



COLLEGE OF SCIENCE  
AND TECHNOLOGY



**Title: Design and performance Analysis of Photovoltaic and  
Uninterruptible Power Supply Backup for Commercial  
Buildings in Kigali**

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A dissertation submitted in partial fulfillment of the requirements for the degree of master of  
MASTER OF SCIENCE IN RENEWABLE ENERGY SYSTEMS.

African Center of Excellence in Energy studies for sustainable development (ACE-ESD) in  
the college of science and technology

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8<sup>th</sup>, October, 2025

## DECLARATION

I declare that this Dissertation contains my work except where acknowledged, and it has passed through the anti-plagiarism system and has been found to be compliant and this is the approved final version of the thesis

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## **ACKNOWLEDGEMENT**

To achieve to what we need regardless challenges we faced, we need help from God that it is why I thank God for protecting and advising me.

I would like to express special gratitude to my advisor, Dr Innocent Nkurikiyimfura and I also thank all the staff of Africa Center of Excellence for Energy Sustainable Development.

I would like to thank my family and my Parents for the support, encouragement and belief in me throughout this time.

## ABSTRACT

An option to reduce the effects of air pollution and the quantity of energy needed to produce and provide services is through efficient energy consumption, also known as energy efficiency. A building can use less energy for heating and cooling, for example, if it is insulated. There are various reasons to increase energy efficiency. If the additional expenses related to putting energy-efficient technologies into place are offset, reducing energy use lowers energy bills and saves consumers money. Because buildings use a lot of energy, they are a key area for increasing energy efficiency worldwide. Building materials also contain embodied energy, and indoor conditions change greatly depending on how the energy is used, making the issue of energy use in buildings complex [1]. Roof-top solar systems are crucial components of environmentally friendly construction and design. They offer numerous advantages, including methods for managing storm water, lowering the urban heat island effect, improving air quality, and being more energy efficient; many cities worldwide are requiring them. The physical model was structured and used throughout the study. The site, electrical needs, performance ratio of UPS system was also assessed to design the solar PV system. The results were mathematically calculated by using different formulas. The performance ratio of solar PV system was 0.843, to indicate that the PV system shall operate effectively. According to the analytical computation, precisely 90 panels are required to satisfy the energy demand. However, the design calls for 95 panels to be installed on the roofs of the buildings that were chosen at location with Average temperature:  $19.2^{\circ}\text{C}$ , Total precipitation: 1063.3mm with system production equal to 1629MWh/year, system losses 0.06kWh/kWp/day, Array losses 0.68kWh/kWp/day. Green roofs for businesses can also significantly increase energy efficiency. Although off-grid PV systems can also save significant energy, grid-connected PV systems are particularly energy-efficient. Considering a particular location, this study calculates the energy demand, GHG emission reduction, and energy export to the grid with rooftop PV system installation.

**Key words:** PV system, energy efficiency, emission reduction

## LIST OF ACRONYMS AND ABBREVIATIONS

<b>Acronyms</b>	<b>Description</b>
m <sup>2</sup>	Square meter
AC	Alternative Current
EKTS	Electrical Control Technique Simulation
MPPT	Maximum Power Point Tracking
PV	Photovoltaic
IC	Charging Current
C	Required capacity (in Ah)
DOA	Number of autonomy days
DOD	Allowable depth of discharge of the battery
CO <sub>2</sub>	Carbon dioxide
DC	Direct Current
GHG	Green House Gases
NPV	Net Present Value
UPS	Uninterruptible Power Supply
CC	Charging Controller
E	Energy consumption
H <sub>b</sub>	Battery charging efficiency
B <sub>v</sub>	Battery bus voltage

## Table of Contents

DECLARATION.....	i
ACKNOWLEDGEMENT .....	ii
ABSTRACT.....	iii
LIST OF ACRONYMS AND ABBREVIATIONS .....	iv
List of tables.....	vii
List of figures.....	viii
1. INTRODUCTION .....	1
1.1 Background.....	1
1.2. Problems statement.....	2
1.3 The objectives of the study .....	3
<b>1.3.1 General objective</b> .....	3
<b>1.3.2 Specific objectives</b> .....	3
1.5. Scope of the project .....	3
1.6. Thesis organization .....	4
CHAPTER 2: LITERATURE REVIEW .....	5
CHAPTER 3. METHODOLOGY .....	8
3.1 Procedures to design solar PV system.....	8
<b>3.1.1 Site assessment</b> .....	8
<b>3.1.3 Physical Structure</b> .....	20
<b>3.1.3.1 UPS</b> .....	21
<b>3.1.3.2 Charge Controller</b> .....	22
<b>3.1.3.3. Maximum Power Point Tracking (MPPT)</b> .....	23
<b>3.1.3.4 Inverter</b> .....	23
<b>4.2. Greenhouse Gas (GHG) Emission Analysis of the Proposed System</b> .....	26
CHAPTER 4: RESULTS AND DISCUSSION .....	29

4.1. Interpretation of results .....	29
<b>3.1.4 Performance ratio (P.R) of the PV System</b> .....	33
CHAPTER 5. CONCLUSION AND RECOMMENDATION.....	34
5.1 Conclusion .....	34
5.2. Recommendation .....	34
References.....	35

## **List of tables**

Table 1 Geographical information of the studied site (Global Atlas) [3] .....	9
Table 2: Electrical Energy consumption.....	12
Table 3 Specification of the system component .....	14
Table 4. Components of the control circuit of the solar UPS backup grid connected.....	24
Table 5.Result .....	29

## List of figures

Figure 1. Average Temperature and Precipitation in Kigali for, 1993-2022 [2].....	9
Figure 2. Global PV power potential map [4] .....	10
Figure 3. Global Horizontal Irradiation map [4] .....	10
Figure 4. Daily solar radiation in Rwanda.....	11
Figure 5. Photovoltaic arrays of several groups .....	16
Figure 6: Physical model of designed system .....	20
Figure 7. Simulation of a solar UPS backup grid connected.....	24
Figure 8. Circuit showing solar ups serving electrical loads .....	25
Figure 9. Circuit Grid serving electrical loads .....	26
Figure 10.129, 856 tCO <sub>2</sub> is equivalent to 23, 783 litres of Gasoline not consumed.....	27
Figure 11.129,856 tCO <sub>2</sub> is equivalent to 129,856 people reducing energy use by 20%.....	27
Figure 12: Power cumulative distribution .....	30
Figure 13: Array voltage distribution .....	30
Figure 14: Annual GHG emissions (tCO <sub>2</sub> ).....	31
Figure 15: Annual cash flows (\$) .....	31
Figure 16. Performance ratio Graph .....	33

# 1. INTRODUCTION

## 1.1 Background

Any plan for eradicating poverty and promoting sustainable development must include clean energy as it is essential to reaching the SDGs. Two energy efficiency goals are reducing the quantity of energy needed to generate goods and services and decreasing the effects of air pollution. Rwanda has made commitments to increase its renewable energy share, and solar energy that plays a key role in reducing greenhouse gas emissions, this contributing to the country's efforts for mitigating the effects of climate change. Energy efficiency reduces the amount of energy needed to produce and provide services as well as the effects of air pollution. For example, insulating a building means it uses less energy for heating and cooling. There are several reasons to increase energy efficiency, and lowering energy use lowers energy costs and saves consumers money if additional costs associated with implementing energy-efficient technology are offset [1]. Renewable energy is the only option for future energy requirements, and the most promising solutions to supply energy in remote areas are photovoltaic (PV) and wind energy are the most promising options for energy provision in remote locations. More dependable and high-quality power is delivered to the connected load by uninterruptible power supplies that are connected to the utility grid and use renewable energy resources [2].

In Rwanda, improved access to sustainable energy services for commercial buildings is necessary for the development of revenue-generating ventures, the enhancement of public health, and an adequate supply of lighting and communication equipment. With 47% of Rwandan households linked to the national grid and 14% using off-grid solutions (mostly solar), the country's cumulative connectivity rate is 61.0%. The Rwandan government made a clear policy determination to diversify its electricity sources beyond the conventional dominant grid, including off-grid connections, during the development of the NST 2.

In 2025, Rwanda released an update energy policy, aiming for universal access to modern, sustainable and affordable energy services by 20230, including a 62.9% increase in electricity generation capacity by 2035, primarily focused on on-grid and off-grid solutions, renewable energy, and clean cooking initiatives. This policy emphasizes the development and utilization of renewable energy sources such as solar systems, hydropower, biomass and geothermal energy. It prioritizes the promotion of the use of those renewable sources for off-grid solutions such as solar systems.

Then, homes located far from the proposed national grid, to lower the cost of obtaining power and remove restrictions on previous government subsidies, coverage has been urged to use alternate, less expensive connections such as mini-grids and solar photovoltaic (PV) [3].

For sensitive loads including data centers, hospital medical support systems, aircraft computers, and communication systems, an uninterruptible power supply (UPS) system supplies clean, conditioned, and uninterruptible electricity. In general, the UPS system's output needs to be sinusoidally regulated with low total harmonic distortion (THD), regardless of sudden changes in the load connected to the system or variations in the input voltage [4]. In addition to the following: unity power factor, low transient response time from online to battery-powered mode and vice versa, high reliability, high efficiency, low cost, small size, and low weight. are additional crucial factors in the UPS system. In general, UPS systems can be divided into two categories: static and rotating. In the event of a grid loss, the rotary UPS system uses motors and generators to process, store, and supply power, whereas the static UPS system uses power electronics converters and inverters. Hybrid UPS systems, which combine both rotating and static UPS systems, are occasionally employed [4]. To achieve effective energy management in integrated systems, a UPS with a PV system assists in peak shaving, mitigating load fluctuations, and compensating for sporadic variations in renewable energy sources. The usage of renewable energy resources is rapidly growing to address the current problems of global warming and greenhouse gas emissions, and UPS is an additional crucial factor in the UPS system. In [5], a photovoltaic-powered broad system was also introduced.

## **1.2. Problems statement**

The biggest issue facing our globe now is climate change brought on by increased greenhouse gas emissions. Compared to prior years, Rwanda's CO<sub>2</sub> emissions increased from 219 thousand metric tons to 229 thousand metric tons in 2023, representing a 4.57 percent increase due to the use of fossil fuels to produce power that is harmful to the environment and public health [6]. These days, computers, workstations, and displays account for 42% of office electricity use since they provide High-quality, extremely dependable power in certain volumes and periods for computer and communications operations. According to estimates, sensitive equipment is now receiving a rising amount of electricity more than 30% of the total power currently obtained from utility providers. Furthermore, data may be lost or distorted if there is even a brief power outage. Important processes may be interrupted and sensitive components may be damaged if internal system communications lock up and need to be rebooted. The building's energy efficiency is also impacted by issues related to power distribution system

disruptions [7], with unbalanced distortion and harmonic distortion being the two main causes. Commercial buildings use a lot of energy and have a big impact on operating expenses and greenhouse gas emissions. Building owners' problems are made worse by a rise in the frequency and intensity of power outages as well as growing electricity costs. Although energy-efficient technology has advanced, there is still much unrealized potential in combining energy storage technologies like uninterruptible power supplies with renewable energy sources like photovoltaic systems. Grid dependability issues and rising electricity costs continue despite calls for creative ways to maximize energy use and guarantee a steady supply of power; combining a photovoltaic system with a UPS offers a viable way to improve resilience and energy efficiency in commercial buildings [1]. However, the best PV with UPS system design decreases grid fragility, maximizes energy savings, minimizes costs, improves power quality, and increases energy efficiency.

