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MASTERS OF RENEWABLE ENERY

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MASTERS'THESIS

TITLE: FEASIBILITY STUDY AND POTENTIAL ASSESSMENT OF HYBRID SOLAR-HYDRO ENERGY GENERATION SYSTEM FOR AGACIRO BUILDING AT THE UNIVERSITY OF RWANDA

THESIS'REPORT
SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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SUBMITTED BY

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COHORT 5 (2023-2024)

UNDER SUPERVISION OF

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DECLARATION

I, KABANDA Theophile, students of university of Rwanda, Africa Center of excellence in Energy for Sustainable Development-College of Science and Technology, Master of Science in Renewable Energy declare that the work presented in this dissertation is my own contribution to the best of knowledge. The same work has never been submitted to any other University or Higher Institution. I, therefore declare that this work is my own for the partial fulfillment of the award of Master's degree with honors in Renewable Energy at University of Rwanda, Africa Center of excellence in Energy for Sustainable Development-College of Science and Technology.

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Date of submission: ………………………

CERTIFICATION

This is to certify that the thesis entitled "Feasibility study and potential assessment of hybrid Solar-Hydro Energy Generation System for Agaciro building at University of Rwanda'' carried out by KABANDA Theophile has been read, checked and approved for meeting part of the requirements and regulations governing the award of Master's degree with honors in Renewable Energy at University of Rwanda, Africa Center of excellence in Energy for Sustainable Development-College of Science and Technology.

SUPERVISOR

Dr. MAXIME BINAMA

Date……………../……..…..…/ 2025

Signature…………………………..….

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ABSTRACT

Integration of Renewable Energy Sources such as hydropower and solar power offers sustainable solution to meet increasing energy demands. This assessment presents a hybrid of solar and hydropower generation system, which combines 84KW micro hydroelectric unit. The micro hydroelectric system provides reliable, consistent power generation, taking an advantage of water flow for electricity production while solar generation system harnesses the abundant of solar energy from solar radiation for producing electricity during day.by putting both two sources, hybrid system improves overall energy reliability, reduces carbons emissions and enhances stability of power supply and grid stability. This study had cleared assess solar-micro hydropower for potential implementation at the top of Agaciro building block in University of Rwanda-College of Science and Technology. Specifically, it results that the roof can support 530 Photovoltaic panels with 256.8 KW per day. This thesis designed and simulated with aids of Mat lab and Homer Software The synergistic operation of solar and micro hydropower system ensures the continuous generation of power output, minimizing dependence on fossil fuel and promoting energy security. The system's energy efficiency, cost-effectiveness and potential for scaling make it viable solution to Rwanda communities and industries aiming transitions toward sustainable energy generation. Current off grid generates 40.5MWh/day This designed project will provide 340.8kWH the potential to address the intermittency issues faced by standalone whole day, it will generate 8179.2kWH/day therefore as IoT and Mechanical Labs need only 235.625kWH /day and it will contribute about 0.02% for current off grid energy.

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CHAP 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Development of Renewable Energy is now considered as the backbone strategy for sustainable energy security. This has recently called for energy transition where all nations worldwide have put in place long and short-term targets in terms of a quick shift from traditional to new and renewable energy sources. While traditional energy sources such as fossil fuels have considerably contributed to the earlier stages of economic development in nations(Converters, 2018), they have also inflicted considerable damages to the environment, mainly due to the associated emissions of greenhouse gases. In addition, their reserves are meant to soon or later deplete, thus again causing energy system sustainability-related concerns to emerge(Fissaha, 2017). This has pushed the global community to put in place initiatives that, among others, call for a quick restructuring of energy systems, where renewable sources should be adopted, and gradually boosted to finally replace the traditional ones. Among the available renewable energy sources, hydropower is the most mature and largest source available so far. It contributes around 17% of annual electricity productions worldwide (2022) (Ogbikaya, 2022)., and serves as the main energy source in more than 52 countries worldwide, including Rwanda. In some of these countries, hydropower can account for more than 90% of national electricity productions (Nasir, 2013).

In Rwanda, by 2022 generation technology mix, 51% was from thermal sources, followed by hydro sources with 43.9% and solar sources with 4.2% Dobrotkov, Z. (n.d.). Recently, the Rwandan government has been investing in expanding and modernizing its hydropower infrastructure to meet the growing energy demand while also exploring other renewable energy sources to ensure a more balanced and resilient energy mix. The 2024 projections include boosting hydro and solar electricity productions, and the development of new sources such as Peat and Methane. Nevertheless, the energy access rate in Rwanda is still low (55.9% of grid-based access as of June 2024) Dobrotkov, Z. (n.d.). and the national grid still faces big challenges needing sustainable solutions, among others, frequent power outages. One of solutions to these issues has been the adoption of off-grid energy systems where, among others, solar-based energy generation systems have seen sustained increase in adoption for the past ten years, reaching a national deployment rate of 23% as of 2024 (Mirgissa et al., 2017). In line with this, initiatives such as solar home systems have been implemented on household level, and institutions have been advised to have their off-grid or integrated renewable energy backup facilities in place.

The University of Rwanda, being one public higher learning and research institution in Rwanda, is committed to enhancing the sustainability and resilience of its campus facilities. In response to possible grid power outages, especially in crucial laboratories, there is a need for reliable backup power solutions. Given the abundance of solar energy and rainfall in Kigali, this project proposes and studies the feasibility of a hybrid solar-hydro energy generation system leveraging rainwater collected from rooftops of the buildings as a viable solution. As an initial feasibility study, the project considers the “Agaciro building” situated on the campus of the University of Rwanda’s College of Science and Technology in Rwanda’s Nyarugenge district. Agaciro is five-story building that houses offices, classes, and two important laboratories, namely, the Internet of Things (IoT) Lab on the 2nd floor and the Mechanical Lab on the underground floor. This system is designed to ensure that experimental activities within these labs continue uninterrupted during power outages, thereby contributing to the sustainability goals of the university.

1.2 PROBLEM STATEMENT

As Rwanda continues to advance its energy infrastructure, the national grid remains susceptible to frequent power outages, posing significant challenges, particularly for critical facilities such as laboratories within academic institutions. The University of Rwanda, a leading public higher learning and research institution, faces the risk of disrupted academic and experimental activities due to these grid instabilities. The Agaciro building at the University of Rwanda's College of Science and Technology, which houses the Internet of Things (IoT) Lab and the Mechanical Lab, is particularly vulnerable to these power interruptions. Given the building's infrastructure and the local availability of renewable resources, the integration of a hybrid solar-hydro energy generation system leveraging rainwater harvested from the building's rooftop offers a promising solution. However, the feasibility and potential of such a system need a thorough investigation to ensure it can provide a reliable power supply during outages, thereby safeguarding the continuity of essential lab activities. This project, therefore, aims to assess the feasibility and energy potential of implementing a hybrid solar-hydro system for the Agaciro building, with the ultimate goal of enhancing the resilience and sustainability of the University of Rwanda’s campus facilities.

1.3 MAIN OBJECTIVE

To assess the feasibility and potential of implementing a hybrid solar-hydro energy generation system using rainwater harvested from the rooftop of the Agaciro building at the University of Rwanda's College of Science and Technology, with the aim of providing reliable backup power to the IoT Lab and Mechanical Lab during grid power outages.

1.4 SPECIFIC OBJECTIVES

a. To assess the power demand of the IoT and Mechanical Labs by evaluating their individual and combined power requirements to determine the system's capacity needs.
b. To analyze the renewable energy resources available in Kigali, focusing on solar irradiance and rainfall, to evaluate their potential for meeting the identified power demands.
c. To design and simulation a hybrid solar-hydro energy system that integrates solar panels and a hydroelectric unit utilizing rainwater, tailored to the power demand of the labs.

1.5 RESEARCH QUESTIONS

a. What are the power demands of the IoT and Mechanical Labs, both individually and together?
b. What is the potential for solar and hydro energy generation at the Agaciro building based on Kigali's climate?
c. How can a hybrid solar-hydro system be designed to meet the labs' power needs and is the hybrid solar-hydro system feasible for the Agaciro building, and what strategies are required for its implementation?

1.6 SCOPE AND LIMITATION OF THE STUDY

The scope of this study encompasses the assessment, design, simulation, and feasibility analysis of a hybrid solar-hydro energy generation system for the Agaciro building at the University of Rwanda's College of Science and Technology. The research focuses on evaluating the power demands of the IoT and Mechanical Labs, analyzing the solar and hydropower potential based on local climate data, and designing a system that integrates these renewable sources to provide reliable backup power during grid outages. The study is bound by the geographical context of Kigali, the specific characteristics of the Agaciro building, and the technical limitations of the available renewable energy resources. It does not include the physical implementation of the system but rather aims to provide a comprehensive feasibility assessment and design blueprint for future deployment.

1.7 THESIS ORGANIZATION

Chapter 1: Introduction. This chapter will introduce the research topic, outlining the background and significance of renewable energy in Rwanda. It will present the problem statement, main objective, specific objectives, and research questions, as well as define the scope and limitations of the study.

Chapter 2: Literature Review. This chapter will review relevant literature on hybrid solar-hydro systems, discussing key concepts, methodologies, and performance metrics. It will highlight similar studies and research gaps that this project aims to address, culminating in a summary of important insights.

Chapter 3: Methodology. This chapter will detail the research design and methods for assessing power demands, evaluating renewable resources, and designing the hybrid system. It will describe the simulation processes using software tools like HOMER and RET Screen, along with a time schedule and budget plan.

Chapter 4: Results and Discussion. This chapter will present the findings from simulations and analyses, including power demand assessments and energy generation potential. The results will be discussed in relation to the research questions, emphasizing their implications for the Agaciro building and comparisons with existing studies.

Chapter 5: Conclusion and Recommendations. The final chapter will summarize the study's key findings and their relevance to the Agaciro building's energy needs. It will provide recommendations for implementing the hybrid solar-hydro system and suggest areas for future research focused on sustainable energy solutions in Rwanda

CHAPTER 2. LITERATURE REVIEW

2.1. INTRODUCTION

Solar Energy Begin with Solar energy technology, particularly photovoltaic (PV) cells, was first developed in the 1950s Ogbikaya, S. (2022). Early solar panels were costly, inefficient, and used primarily for niche applications like space missions. Early Hybrid Systems started in 1980s Ogbikaya, S. (2022), the idea of combining solar and hydro systems began to gain attention, especially in off-grid locations or areas where grid infrastructure was limited. Early hybrid systems were often used in remote areas, such as rural communities in developing countries, where both solar energy (for daytime power) and hydroelectric power (for continuous, low-maintenance energy) could complement each other. Modern Hybrid System begun in the 2000s (Nasir, B. A. (2013), as both solar and hydropower technologies improved, solar-hydro hybrid systems became more practical and widely used. Solar power from photovoltaic (PV) panels refers to the process of converting sunlight into electricity using semiconductor materials mostly silicon sells It Work from Solar Cells as component of a PV panel is the solar cell, which is made of semiconductor materials, typically silicon F(issaha, S. G. (2017). These cells are designed to absorb sunlight using Photovoltaic Effect where sunlight hits the solar cells, it excites the electrons in the material, causing them to flow. This movement of electrons generates direct current (DC) electricity, Inverter converts electricity generated by the PV panels into to AC form, but most appliances and the electric grid use alternating current (AC). To make this electricity usable, an inverter is used to convert the DC power into AC power. Electricity Distributes power can be used to supply energy to homes, businesses, or even be fed back into the grid if the system is designed for it (in net-metering systems) (Fissaha, S. G. (2017).Components of a PV Solar Hydro Power System consists of Solar panels that collect sunlight and generate DC electricity, Inverter: Converts DC to AC electricity, Battery (optional): In some systems, a battery is used to store excess electricity for use at night or on cloudy days, Charge Controller (optional): In off-grid systems, this regulates the flow of electricity to and from the battery to prevent overcharging, and source of water turns turbine generator for generating electricity by induced electromagnetic field in windings of generator.

2.2. BASIC CONCEPTS

In the introduction of solar photovoltaic (PV) clusters for private, commercial, or agricultural operations; a crucial idea is to determine the merits of the site, Identifying the place and position of the panels is a crucial step in designing a PV system, as the later components will be streamlined to this step. A few concepts and tips one must keep in mind while performing the site assessment are.

2.2.1 SHADE ANALYSIS

Shading can be a problem for the solar panels as they decrease the maximum power that can be generated. Several factors contribute to this issue, the most common cause of shade on a solar panel are; Shade from neighboring trees and buildings in vicinity, Typical cloudy weather and Shade from adjacent solar panels while designing a solar PV system one must investigate these factors thoroughly so that maximum output can be obtained. One of the tools most commonly used is solar pathfinder, which gives the direction of the sun throughout the year and how much any specific area will receive sunlight throughout the year Apart from having this tool, it is important that the site assessment is done properly to locate the best site keeping in mind all the aspect Bouchaala, A. D., & Boukadoum, A. (2023).

2. 2.2. SUN HOURS

Sun hours are important to know how much radiance will be required to generate the needed output wattage. This parameter gives us the knowledge of number of hours an area will receive maximum sunlight with advances in technology, data available online and anyone can use it Anandhi, R. J., Singh, N., Palakurthy, D., Yadav, D. K., Albawi, A., Parashar, A. K., & Jithendar, P. (2024).

2.2.3. TILT ANGLE

Tilt angle is the setting of the panels one needs to have to get the maximum radiance. Ideally, the tilt angle is the latitude of the geographic location. It is suggested to have an adjustable panel frames as the sun hours keep changing with respect to the tilt in winters and summers. Hence, for any area a specific tilt angle is calculated to get the maximum irradiance throughout the year for a fixed panel. In addition, it is advised to have the panels facing the south to get the maximum afternoon sun. A couple of devices are used in the process of finding the tilt angle and the irradiance that will fall upon panel at that tilt angle are inclinometer and pyrometer, respectively. An inclinometer is kept on the panel and the degrees are read to find the latitude of the area as it is perpendicular to the Sun’s radiations when it is at its highest point in the sky. Pyrometer measures the solar irradiance that will fall at a given tilt angle. It measures solar irradiance in Watts per meter Sq. (W/m^2) Anandhi, R. J., Singh, N., Palakurthy, D., Yadav, D. K., Albawi, A., Parashar, A. K., & Jithendar, P. (2024)

2.2.4. ENERGY CALCULATIONS

The consensus is to add wattage of the equipment that are going to be powered using the PV system. Alternatively, for this task, use baseload calculators that are available on the internet. In addition, use one such tool to calculate the baseload of our project; every device has fixed power consumption that can be found on its nameplate details. Data from all the devices that are going to be used should be retrieved. Other data that needs to be entered is number of each appliance that are going to be used and number of hours the appliance is supposed to remain ON. Total Watt-hours that are going to be used i.e. the total energy consumed or the wattage of the PV system. Another point one must pay attention to is the system voltage. It is required that the system level chosen before further probe into designing.

2.2.5. PV PANEL SIZING

Once the total load to be, energized using the PV system is calculated find out what area of solar panels would be required to generate that much amount of power. It is an inherent property of any panel to have internal losses. This factor should be kept in mind. As in the energy, calculation already found that the total watt-hours, for finding the wattage of panels that would be required divide the total watt-hours with peak sun hours.

2.2.6. BATTERY SIZING

PV battery system assesses various strategies from a financial perspective. The valuable existence of the battery is limited to 5,000 cycles or in the planned living time of 20 years. The maintenance of photovoltaic and rechargeable annual activities and expenditure systems is set at 1.5% per the speculative cost. Assume that the cost system for the battery and PV is comparable to their size. Use this for sizing battery:

$$\text{Battery capacity(Ah)} = \frac{\text{Total watt}-\text{hours per day used by appliances} \times \text{Days of autonomy}}{0.85 \times 0.6 \times \text{nominal battery voltages}} \quad (1)$$

Fissaha, S. G. (2017)

2.2.7. INVERTER SIZING

Inverter deals with following main tasks of energy: Convert DC from PV module to AC, ensure that the cycle of alternating current cycles is 60 cycles, reduce voltage variations, ensure that the condition of the AC waveform is suitable for the application. Most system-connected inverters can be introduced externally, and most of the off-grid inverters are not weather-resistant. There are two types of grid intelligent Inverters: Those designed for batteries and those designed for systems without battery-connected inverter systems and give excellent void-quality strength. Grid-connected systems measure the power of extracting PV clusters rather than a bunch of prerequisite buildings. It asserts that what each power supply needs are what the matrix-related PV system can give naturally is drawn from the net. Invertors used for solar PV systems are usually based upon the total wattage of the solar panels, as the invertor will be continuously converting the power generated. The second consideration one must investigate is the voltage level of the system. For example, if the system is designed to generate 2000 Watts at a voltage level of 12 V then the invertor selected should be rated 12V, 2000 Watts Martin, S., & Susanto, J. (2020).

2.2.8. PV PANELS CHARGE CONTROLLER SIZING

The charge controller, sometimes referred to as a photovoltaic controller or charger, is only necessary for the system, which involves a battery. The main capacity of the charge controller, is to counteract the battery spoofing. The basic function of charge controller is to monitor charging and discharging of the battery. It prevents the battery from being completely charged or discharged. This is important because over charging can lead to destruction of the battery and under charging decreases the battery life. Another important reason to use a charge controller is to prevent a reverse current flowing from battery to the system. There are two types of controllers that are widely available in the market: Pulse width Modulation (PWM) and Maximum Power Point Tracking (MPPT)

2.2.8.1. PULSE WIDTH MODULATION

A pulse width modulation charge controller is set match the input power of the battery irrespective of the power generated by the panels. There is an inherent loss in power observed in this type of charger(Ogbikaya, 2022).

2.2.8.2. MAXIMUM POWER POINT TRACKING (MPPT)

This type of charger helps to get the optimum charging power for any given point of time and offers better efficiency that PWM (Khamisani’ & A., 2018).

