COLLEGE OF SCIENCE AND TECHNOLOGY

FEASIBILITY STUDY OF USING SOLAR PANELS TO POWER BTS OR TELECOMMUNICATION SITE FOR COST MINIMIZATION PURPOSES.

CASE STUDY: RWANDA

ACEESD/EPS/21/12

A project submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD), College of science and technology, University of Rwanda.

In partial fulfillment of the requirement for the degree of Master of Science in electrical power systems

By: SEBASINGA Jean Pierre with Ref:220000121

Supervisor: Prof. Etienne NTAGWIRUMUGARA

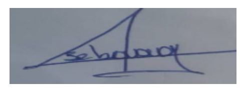
Co-supervisor: James NTAGANDA

November 2021

Kigali-Rwanda

DECLARATION

I, the undersigned, hereby confirm that this Project is my original work and that it has not been submitted for a degree at the University of Rwanda or any other university. All sources of materials used in the research project have been fully recognized.

Names: SEBASINGA Jean Pierre Signature 

APPROVAL

Submission Date: 05/11/2021

This thesis has been submitted for examination with my authorization as a university supervisor.

Prof Etienne NTAGWIRUMUGARA and James NTAGANDA

……… ……………………..

Thesis Supervisor Signature

ACKNOWLGEMENT

My sincerely gratitude and appreciation go to: Our Lord and Savior Jesus Christ, the Almighty God, whose grace is sufficient.

My supervisors, Professor Étienne NTAGWIRUMUGARA and James Ntaganda, for their patience, motivation, and spiritual guidance throughout the study period.

University of Rwanda administration, college of science and technology African Center of Excellence in Energy and Sustainable Development (ACE-ESD), lectures from the electrical power system for skills and their treasured knowledge that have been a major tool for guidance to achieve this educational level.

Government of Rwanda gave me a loan of study. Also, incredibly thankful to, All of my classmates for their sincere cooperation in sharing ideas and knowledge throughout the course.

All electrical engineer where we did electrical placement from year 1 up to year 2

Finally, not all I have mentioned and whose contribution was invaluable to this study, I extend My sincerest thanks and profound appreciation.

ABSTRACT

Today, Telecommunication services are a valuable tool for socioeconomic development of a nation. Network technology is now used in almost every daily activity and service, aside from communication. Mobile phones connect the users to a mobile web with multiple applications. In Rwanda, citizens use IREMBO platform to request different services like land registration, requesting driving license, check driving test score and so on.

The fast increase in mobile communication technology correlates with rise in the number of Base Transceiver Stations (BTS). A BTS telecom site without power supply source cannot work, all equipment become completely OFF, and the users cannot use it.

Our effective organization is divided into two power system configurations: on-grid and off-grid sites. To maintain uninterrupted power supply when grid goes OFF or when it is unstable, Diesel Generators (DG) are supposed to run as backup power source on the sites. Although the initial installation cost of a diesel generator is not very high, there are other factors considered that operators suffer from, such as continuous maintenance, increasing fuel consumption resulting in high expenses.

In thesis, PVsyst software has been used in simulation, the result shows the fuel cost has been reduced by 90.19%.

KEY WORDS:

OFF grid site, Base Transmitter Station (BTS), hybrid system, diesel generator, renewable energy, photovoltaic system, electrical power sources, generators, telecom tower.

Contents

LIST OF FIGURES

List of tables

LIST OF ABBREVIATIONS:

GSM: Global System for Mobile Communications

BTS: Base Transceiver Station

BSS: Base Station Subsystem

ACCU: AC Connection Unit

ATS: Automatic Transfer Switch

RBS: Radio Base Station

DGRH: Diesel Generator Running Hours

DG: Diesel generator

PSTN: Public Switched Telephone Network

MNO: Mobile network operator or mobile operator

ISDN: Integrated Services Digital Network

BFU: Battery Fuse Unit

BSC: Base Station Controller

HLR: Home Location Register

AUC: Authentication Center

OMC: Operation and Maintenance Center

DiffHor :Horizontal diffuse irradiation

RURA: Rwanda Utilities Regulatory Authority

GlobHor: Global horizontal irradiation

T_Amb :Ambient Temperature

GlobInc: Global incident in coll. plane

EArray: Effective energy at the output of the array

E_User:Energy supplied to the user

SolFrac: Solar Fraction (E-used/E-load)

E_Solar: Energy from the sun

E_GridEnergy injected into grid

EFrGrid: Energy from the grid

GlobInc [W/m²]: Global incident Irradiance

CHAPITER ONE

1. INTRODUCTION

1.1Background

Because of rising electricity prices, mobile operators' operational costs have risen as a result of the high advancement for mobile communication technology and their increases in the number of cellular base stations [1]. It is very crucial to identify alternative solutions to reduce operation and maintenance cost, Solar energy is regarded as a cost-effective option[2]. In GSM terminology, BTS stands for base Transceiver Station. It is made up of an antenna and radio equipment that is used to link between mobile stations. Every BTS contain a specific area known as a cell and is managed by a base station controller (BSC), which is then managed by a mobile switching center (MSC)[3].