### **1.3 The objectives of the study**

#### **1.3.1 General objective**

The main objective of this project is to design a Photovoltaic-Uninterruptible power supply system, a backup grid system for improving energy efficiency in commercial buildings.

#### **1.3.2 Specific objectives**

- To assess the solar resources
- To assess electricity needs
- To build a physical model of the system
- To design a PV array
- Simulation of the system
- Performance Analysis

### **1.5. Scope of the project**

This thesis's primary objectives are to design a photovoltaic-uninterruptible power supply backup system to increase energy efficiency in commercial buildings, provide a general overview of the system, discuss its advantages for commercial buildings, human health, and the environment, and simulate the system as designed by EKTS.

## **1.6. Thesis organization**

**Chapter One:** "Overall Overview" The introduction, problem statement, the study's goals, and scope of the project.

**Chapter Two:** "Review of Literature" This chapter discusses the various types of Uninterruptible Power Supply (UPS) and the global working principle of its equipment through various diagrams that refer to the theoretical work done by other authors and researchers on the solar system and its components. The resources used in this chapter will come from books, magazines, journals, publications, catalogs, newspapers, and papers that are helpful for system design regarding the relevant information found via those resources.

**Chapter Three:** "Methodology." This chapter covers the mathematical expression of the system as well as explanations of the various components and processes that will be used in the project.

**Chapter Four:** "Results and Discussion": This will involve a discussion of the expected outcome as well as the simulation of the intended system using RET Screen and PVsyst

**Chapter Five:** " Conclusion and Recommendation." In this final chapter, the thesis will be concluded and various institutions, particularly commercial buildings, will receive suggestions. The sources of some of the information used in the main report and support documents are listed in the references after this chapter, respectively.

## CHAPTER 2: LITERATURE REVIEW

Regarding previous sustainability discussions, solar PV electricity generation might be viewed as advantageous when compared to numerous other energy sources. With almost no emissions while in operation and only the incoming light from the sun as fuel, solar photovoltaic is regarded as a low-emission energy source [8]. In contrast to non-renewable energy sources, solar PV systems have substantially reduced lifetime greenhouse gas emissions from mining, manufacture, and post-operation disposal.

Tobias Bengtsson Håkan Hult wrote on “Combination of Solar Energy and UPS System” where he employs MATLAB, an exploratory computer simulation program, to model a combined system before conducting actual experiments with it. Once more, he was conducting tests on a real prototype system that was built using fundamental solar power and UPS components. Additionally, he was conducting an economic analysis of energy balances and investment costs, contrasting two different systems (solar power and UPS separately) to a single system (solar power and UPS combined). The prototype system's results demonstrate that adding solar power to a UPS system does not significantly affect its operation; however, further integration would be required for best results. Conversely, under some operating situations, the extra power terminal that the solar panels provide can improve system performance. According to the economic analysis's findings, a combined system may result in lower investment costs because its components are less expensive and more energy savings because of its lower conversion rate [9]. The design of such a system, its analysis, its impact on energy generation and profitability, and the payback period estimates were not presented in this paper. In order to determine the system's net present value (NPV), he suggested conducting a comprehensive LCC analysis of all expenses related to the solar energy and UPS system.

David Velasco de la Fuente, César L. Trujillo Rodríguez, Gabriel Garcerá and Rubén Ortega González work on “Photovoltaic Power System with Battery Backup with Grid-Connection and Islanded Operation Capabilities. They present the analysis, design, and experimental results of a photovoltaic energy management system with battery backup. The system can operate in both grid-connected and island modes, and its main advantage is that in grid-connected mode, the inverter acts as a current source in phase with the grid voltage, injecting power to the grid and controlling the dc-link voltage, while the dc/dc converter controls the battery charge. In islanded mode, the inverter control is rearranged to function as a voltage source using droop schemes, and the DC/DC converter regulates the DC-link voltage to allow the maximum power

point tracking reference to be followed. An operation protocol is suggested to guarantee the energy supply's quality and reduce energy loss.

To store energy for islanded operation mode, a battery bank is linked to the DC link. Their study attempts to demonstrate that the suggested system operates as intended, free from hazardous transients for the loads or the inverter [10]. Through the use of experiments, simulations, and prototypes, their research demonstrated the viability of their suggested control technique. Their study did not, however, demonstrate whether their system could maximize the energy it produced.

Haris Jawaida, Nadeem Ehsanb, Ebtisam Mirzac, and Muhammad Waseem Bhatti work on 'Solar powered UPS'; To satisfy the needs of families and small offices that demand alternative energy sources, they do research on the development of a solar-powered UPS for the Pakistani market. Where they present the market study's design, methodology, and overall research conclusions. A solar panel and a specially made inverter circuit are part of the solar UPS's design. The solar panel's specifications and needs have been taken into consideration when designing the inverter circuit. To improve the current circuit, they examine more sample circuits that have been researched. Design engineers of UPSs that are currently on the market have also been enlisted to help identify potential substitutes if any components fail or become unavailable.

The investigation of the potential design and operation of a solar-powered UPS is presented in their article. It implies that solar UPSs have the potential to be a very effective and profitable substitute for electrical UPSs on the market. The design consists of two primary parts: an inverter circuit that transforms solar energy into alternating current for use in household appliances, and an external solar panel made up of solar cells that will transform solar energy into electrical energy. They found that solar panels are used as the high cost of maintenance-free batteries, lower efficiencies, higher prices of charge controllers, and high prices of silicon solar cells were the main reasons why solar energy was not being used domestically [1]. An average household's monthly consumption of 150 kWh will require an investment of US \$11000 to replace grid electricity with solar energy, which is too pricey for domestic customers to accept.

They have experience calibrating and configuring electrical UPS systems, and they use a test setup in a home lab with the majority of locally manufactured and seeking the knowledge and experience of some market power experts to arrive at the most practical answer. The outcome of the uncommon situation is a brief day of sunshine during the August monsoon,

with 1.67KWh of power available every day. If not, the amount of power available each day is 2.48 kWh or more, which is enough to support 800Watt households during a three-hour daily outage. Batteries that cannot be fully charged by solar panels in extreme situations, such as prolonged outages and heavy forecasts, can be charged using a dual input charge controller, which prioritizes solar power when the sun is shining and uses grid power to recharge the batteries if solar power is cut off [11]. They suggested using CPV and CPVT, two cutting-edge solar technologies that will be highly effective in Pakistan. Additionally, as solar panel prices continue to drop globally, the solar UPS will become an even more attractive home choice [4].

The power from the solar system cannot power the load without passing via the battery, since in many earlier works, the solar modules were simply connected to the battery. The solar panels are only utilized to fully recharge the battery pack in the event of a power outage because the battery in a UPS system must be maintained at full charge. The solar panels are not used until the battery is completely charged. Grid system design, solar PV, and a UPS that serves as a battery are used to provide stable and dependable energy in both normal and blackout situations.

## CHAPTER 3. METHODOLOGY

In order to reduce the cost of electricity from the power grid, the system in this thesis is built to always prioritize the use of energy from the solar modules. The solution suggested in this thesis depends on autonomous control and does not require a central control system because load management is isolated from the UPS. The procedures listed below will be used to create a photovoltaic system with a UPS as a backup to increase commercial buildings' energy efficiency.

### 3.1 Procedures to design solar PV system

Solar PV equipment for residential, commercial, and industrial buildings. The PV device will normally connect to the Main Distribution Board (MDB) of the premises, which means that, in the first case, all electricity produced would be consumed internally. Below are processes which guide the installation of a PV system [8]:

It ensures that fire prevention is taken into account. The following are some of the main elements that are known to raise the risk of fire in a solar PV system: Poor installation techniques, improper equipment uses, and the use of faulty and damaged equipment, inaccurate construction and wiring standards, and due to an incident of lightning. The following procedures help to correctly install the PV system are:

#### 3.1.1 Site assessment

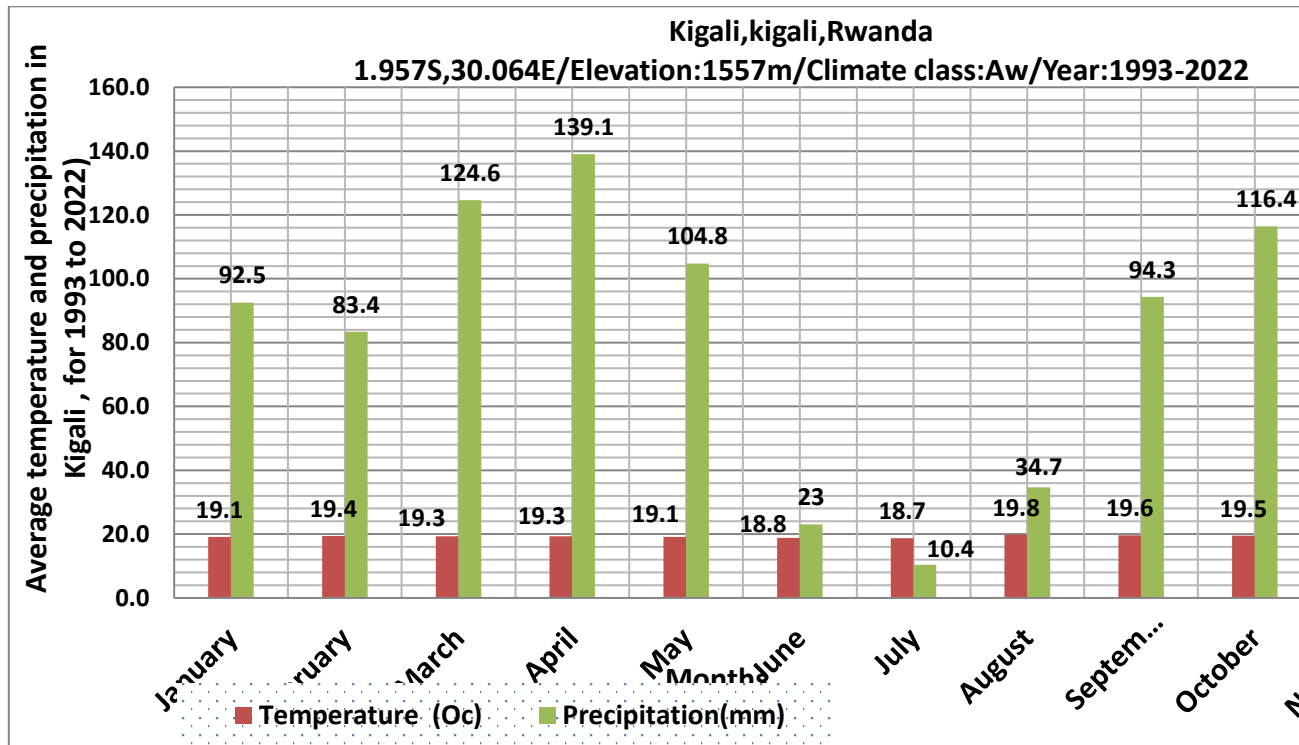
i) Select a location (e.g. space on rooftop)