3. THE HYBRID MICRO GRID AND POINT OF COMMON COUPLING

The hybrid micro grid has topology for both power source AC and DC output. In addition, AC and DC buses are connected to each other through a bidirectional converter, allowing power to flow in both directions between the two buses. Point of common coupling (PCC): This is the point in the electric circuit where a micro grid is connected to a main grid. Micro grids that do not have a PCC are called isolated micro grids, which are usually present in remote sites (e.g., remote communities or remote industrial sites) where an interconnection with the main grid is not feasible due to either technical or economic constraints. (Ogbikaya, 2022)

4. WORKING PRINCIPLE OF HYDRAULIC TURBINES.

Turbines are machines which convert hydraulic energy into mechanical energy in form of rotation where the fluid strikes turbine blades and then produces rotational energy. The turbine shaft is directly coupled to an electrical generator which converts mechanical energy into electrical energy. This electrical power is known as hydroelectric power (Martin, S., & Susanto, J. (2020).

4.1 CLASSIFICATIONS OF TURBINE

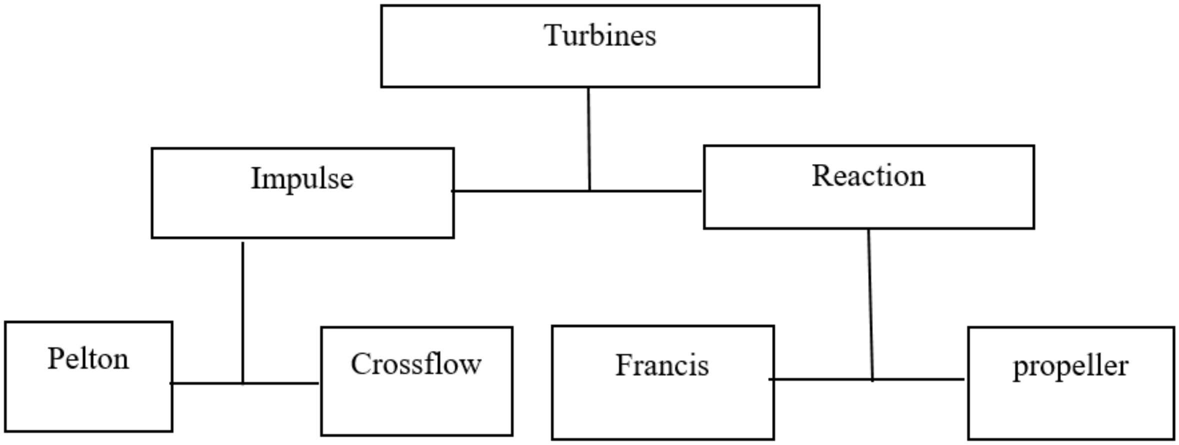

Figure 2. 1Micro hydro energy system components (Ogbikaya, 2022)

4.2 WATER SOURCE (RAIN FALL)

The source of the flowing water that provides the mechanical energy required to generate electricity. The flow rate and the available head (vertical drop) are crucial factors in determining the system's capacity.

4.3 INTAKE STRUCTURE

Directs water from the roof into the system, usually through a pipe (penstock). It often includes filters to prevent debris from entering the turbine.

4.4 PENSTOCK

A pipe that carries water from the intake to the turbine. The design and diameter of the penstock are important to ensure efficient water flow

4.5 TURBINE

Converts the kinetic energy of flowing water into mechanical energy. There are different types of turbines, such as Pelton, Francis, or Kaplan, each suitable for different flow conditions.

4.6 GENERATOR

Connected to the turbine, the generator converts mechanical energy into electrical energy (AC or DC, depending on the system).

4.7 INVERTER (IF REQUIRED)

In some micro hydro systems, an inverter is used to convert DC to AC electricity for compatibility with household appliances.

4.8 CONTROL PANEL

The control system monitors and manages the operation of the micro hydro system. It includes protection devices, automatic load controllers, and voltage regulators to ensure stable power output.

4.9 TAILRACE

The channel or pipe that carries the water back to the stream or river after it has passed through the turbine. It ensures that water flows back into the ecosystem without harming the environment.

4.10 BATTERY STORAGE (OPTIONAL)

In off-grid micro hydro systems, batteries may be used to store excess energy, just as with solar systems.

5. SOLAR-MICRO HYDRO ENERGY SYSTEMS EFFICIENCY

Micro hydro systems generally offer higher efficiency compared to solar systems, particularly in terms of energy conversion. The mechanical energy captured from flowing water is much denser and easier to convert than sunlight Solar energy systems tend to be less efficient, but they benefit from the simplicity of installation, lower maintenance, and scalability. The key challenge for solar systems is the variability of sunlight, whereas micro hydro systems are more consistent as long as the water source is reliable.

6. SOLAR IRRADIANCE

Solar irradiance is the amount of solar power (energy) incident on a given area, typically the Earth's surface. It is expressed as W/m² (watts per square meter). it can be measured globally (total incoming solar radiation), as well as separately for different wavelengths (e.g., ultraviolet, visible, infrared).

6.1 TYPES OF SOLAR IRRADIANCE

6.1.1 GLOBAL HORIZONTAL IRRADIANCE (GHI)The total solar radiation received on a horizontal surface, including both direct sunlight and diffuse radiation scattered by the atmosphere.

6.1.2 Direct Normal Irradiance (DNI)**:** The solar radiation received from the Sun's direct rays, measured perpendicular to the Sun's beam, which is important for concentrating solar power systems.

6.1.3 Diffuse Horizontal Irradiance (DHI)**:** The solar radiation that is scattered by clouds and atmospheric particles and reaches the surface from all directions, not directly from the Sun.

6.1.4 Factors Affecting Solar Irradiance

6.1.4.1 Latitude: Solar irradiance varies with latitude because of the angle at which sunlight strikes the Earth's surface. Areas near the equator receive more direct sunlight and thus higher irradiance.

6.1.4.2 Time of Day**:** Solar irradiance is highest around noon when the Sun is at its peak position in the sky, and decreases in the morning and evening when the Sun is lower on the horizon.

6.1.4.3 Season**:** During summer months, the Sun's path is higher in the sky, resulting in greater solar irradiance. In contrast, during winter, the angle of the Sun is lower, and irradiance is reduced.

6.1.4.4 Weather and Atmospheric Conditions**:** Cloud cover, humidity, air pollution, and dust can scatter or absorb solar radiation, reducing the amount that reaches the Earth's surface. Clear skies allow for maximum irradiance, while cloudy or polluted conditions reduce it significantly.

6.1.4.5 Altitude**:** Higher altitudes receive more solar radiation because the atmosphere is thinner, allowing more sunlight to reach the surface.

7. Solar Irradiance Values**:** on a clear, sunny day at noon, the global horizontal irradiance (GHI) can range from about 800 to 1000 W/m² depending on location and atmospheric conditions.

7.1 Direct normal irradiance (DNI) at solar noon can be as high as 1000 to 1200 W/m² at the Earth's surface, especially in regions close to the equator. The average global irradiance on Earth, over the entire surface, is about 1361 W/m**²** at the top of the atmosphere, known as the solar constant. However, due to atmospheric absorption and scattering, only a fraction of this reaches the surface.

8. Solar Irradiance and Solar Panel Performance

The efficiency of solar panels depends heavily on the amount of solar irradiance received by the panels. Panels perform best when they are exposed to direct sunlight (high irradiance) and at optimal angles.

8. 1 Solar panels are rated based on Standard Test Conditions **(STC)**, which assume 1000 W/m² of solar irradiance at a temperature of 25°C. This is a standard reference used to compare different panel types and technologies.

9. Measurement of Solar Irradiance**:**

Pyrometer uses as A common instrument used to measure the global irradiance (GHI) on horizontal surfaces**.** Pyrheliometer is Used to measure direct normal irradiance (DNI) by pointing the device directly at the Sun. Solar irradiance maps is the Tools such as satellite imagery and weather data allow scientists to estimate solar irradiance across different regions. These maps help in planning solar power installations and estimating potential energy generation Solar irradiance is a critical factor in determining how much solar energy can be harvested by solar panels. The efficiency of solar systems is largely dependent on the intensity and consistency of solar irradiance at a given location. Understanding solar irradiance and its variability is essential for optimal solar energy system design and installation.

10. Components influencing rainfall collection efficiency

10. 1 Catchment Area

(or roof area) is the surface where rainfall is collected. The larger the catchment area, the more rainwater can be collected. the material of the catchment surface also impacts collection efficiency it can be Smooth, clean surfaces (like metal, tiles, or sloped roofs) are better for collecting rainwater compared to porous or rough surfaces.

10.2 Gutter and Downspout Design

Gutters and downspouts collect and direct rainwater from the catchment area to the storage system. The design of these components must be properly sized to handle the volume of water expected during heavy rainfall but Clogging due to leaves or debris can reduce the efficiency of water collection, so regular maintenance is necessary.

10. 3 First Flush Diverters**:** In most rainwater harvesting systems, the first rainwater that falls after a dry period may contain contaminants such as dust, dirt, and debris. First flush diverters are designed to divert the initial dirty water away from the storage tank, improving the quality of the collected water. while this improves water quality, it can slightly reduce collection efficiency, as the first part of the rainfall is not captured.

10.4 Storage System: The efficiency of the storage system also affects overall collection efficiency. Larger, well-maintained tanks that are properly sealed to prevent evaporation and contamination will retain more water. If the storage system is too small for the expected rainfall, overflow can occur, leading to a loss of water.

10.5 Evaporation Losses

In warm climates, evaporation from open storage tanks or collection surfaces can significantly reduce the total volume of water stored. Using covered tanks or implementing other mitigation strategies like shading can help reduce evaporation losses.

10.6 Rainfall Intensity and Duration

The intensity and duration of rainfall directly impact collection efficiency. In regions with intermittent or light rain, collection efficiency tends to be lower, while heavy downpours can result in more water being collected quickly. Very heavy rain can lead to overflow if the system is not designed to handle large volumes.

10. 7 Losses During Transportation**:**

Water can also be lost due to leakage in pipes or during the transportation from the catchment area to the storage tanks. Proper installation and regular inspection of the system are crucial to minimize these losses.

11 Calculating Collection Efficiency:

Rainwater collection efficiency is typically expressed as a percentage and is calculated by comparing the volume of rainwater actually collected to the volume of rainwater that fell on the catchment area.

$$\text{rain water collection efficiency} = \frac{\text{Volume of collected water}}{\text{Volume of rainfall on catchment area}} \times 100 \qquad (2)$$

Where Volume of collected water is the total amount of water collected in the storage system after a rainfall event and Volume of rainfall on catchment area is the total volume of rain that falls on the catchment area during the event where Volume of rain fall is catchment area times rainfall depth, Rainfall Depth is the amount of rainfall (in meters or millimeters) that fell during the event. Rainfall collection efficiency depends on various factors, including the catchment area, gutter design, first flush systems, and storage conditions. With proper design and maintenance, rainwater harvesting systems can achieve high collection efficiencies, making them a valuable tool for water conservation, particularly in areas facing water scarcity or looking to reduce their environmental footprint

2.1 Table of Energy Demand versus Generation Capacity(Ogbikaya, 2022)

Aspect	Energy Demand	Generation Capacity
Definition	The total amount of energy needed by consumers at any given time.	The maximum amount of energy a power system can produce.
Measured in	Kilowatt-hours (kWh) or Megawatt-hours (MWh).	Megawatts (MW) or Gigawatts (GW).
Factors Influencing	Population growth, economic activity, weather, technology adoption, and energy efficiency.	Technology type, fuel availability, grid infrastructure, and weather conditions (for renewables).
Fluctuations	Varies with time of day, season, and weather.	Dependent on plant performance, fuel resources, and weather conditions (for renewables).
Forecasting	Important for utilities to plan for future power generation needs.	Used to ensure that enough capacity is available to meet demand, especially during peak periods.

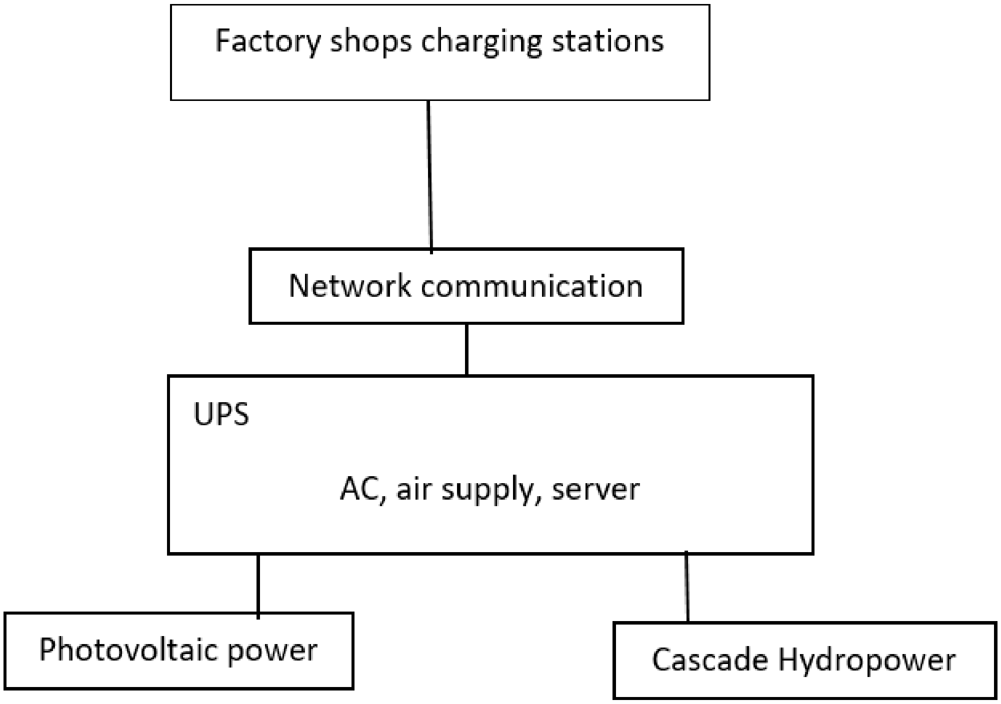

Figure 2. 2 load-side, management center, and hydro-solar cascade (Niaz et al., 2023).

The figure above consists of UPS system to manage cascade process of the power transmission. Control center is a main part of our module that is useful for power scheduling process.(Niaz et al., 2023).

Components functions of solar p v and mini-hydropower

1.Pump
It is used to eject water on the turbine.
2. Turbine
It converts kinetic energy of water into mechanical energy.
3. DC Generator
The DC generator is used to converts mechanical energy into electrical energy
4. Solar Panel
It collects solar radiations, it is a set of solar photovoltaic module electrically connected and mounted on a supporting structure.
5. Battery
It stores the energy generated by the systems.
6. Stabilizer
regulate the voltage up to charge level of battery.
7. Inverter
It is a device, which converts the dc voltage into ac voltage.
8. PIC Microcontroller: It is 8-bit microcontroller with 10bit ADC which amplifies relay driver and control motor driver.(Nigussie et al., 2017),.the foundational equation for calculating the nominal electric power of a photovoltaic (Ppv) generator, expressed in watts (W), establishes the relationship between the outputted hydraulic energy and the energy received from solar radiation. The mathematical expression is shown as follow:

$$\mathrm{P\ pv} = \frac{1000}{\mathrm{flm}[1-\alpha\mathrm{c}(\mathrm{Tpv}-\mathrm{T0})]} \times \frac{\mathrm{H\ E}}{\mathrm{SE}} \qquad (3)$$

HE and SE stands for output hydraulic energy and input solar energy of photovoltaic generator system(Anandhi et al., 2024).

14. Solar resource assessment of the village

To meet electrical load demand, the next step is investigating solar resource potential of the village. HOMER runs based on directly imported solar resources from the NASA surfaces Methodology and Solar Energy database by entering the GPS coordinates. This data has been used in order to assess the solar energy potential of the site. The clearance index and daily radiation the village is obtained from NASA surface metrology at latitude 8.85°N and longitude of 37.71°E. For a photovoltaic system, the monthly solar resource can be seen on Figure below

Table1: Estimating PV output of the village(Nigussie et al., 2017)

Months	Clearness index	Average radiation (Kw/m$^{2/}$day)
January	0.693	6.263
February	0.654	6.331
March	0.641	6.583
April	6.412	6.412
May	6.375	6.375
June	5.569	5.569
July	4.563	4.563
August	0.452	4.692
September	0.585	6.019
October	0.685	6.716
November	0.713	6.519
December	0.709	6.233
Selected Average annual		6.02(Kw/m$^{2/}$day)

15. COMPONENTS OF SOLAR PV AND MINI-HYDROPOWER

The micro grid modelling components of this system contain two sources of renewable generation, namely photovoltaic systems, Hydro turbines, battery storage, loads, and all components associated with power converters. The PV source is connected to the DC bus by the power converter represented by the boost converter DC/DC, and the DC bus connected by the AC/DC rectifier connects the hydro turbine. Battery banks connected to a buck boost converter and connected to a DC bus are charged and discharged. Power generation loads are received from system sources only and connected to an inverter (DC/AC)(Bouchaala & Boukadoum, 2023).

