0.00	($2,422.93)	$114,472.68

Table 13: Cost summary of solar PV production power system to Gitwa Village.

This off-grid solar photovoltaic (PV) system aims to provide a sustainable and economically viable electricity solution for a remote village, relying entirely on renewable solar energy. The system's core component is an 82.3 kW mean power solar PV array, designed to capture sunlight and convert it into direct current (DC) electricity. To ensure a consistent power supply, even during periods of low sunlight or at night, the system incorporates a battery bank composed of BAE SUNDEPOT 24-420 batteries, each with a 327 Ah capacity, enabling energy storage and reliable power delivery. A 32 kW DC to AC converter (inverter) then transforms the stored DC electricity into alternating current (AC) electricity, suitable for powering typical village appliances. Financially, the system boasts a Levelized Cost of Energy (LCOE) of $0.07469/kWh, meaning each kilowatt-hour of electricity generated over the system's lifetime costs. The total Net Present Cost (NPC) of the system, which accounts for all costs over its lifetime discounted to present value, is $114,472.7. This includes an initial capital investment of $61,538, covering the purchase and installation of all components, and ongoing operating costs of $4,095, which account for maintenance, repairs, and potential component replacements. *The relatively low LCOE suggests the system is economically competitive with traditional diesel generators or grid extensions, making it a promising solution for Gitwa electrification.* The 82.3kW "mean power" indicates the average power output, it will have a peak power output at solar noon, and less power during other times of the day. The battery system is critical for this off-grid system, and the 32kw inverter limits the maximum power that can be pulled from the batteries at any moment. The design indicates a careful balance between power generation, storage, and conversion, optimized for the specific energy needs and economic constraints of the Gitwa village.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study successfully demonstrates the feasibility and effectiveness of a PV microgrid system as a sustainable solution for electrifying Gitwa Village. The research process involved a thorough assessment of the village's energy needs, a technical evaluation of solar energy potential, and the design of a cost-effective standalone PV microgrid. By leveraging Rwanda's abundant solar resources, the system was designed to meet a daily electricity demand of 324 kWh while ensuring reliability through an optimized configuration of PV panels, battery storage, and inverters.

The HOMER software simulation results confirm that the proposed microgrid system can provide stable and continuous power to the community while maintaining economic feasibility. The Levelized Cost of Energy (LCOE) of $0.07469/kWh demonstrates the affordability of solar microgrids compared to traditional electrification methods. Furthermore, the study underscores the transformative impact of access to electricity in rural areas, as it enhances economic activities, improves healthcare services, and supports educational institutions.

Despite the promising results, several challenges remain in implementing PV microgrids on a larger scale. High upfront costs, limited access to financing, and maintenance requirements pose barriers to widespread adoption. Additionally, integrating energy storage solutions to ensure uninterrupted power supply remains a key consideration for long-term sustainability.

6.2 Recommendations

To enhance the effectiveness and scalability of PV microgrid solutions in rural Rwanda, the following recommendations are proposed:

Government and Private Sector Investment: There is a need for increased collaboration between the government, private investors, and international organizations to provide financial support for PV microgrid projects. Incentives such as subsidies, low-interest loans, and tax exemptions can encourage investment in rural electrification.

Capacity Building and Training: Establishing training programs for local technicians and engineers is crucial to ensure the proper maintenance and long-term sustainability of PV microgrids. Developing local expertise will also reduce reliance on external specialists, making microgrid systems more cost-effective.

Improved Battery Storage Solutions: Research and development efforts should focus on cost-effective and high-efficiency battery technologies. Exploring second-life battery applications and advancements in lithium-based storage can help reduce costs and improve energy reliability.

Policy and Regulatory Support: The government should establish clear policies and regulatory frameworks to support decentralized energy solutions. Streamlining the licensing process for mini-grid developers and integrating microgrids into Rwanda's national energy strategy will accelerate rural electrification efforts.

Future Research on Hybrid Systems: Exploring hybrid renewable energy systems that combine solar power with other renewable sources, such as wind or hydropower, could enhance the resilience and reliability of microgrids, particularly during periods of low solar availability.

By implementing these recommendations, Rwanda can accelerate progress toward universal electrification and create a sustainable energy model that benefits rural communities. PV microgrids offer a practical, scalable, and economically viable approach to bridging the electricity gap while promoting environmental sustainability and socio-economic development.

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Appendices:

ELECTRICAL DATA | STC*

CS6X	310P	315P	320P	325P
Nominal Max. Power (Pmax)	310 W	315 W	320 W	325 W
Opt. Operating Voltage (Vmp)	36.4 V	36.6 V	36.8 V	37.0 V
Opt. Operating Current (Imp)	8.52 A	8.61 A	8.69 A	8.78 A
Open Circuit Voltage (Voc)	44.9 V	45.1 V	45.3 V	45.5 V
Short Circuit Current (Isc)	9.08 A	9.18 A	9.26 A	9.34 A
Module Efficiency	16.16%	16.42%	16.68%	16.94%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1000 V (IEC) or 1000 V (UL)			
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)			
Max. Series Fuse Rating	15 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, 6 inch
Cell Arrangement	72 (6×12)
Dimensions	1954×982×40 mm (76.9×38.7×1.57 in)
Weight	22 kg (48.5 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP67, 3 diodes
Cable	4 mm² (IEC) or 4 mm² & 12 AWG 1000V (UL), 1150 mm
Connector	T4 series or PV2 series
Per Pallet	26 pieces, 620 kg (1366.9 lbs)
Per Container (40' HQ)	624 pieces