Kigali

-01.950851<sup>0</sup>, 030.061507<sup>0</sup>

Kigali, Kigali City, Rwanda

Time zone: UTC+02, Africa/Kigali [CAT]



Average temperature: 19.2°C, Total precipitation: 1063.3mm

Figure 1. Average Temperature and Precipitation in Kigali for, 1993-2022 [2]

Table 1 Geographical information of the studied site (Global Atlas) [3]

Solar radiation data	Abbreviation	Value
Direct normal irradiation	DNI	1274.6 kWh/m <sup>2</sup>
Global horizontal irradiation	GHI	1890.1 kWh/m <sup>2</sup>
Diffuse horizontal irradiation	DIF	955.2 kWh/m <sup>2</sup>
Global tilted irradiation at optimum angle	GTI <sub>opta</sub>	1895.3 kWh/m <sup>2</sup>
Air temperature	TEMP	19.7°C
Terrain elevation	ELE	N/A
Optimum tilt of PV modules	OPTA	5/0°

the theoretical and practical amount of electricity that could be generated from solar energy using photovoltaic systems worldwide. This potential is determined by factors like solar radiation levels, system efficiency, available land area, economic constraints, and soft

constraints like regulations, population density, and proximity to human activity centers. Studies like the World Bank's Global Photovoltaic Power Potential by Country provide comprehensive data, identifying areas with significant untapped potential for PV development.

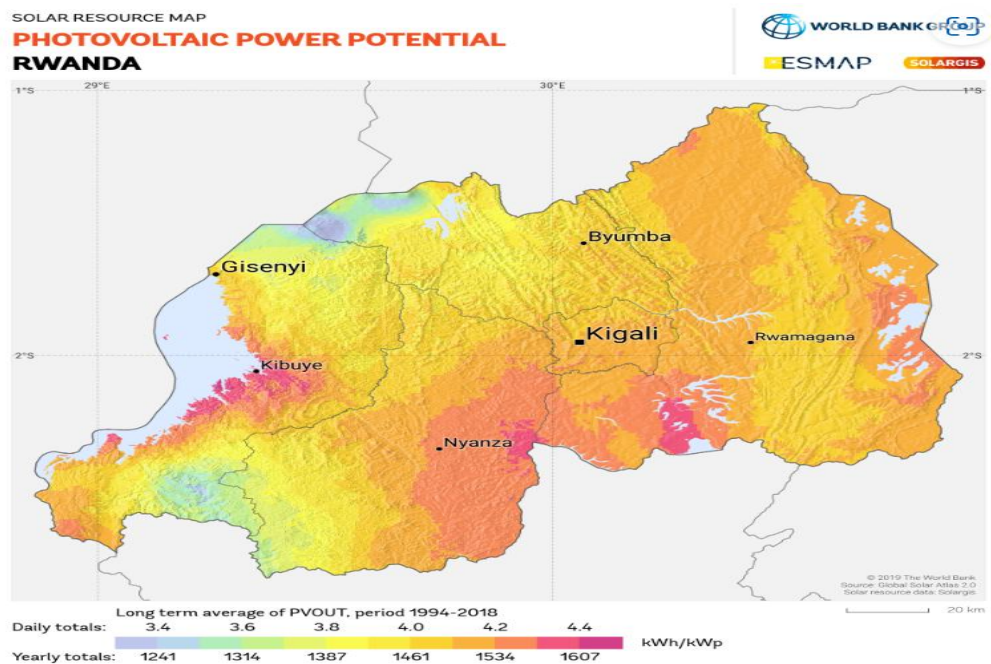


Figure 2. Global PV power potential map [4]

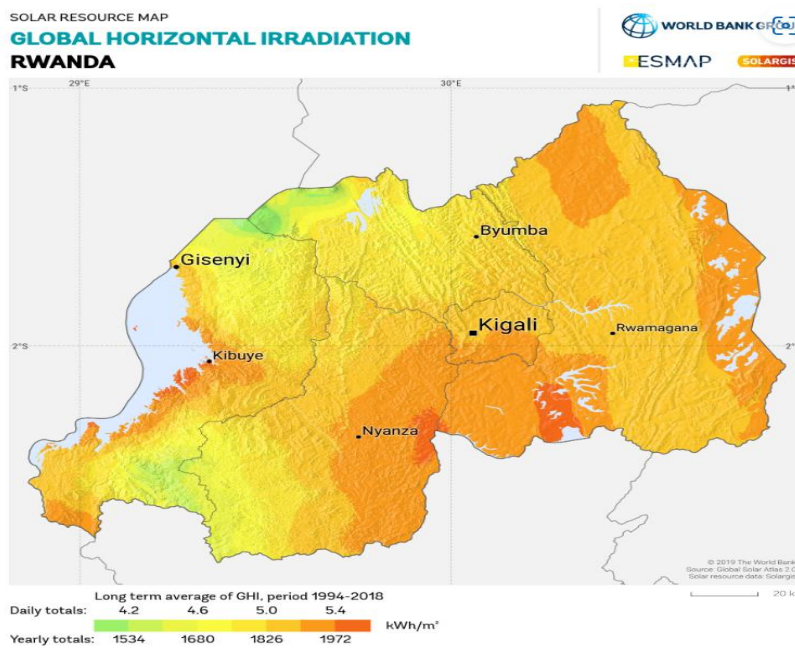


Figure 3. Global Horizontal Irradiation map [4]

the total solar radiation received on a horizontal surface at the Earth's surface, encompassing both direct sunlight and diffuse radiation scattered by the atmosphere. It's a critical measurement for understanding solar energy potential, particularly for photovoltaic (PV) power plants.

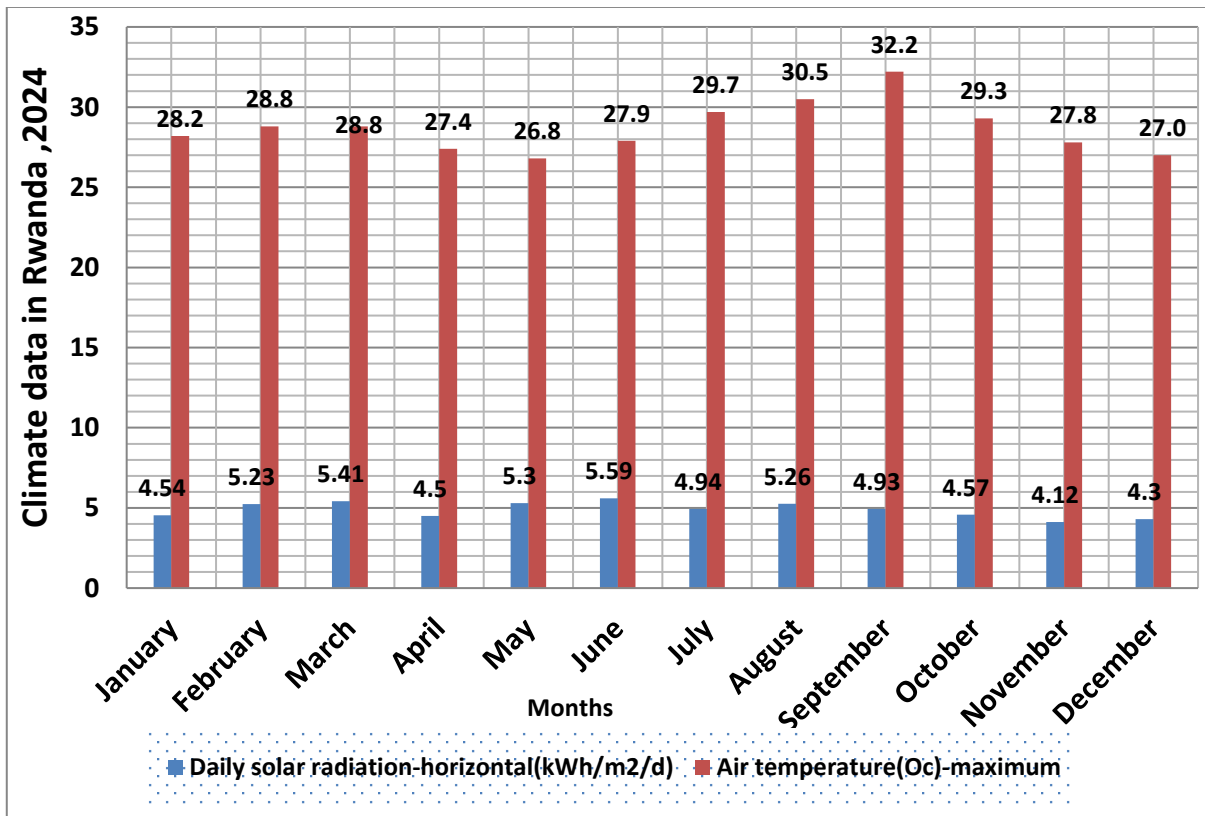


Figure 4. Daily solar radiation in Rwanda

the total amount of solar energy (sunlight) that strikes a specific surface area over the course of one day, typically measured in units like kilowatt-hours per square meter per day .It's a crucial factor for understanding and influencing plant growth through photosynthesis, as well as for designing and sizing systems like photovoltaic (PV) panels.

- ii) Assess the electricity demand of the building and choose the right size for the solar PV system: the process of forecasting future and current power needs to ensure sufficient, reliable, and efficient electricity supply, involving the measurement of electricity usage over time and at peak moments. This assessment includes understanding consumption

(total energy used in kWh) and demand (the rate of energy use in kW), and is vital for grid operations, cost management, and planning for new energy infrastructure like mini-grids. In this case, the building's electricity demand is generated by solar PV installations with a capacity of less than 50 kW and those with a capacity of more than 50 kW but not more than 5 MW.