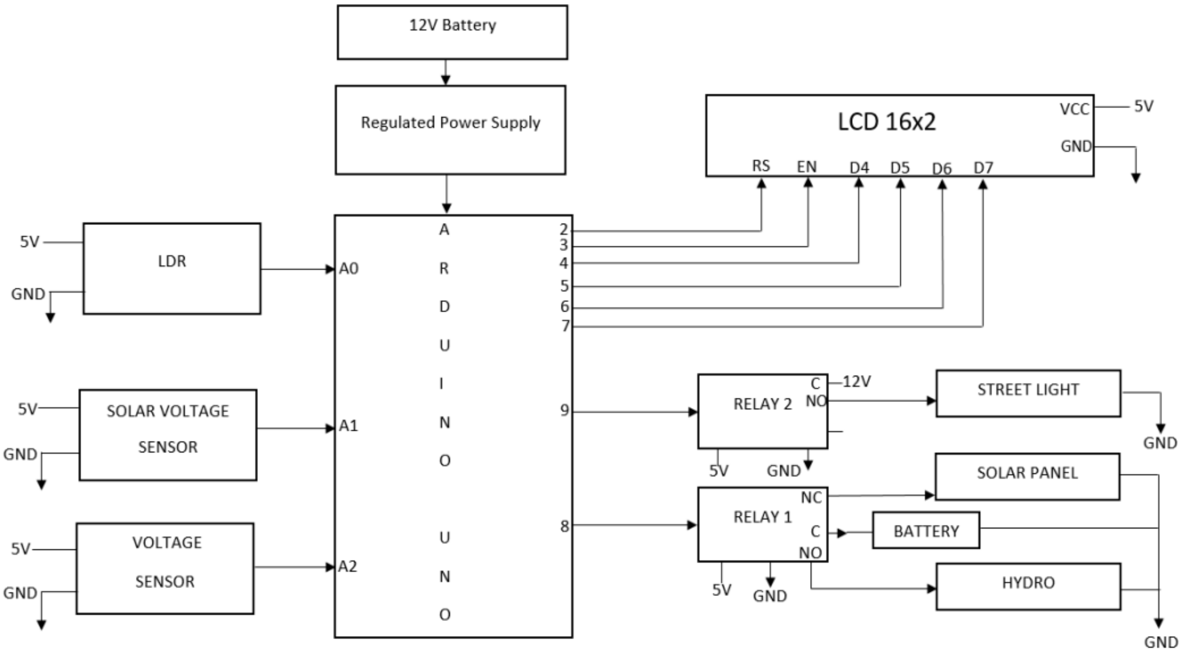

Figure 2. 3 Block diagram of Solar PV and mini-hydro power (Implementation of Solar-Hydro Hybrid Power Utilization) (Niaz et al., 2023).

Load(kWh/day)	Cost of energy/kWh	PV production (Kw/year)	Average output in kW	Rectifier mean output/kWh	Inventers mean output/kWh
1.54	1.02	0	10.006	0.528	0.403
219	2.56	46629.26	10.006	0.766	1.544
277	3.60	97387.76	10.006	0.732	2.888
308	3.98	123429.7	10.006	0.661	3.685

Table 2.2 component outputs per load scaled annual average(Marc et al., n.d.)

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Load(kWh/day)	Production(kWh/year)	O&M cost /year	Levelized cost of energy/kWh	Cost/day
1.54	122072.79	40455.21	0.331	110.84
219	190637.2	122112.94	0.641	334.56
277	269663.4	210475.95	0.781	576.65
308	309699.53	251649.21	0.813	689.45

Table 2.3 Cost structure per load scaled annual average(Marc et al., n.d.)

PERFORMANCE PARAMETERS OF PV SOLAR PANES

1.Efficiency: The ratio of the electrical output of the PV system to the total solar energy incident on the panels.
2. Power Output (P): The actual electrical power generated by the PV system at a given moment, typically measured in watts (W). The output varies based on solar irradiance, temperature, and the system's condition(Marc et al., n.d.)

3. Peak Power (P): The maximum power output the PV system can produce under optimal conditions (usually standard test conditions). Provides a reference for the maximum capability of the system(Marc et al., n.d.)

4. Energy Yield (E): The total energy output over a specified period, usually measured in kilowatt-hours (kWh) (Marc et al., n.d.)or megawatt-hours (MWh). Shows how much electricity the system can generate over time. This depends on the system size, location, and environmental conditions(Marc et al., n.d.)

5. Performance Ratio (PR): The ratio of the actual energy output to the theoretical maximum energy output under ideal condition (Marc et al., n.d.)

6. Capacity Factor (CF): The ratio of the actual energy output to the maximum possible output (if the system operated at peak power all the time) (Marc et al., n.d.)

7.Temperature Coefficient: This indicates how the power output of the PV system changes with temperature. As temperature increases, PV efficiency typically decreases. Understanding this parameter is critical for evaluating the system's performance in hot climates(Marc et al., n.d.)

TYPES OF POWER SYSTEM HYBRID

1.Solar-Wind Hybrid Power System

This system combines solar power (photovoltaic panels) with wind power (wind turbines). Both solar and wind energy are intermittent, so this combination ensures that power generation can continue even if one source is not available. Increased reliability, as wind and solar energy often complement each other (e.g., when it’s sunny, it might be windy, or vice versa). Remote areas, off-grid locations, or hybrid micro grids Fabien. (2016-2017).

2. Solar-Diesel Hybrid Power System

This system combines solar power with diesel generators. Solar panels generate electricity during the day, and the diesel generator kicks in when solar generation is insufficient (at night or during cloudy weather) Reduces fuel consumption and operational costs by using renewable energy as the primary power source and the generator as backup. Remote or off-grid locations where solar resources are available but grid power is not Fabien. (2016-2017)

.3. Solar-Hydro Hybrid Power System

This hybrid system integrates solar energy with hydropower. Solar panels generate power during the day, and the hydroelectric plant provides energy when solar generation is low (typically at night or in cloudy weather). Renewable energy sources complement each other, ensuring a more stable and reliable power supply. Regions with access to both sunlight and flowing water, such as mountainous areas.

4. Hybrid Grid Power System (Grid-Tied Hybrid Systems)

This system integrates renewable energy sources (like solar or wind) with the electric grid and conventional power sources. It often includes energy storage to balance supply and demand and to improve system reliability. Provides access to grid power when renewable sources are not producing sufficient energy, reducing reliance on fossil fuels. Urban and suburban areas, industrial applications, or areas looking to improve grid resilience.

5.Hybrid Electric Vehicle (HEV) Power System

This involves combining an internal combustion engine (usually powered by gasoline or diesel) with an electric motor powered by batteries. The system alternates between using the internal combustion engine and the electric motor to optimize fuel efficiency and reduce emissions. Increased fuel efficiency, reduced emissions, and flexibility in energy use. Passenger vehicles, buses, trucks, and other transportation systems.

Photovoltaic technology

Photovoltaics Cells

A typical Solar cell consists of a p n junction formed in a semiconductor material similar to a diode. Figure 1 shows a schematic diagram of the cross section through a crystalline solar cell. It consists of a 0.2–0.3mm thick mono- crystalline or polycrystalline silicon wafer having two layers with different electrical properties formed by ‘‘doping’’ it with other impurities (e.g., boron and phosphorus). Fabien. (2016-2017.An electric field is established at the junction between the negatively doped (using phosphorus atoms) and the positively doped (using boron atoms) silicon layers. If light is incident on the solar cell, the energy from the light (photons) creates free charge carriers, which are separated by the electrical field. An electrical voltage is generated at the external contacts, so that current can flow when a load is connected. The photocurrent (Iph), which is internally generated in the solar cell, is proportional to the radiation intensity. Fabien. (2016-2017

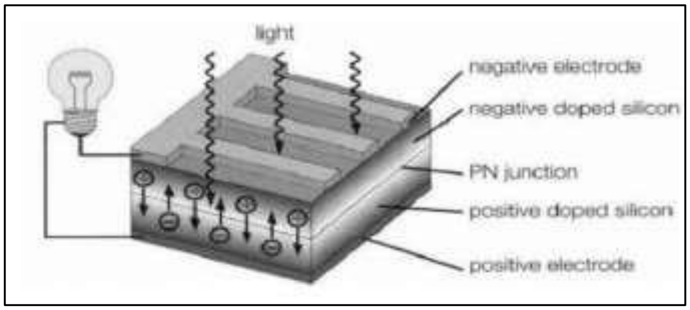


Figure 2. 4Solar cell Fabien. (2016-2017)

A simplified equivalent circuit of a solar cell consists of a current source parallel with a diode as shown in Figure below**. A** variable resistor is connected to the solar cell generator as a load. When the terminals are short-circuited, the output voltage and also the voltage across the diode are both zero. The entire photocurrent (Iph) generated by the solar radiation then flows to the output. The solar cell current has its maximum (Isc). Fabien. (2016-2017)

If the load resistance is increased, which results in an increasing voltage across the p n junction of the diode, a portion of the current flows through the diode and the output current decreases by the same amount. When the load resistor is open circuited, the output current is zero and the entire photocurrent flows through the diode.
The relationship between current and voltage may be determined from the diode characteristic equation:

$$I = I_{ph} - I_0 \left(e_{kt} - 1\right) = I_{ph} - I_d \tag{4}$$

where I_0 is the saturation current of the diode, q is the elementary charge $1.6x10^{-19}$ Coulombs, k is a constant of value 1.38x10-23J/K, T is the cell temperature in Kelvin, and *V* is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). The current versus voltage (I-V) of a solar cell is thus equivalent to an ‘‘inverted’’ diode Fabien. (2016-2017)

The types of Photovoltaic cells

The most common types using silicon semiconductor material (Si) are:

- Monocrystalline Si cells
- Polycrystalline Si cells
- Amorphous Si cells

1.Monocrystalline silicon cells.

Monocrystalline Silicon The monocrystalline silicon solar cell is made of a large single crystal of pure silicon. This single crystal is mostly fabricated owing to the Czochralski method. It consists of melting high-purity, semiconductor-grade silicon having only a few parts per millions of impurities in a crucible at 1425 degree Celsius. During this melting process, dopant impurity atoms such as boron (for p-type semiconductor) or phosphorus (for n-type semiconductor) are added to the molten silicon to dope the silicon; for PV-cells the preferred dopant is boron. The second step consists to dip a rod-mounted seed crystal into the molten silicon. The seed crystal has a well-defined crystal orientation. Next, the crystal's rod is carefully pulled out and rotated simultaneously. The temperature gradients, the pulling-rate and the rotation speed must be controlled precisely. Doing so results in the extraction of a large, single-crystal, cylindrical ingot from the melt. The melting process needs both, an inert atmosphere (e.g. argon) and an inert chamber (e.g. quartz). The disadvantages of the classical melting process are the very low speed and the energy intensive production costs. In addition, the ingot must be sawed in order to produce thin solar cell wafer. This process is time consuming and furthermore results in loss of valuable material. A lot of R&D effort is undertaken by the PV industry to improve the fabrication process. The appearance of the MonoSi is mostly black (see figure below). (Zimmer, T. (n.d.)

Figure2.5 Polycrystalline silicon cells(Zimmer, T. (n.d.)

2. Polycrystalline silicon cell

Polycrystalline silicon is also referred to as polycrystalline silicon or more simply Poly-Si. Solar cells based on Poly-Si are very similar to monocrystalline modules. The same theory applies; the main difference is the fabrication process. Poly-Si cells are fabricated from pure molten Si in a square-like tank; the cooling down is an essential step because it determines the grain size and the distribution of impurities. The obtained ingots are cut in bars with a cross-section of 15.6cm x 15.6cm; finally, they are sawn to get thin wafers. This fabrication process gives life to a multi-grain crystal structure. Compared to monocrystalline Si, the structure is less ideal resulting in a loss of efficiency (of about 1% compared to Mono-Si) , but this drawback is overcome by lower wafer costs. A second advantage is the arrangement of the cell modules which are typically rectangular, rather than “pseudo-square” compared to Mono-Si, so they can be packed very closely in the modules. The appearance of the Poly-Si is distinctly blue (see figure 3) due to the missing absorption of higher energy photons. In fact, these high energy photons from the upper part of the visible spectrum are back reflected. Zimmer, T. (n.d.)

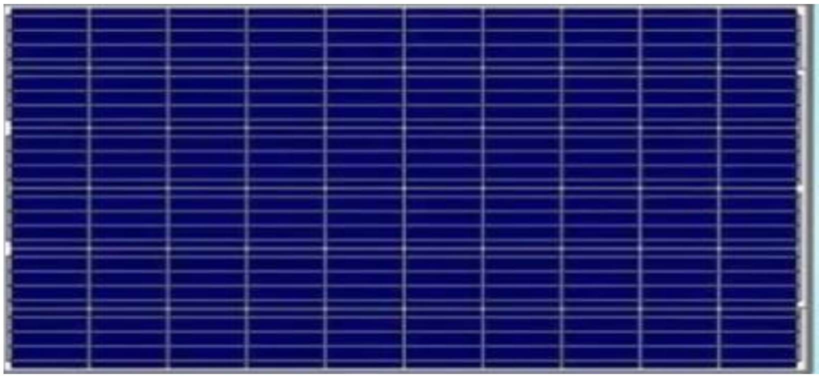


Figure 2. 6 Polycrystalline cell (Zimmer, T. (n.d.)

3.Amorphous silicon.

Amorphous silicon (a-Si) is the non-crystalline form of silicon. Amorphous silicon panels are fabricated using the vapor-deposition process to create a thin layer of silicon material of about 1 µm thickness on a substrate material such as glass or metal. The main advantage here is the possibility to deposit amorphous silicon at very low temperatures. The basic form consists in a single sequence of p-i-n layers. The p-i-n layers are used in order to create an electric field that helps moving the carriers; in fact, amorphous silicon has a very low mobility of about 1 cm2/Vs compared to the mobility of more than 1000cm2/Vs in monocrystalline Si-cells. A well-known drawback of amorphous thin Si films is the significant degradation in their power output when exposed to the sun (in the range 15-35%). The stability can be improved when using thinner layers. However, doing so, light absorption will be reduced as well as cell conversion efficiency. A workaround consists in the use of tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other. They are separated by thin tunnel junctions (not shown on the schematic cross section, each p-i-n cell layer has specific additional atoms in order to adjust the energy gap. (Zimmer, T. (n.d.). solar cell can be operated at any point along its characteristic current–voltage curve below. Two important points on this curve are the open circuit voltage (Voc) and short-circuit current (Isc). The open-circuit voltage is the maximum voltage at zero current, whereas the short circuit current is the maximum current at zero voltage. Fabien (2016-2017)

For a silicon solar cell under standard test conditions, Voc is typically 0.6–0.7 V, and Isc is typically 20–40mA for every square centimetre of the cell area. To a good approximation, Isc is proportional to the illumination level, whereas Voc is proportional to the logarithm of the illumination level. Fabien (2016-2017)

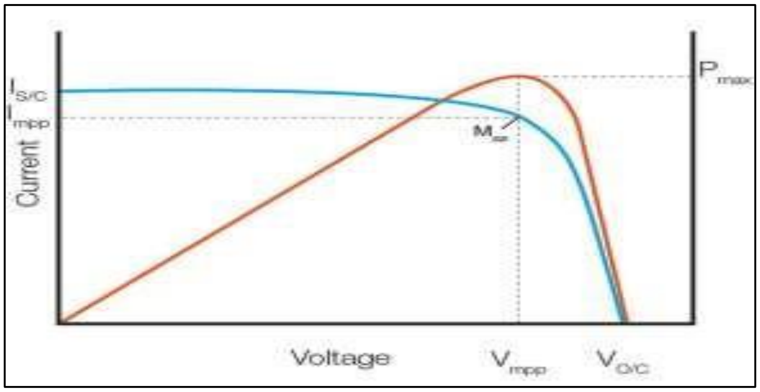


Figure 2. 7 I-V characteristic of solar energy Ogbikaya, S. (2022

A plot of power (P) against voltage (V) for this device (Fig. 3) shows that there is a unique point on the I-V curve at which the solar cell will generate maximum power. This is known as the maximum power point (Vmp, Imp). To maximize the power output, steps are usually taken during fabrication to maximize the three basic cell parameters: open-circuit voltage, short-circuit current, and fill factor (FF). Fabien (2016-2017

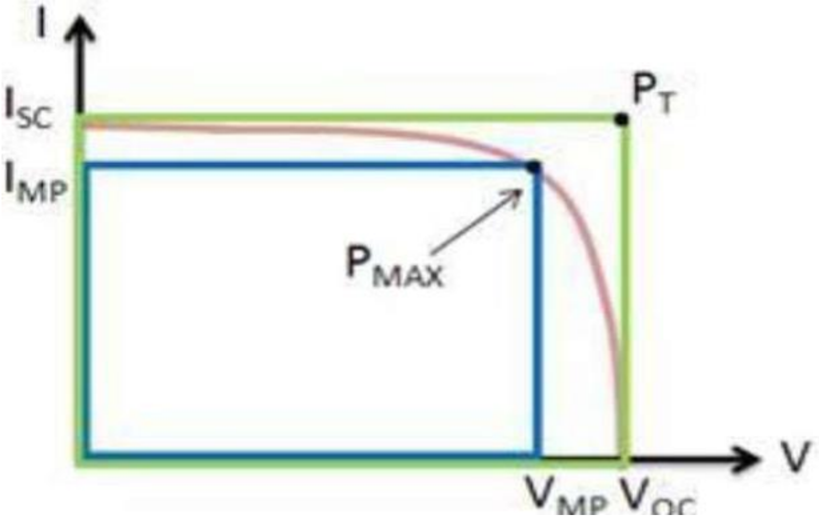


Figure 2. 8 Getting the Fill Factor from the I-V Curve Ogbikaya, S. (2022).

A larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like.
Typical fill factors range from 0.5 to 0.82.

Because silicon solar cells typically produce only about 0.5 V, a number of cells are connected in series in a PV module. A panel is a collection of modules physically and electrically grouped together on a support structure. An array is a collection of panels. it is described in the following figure: Oluwadare, B. S., Ojoakindele, D., & Adeleye, S. A. (2024).

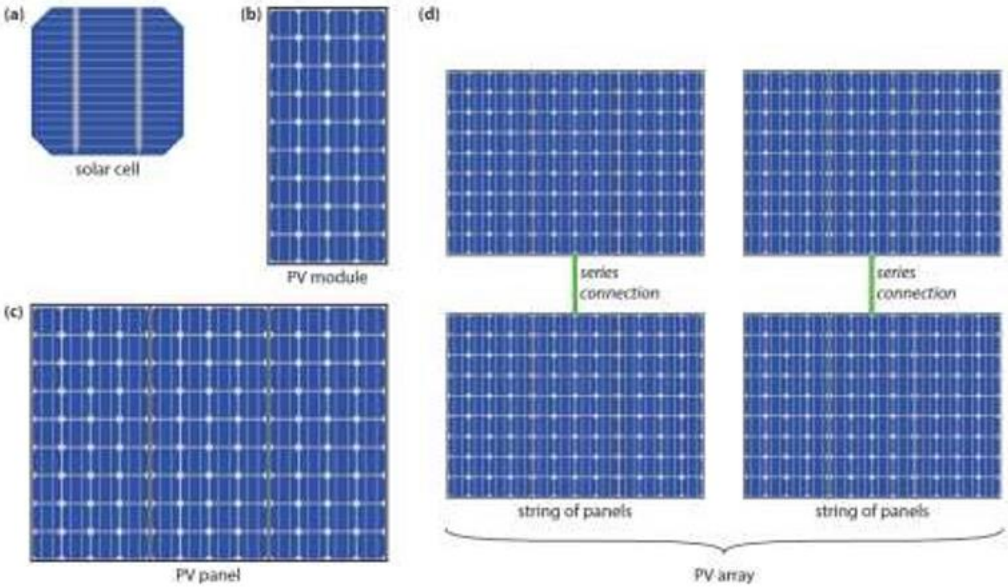


Figure 2. 9 Elements of solar PV System (Ogbikaya, S. (2022)

Efficiency (η)

Efficiency is the ratio of the electrical power output *Pout*, compared to the solar power input, *Pin,* into the PV cell. *Pout* can be taken to be *PMAX* since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

$$\eta = \frac{\text{Pout}}{\text{Pin}} \quad \text{or} \quad \eta max = \frac{\text{Pmax}}{\text{Pin}} \qquad (4)$$

Pin is taken as the product of the irradiance of the incident light, measured in W/m^2 or in suns (1000 W/m^2), with the surface area of the solar cell [m^2]. Oluwadare, B. S., Ojoakindele, D., & Adeleye, S. A. (2024).

The maximum efficiency (ηmax) found from a light test is not only an indication of the performance of the device under test, but, like all of the I-V parameters, can also be affected by ambient conditions such as temperature and the intensity and spectrum of the incident light. Oluwadare, B. S., Ojoakindele, D., & Adeleye, S. A. (2024).

The layer of module

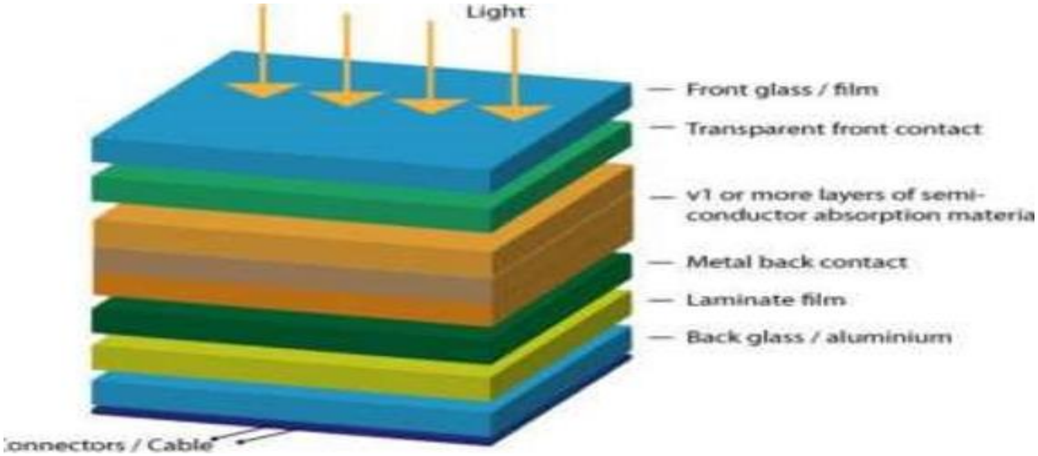


Figure 10:The layer of module Oluwadare, B. S., Ojoakindele, D., & Adeleye, S. A. (2024

All PV- modules contain a number of layers from the light-facing side to the back:

- **Protection Layer:** Usually made from glass, though in thin-film modules this can also be transparent plastic.
- **Front Contact:** The electric contact at the front, has to be transparent, as otherwise, light would not get into the cell.
- **Absorption Material:** The heart of the module is the layer where the light is absorbed and converted into electric current. All materials used are semiconductors. In many cells, this is just one material, in most instances, silicon. However, in order to improve performance, there could be multiple layers of different materials. In addition, all layers are doped. I.e. each layer is split further into an n-doped and a p-doped zone.
- **Metal back contact:** A conductor at the back completes the electric circuitry.
- **Laminate Film:** A laminate ensures that the structure is water-proof and insulated from heat.
- **Back glass:** This layer gives protection on the back side of the module. It may be glass; it may also be made of aluminum or plastic.

Connectors: Finally, the module is fitted with connectors and cables, so it can be wired

The types of PV Solar system

Photovoltaic power systems can be classified as follows:

Stand-alone PV Solar System

Stand-alone PV systems, are used in remote areas with no access to a utility grid.

Stand-alone systems rely on solar power only. These systems can consist of the PV modules and a load only or they can include batteries for energy storage. When using batteries charge regulators are included, which switch off the PV modules when batteries are fully charged, and may switch off the load to prevent the batteries from being discharged below a certain limit.

The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather [6]

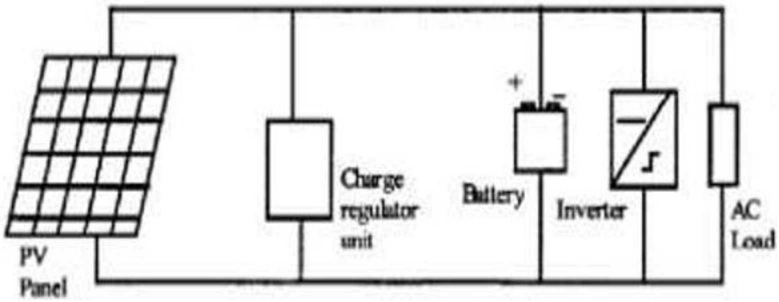


Figure 2. 11 Standy Alone system Fabien (2016-2017)

2.4.1.2. Hybrid PV systems

Conventional power systems used in remote areas often based on manually controlled diesel generators operating continuously or for a few hours. Extended operation of diesel generators at low load levels significantly increases maintenance costs and reduces their useful life. Renewable energy sources such as PV can be added to remote area power systems using diesel and other fossil fuel powered generators to provide 24-hour power economically and efficiently. Such systems are called ‘‘hybrid energy systems.’’ Fabien (2016-2017)

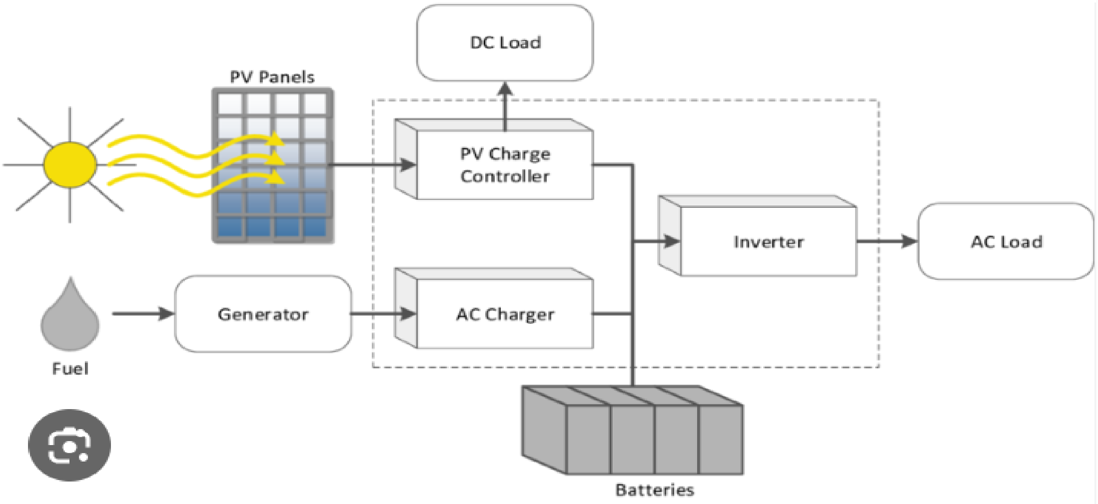


Figure2. 12 P-V Diesel Hybrid system Fabien. (2016-2017)

The Component of PV System

Although, the solar panels are the heart of a PV system, many other components are required for a working system. Together, these components are called the Balance of System (BOS). Which components are required depends on whether the system is connected to the electricity grid or whether it is designed as a stand-alone system. The most important components belonging to the BOS (Balance of System) are:

- **A mounting structure**

It is used to fix the modules and to direct them towards the sun.

- **Energy storage**

It is a vital part of stand-alone systems because it assures that the system can deliver electricity during the night and in periods of bad weather. Usually, batteries are used as energy storage units.

- **DC-DC converters**

They are used to convert the module output, which will have a variable voltage depending on the time of the day and the weather conditions, to a fixed voltage output that e. g. can be used to charge a battery or that is used as input for an inverter in a grid-connected system.

- **Inverters or DC-AC converters**

They are used in grid connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid.

- **Cables**

They are used to connect the different components of the PV system with each other and to the electrical load. It is important to choose cables of sufficient thickness in order to minimize resistive losses. Even though not a part of the PV system itself, the electric load, i.e. all the electric appliances that are connected to it have to be taken into account during the planning phase. Further, it has to be considered whether the loads are AC or DC loads.

The different components of a PV system are schematically presented in Figures bellow:

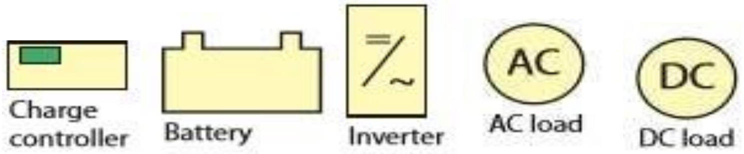


Figure 2. 13 A schematic of the different components of a PV system (MiroZeman, K. O. (1 September 2014).

The position of the sun

For planning a PV system, it is crucial to know the position of the sun in the sky at the location of the solar system at a given time. In this section we explain how this position can be studied Since celestial objects like the sun, the moon and the stars are very far away from the earth it is convenient to describe their motion projected on a sphere with arbitrary radius and concentric to the earth. This sphere is called the celestial sphere. The position of every celestial object thus can be parameterized by two angles. (MiroZeman, K. O. (1 September 2014).

For photovoltaic applications it is most convenient to use the horizontal coordinate system, where the horizon of the observer constitutes the fundamental plane. In this coordinate system, the position of the sun is expressed by two angles that are illustrated in Figure below:

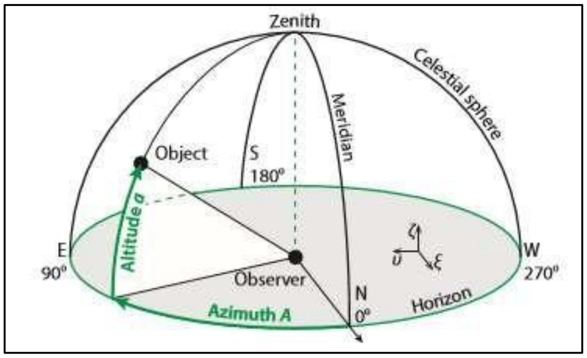


Figure 2.14 altitude and the azimuth A in the horizontal coordinate system. (MiroZeman, K. O. (1 September 2014).

The altitude that is the angular elevation of the center of the solar disc above the horizontal plane. Its angular range is $a \in [-90^\circ, 90^\circ]$, where negative angles correspond to the object being below the horizon and thus not visible. The azimuth A that is the angle between the line of sight projected on the horizontal plane and due North. It is usually counted eastward, such that $A = 0^\circ, 90^\circ, 180^\circ, 270^\circ$ correspond to due North, East, South and West, respectively. Its angular range is $A \in [0^\circ, 360^\circ]$. In a different convention also used by the PV community, due South corresponds to 0° and is counted westward, the angles then are in between −180° and 180°. Figure 16.1 also shows the meridian, which is great circle on the celestial sphere passing through the celestial North and South poles as well as the zenith. (MiroZeman, K. O. (1 September 2014)

Fractional open circuit voltage method

One of the most common indirect MPPT techniques is the fractional open circuit voltage method. This method exploits the fact that – in a very good approximation – the V_{MPP} is given by

$$V_{MPP} = k \cdot V_{OC} \tag{5}$$

where k is a constant. For crystalline silicon, k usually takes values in between 0.7 and 0.8.

2.3. HYBRID OF SOLAR-HYDROPOWER PREVIOUS METHOD

Data collection such as efficiencies of the system elements, total estimated daily load profile (kW), hourly average solar insolation/irradiation (kW/m2) and life-cycle costs of the hybrid power systems

Data Analysis with help of efficient topology where is selected based the total power (directly and/or via the battery bank) delivers to the load. This is conducted by taking the efficiencies of the battery bank, power electronic and storage devices to compare the power delivers to the load graphically by using Microsoft excel

For each energy management strategy, mathematical models are generated for equations of energy balance, power balance, control Genet, charging/discharging battery bank and then, all these equations are modeled using MATLAB/Simulink blocks.

RESEARCH METHOD1: Data collection such as efficiencies of the system elements, total estimated daily load profile (kW), hourly average solar insolation/irradiation (kW/m2) and life-cycle costs of the hybrid power systems

Data Analysis with help of efficient topology where is selected based the total power (directly and/or via the battery bank) delivers to the load. This is conducted by taking the efficiencies of the battery bank, power electronic and storage devices to compare the power delivers to the load graphically by using Microsoft excel for each energy management strategy, mathematical models are generated for equations of energy balance, power balance, control Genet, charging/discharging battery bank and then, all these equations are modeled using MATLAB/Simulink blocks.

INVESTIGATIONSYSTEM11: hybrid solar pv-genset battery storage power system for a remote off grid application: case study in Ethiopia90(Fissaha, 2017) INVESTIGATION11: Environment Friendly Hybrid Solar-Hydro Power Distribution Scheduling on Demand Side (Niaz et al., 2023)

RESEARCH METHOD 2: Location selection based on preliminary geographical and meteorological evaluation data and analysis to ensure it meets the crucial requirements for each solar and hydroelectric energy production

Uses numerical calculations of system components parameters and plotting as graph

INVESTIGATIONSYSTEM 2: Hybrid Solar-Hydropower Systems for Green Energy Production: A Comprehensive Analysis((Anandhi et al., 2024). RESEARCH METHOD 3: use of mat lab Simulink for analysis of components parameters. INVESTIGATION 3: Modeling and Simulations of off grid micro-grid (Bouchaala & Boukadoum, 2023). RESEARCH METHOD 4: Hybrid Power Generation System Using MATLAB/Simulink block diagram. INVESTIGATION 4: Design and Development of solar-hydro hybrid power generation system (Converters, 2018). RESEARCH METHOD:5 Data collection and analysis and use of SCADA for Hydro & Solar hybridization. INVESTIGATION 5: Hydro-connected solar in West Africa theoretical framework (Dobrotkov, n.d.). RESEARCH METDOD6: Use of Homer pro INVESTIGATION 6: Optimization of a hybrid renewable energy system for a rural community using PSO (Marc et al., n.d.)

RESEARCH METDOD7: Data collection and analysis and use of SCADA, use of graphical presentation to analyze. INVESTIGATION 7: Supplying power to remote villages in Lao PDR. The role of off-grid decentralized energy options (Martin & Susanto, 2020).

RESEARCH METDOD8: Collecting data at catchment and use of Arc GIS software, use of Solid works software to model and simulate mechanical components.
INVESTIGATION 8: Design and Manufacturing of cross-flow turbine to power coffee processing plant & nearby community village in KAFFA zone (Mirgissa et al., 2017)

RESEARCH METDOD9: Data collection and analysis with help of Homer pro software. INVESTIGATION 9: Implementation of Solar-Hydro Hybrid Power Utilization((Naik et al., 2021)

RESEARCH METDOD10: Data collection, mathematical modeling using flow equation and presentation with help of flowchart in Mat lab Simulink and graphical presentation. INVESTIGATION 10: Design of Micro -Hydro - Electric Power Station (Nasir, 2013) RESEARCH METDOD11: Mathematical modeling using equations and graphical presentations of different parameters with respect to time.
RESEARCH METDOD12: Design micro hydro-PV-DG-battery hybrid power system, one has to provide some inputs such as hourly load profile, Flow data, monthly solar radiation value for a PV system, Use of homer software for load-hourly profile, Use of equations for demonstrations, Use of Homer for design and analysis of hybrid solar-hydro and Diesel, Using RET screen software for system cost analysis and mat lab for simulation and analysis. INVESTIGATION12: Feasibility study for power generation using off- grid energy system from micro hydro-PV-diesel generator-battery for rural area of Ethiopia: The case of Melkey Hera village, Western Ethiopia (Nigussie et al., 2017)

RESEARCH METHODS 13: Data collection and mathematical equations, Use of Homer pro software for modeling and analysis. INVESTIGATION 13: Design And Simulation Of A Micro grid System For A University Campus In Nigeria (Ogbikaya, 2022).RESEARCH METHODS 14: Identification of materials and equipment used in design, Use of solid work for making mechanical assembly drawing, Use of mathematical equations and flow chart to compare different parameters. INVESTIGATION14: Design and Performance analysis of solar Hydro Power system (Oluwadare et al., 2024).