### 3.1.2 Assessment of electricity needs

**Table 2: Electrical Energy consumption**

Appliance	Voltage(V)	Current(A)	Power(W)	Hour of use per day(hours)	Annual Energy
Kettle	230.00	9.57	2200.00	4.00	3212.00
Microwave	231.00	13.00	3003.00	3.00	3288.21
Vacuum cleaner	222.00	9.00	2000.00	3.00	2190.00
Water Heater	230.00	13.04	3000.00	2.00	2190.00
Air conditioner	230.00	4.87	1119.00	20.00	8168.70
Television	230.00	1.30	300.00	22.00	2409.00
Washing machine	230.00	9.13	2100.00	1.00	766.50
Lighting bulb-Energy saving	230.00	0.26	60.00	24.00	525.60
Cooker	230.00	19.57	4500.00	4.00	6570.00
Refrigerator	230.00	0.61	140.00	18.00	919.80
Fan	230.00	0.37	85.00	24.00	744.60
Pressing Iron	230.00	8.70	2000.00	2.00	1460.00
Toaster	230.00	6.09	1400.00	2.00	1022.00
<b>Total</b>					<b>33466.00</b>

The formula used for calculation in the table:

$$\text{Daily Energy} \times \text{Annual Activity (365 days)} = \text{Annual Energy} \quad (1)$$

$$\text{Energy (Wh)} = \text{Power (Watt)} \times \text{Time} \left( \frac{\text{hour}}{\text{day}} \right) \times 365 \left( \frac{\text{Day}}{\text{Year}} \right) \quad (2)$$

Recall that

$$\text{Total energy demand (kWh)} = \text{Total energy supplied (kWh)} \quad (3)$$

Next, we calculate the size of the PV system that will match the demand

$$\text{System Size (KW)} = \text{Average daily insolation} \left( \frac{\text{kWh}}{\text{m}^2 \text{ day}} \right) \times 365 \left( \frac{\text{days}}{\text{yr}} \right) \times \text{Efficiency (\%)} \quad (4)$$

The average daily insolation for the understudied location is  $5 \left( \frac{\text{kWh}}{\text{m}^2 \text{ day}} \right)$  so that the annual insolation is  $1620 \left( \frac{\text{kWh}}{\text{m}^2 \text{ day}} \right)$  (See table). In this study 85% system efficiency is assumed. Parts of the losses occur in the inverters and other components.

To obtain the required number of panels, we divide the system size by panel rating. In this project, 270Wp polycrystalline is used for design.

$$\text{Number of Modules} = \frac{\text{System Size (kW)}}{\text{Module power}} \quad (5)$$

Evaluate the installation site's space needs and maintenance access: When you are planning the installation site, you must first calculate the total amount of space that is required for the storage system. Consider future expansion, and plan accordingly. To evaluate an installation site's space and access needs, first, determine the required footprint of the equipment and its operational space, including service clearance and future growth. Then, assess environmental needs, plan access routes, and check for obstructions like doorways, stairs, or tight corners that could impede installation or maintenance. Finally, coordinate with maintenance personnel to ensure their access is adequate for routine and emergency tasks.

Solar PV System Integrator: This Licensed Contractor will be in charge of designing and executing the Solar PV System's connection to the electrical installation. Choose the PV Module, a) the quantity of PV modules required, b) Rating and kind, c) the mounting technique. To convert sunlight into electrical energy, a "photovoltaic array consisting of several groups" is made up of numerous modules. To increase dependability and reduce the cost of the necessary system voltage, a big array is split up into smaller sub-arrays. To generate the full array current at system voltage, these sub-arrays are connected in parallel. Additional justifications for splitting an array into sub-arrays include: (i) The charging controller (CC) may not be able to manage the charging current (I<sub>c</sub>), (ii) A large cable is required to transport the entire array current. (iii) Certain modules or charge controllers can be maintained or repaired without shutting down the entire system.

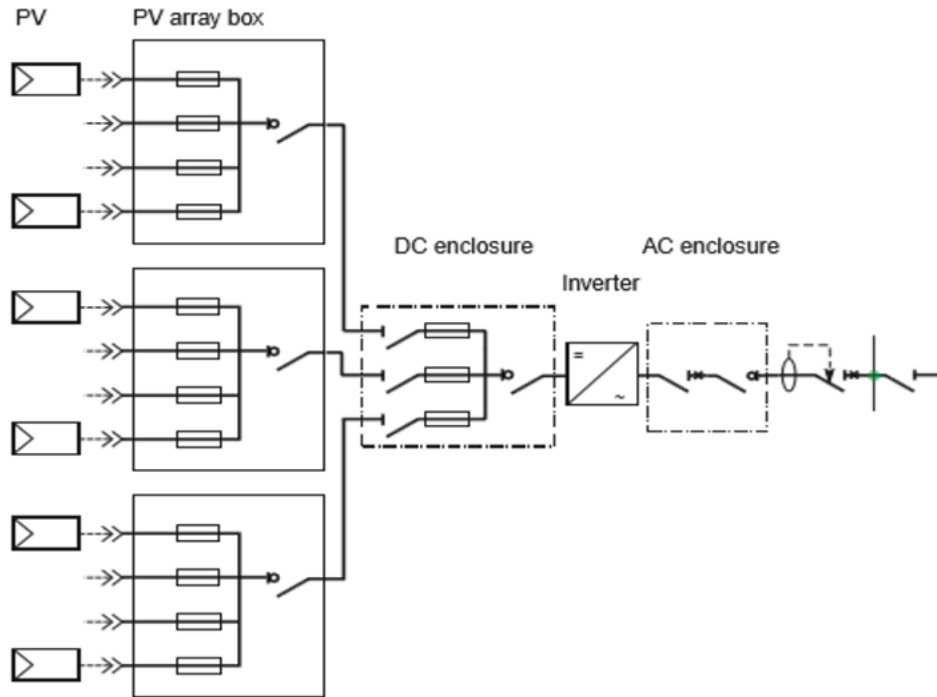
**Table 3 Specification of the system component**

Components	Specifications	Values
Module	Power (peak) Pmax(Wp)	270
	Tolerance-Pmax (W)	0 ±5%
	Maximum Power Voltage-Vmpp(V)	29.80
	Maximum Power Current-Impp(A)	8.31
	Open circuit voltage- Voc(V)	37.00
	Short Circuit Current -I <sub>sc</sub> (A)	8.92
	Module Efficiency(η)	16.60%
	Dimensions(m×m)	1640×992

Inverter	Nominal input voltage(V)	360
	Nominal output voltage (V)	220/230/240;180-280
	Maximum Short circuit(A)	15
	Input current(A)	11
	Frequency (Hz)	50
	Power factor	0.8
	Output power(w)	3600,4200,4600,5000
	Weight(m×m)	480*420*215
UPS	Time	30min
	Charging time	8hours
	Quantity	Two (48KW for UL-II,15KWfor PVC-II)
	Redundant	125% Overload for 10min,150% for 1min,250% for 20min
	Two battery units	48KW UPS has 320 Battery units (200AH each) while 16KW has 4000 units each (50AH).
	Voltage inspection range	-15% to +30%
Charge Controller	Rated voltage	15v-150v
	Charger current	50A -
	Ambient temperature	50C.....400C
	Weight	3140G

The number of charge controllers (NCC) and sub-arrays determined in this formula below:

$$N_{cc} \text{ or } N_{\text{sub-array}} = \frac{N_p \times I_{mp} \times 1.25}{I_{cc\text{-rating}}} \quad (6)$$



**Figure 5. Photovoltaic arrays of several groups**

**It's working principle:**

In the PV array boxes for each subgroup, the strings are paralleled. These boxes are equipped with monitoring devices, safety devices, and the required measuring tools.

A PV array box close to the inverter has the outputs of these boxes connected in parallel. A load block switch, which may or may not be installed in the PV array box, can be used to isolate the array from the inverter. The direct current flowing across the array is roughly 1000 V DC. In a photovoltaic array, every module should be identical (of the same type and brand) and chosen to provide the same amount of power. For instance, even though the same PV module product range includes modules with different power levels (170 W, 180 W, and 190 W), all of the modules should be 180 W. To facilitate maintenance, the DC and AC protection devices ought to be placed of close to the inverters [5].

**The general formula for calculating the array sizing and modules needed for any PV system is given below:**

Finding the estimated design insolation, or peak sun, for the specified location is the first stage in array sizing.

The minimal insolation (monthly average) ought to be regarded as the estimated design insolation for safety's sake.

Finding the array's total output current is the second stage in array scaling.

$$I_{array} = \frac{\text{Total Average Daily Load Ah System Voltage}}{\text{Peak Sun} \times \text{Derating Factor} \times \text{Coulombic Efficiency}} \quad (7)$$

Typically, the coulombic efficiency is 0.95 and the derating factor is assumed to be equal to 0.9. Note: The required number of modules is one of Imp's features. The number of modules required decreases as the Imp value increases. However, a higher Imp module has a greater price.

Finding the number of modules that must be connected in parallel ( $N_p$ ) to produce the required current, the number of strings of modules ( $N_s$ ) that must be connected in series to produce the necessary device voltage, and the total number of PV modules ( $N_t$ ) required to supply an average daily load (in Ah) at the system voltage constitute the third step.

$$N_p = \frac{I_{array}}{I_m} \quad (8)$$

$$N_s = \frac{\text{Nominal System Voltage}}{\text{Nominal module voltage}} \quad (9)$$

$$N_t = N_p \times N_s \quad (10)$$

III) Choose an inverter that complements the PV array: A) the quantity of inverters required. b) Type and rating of inverter. c) Inverter location (available for maintenance and inspection). In solar PV applications, inverters are utilized to supply electricity to devices and equipment that are powered by an AC source. DC to AC conversion is necessary since the solar PV system only produces and stores energy as DC voltage and current. Finding the power in the VA and selecting the right voltage input/output ratings determines the size of an inverter [6]. The inverter's power factor is PF, which is typically regarded as being equal to 0.8.

### **Fill Factor**

The ratio of maximum power output ( $P_{max}$ ) to the product of the open-circuit voltage and the short-circuit current is known as the fill factor. The array's quality is indicated by the fill factor. The array may generate more power the closer FF comes to 100% (unity). FF often falls between 0.7 to 0.8.

$$\text{Mathematically } FF = \frac{P_{\max}}{V_{oc} \cdot I_{sc}} \quad (11)$$

$$= \frac{V_{\max} \cdot I_{\max}}{V_{oc} \cdot I_{sc}} \quad (12)$$

Plugging in the values indicated in the table

This reveals the quality of the panel.

The rated capacity of the chosen Pi inverter is chosen to be double that of Pi min to guarantee that surging power is taken into consideration. If the total AC load (PL) is known, the minimum inverter VA (Pi) rating is determined using the formula below, which also helps determine Pi min and battery capacity (C):

$$P_{\text{in min}} = \frac{Pl}{PF} \quad (13)$$

$$C = \frac{E \times DOA}{\eta b \times DOD \times Bv} \quad (14)$$

**C**: Required capacity (in Ah) of the battery of Bv voltage; **E**: Average daily energy consumption by the load (in Wh); **DOA**: Number of autonomy days (in numbers);  $\eta b$ : Battery charging efficiency (value ranging from 0.8 to 0.95); **DOD**: Allowable depth of discharge of the battery and Bv: Battery bus voltage or working voltage (in Volts).