RESEARCH METHODS 15: Data collection and use of Mat lab/Simulink block diagram software.
INVESTIGATION15: Power Quality Improvement by Solar-Hydro Hybrid System (Shinde, 2024)

CHAPTER 3. METHODOLOGY

3.1 DATA COLLECTION AND RESEARCH METHODS

3.1.1 DATA COLLECTION

This Thesis conducted in university of Rwanda-college of science and Technology especially in Agaciro Building Block houses Internet of Things and Mechanical Laboratories for collecting data related to daily consumption capacity in two labs. The following steps had been achieved during data collection and Methods:

1. Data Measurement of top area of the roof using scaffolding houses the Agaciro building block finally top surface was 990 m^2**.**

2.Measurement straight vertical height of Agaciro building block for Francis turbine head with help of Long tape measure the result was 15.5m.

2.Measurement straight vertical height of Agaciro building block for Francis turbine head with help of Long tape measure the result was 15.5m.

3.Third data collected through both two labs by visual observation of unit consumptions equipment and tools located in Agaciro building.

3.1.2 RESEARCH METHOD

3.1.2.1. RESEARH METHOD INTRODUCTION

In this work, a technical study of Agaciro building block roof water fall for small hydro system and solar photovoltaic panels can laid on top of building for electricity generation and uses solar backup battery for storing electrical energy. Site identification, data collection, load demand calculation, renewable energy evaluation of the study region, and hybrid system component modeling utilizing Mat lab Simulink and HOMER software are main tools for achieving objectives.

3.1.2.2. DESCRIBING THE STUDY AREA

Agaciro Block; Address: University of Rwanda College of Science and Technology; Location: Nyarugenge District, Kigali, Rwanda, East Africa, Africa; Latitude. -1.95798° or 1° 57' 29" south. The University of Rwanda - College of Science and Technology (UR-CST) is located in Kigali, the capital city of Rwanda. The altitude of Kigali, where the university is situated, is approximately 1,500 meters (4,920 feet) above sea level. This elevation can vary slightly depending on the specific location within Kigali, but it generally ranges from 1,400 to 1,600 meters above sea level. The minimum temperature in Kigali typically ranges from 15°C to 18°C (59°F to 64°F), especially during the cooler months of the year (June to September). The maximum temperature generally ranges from 24°C to 28°C (75°F to 82°F), with the warmest months being from November to March. The University of Rwanda - College of Science and Technology (UR-CST) is located in Kigali**,** Rwanda, which experiences a tropical highland climate with distinct rainy and dry seasons. Long Rainy Season (Mid-March to May) it is the primary rainy season, with the heaviest rainfall occurring between April and May**.** The weather is often characterized by frequent, intense showers, although rain is usually intermittent rather than constant. Short Rainy Season (October to December). The shorter rainy season typically occurs from October to December, with lighter and less frequent rain compared to the long rainy season. While it can still experience substantial rainfall, it tends to be more sporadic The minimum rainfall occurs during the dry season, which runs from June to September. During this period, rainfall can be as low as 30 to 50 mm per month, especially in the months of June and July. The maximum rainfall occurs during the long rainy season (March to May), with the wettest months being April and May. During these months, rainfall can range from 150 mm to 200 mm per month, with some years experiencing higher.

3.1.2.3. LOAD ASSESSMENTS

Load assessment done through recording labs equipment, tools unis consumptions and preparation questionnaires and practice Interviews to Agaciro building block population by consideration of devices and equipment power consumption when it is available. Peak load, unit consumption per day calculated.

CHAPITER 4. PROJECT RESEARCH DESIGN

4.1 POTENTIAL MINI-HYDROPOWER SYSTEM POWER OUTPUT DESIGN

Agaciro Building Block Mini-Hydropower system output assessed using homer software. The parameters should be assessed to nominal capacity of mini-hydropower, average output power, capacity factor of the system, annual total production, minimum output power, maximum output power, mini-hydro penetration, operational hours throughout the year and levelized cost.

Equation below provides an empirical formula for calculating the electrical power produced by mini- hydro system.

$P_t = \eta_t \rho gQH$, $P_g = \eta_g P_t$ where η_t is turbine efficiency, ρ is density of water, g is gravitational force, Q is water flow rate, H is head of flowing water, P_t is turbine power, P_g is generated power, while η_g is Generated Efficiency. yearly average rain fall in mm at Gitega sector Nyarugenge district is 213.59 therefore this values can have referred as rain fall at Agaciro Building block, the quantity of rain water falls to the roof of Agaciro building block can be calculated using the following formula:

$$\text{Volume}e = Rain\ fall\ in\ mm \times \text{ area of rain hit the roof} \qquad (1)$$

$$\text{Volume} = 213.59mm \times 990\text{m}^2$$

$$\text{Volume} = 211.4541\text{m}^3,$$

$$\text{hourly flow rate(Q)} = \frac{\text{Volume}}{8760\text{hours}} \qquad (2)$$

$$Q = \frac{211.4541}{8760} = 0.0242\text{m}^3/\text{hour}.$$

Assuming frictionless, Power produced from mini Hydro(P)=$0.95 \times 1000 \times 9.81 \times \frac{0.0242}{1} \times 15.5$ therefore P=3.5kW/h . Mini-hydro Power produced whole day$= \frac{3.5\text{kW} \times 24\text{h}}{1\text{h}} = 84\text{kW}$

4.2. POTENTIAL POWER PRODUCED FROM PHOTOVOLTAIC PANELS

Kigali city and capital of Rwanda is located in the center of country, University of Rwanda –College of Science and Technology have the following coordinates 1.9587° S, 30.0642° E. these referred during gathering annual solar data at Agaciro building block including Solar radiation, irradiance and Temperatures. Rwanda Meteorology Agency will be used during solar data collection, as it is located near to Agaciro building block

Average Monthly GHI in kWh/m^2/day

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2.5	3.4	1.8	1	1.2	2.6	5	4.5	3.7	4	3.2	3

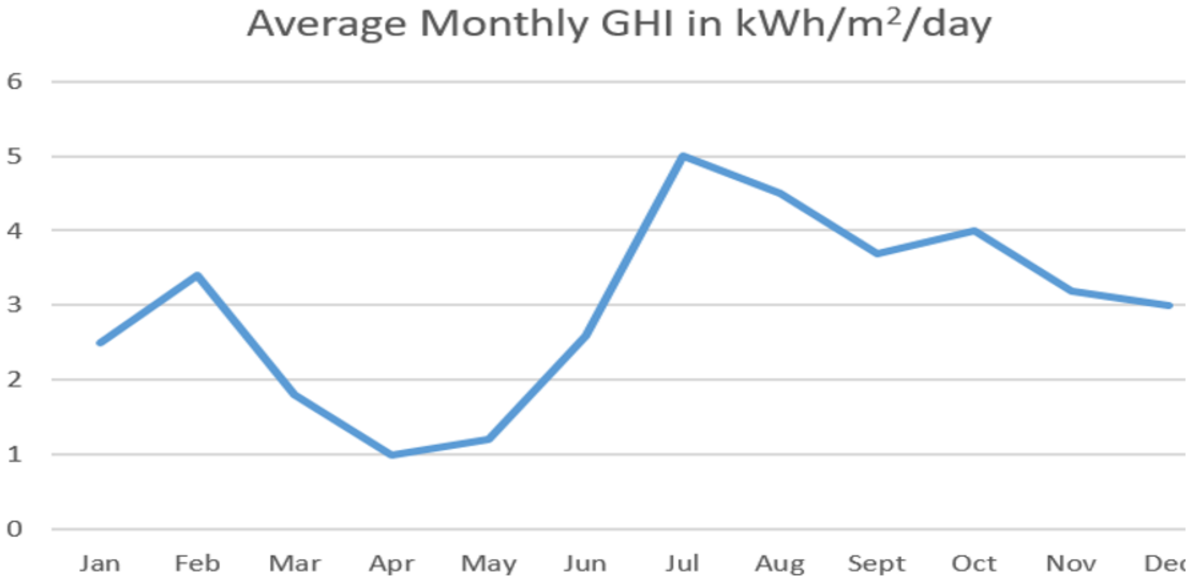


Figure 4. 15Average Monthly GHI in Kw/m^2/day

4.2.1. SELECTION OF SOLAR PANELS

A typical solar PV mono-crystalline selected for design and modeling research, which is in market available (model: Sun Power SPR-305E-WHT-D). it selected according to watts-power peak needed at Agaciro building block.

4.2.2. SIZING OF PV PANELS

Let choose Panel has the following properties: Rated power(Pr)=380W, output voltage(Voc)=48.8V, short circuit current(Isc)=9.94A, Efficiency=19.5%, Standard area of Solar panel = 1m×1.7m, Daily consumption in KWH=235.625 in two labs and let choose panels in

Parallel with taking 90-meter square for PV maintenance access.

$$\text{Number of panels}(N) = \frac{\text{available roof area in meter square}}{\text{area of each panel in meter square}} \qquad (3)$$

$$\text{N}= \frac{900}{1.7} = 530$$

$$\text{P(power)=Vtotal×Itotal} \qquad (4)$$

$$I\ \text{total}=ISC\times\text{number of panels} \qquad (5)$$

$$I\ \text{total}=9.94\times530=5262.4A$$

$$V\ \text{total}=Voc, \qquad \text{hence } V\ \text{total}=48.8V$$

P=48.8×5262.4=256.8kW this is the total power produced from photovoltaic panels when laying through all top roof of Agaciro building bloc

4.2.2.1SIZIN GPHOTOVOLTAIC PANELS CONSIDERING CURRENTCONSUMPTION

Agaciro building block Sun peak hour=5hours

$$\text{PV power}=\frac{\text{Daily Consumption in KWH}\times1.3}{\text{Sun peak hours}} \qquad (6)$$

$$\text{PV Power}=\frac{235.625\times1.3}{5}=61.3kW$$

$$\text{Number of PV panels}=\frac{\text{PV Power}}{\text{rating power of panel}} \qquad (7)$$

$$\text{Number of PV panels}=\frac{61.3}{0.380\text{KW}}=162,$$

so the area required on top of Agaciro building block that can accommodate $1.7\text{m}^2\times162=275.4\text{m}^2$ to supply current consumption in IoT and Mechanical Laboratories hence as top of Agaciro building block has total area of 900m^2 with90m^2 for maintenance and inspection access.

4.2.2.2 SIZING OF BATTERIES BANK

Let choose battery has the following properties

Battery type: Lithium iron ,Rated voltage(Vr)=12V, battery rating=250Ah, depth of discharge(DOD)=50%, efficiency=85%,

Guideline in system voltages:12V-small installation(<1200W),24V-medium sized installations(1200-2400W),48V-large installations(>2400W),

$$\text{Battery bank capacity}(C)=\frac{\text{daily consumption}}{\text{DOD}\times\text{Efficiency}\times\text{System voltage}} \qquad (8)$$

$$C=\frac{\text{daily consumption}}{\text{DOD}\times\text{Efficiency}\times\text{System voltage}}=\frac{235.625\text{kWh}}{0.5\times0.85\times48\text{V}}=11550.3\text{Ah}$$

$$\text{Number of string}=\frac{\text{Battery capacity}}{\text{battery rating}} \qquad (9)$$

$$\text{Number of string}=\frac{11550.3}{250}=47$$

$$\text{Number of battery in series}(Ns) = \frac{\text{System voltages}}{\text{Rated voltage}} \qquad (10)$$

$$Ns = \frac{48}{12} = 4$$

4.2.2.3. SIZING OF SOLAR CHARGER CONTROLLER(SCC)

Let choose solar charger controller has the following properties

Maximum voltage(Vmax)=200V, rated Icc=50A

$$\text{Number of series(Nis)} = \frac{\text{Vmax}}{\text{Voc of panel}} \qquad Nis = \frac{200}{48.8} = 4$$

$$\text{Number of strings}(Nit) = \frac{\text{Number of PV panels}}{\text{number of series}} \qquad (11)$$

$$\text{Nit} = \frac{162}{4} = 40.5 \approx 41$$

Current charger controller(Icc)=Isc×number of strings×1.25 (12)

Icc=50×41×1.25, Icc=2562.5

4.2.2.4. SIZING OF INVERTERS

Let choose inverter has the following capacity : Peak power(Wp)=3000W, Maximum Vdc Input=500V, Maximum input current=18A, maximum efficiency=85% ,safey factor=1.25

$$\text{Inverter should be sized as} = \frac{\text{Total wattage×safety factor}}{\text{Efficiency}} \qquad (13)$$

$$\text{Inverter should be sized as } \frac{98693.4 \times 1.25}{0.85} = 145.2\text{Kw}$$

4.2.2.5 MODELING HYBRID OF SOLAR-HYDROPOPWER SYSTEM USING HOMER

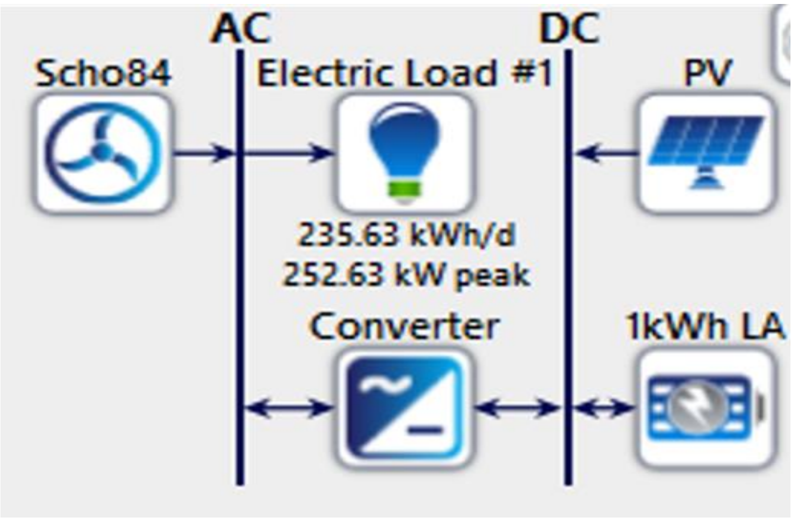


Figure4. 16 Hybrid model of solar-micro hydropower

Hybrid model developed through homer software by combining solar-photovoltaic which generates direct current DC Electricity and micro hydropower which produce alternative current AC. Direct current from solar collected on DC bus bar and battery backup direct current from DC bus bar. Inverter that convert DC into AC produces alternative current for putting together with alternative current from micro hydropower plant.

5.2.2.6. MODELING HYBRID OF SOLAR-HYDROPOWER SYSTEM USING MATLAB

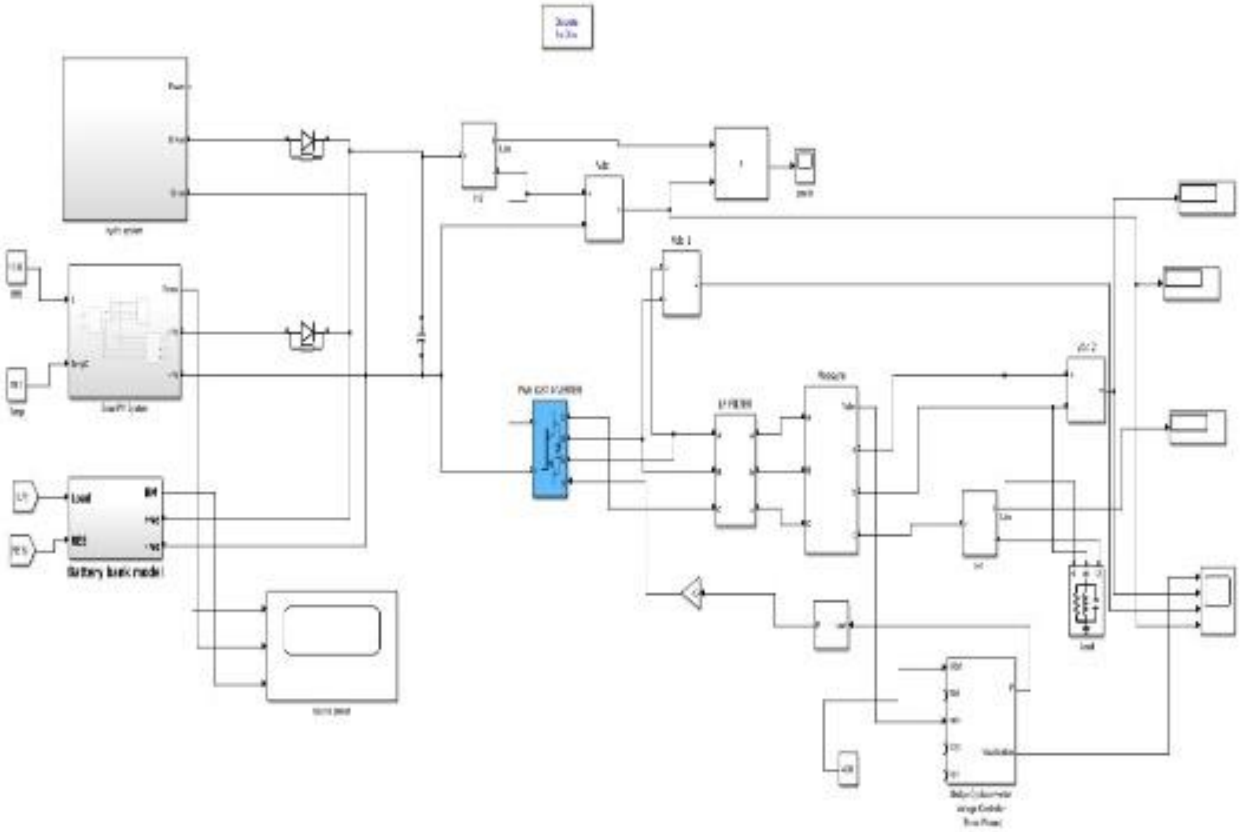
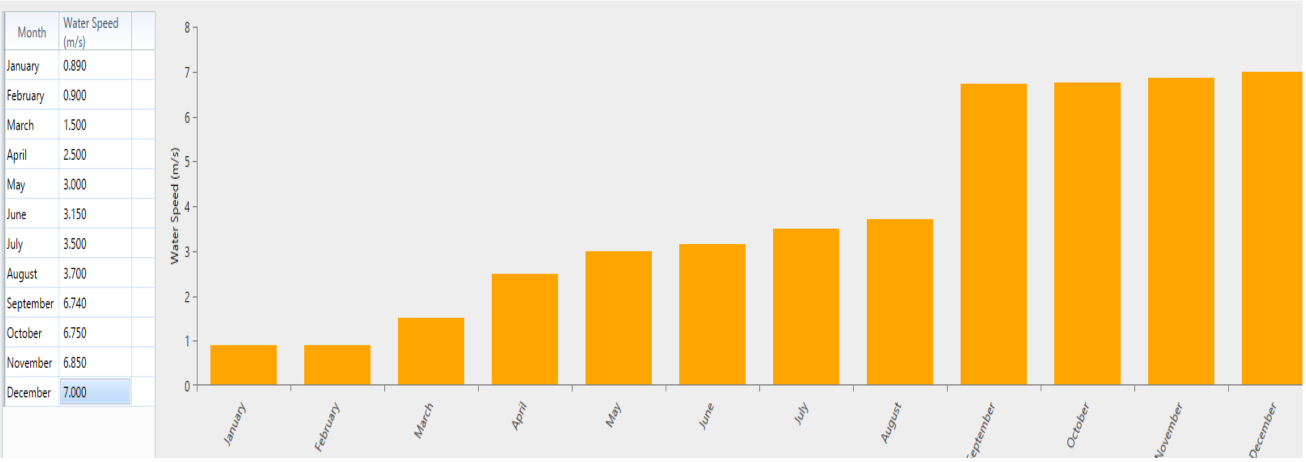


Figure 4. 17 Matlab solar-micro hydro model

Hybrid model combines solar photovoltaic system (PV panels, solar charge controller, batteries, inventers and rectifier such as diodes, transistors) even Microhydropwer system like cross flow turbine with generator.

CHAP 5. RESULTS AND DISCUSSIONS

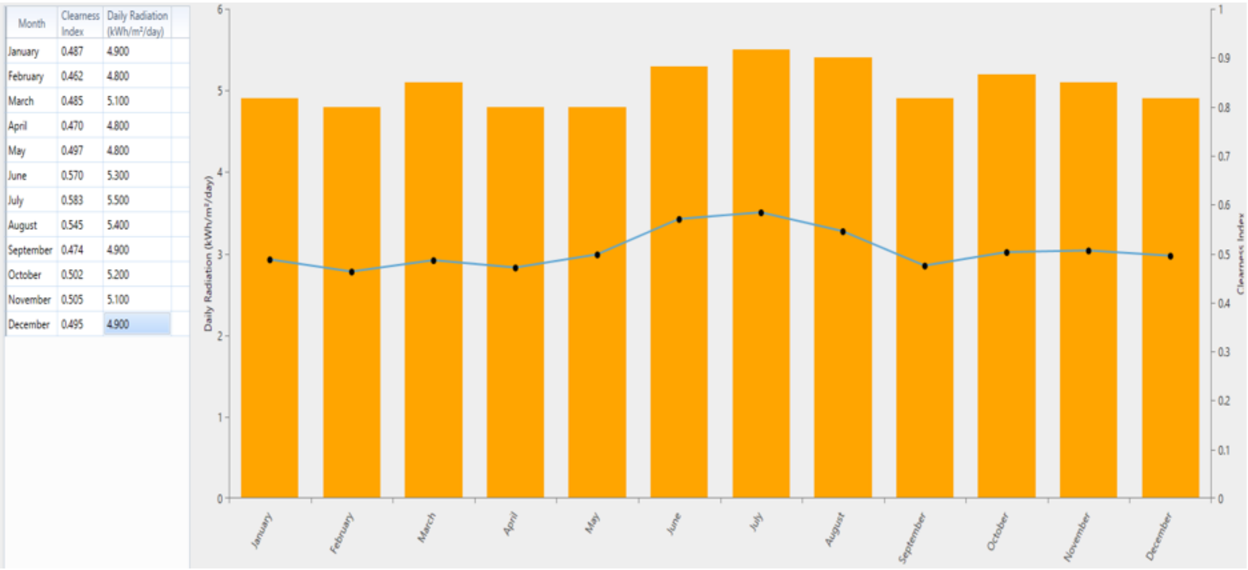
In-depth discussions regarding the system design, modeling, testing of the supply's voltage equipment stability under various circumstances, and the implications of battery charging with hybrid of solar and hydro system at Agaciro building block. Finally, the voltage from the grid will be switched off, and a battery bank will have utilized to power the load in order to test difficult scenarios. The complete system model elaborated using Mat lab Simulink and homer software. From homer software following are the results parameters:



Month	Water Speed (m/s)
January	0.890
February	0.900
March	1.500
April	2.500
May	3.000
June	3.150
July	3.500
August	3.700
September	6.740
October	6.750
November	6.850
December	7.000

Figure 4.18 Monthly Average water speed

The previous figure represents not only the monthly but also average water speed required for generating output power of 84Kw. It is clear that water speed increasingly regularly from January to August and the last months are small incremental.



Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.487	4.900
February	0.462	4.800
March	0.485	5.100
April	0.470	4.800
May	0.497	4.800
June	0.570	5.300
July	0.583	5.500
August	0.545	5.400
September	0.474	4.900
October	0.502	5.200
November	0.505	5.100
December	0.495	4.900

Figure 4.19 Monthly average global horizontal solar irradiance

The figure represents daily radiation in kW/m²/day plotted available Agaciro building block data in homer software where it generates clearness index of each month according to radiation quantity of month.

Figure4.20 Time series Analysis of yearly hour of each month against load power in Kw

This figure shown is a distribution pattern of all monthly power generation in kW by considering in hours of the monthly for hybrid of solar photovoltaic and micro hydropower.

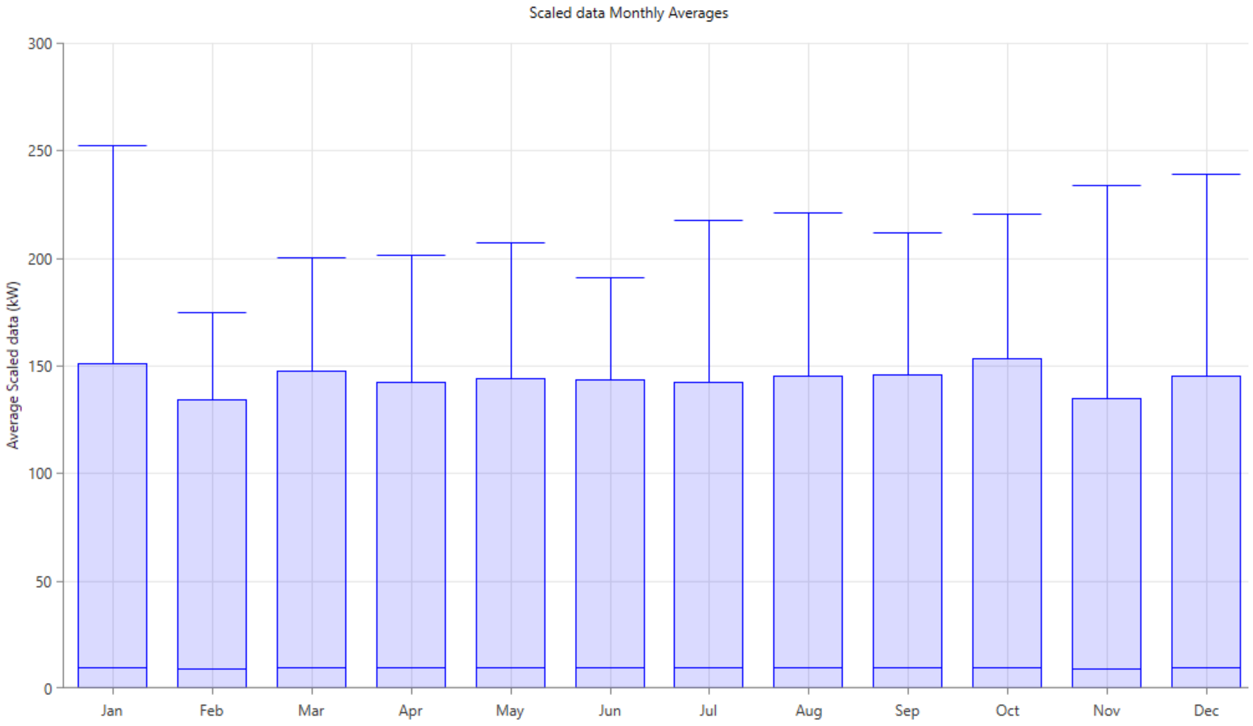


Figure 4. 21Monthly time series against load power in Kw

As it is homer software display Power generation pattern for each month, it is clear that more generation energy will happen in January and December above 250kW while less energy generation is in February around 175kW.

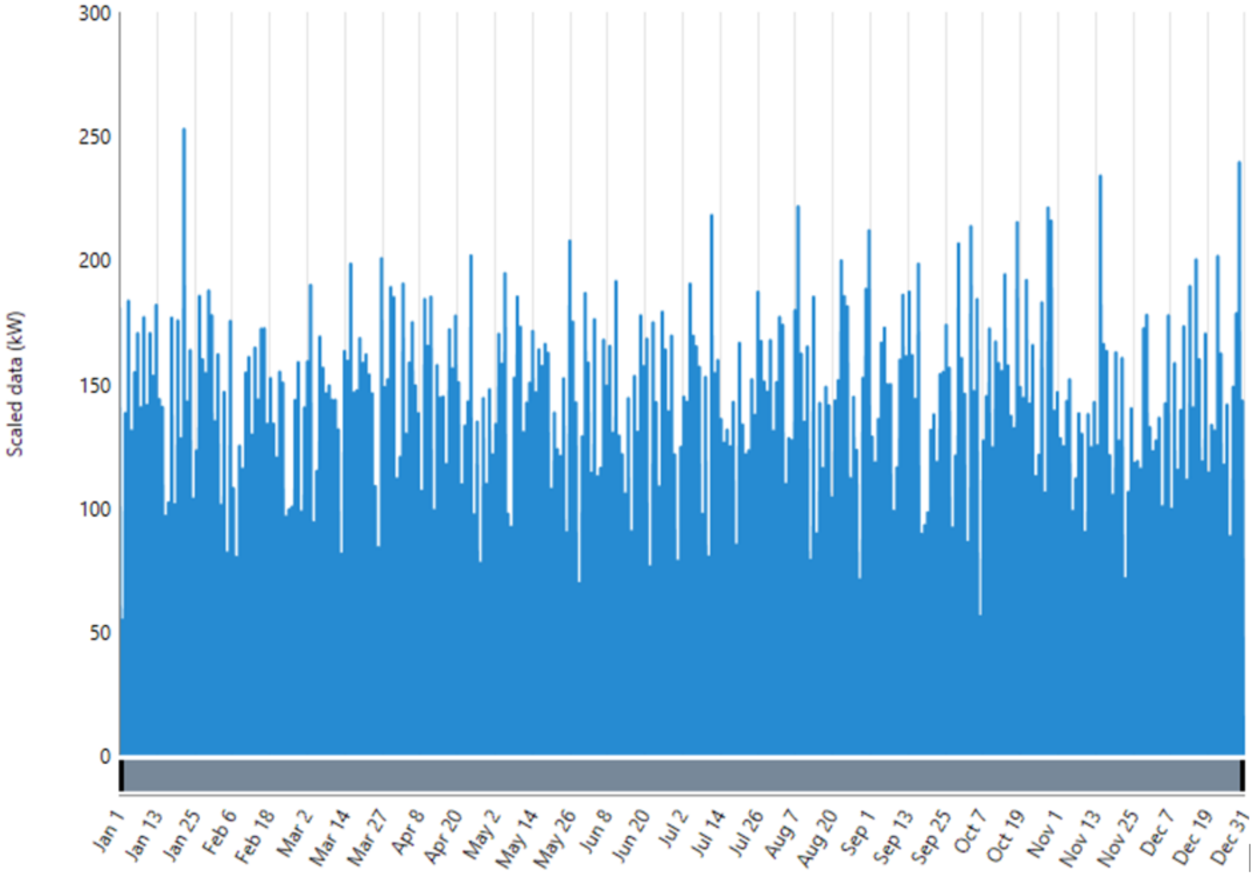


Figure 4. 22 Hourly time series detail Analysis of whole months against load power in kW

It is clear that energy generated from January to December, power changing as wave form forth to above 250kW and decreases accordingly but the minimum generated power is around to 50kW.

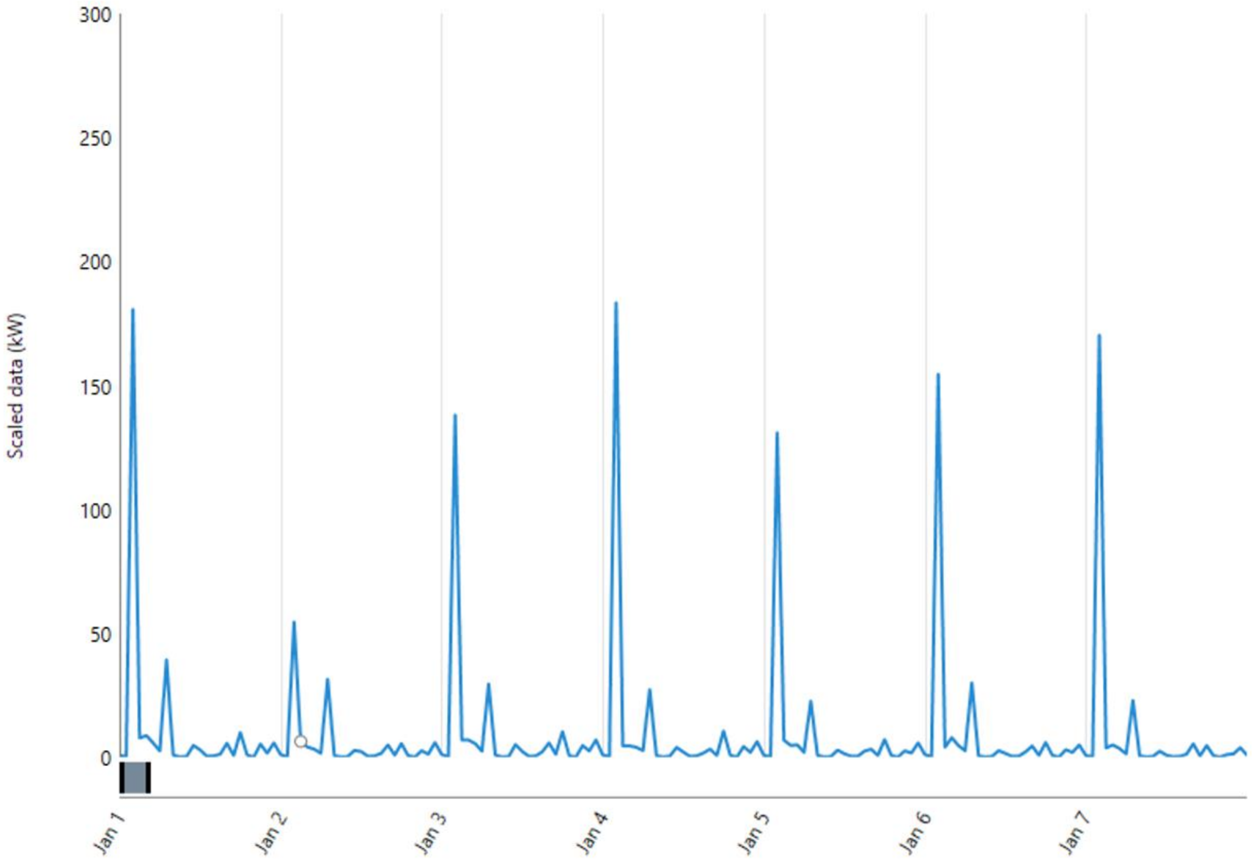


Figure4. 23 Power generation against monthly time

This figure illustrated that generated power starts from January up to July, it is characterized by lowest power is below to 50kW.