**Charge Controller Sizing (CC)** The device's voltage, maximum charging current, and maximum load current are the three fundamental factors that will determine which CC is best. The charging and load current measurements must be met by the ratings of the selected CC.

$$I_L = \frac{Pt}{Bv} [A] \quad (14)$$

$$I_c = \frac{E}{H_p \times Bv} [A] \quad (15)$$

Where: **Pt**: the total power of the devices to be powered from the system; Load current (IL); **Bv**: the battery bus voltage; The rated charging current (IC) means the solar module/array current supplied to the battery; **E**: Total energy consumed per day (Wh); **H<sub>p</sub>**: Peak sun (Hours) and **Bv**: Battery bus voltage (Service working voltage).

- For the solar PV system, choose the best mounting system (mechanical structure). Make sure mounting and attaching points are available.
- Evaluate the suggested mounting arrangement: a) It is necessary to check the additional load that the solar PV system on the roof has introduced. b) More wind loads need to be examined. c) Roof waterproofing must not be compromised during installation.

- Use several Maximum Power Point Tracking (mppt) tracking inverters or make sure all PV modules connected to the same inverter face the same direction.
  - Verify that PV modules are positioned at the ideal tilt angle based on the installation circumstances; generally speaking, a tilt angle of 10° to 20° is advised.
  - Make sure there is enough room behind the PV array for air to provide cooling.
  - Verify that: a) The cabling is rated appropriately for use in the environment and has a sufficient current-carrying capability. b) DC cables are double-insulated and single-core. c) Outdoor wires need to have insulation that can tolerate high temperatures.
  - Assess the necessity of a lightning protection system. Speak with a lightning expert. Make sure the installation satisfies all of the criteria of the most recent edition of the Electricity Wiring Regulations, including testing, inspection, labeling, and isolation and switching, Protection, and general principles.
- a) PV systems should only be installed by trained and experienced installers; b) safety regulations must be followed; c) the installer must wear personal protective equipment (PPE); and d) only appropriate approved safety equipment, such as scaffolding, stepladders, etc. Cables need to be routed, secured, and connected correctly. Verify that insulation and continuity tests are completed. The completion of the necessary testing, inspection, and documentation. and Verify that the design satisfies local utility approval and connectivity requirements.

Five conditions must be satisfied until interconnected network processes synchronize [9]. The source's line voltage, frequency, phase sequence, phase angle, and generator or sub-network waveform must all match those of the system it is synchronized with.

### **Advantage of Solar Power System**

The benefits of solar electricity generation are numerous, including some examples of renewable energy are as follows: during the day, solar energy can take the role of traditional power sources. Although solar power plants don't occupy a lot of land, they still need a lot more room than a fossil fuel power plant of comparable capacity. Large, continuous tracts of land are not necessary for solar power to produce electricity, though. Waste products like carbon dioxide and other chemical pollutants are produced in small or negligible amounts by solar power. And Solar power, which is generated from the sun, lowers operating expenses.

### 3.1.3 Physical Structure

It demonstrates how to connect two power sources (the power grid and a photovoltaic array) to a UPS using a charging controller. This makes the system easy to use and inexpensive. It also prevents battery overcharging, blocks reverse current, maintains a steady voltage, overcomes conditions, and tracks maximum power point (MPPT). The system can drive 500 Wattage AC-DC devices, including UPS battery charging. The Advance Controller makes the system efficient. The battery bank (UPS) will receive DC from the charging controller and store it as DC while the AC from the charging controller will continue to serve the AC loads. Batteries will supply the DC to DC loads directly, bypassing the inverter, and an inverter will convert the DC from the batteries into the AC needed by the AC loads as a backup power source during utility power outages [7]. It should be noted that the charging controller's and the inverter's AC cannot run concurrently; rather, they must be interlocked, with one operating while the other is off.

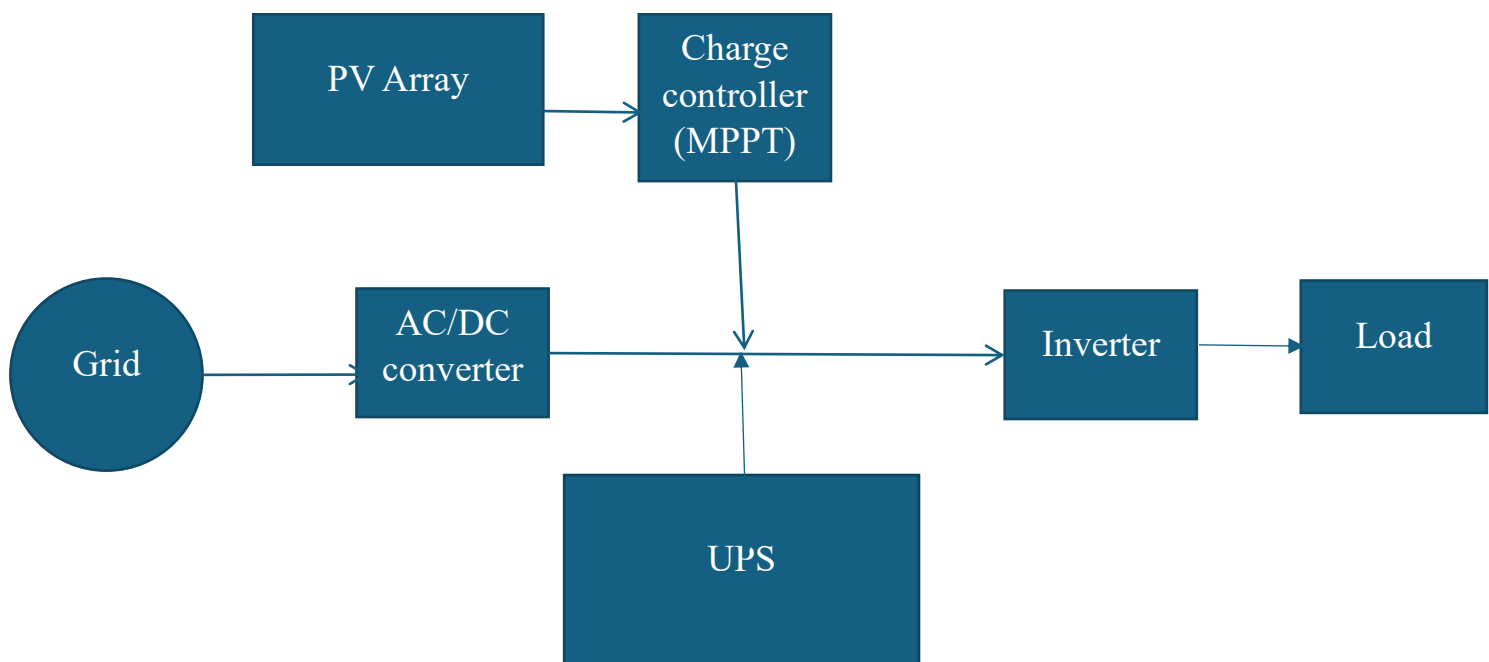


Figure 6: Physical Structure of designed system

### 3.1.3.1 UPS

The UPS system evaluates different tactics from a budgetary standpoint. The UPS's useful life is restricted to 5,000 cycles or 20 years of anticipated life. An annual maintenance budget of 1.5% of the speculative cost is allocated to photovoltaic and rechargeable systems. Assume that the PV and UPS systems have similar costs based on their respective sizes. The formula that follows will allow them to determine the appropriate battery size.

Battery capacity is used to compute UPS capacity.

$$\text{Battery capacity} = \frac{\text{Total Watt-hours per day used by appliances} \times \text{Days of autonomy}}{(0.85 \times 0.6 \times \text{nominal battery voltage})}$$

(16)

Power need, power factor, cost, size and weight, grid environment, protection, reliability, required level of power quality, and battery bank size are some of the variables that can be utilized to choose the UPS [4].

#### **Here are the steps followed when choosing the UPS system**

Identifying the necessity of a UPS system: The application for which the system is selected has a significant influence on the UPS system selection. Military equipment, communication devices, hospital life support and medical equipment, and other applications cannot withstand even brief power outages. For such an application, a UPS system should be used to supply backup power until the electrical grid is restored. The backup process for data centers might only take a few seconds before the machines are turned off. Statistics regarding UPS system selection can be improved by looking at power providers' historical business outages.

Finding the UPS system's power requirements: The UPS system's size is determined by specifications including load kVA, power factor, inrush current, load voltage, number of phases, frequency, and backup duration. Depending on the load, the load power factor should be between 0.7 and 1. The magnitude of the load and the amount of time needed for backup until the essential load is safely turned down determine the battery size. As the rate of discharge rises, ampere-hour (AH) capabilities fall [12]. The approximate size of the battery for varied loads is determined by adding the ampere-hour of each load.

Selecting type of UPS system: Selection of UPS system depends upon the power quality, protection, efficiency, volumetric size, and weight of the system [8].

Select configuration of UPS system: The level of protection and the power requirement of the load determine the type and configuration of the UPS system.

Transformer-based UPS are more suitable for high power applications. They are more suitable to provide protection even in the polluted grid environment to more sensitive equipment like medical equipment and data centers because of the galvanic isolation. While the transformerless UPS systems are cheaper, with a smaller size, and are suitable for low power applications. They are more suitable for circumstances, where the grid supply is less polluted. Similarly, the complex control system also escalates the cost of the UPS system. So the choice of the UPS system is determined by the balance between the performance and cost, taking into consideration the acceptable level of other factors, which best suits the circumstances.

Safety of UPS system: Safety should be given utmost importance before selecting any UPS system. For safety, it is preferred to follow the codes and standards adopted by government and commercial agencies. Battery bank needs special care and safety for its sound operation

Availability of UPS system: Since the UPS system provides backup to critical loads without any interruption. The availability and reliability of the system is very crucial. The availability of the UPS system, MTBF is the Mean Time before Failure, and MTTR is the Mean Time to Repair, are used to calculate the availability of the system and reliability. The reliability of the UPS system can be improved by introducing the redundant units in parallel, where each one is capable of sharing the connected load. And then check if the UPS system you selected is affordable [9]

### **3.1.3.2 Charge Controller**

The charge controller, sometimes referred to as a photovoltaic controller or charger, is only necessary for the system that involves a battery. The main capacity of the charge controller is to counteract the battery spoofing. The basic function of a 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 overcharging can lead to destruction of the battery, and undercharging decreases the battery life. Another important reason to use a charge controller is to prevent a reverse current flowing from battery to the system.

Two types of controllers are widely available in the market: Pulse width Modulation (PWM) and Maximum Power Point Tracking. [10]

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.

### **3.1.3.3. 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 than PWM. Though the MPPT charge controllers enable you to have better efficiencies and provide more power than PWM for similar conditions, the main cause of not opting for MPPT is the price of it, because MPPT charge controllers are more expensive than PWM. To select the size of the charge controller, one must know the voltage level of the system and the maximum operating current. In the system design, I will use MPPT as a charge controller.

### **3.1.3.4 Inverter**

Inverter deals with the 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 and ensure that the condition of the AC waveform is suitable for the application.

Inverters used for solar PV systems are usually based upon the total wattage of the solar panels, as the inverter will be continuously converting the power generated. The second consideration one must investigate, is the voltage level of the system.

For companies investing in solar energy or other renewables, a commercial inverter is the gateway that makes clean power usable and efficient. A well-designed inverter ensures that solar generation is synchronized with building loads, stored effectively when paired with a battery system, and exported back to the grid when beneficial.

business inverters are designed with hybrid functionality, enabling businesses to harness solar power while also supporting battery energy storage. This opens the door to greater energy autonomy and long-term cost savings while aligning with global climate.

## Electrical Control Techniques Simulator (EKTS)

The simulation was simulated using the software Electrical Control Techniques Simulator (EKTS), which is a simulation of motor control software for electrochemical systems design. Which use relays, time relays, contactors, buttons, motors, switches, and other simple mechanical systems to build a variety of electromechanical systems. EKTS motor control circuit simulator allows building custom motor circuits using different motor types, including single and three phase motors in different quantities.

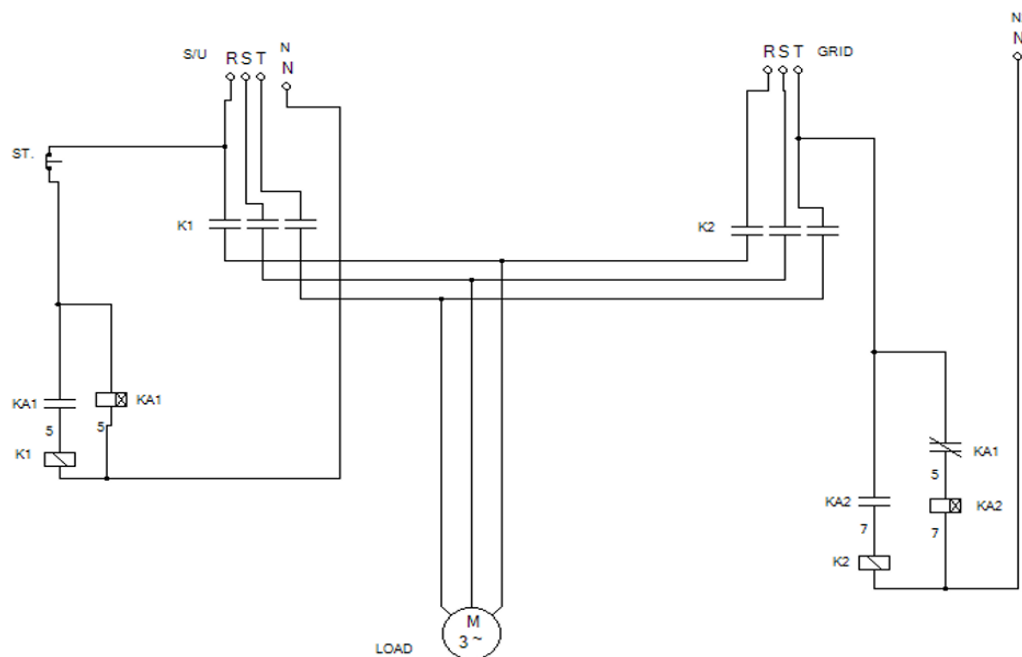


Figure 7. Simulation of a solar UPS backup grid connected

	Element	Quantity	Label	⏏	⏏
	On-delay Time Relay	2	KA2 KA1	1 1	0 1
	Contactor	2	K1 K2	3 3	0 0
	Stop Button	1			
	Neutral	2			
	Three Phase Induction Motor	1			
	3-Phase Supply	2			

Table 4. Components of the control circuit of the solar UPS backup grid connected

### At normal operating mode

Solar-UPS serves electrical loads in regular operating mode: solar with UPS as back-up power source, by using alternating current from an inverter output. Remember that the inverter's input power comes from direct solar current or storage (UPS). This means that the Solar-UPS is ON, but the Grid is OFF. The coils of time relay KA1 is energized as well as coils of contactor K1 that help activate the contactor K1 and disconnect the normal closed time relay KA1. then electricity flowing into electrical loads.

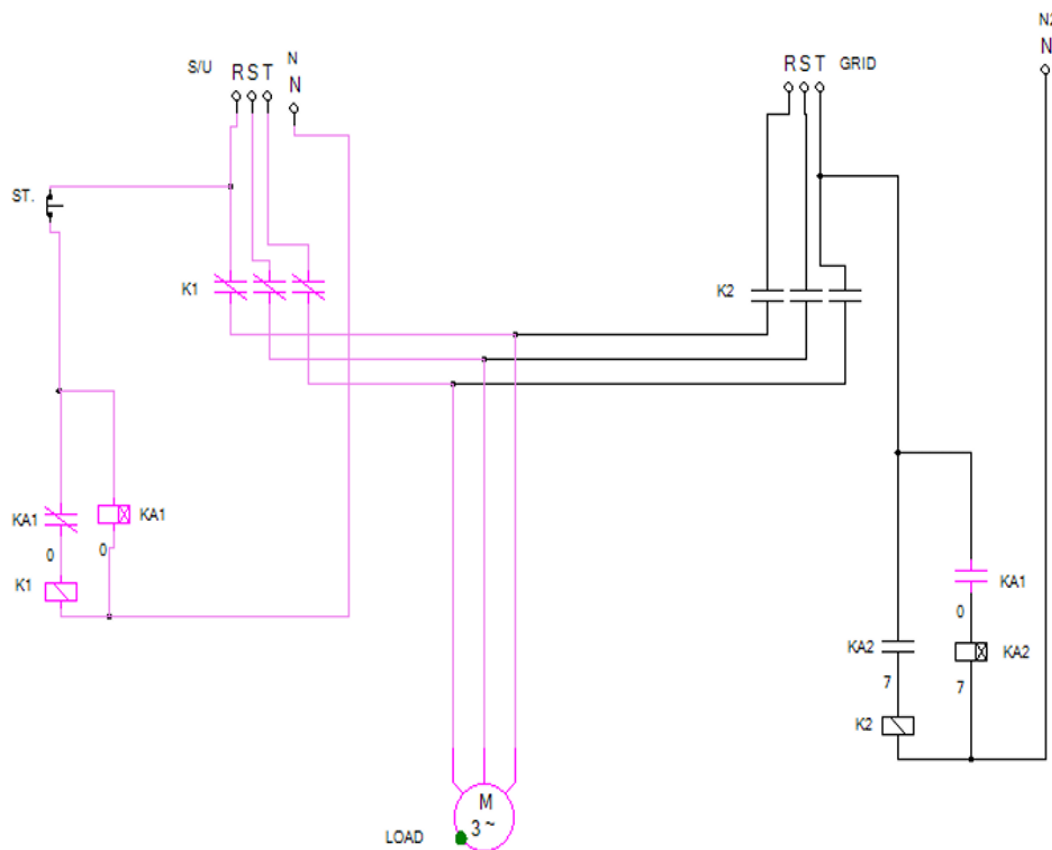
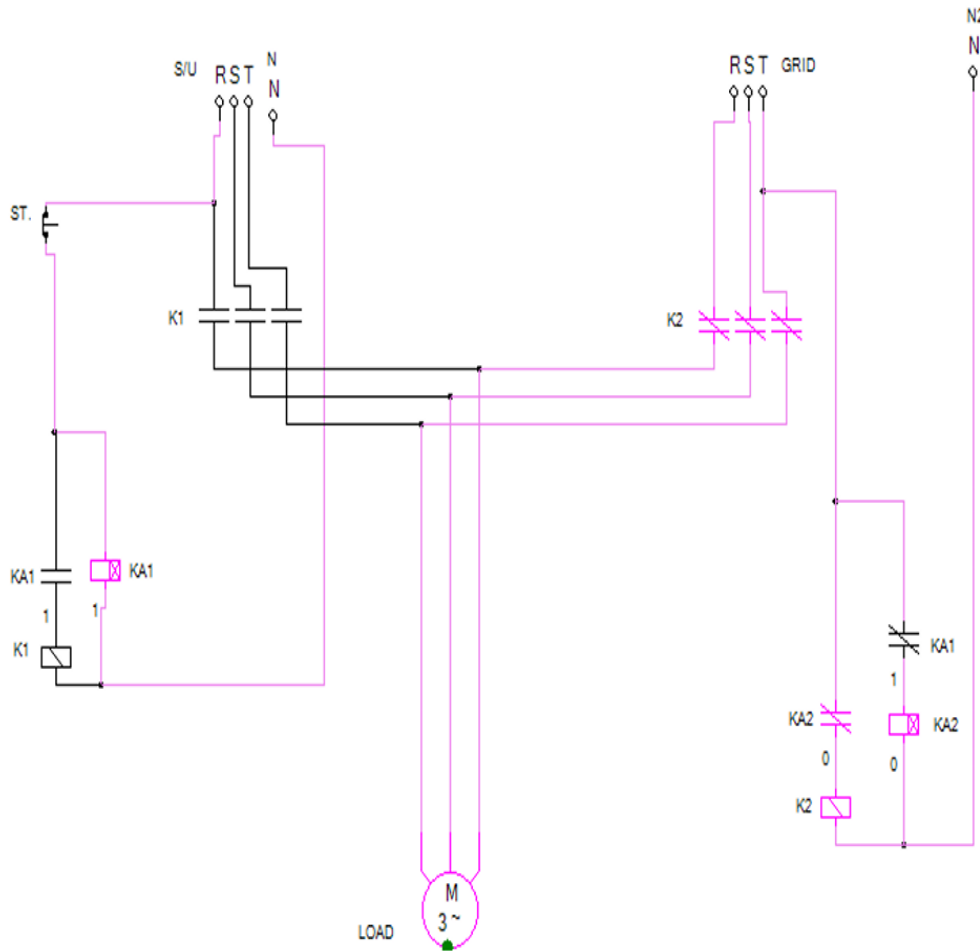


Figure 8. Circuit showing solar ups serving electrical loads

**In abnormal operating mode:** The time relay will account for 7 seconds, then the grid starts to serve electrical loads in regular operating mode. Note that interlocking indicates that the solar ups power is OFF while the grid is running. When electricity flows through it, coils of time relay KA2 are energized as well as contactor coils K2 that help activate the contactor K2 and disconnect normal closed time relay KA1. Then electricity flowing into the electrical loads.



**Figure 9. Circuit Grid serving electrical loads**

#### **4.2. Greenhouse Gas (GHG) Emission Analysis of the Proposed System**

GHG (greenhouse gas) emissions are produced throughout the solar photovoltaic power generation process, and the materials used to make the cells are potentially unstable and could eventually run out. The system requires harmful materials that pollute the environment, and research is currently ongoing to find a workable method for recycling solar waste. A significant quantity of energy is needed for panel production, most of which comes from Rwandan coal-fired plants. For example, enough data indicating human labor and water consumption are not

accurately analyzed to determine whether waste is released into the air, water, or soil during the production phase due to a lack of systematic and reliable analysis in the scientific literature.