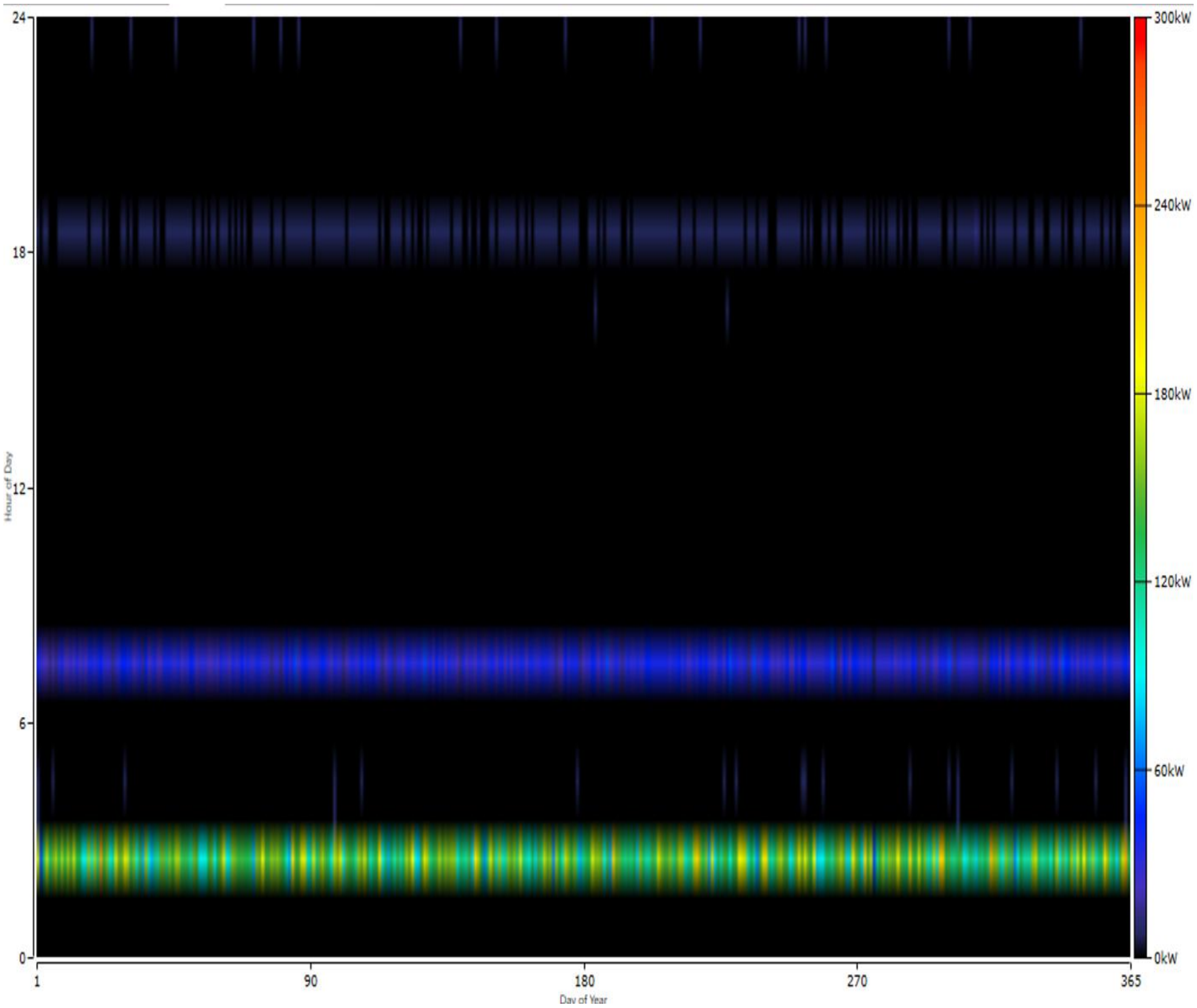


Figure4. 24 Load Analysis of day of year against hour of day

This simulated figure represents day of the year which is plotted on x-axis and right and left of y-axis, there is generated power and time of in hour of day.it demonstrated that maximum power generation between 120kW. and 180kW but maximum can reach up to above 300kW with a round of 24 hours of day while minimum power starts from o to 60kW with around 6hours of day.

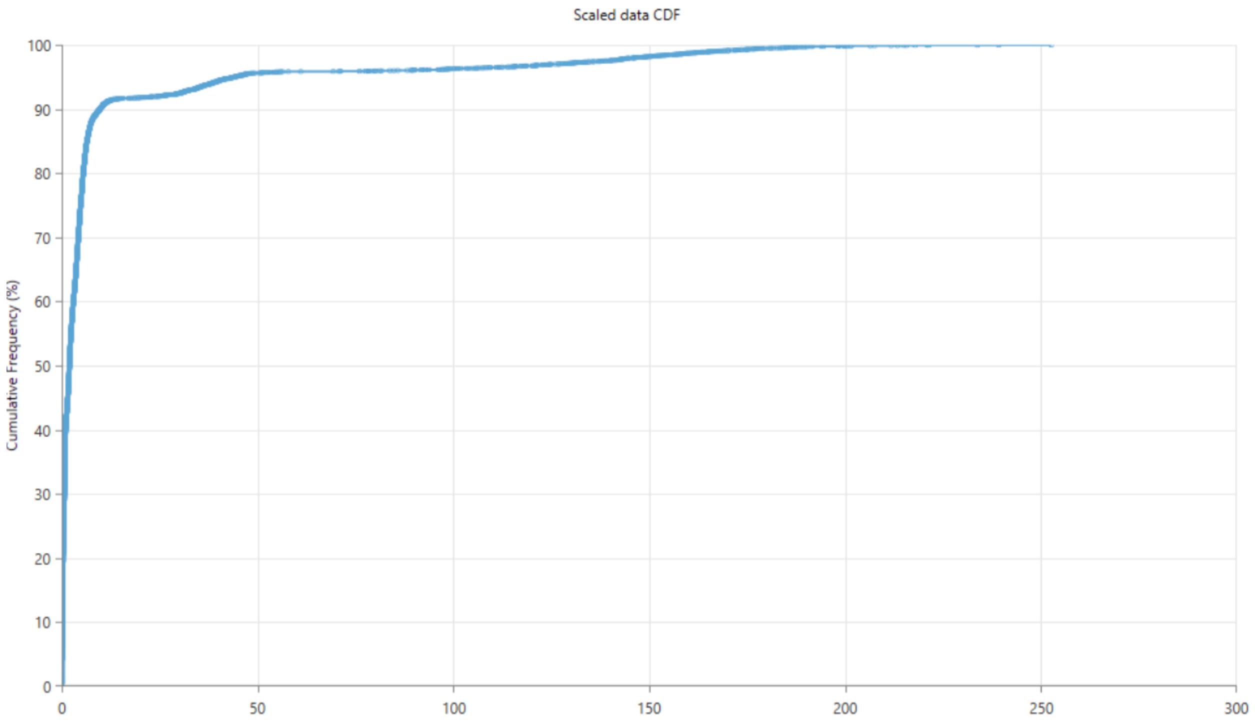


Figure4. 25 CDF load analysis

This figure shown is cumulative distribution function load analysis simulated in homer where load up to 300kW displayed on x-axis and frequency in percentages is plotted on y-axis. For example, when the power is around to 25kW it is corresponding with 90% of frequency while when power is 250kW, frequency tends to be 100%.

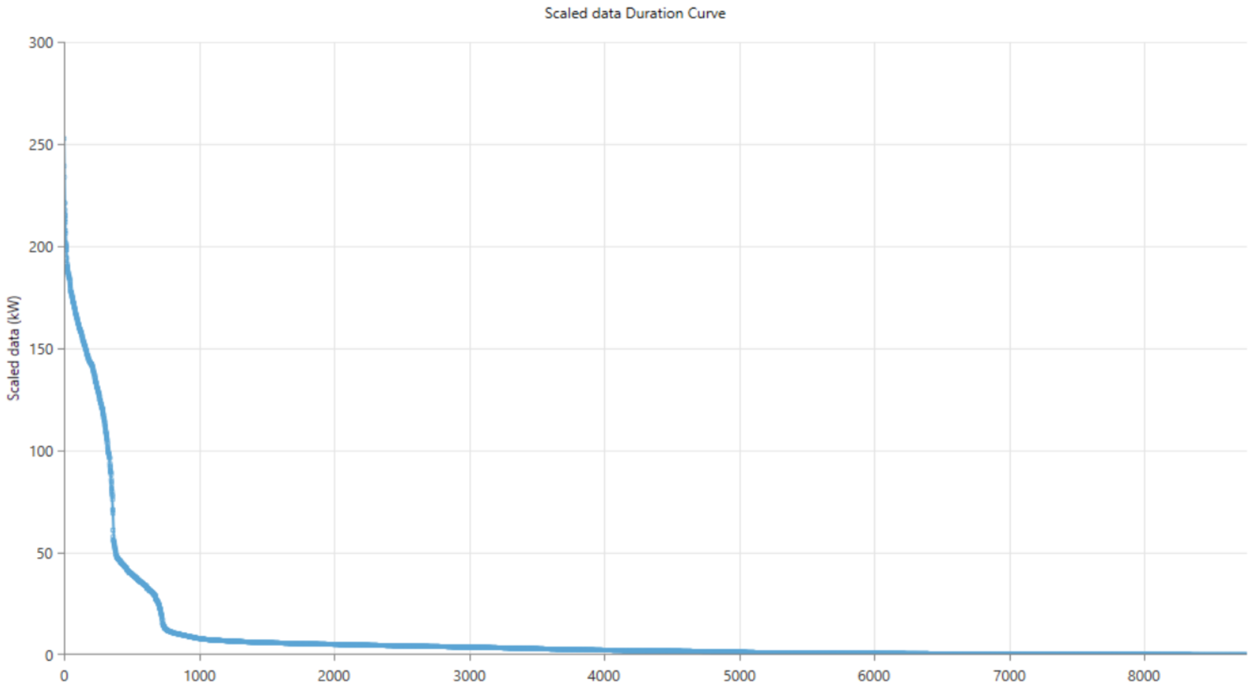


Figure4. 26 Duration curve with respect to power output

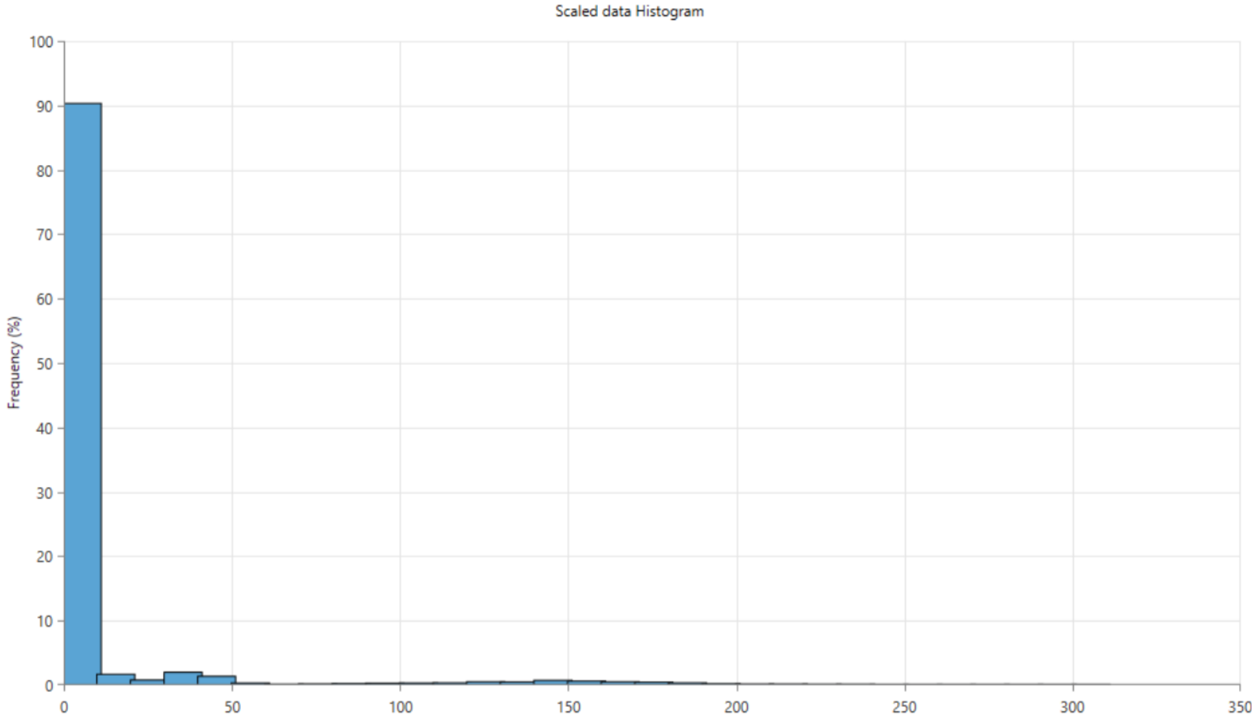
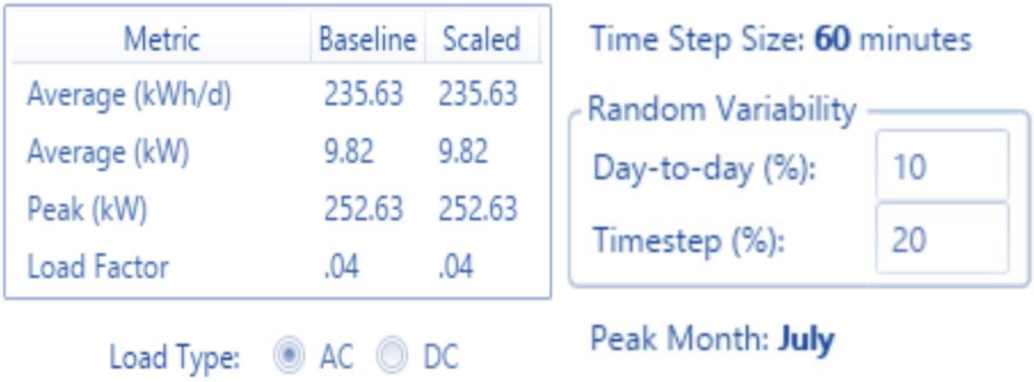


Figure 27Generated power with Frequency Analysis by histogram



Metric	Baseline	Scaled
Average (kWh/d)	235.63	235.63
Average (kW)	9.82	9.82
Peak (kW)	252.63	252.63
Load Factor	.04	.04

Load Type: ● AC ○ DC

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 10

Timestep (%): 20

Peak Month: **July**

Figure 4. 28 Base line data, step size and peak month from Homer software.

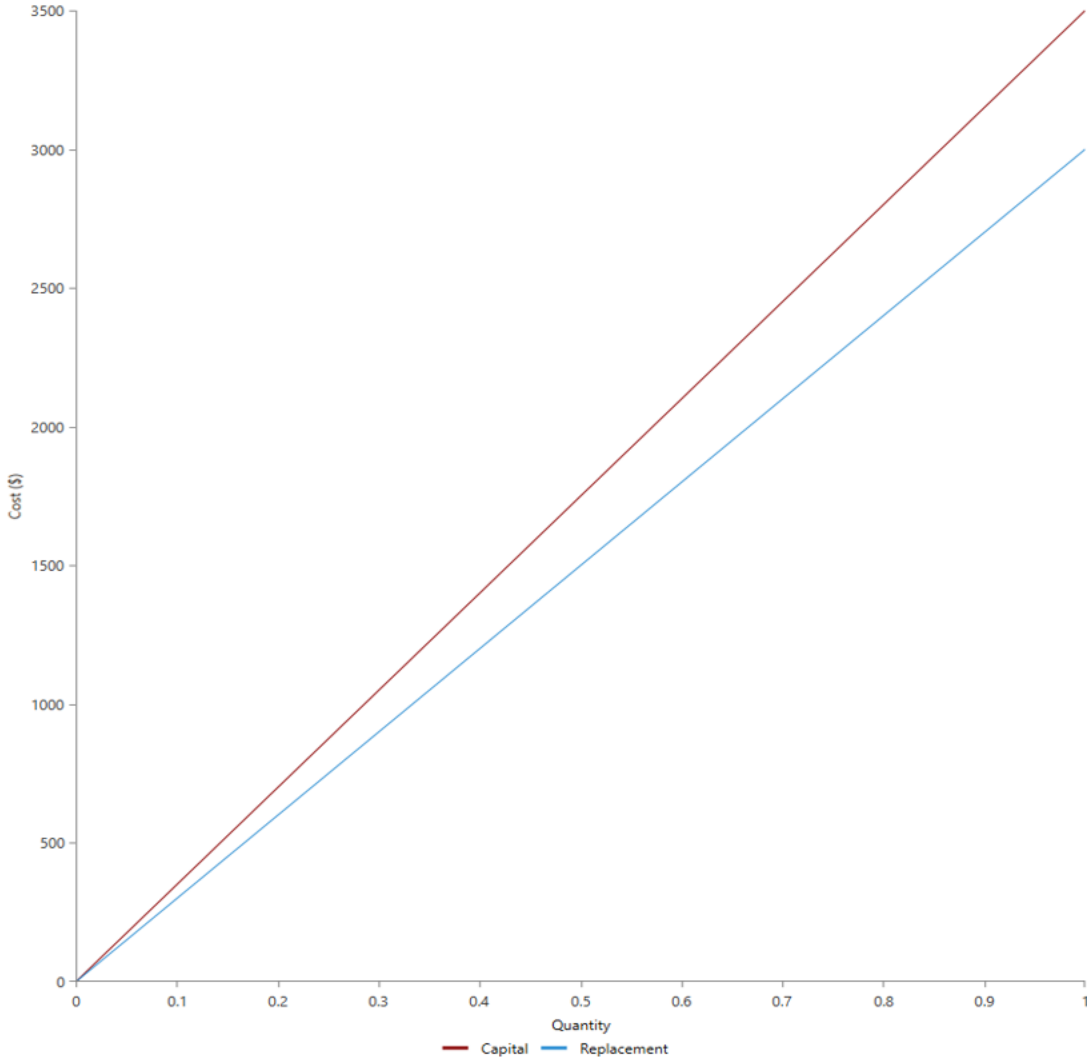


Figure 4.29 Capital and replacement Cost Curves

Plotted figure represents capital and replacement costs, as it is displayed, capital and replacement costs start at the same point. As time goes on, capital and replacement cost separately at regular interval.

5.1. SOLAR SYSTEM DESIGN, MODELING AND OUTPUTS DISCUSSIONS RESULTS

As discussed previously, typical solar PV mono-crystalline selected for design and modeling this research, which is in market available (model: Sun Power SPR-305E-WHT-D).it happened according to watts-power peak needed at Agaciro building block. In order to get an optimum shunt diode model, solar cells are typically modeled as a single diode with an additional shunt resistance used in parallel. With a single diode model, the I-V characteristics of a PV cell can be determined. DC-DC converter in the system needs to convert the varying output voltage of the boost converter to a stable amount of DC bus distribution voltage. In MATLAB, the buck converter is cascaded with the boost converter. The output voltage of the buck converter regulated at certain amount while the input voltage varies depending on the solar irradiance, temperature and load. In order to get a regulated voltage at the DC bus, the controller compares the output voltage of the buck converter (DC bus voltage) to the reference voltage. Its operating voltage determines the amount of power that the PV module generates. The PV's maximum power extracted when the operational voltage of the module is approximately, where the I-V curve knees. The boost converter's duty cycle must be changed in order to extract the most power, forcing the PV array to operate near the I-V curve's knee. Boost converters use the duty cycle based on the voltage generated by the PV module to regulate the voltage. The temperature and solar radiation from the two tests are displayed. The PV module is I-V characteristics depend on different temperatures and irradiances. Temperature primarily affects the PV module's output voltage, whereas solar radiation predominantly affects the PV module's output current. The PV module's maximum voltage alternates dynamically between these two settings. The PV array's output voltage drops with rising temperatures. The average annual temperature of Agaciro building block will be measured. Seasonal variations in temperature and minimum also will be measured and even maximum temperature, availability of solar irradiance throughout the year. After this important information, Output voltages and output current with varying solar irradiations.