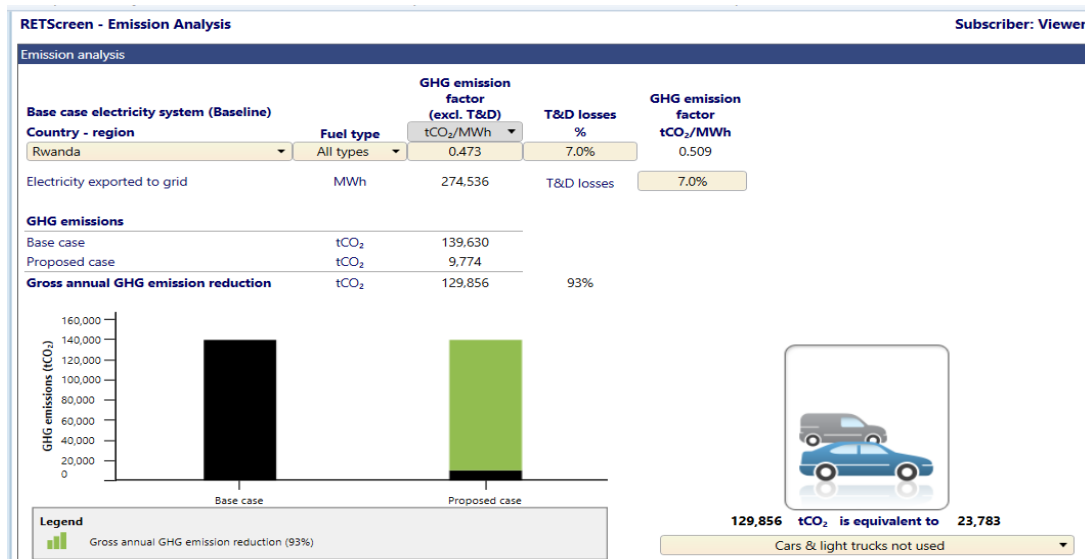


Figure 10.129, 856 tCO<sub>2</sub> is equivalent to 23,783 litres of fuel not consumed

The simulation results here show 11,839,248 litres of fuel not consumed with 95 panels on the roof. The petroleum product is the most consumed in Rwanda due to its large reserve and its production. If carbon foot-print is reduced by 27,554 tCO<sub>2</sub>, in these buildings, then yearly target can be achieved when other selected buildings in strategic locations are retrofitted in like manner.

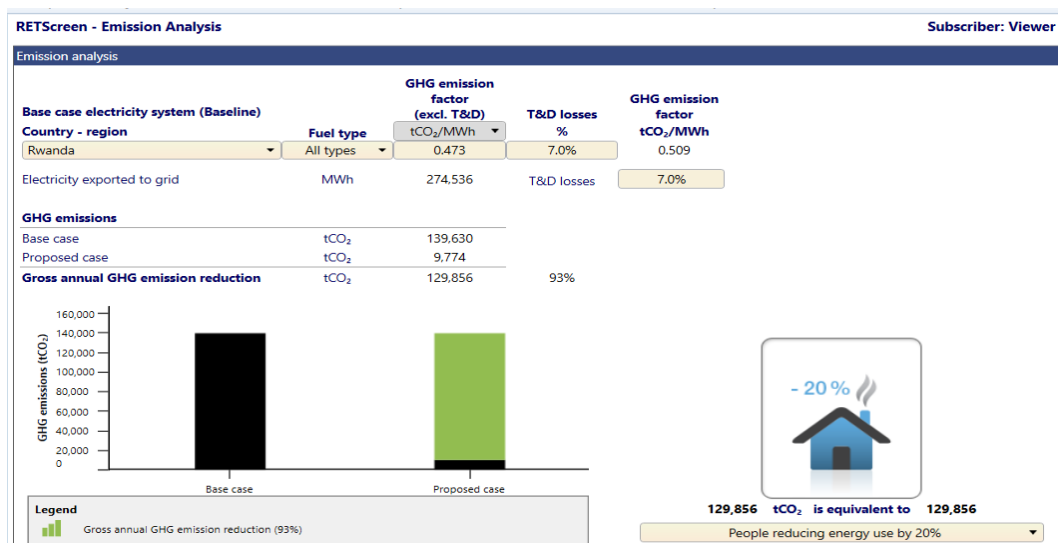


Figure 11.129, 856 tCO<sub>2</sub> is equivalent to 129,856 people reducing energy use by 20%

The RET Screen results indicate a percentage energy decrease of 129,856 tCO<sub>2</sub>. Since the generator runs on fuel, installing 95 panels will result in a 20% decrease in energy consumption and a smaller carbon footprint. Approximately 129,856 people reduced their energy use by 20% (fig.11). The main topic of this study is energy efficiency. The technical definition of energy efficiency is the ratio of usable energy output to total energy intake. For accurate analysis, the concept of energy efficiency usually includes wasted energy. Waste or wasted energy is converted into heat, which is then released into the atmosphere via the radiator or exhaust.

**Base Case:**

$$\text{Electricity exported to the grid} \times \text{Emission factor} \tag{17}$$

**Proposed Case:**

Electricity exported to the grid  $\times$  Emission factor  $\times$  Transmission and Distribution factor (18)  
 (T&D) Plug in the values including (T&D) which is 7% in RET screen:

**Gross Annual GHG Emission Reduction (tCO<sub>2</sub>):**

$$\text{Base case tCO}_2 - \text{Proposed Case tCO}_2 \tag{19}$$

**Percentage Annual GHG Emission Reduction:**

$$\frac{(\text{Gross annual GHG emission reduction})(\text{tCO}_2)}{\text{Base case}(\text{tCO}_2)} \tag{20}$$

## CHAPTER 4: RESULTS AND DISCUSSION

### 4.1. Interpretation of results

Table 5.Result

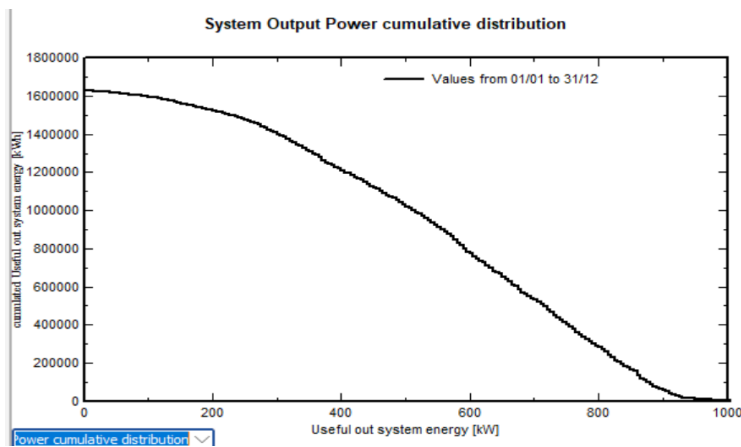
Item	Value
Annual Energy(kWh)	33466.5
System size(kW)	24.3009
Number of modules	90
Fill factor	0.75
Performance ratio	0.843
Gross Annual GHG Emission Reduction	129,856
Percentage Annual GHG Emission Reduction	0.93

According to the analytical computation, precisely 90 panels are required to satisfy the energy demand. However, the design calls for 95 panels to be installed on the roofs of the buildings that were chosen at location with Average temperature: 19.2<sup>0</sup>C, Total precipitation: 1063.3mm with system production equal to 1629MWh/year, system losses 0.06kWh/kWp/day, Array losses 0.68kWh/kWp/day and performance ration 0.858 as it was shown in methodology and simulation.

The graphs and the chart bar show the Power cumulative distribution, Array voltage distribution, Annual GHG emissions (tCO<sub>2</sub>), Annual cash flows (\$), Energy profile chart bar and Performance ratio Graph.

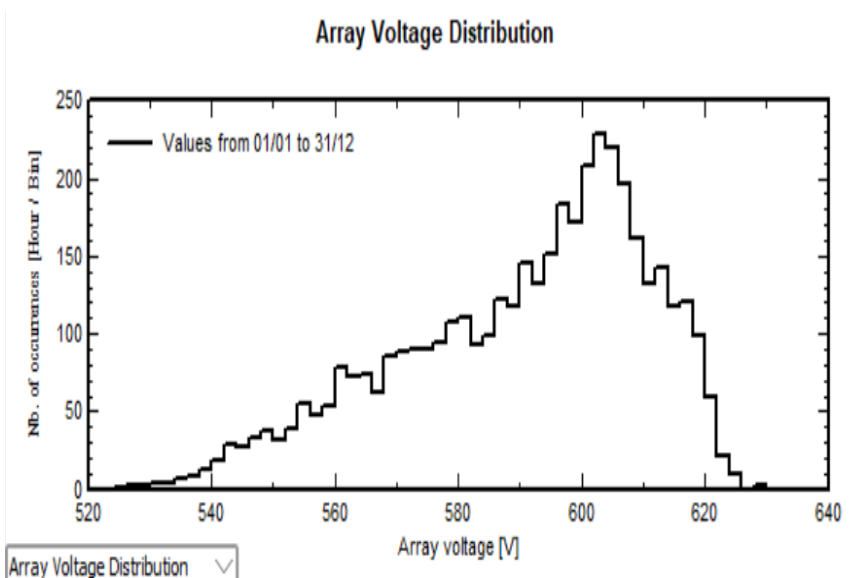
The cumulative distribution function is used to describe the probability distribution of random variables. It can be used to describe the probability for a discrete, continuous

or mixed variable. It is obtained by summing up the probability density function and getting the cumulative probability for a random variable.



**Figure 12: Power cumulative distribution**

This figure describes the power cumulative distribution by using two variables. Useful out system energy (kW) and cumulative useful system energy (kWh). As the useful out system energy increases, the cumulated useful out system energy (kWh) decreases and vice versa. Annual data were used to illustrate that figure.



**Figure 13: Array voltage distribution**

It is described that, in case an array exposed to solar energy, voltage distribution shows the peak which is corresponding to peak sunlight hours. Therefore, the higher the sunlight, the

higher occurrence of voltage value in Bins. When the sunlight gets weak, the occurrence of voltage is fall down too.

It is proposed that this designed system will have power capacity of 1000kw and capacity factor of 0.8%, initial cost will be 1900\$/kw-year O&M cost (saving) 25000\$, thus, electricity will export to grid 70080 kWh with export revenue of 7008\$.