5.2 MINI-HYDRO SYSTEM MODELING AND OUTPUT

Cross flow, turbines will be chosen since they could be readily produced locally and were inexpensive. When it comes to freestanding off-grid systems, induction generators are the ideal choice because they are more efficient with mini-hydropower. With the exception of electromechanical device and control equipment malfunctions, the hydro system power generation is continuous. Using the proper converters, the various sub-models, such as the induction generator, excitation system, hydro turbine governor, and three-phase RL or R load, are integrated to create the whole block diagram of the micro hydropower plant. Hydro system MATLAB modeling with boost converter and rectifier designed even analyzing other parameters like inverter output voltages, three phases RMS voltages and AC load voltage.

5.3. AGACIRO BUILDING BLOCK MINI-HYDRO AND SOLAR PHOTOVOLTAIC SYSTEMS

The solar and hydro system operates parallel during the load demand. The system can work safely using hybrid power generation and when the load demand maximum. When the load demand is lower than the generated power can charge the battery system. The two sources designed with appropriate voltage stability for system energy demands. Battery modeling: Lead-acid battery type is the optimum choice for the isolated backup system. The figure below represents hybrid of solar-micro hydropower output current versus voltage from mat lab software.

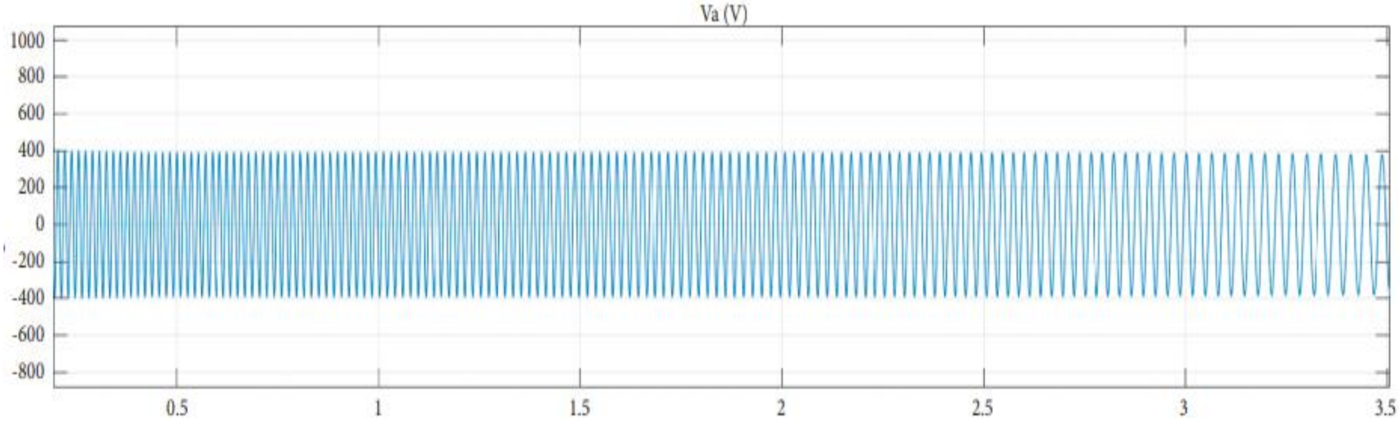


Figure 4. 30 Voltage versus time

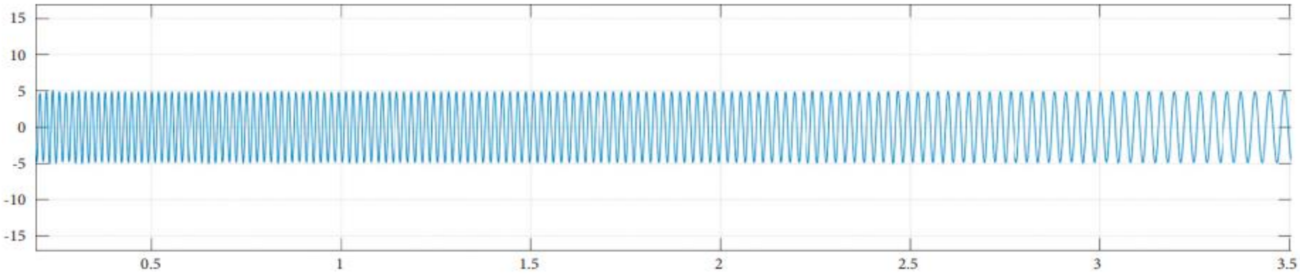


Figure 4.31 Current versus time

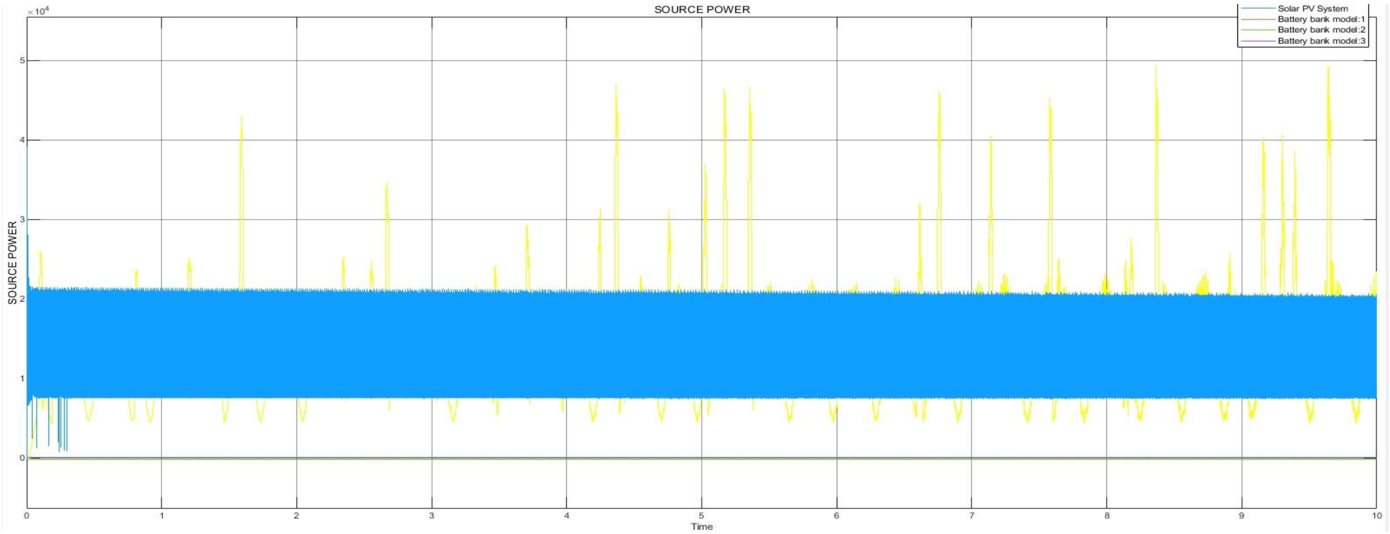


Figure 4.32 Solar-Hydro Power Generation versus time

5.3. AGACIRO BUILDING BLOCK SOLAR PHOTOVOLTAIC AND MINI-HYDRO SYSTEMS WITH BATTERIES STORAGE

When load demand exceeds power provided for a given period, the hybrid system micro grid power generation uses storage battery devices to maintain the community's electrical supply. In order to balance the power generated and demanded, the battery can deliver energy. During the Mat lab Simulink toolbox simulation procedure, this system simulated a consistent battery time response. The following steps will be used in analysis of Agaciro building block Solar photovoltaic and mini-hydro systems with batteries storage: DC link voltage by plotting inverter voltage versus time, Inverter output voltage without LC filter by plotting load voltage versus time, AC output load voltage by plotting modulation index

5.4. TOTAL COST OF AGACIRO BUILDING BLOCK SOLAR PHOTOVOLTAIC AND MINI-HYDRO SYSTEMS.

One of the main problems and restrictions on the widespread use of renewable energy sources worldwide is their initial investment cost. The total cost of the AC micro grid, which includes all necessary electromechanical costs that are integrated into other study-related costs. A system's overall net present cost is equal to the present costs it incurs over the course of its lifetime less the present value of all the revenue it generates. Costs include capital costs, replacement costs, Operation and Maintenance costs, fuel costs, emission penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. The following formulas could be used with Homer software to estimate the system cost analysis.

$$NPV=IC+OMC+RC+FC-SV$$

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). HOMER defines the Levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost) by the total useful electric energy production (EU). Payback period is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment

$$\text{Payback period}=\frac{Cnpc}{Cann,tot}$$

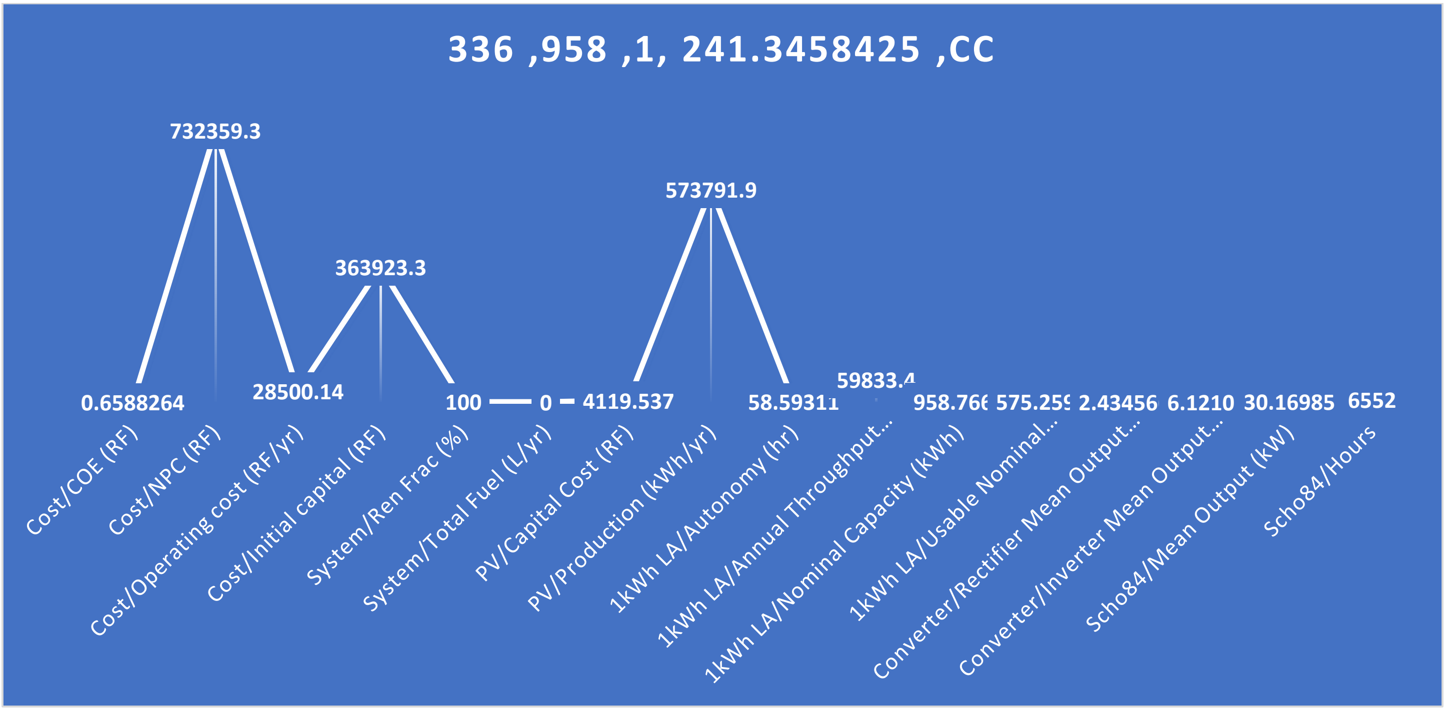


Figure 4. 33 Solar- hydro results from homer software cost analysis and other parameter

The value that a power system component has left at the conclusion of the project's lifespan is known as its salvage value. According to Homer's assumption of linear component depreciation, a component's salvage value is directly correlated with how long it has left to live. Furthermore, it is assumed that replacement costs, not initial capital costs to determine salvage value. The system cost analysis has done using Homer software with the total Net present value and annualized cash flow cost

CHAP 6. CONCLUSION

A hybrid of solar-micro hydropower system of energy generation leverages strengths and offering more reliable, sustainable even efficiency for energy production but it may come certain challenges especially environmentally and cost. It represents a promising solution for the areas where all solar and micro hydropower resources are available. This study had cleared assess solar-micro hydropower for potential implementation at the top of Agaciro building block in University of Rwanda-College of Science and Technology. Specifically, it results that the roof can support 530 Photovoltaic panels with 256.8 KW per day but current IoT and Mechanical labs need only 235.625 units per day to run equipment. This thesis designed and simulated with aids of Mat lab and Homer software for cost analysis and other parameters such as output power, output voltage, frequency analysis, potential rain falls at Agaciro Building Block and available head(15.5m) that results the potential power from micro hydropower.

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APPENDIX

1 ENERGY CONSUMPTION TABLES

LAB NAME	EQUIPMENT	POWER IN W	QUANTITY	TOTAL POWER IN W	DURATION IN HRS	TOTAL CONSUPTION IN KWH
IOT LAB 1	IF lamps	3	24	72	12	0.864
	3D-Printer	216	1	216	1	0.215
	Computer Desktop	950	19	18050	8	144.4
	HV AC	1000	1	1000	5	5
	Automatic stabizer Servo type	100	7	700	8	5.6
	Duratool	320	6	1920	2	3.84
	Weller WE 1010	85	13	1105	2	2.21
	Full Automatic AC voltage Regulator	1540	3	4620	8	36.96
	Digital Oscilloscope	80	3	240	3	0.72
	TV	72	1	72	3	0.216
	solder fume extractor	23	12	276	1	0.276
	Camera	75	2	150	24	3.6
	Destop	14.5	20	290	8	2.32

IoT LAB 2	IF Lamps	3	8	24	12	0.288
	TV	72	2	144	3	0.432
	camera	75	1	75	24	1.8
	HV AC	1000	1	1000	5	5
	IF Lamps	3	20	60	12	0.72
MECH LAB	Pelton turbine 1	750	1	750	1	0.75
	Pelton turbine 2	1512	1	1512	1	1.512
	Francis turbine	9200	1	9200	1	9.2
	Flowmeter	750	1	750	1	0.75
	Machine used for hardness test-1	15	1	15	1	0.015
	Machine used for hardness test-2	15	1	15	1	0.015
	System used for production Biodiesel	63	1	63	2	0.126
	Torsion meter	15	1	15	1	0.015
	Bench top projector unit	950	1	950	1	0.95

LAB NAME	EQUIPMENT	POWER IN W	QUANTITY	TOTAL POWER IN W	DURATION IN HRS	TOTAL CONSUPTION IN KWH
MEC LAB	Universal Testing machine	1500	1	1500	1	1.5
	Computer controlled balance of Reciprocating mass unit	480	1	480	1	0.48
	Balancing machine for crankshaft and drive shaft	4500	1	4500	1	4.5
	Doro Renzo	100	6	600	1	0.6
	Dead Weight Test	750	1	750	1	0.75
		Total	Consumption	In kWh/day		235.625

Table8. 4 IoT and Mechanical Labs Data

LAB NAME	EQUIPMENT	POWER(W)	QUANTITY	TOTAL POWER (W)	MULTIPLIER	TOTAL POWER(W)
IoT LAB 1	IF Lamps	3	24	72	1.3	93.6
	3D-Printer	216	1	216	1.3	280.8
	Computer Destop	950	19	18050	1.3	23465
	HV AC	1000	1	1000	2	2000
	Automatic stabizer Servo type	100	7	700	1.3	910
	Duratool	320	6	1920	1.3	2496
	Weller WE 1010	85	13	1105	1.3	1436.5
	Full Automatic AC voltage Regulator	1540	3	4620	1.3	6006
	Digital Oscilloscope	80	3	240	1.3	312
	TV	72	1	72	1.3	93.6
	solder fumer extractor	23	12	276	2	552
	Camera	75	2	150	1.3	195

LAB NAME	EQUIPMENT	POWER(W)	QUANTITY	TOTAL POWER (W)	MULTIPLIER	TOTAL POWER(W)
IoT lab 2	Destop	14.5	20	290	1.3	377
	IFLamps	3	8	24	1.3	31.2
	TV	72	2	144	1.3	187.2
	camera	75	1	75	1.3	97.5
	HV AC	1000	1	1000	2	2000
MEC LAB	IFLamps	3	20	60	1.3	78
	Pelton turbine 1	750	1	750	3	2250
	Pelton turbine 2	1512	1	1512	3	4536
	Francis turbine	9200	1	9200	3	27600
	Flowmeter	750	1	750	1.3	975
	Machine used for hardness test-1	15	1	15	3	45
	Machine used for hardness test-2	15	1	15	3	45

LAB NAME	EQUIPMENT	POWER(W)	QUANTITY	TOTAL POWER (W)	MULTIPLIER	TOTAL POWER(W)
MEC LAB	System used for production Biodiesel	63	1	63	2	126
	Torsion meter	15	1	15	2	30
	Bench top projector unit	950	1	950	1.3	1235
	Dead Weight Test	750	1	750	2	1500
	Universal Testing machine	1500	1	1500	3	4500
	Computer controlled balance of Reciprocating mass unit	480	1	480	2	960
	Balancing machine for crankshaft and drive shaft	4500	1	4500	3	13500
	Doro Renzo	100	6	600	1.3	780
		Total	Minimum	Power in	watts	98693.4

Table8. 5 IoT and Mechanical Labs Consumption power