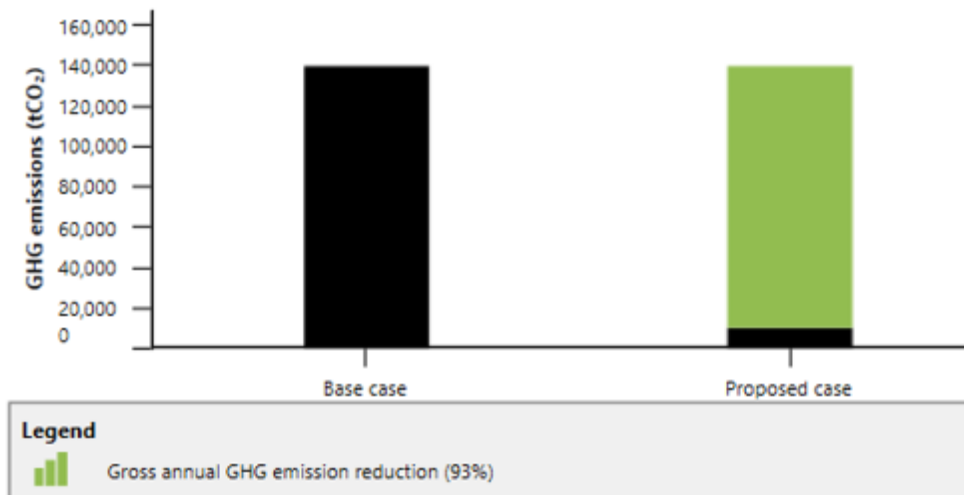


Figure 14: Annual GHG emissions (tCO<sub>2</sub>)

Based on simulation results, it was observed that 93% equivalent 129,856 tCO<sub>2</sub> of the gross annual GHG emission of base case (139,630 tCO<sub>2</sub>) should be reduced to 7%, the remaining rate of annual GHG emission as proposed case which is equivalent to 9774 tCO<sub>2</sub>emissions.

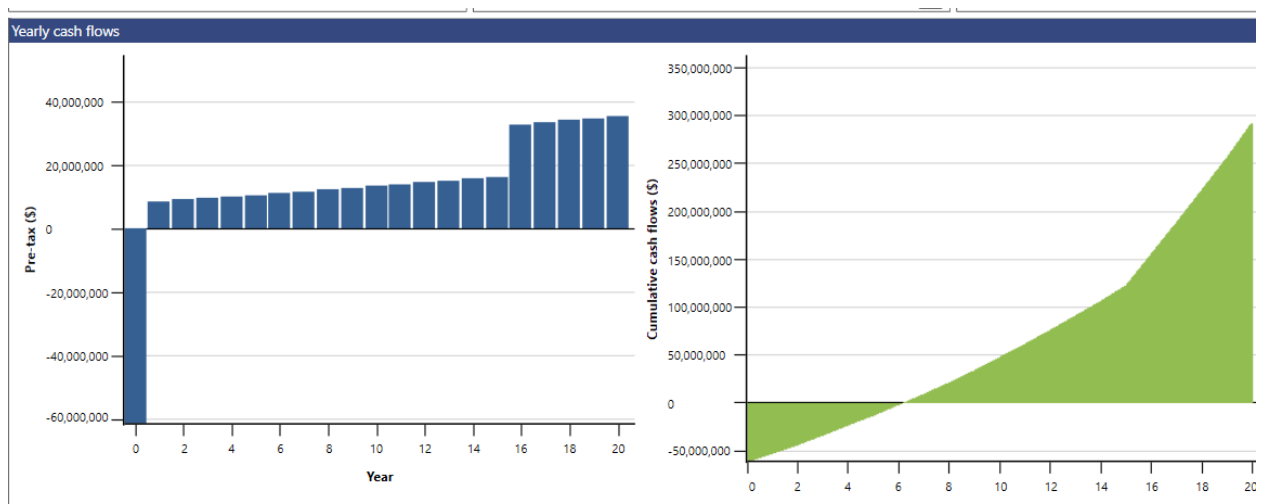


Figure 15: Annual cash flows (\$)

The results described the relationship between pre-taxes (in dollars) and cumulative cash flows at every year where the Net present value was equivalent to 66,837,220\$ per Year.

Most buildings are upgraded bit by bit as their components age and need repair. Often, a better way to improve energy efficiency is to use a whole-building approach and take advantage of the opportunity to implement deep retrofits. The upfront cost may be more, but the potential long-term savings will be greater over the life of the building.

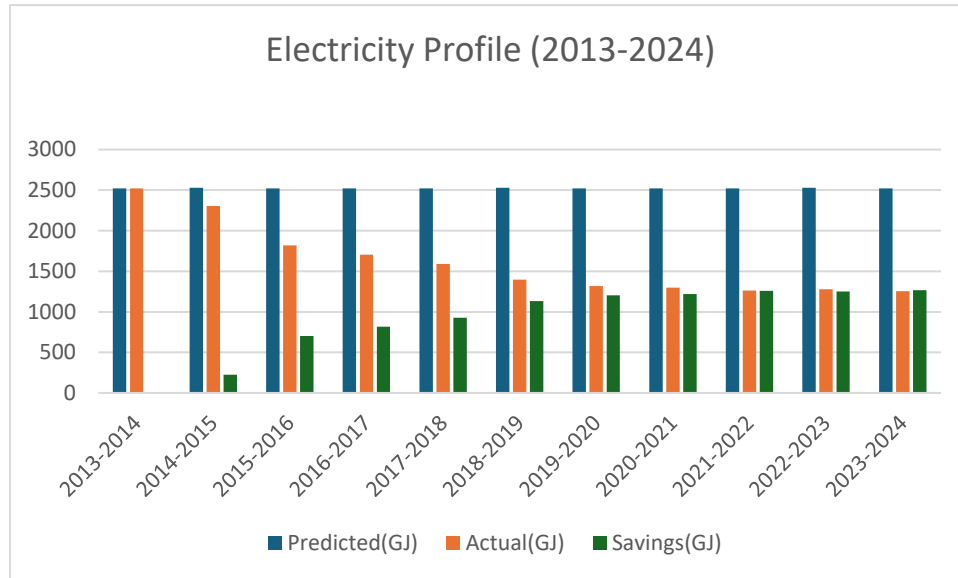
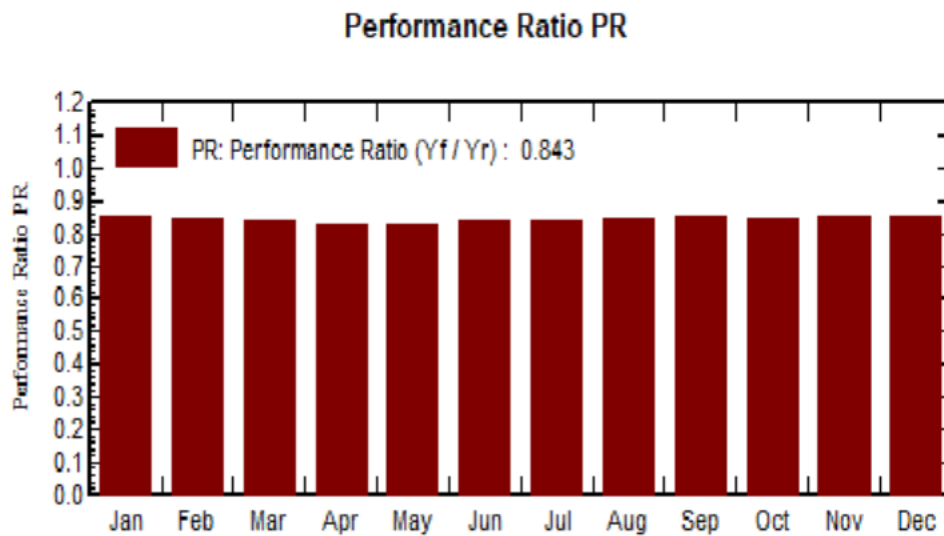


Figure 16. Energy profile chart bar [2]

The predicted electricity consumption remains consistently high, around 2500 GJ, for every year from 2013-2014 to 2023-2024. This suggests a consistent high target or baseline for energy usage. The actual electricity consumption shows some fluctuation but is generally below the predicted consumption. The actual consumption is consistently lower, hovering around 1250-1300 GJ. This lower actual usage indicates an improvement in energy efficiency or a reduction in energy demand compared to the predicted baseline. The data suggests a significant and sustained improvement in energy efficiency starting around the 2015-2016 period. The gap between the consistently high predicted consumption (2500 GJ) and the consistently lower actual consumption, which is represented by "Savings (GJ)" bar (peaking near 1000-1250 GJ), is evidence of successful implementation of energy-saving measures or a systemic reduction in energy needs over the 11-year period.

### 3.1.4 Performance ratio (P.R) of the PV System

Performance ratio is one of the most crucial variables for assessing a PV system's efficiency. It is specifically defined as the ratio of the system's theoretical (estimated) potential energy outputs to the actual reading of the plant output (kWh annually) [15]. It mostly depends on the PV plant's orientation and the incident solar radiation in the understudied area. For this reason, PV plants that supply the grid at various places worldwide are compared using performance ratios. [15] Since the performance ratio is a location-independent indicator of a PV plant's quality, it is frequently referred to as a quality factor. Although a 100% performance ratio indicates effective operation, real-time efficiency cannot be reached because of inevitable losses related to the PV system or plant. Performance ratios are primarily used to inform a PV system's energy efficiency and dependability. Thermal losses brought on by the PV module's heating are a common example. On the other hand, high performance systems typically achieve an 80% performance ratio. [15]



**Figure 17. Performance ratio Graph**

As results, the calculated performance ratio was 0.843. This implies that effective operation of designed PV system is high. The low performance ratio indicates the low effectiveness of the PV system operation and the higher the performance ratio, the higher the effectiveness of the PV system operation.

## **CHAPTER 5. CONCLUSION AND RECOMMENDATION**

### **5.1 Conclusion**

The tilting angle and module orientation are crucial engineering concerns in solar installations. Solar energy is primarily sourced from the sun, and panels oriented directly toward the sun absorb more energy. Panels facing south generate more electricity. Proper orientation depends on the panel's location, with northern hemisphere panels facing true south and southern hemisphere panels facing true north. and the study shows that an uninterruptible photovoltaic-power supply backup in commercial building is feasible and it can improve energy efficient.

### **Grid-Connected PV System and Net-metering**

Net-metering allows customers to export excess solar energy to the grid, offsetting imported electricity. Energy suppliers receive credit when excess energy is returned, becoming prosumers. Off-grid systems don't require batteries, but grid-tie systems do. Selling stored energy back at peak prices offers additional benefits.

### **5.2. Recommendation**

The following suggestions are encouraged following the completion of this technical feasibility study. It suggests that the appropriate institution should put this into practice. According to the seventh sustainable development goal, energy may be improved by investing in solar, wind, and thermal power. Making sure everyone is energized and productive is crucial. More work is recommended to fully assess the country to achieve SDG 7 by 2030. It might be able to generate enough gigawatts of solar power.

The government of Rwanda is also encouraged to try its hand at solar technologies, especially the ministry of education. Because it might be used to generate power, cook, and heat water. To guarantee that the current issue in the industrial sector may serve as the foundation for the research, the University of Rwanda (UR) is also encouraged to work with impressive firms. Additionally, it is recommended that UR reimburse students for their research costs to facilitate the collection of field data, especially for graduate students.

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