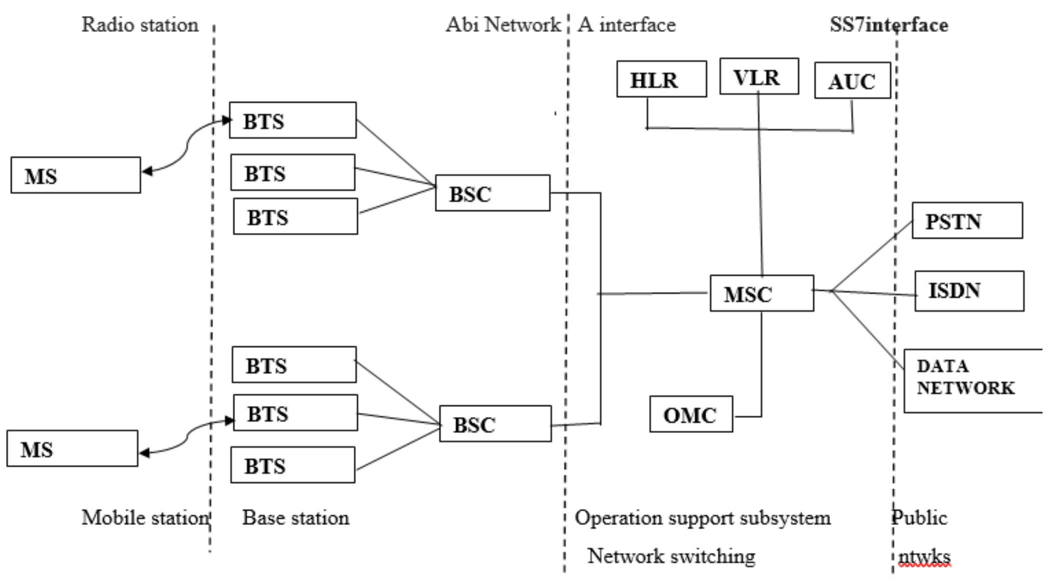


Figure 1. 1: GSM architecture [3]

The load for a BTS site varies depending on where the site is located and the time/hour of the day. BTS site load is conventionally composed by Base station transceiver equipment or base station RBS and microwaves , loads for lighting and air conditioner [4].

From the figure1.1, The highest power consumed for air conditioner is 1800 W, whereas the power and plus various loads (battery charging load and lighting) of the BTS equipment are 1.5 kw and 0.48 kw, respectively.

For this selected site located in remote area where is no grid power, According to the level of usage, the load is divided into three categories: small hour load, medium hour load, and occupied or busy hour load. The first category occurs between 12 a.m. and 6 a.m. in the morning, while the second occurs between 7 a.m. and 10 a.m. from morning and again from 6 p.m. to 11 p.m. in the evening. The third category typically occurs between 10 a.m. and 6 p.m. (during the business hours of the day)[4].

Figure 1. 2 : General PV–wind–diesel powered mobile base station OFF-grid [4].

The BTS tower is made up of different devices, including a radio antenna, a transmission antenna, and a module that functions as a transmitter and receiver, providing services to a mobile station or a mobile phone. Because BTS devices have direct current voltage characteristics, using AC voltage from the utility grid necessitates the use of a rectifier. The BTS requires a minimum of 1500Wh of operating power[5].

In Rwanda, many BTS sites typically use diesel generators, despite the fact that fuel prices are not decreasing.

In Rwanda's Southern and Eastern provinces, solar irradiation par day ranges from 4 kWh/m2 north of the city of Ruhengeri to 5.4 kWh/m2 south of the capital, Kigali[6].

1.2 POWER REQUIRED BY TOWER

Generally ,the tower needs energy ranging from 1KW to 3KW (the aged installation consumes more power in comparison to new ones because of technological advancement

If we assume that each tower's average power consumption is 1.2kw, then the total CO_2 emissions from all of these towers are 105.6 lakh ton per hour [4]. In India, approximately 70percent of telecommunication towers towers are located in rural areas. Currently, grid electricity meets 40percent of power requirements, while diesel generators meet 60%. The diesel generators range in size from 10 to 15 KVA with consumption up to 3 liters of diesel per hour[7].

*1.*3 Statement of the Problem

Existing network operators and companies who are the owner of towers are dealing with unreliable and high cost of electricity. BTS sites need uninterrupted power supply to operate, and failure of power sources cause the site to go down. One issue for the telecom industry is providing the necessary and continuous energy for its towers in remote rural areas where there is no electricity from utility grid. This requires the use of diesel generators as backup sources with battery banks, which raises the operating and maintenance costs. Also, where there is grid power, telecom companies pay more money to buy electricity. Also, national grid is not stable which causes generator to run many hours.

- In most of the rural areas, Conventional grid power are not available
- Available grid power quality not uniform
- The operators of Telecom mainly consider the battery and standby DG
- The average fuel consumption is 8.76Kl per years. By taking 8 hours of operation by DG set

Below are issues with diesel generator:

- Escalating diesel price
- Widespread diesel theft resulting to increase the security cost plus unplanned refueling
- High DG maintenance cost
- High diesel transportation cost
- Environment destruction

Technical issue on diesel generator:

Control panel, which is faulty, water may mix with fuel in the tank, different alarms on generator control panel, AVR card issues, starter battery issues and injector pump issues. All these affect the site.

Different topologies of power sources commonly used on BTS site:

- Grid-generator topology

- Hybrid-generator topology (battery bank and generator)
- Grid only topology

All the above topologies increase the operation and maintenance cost. More generator running hours more money is spent. Now our project is going to introduce solar energy for the purpose of cost minimization purpose.

1.4 Objectives

1.4.1Major objective

The primary goal for this research is to conduct a feasibility study on the use of solar panels on a telecommunications site in order to reduce costs.

1.4.2 Specific objective

Analyze the use of solar/generator in areas where is no grid power, analyze the use of solar/grid in the place where generator is not allowed due to noise and lastly compare the cost of using solar energy and grid power energy sources.

1.5 Scope of the study

This will focus on the analysis of using solar to power BTS sits cost reductionof using other source of power such standby generator, mobile generator or grid.

1.6 Outcomes Expectation and significance of the study

1.6.1Expected outcome of the study

- **Reduction of maintenance and operation cost as no fuel to burn**

  Because solar panels do not require fuel, the operational costs are very low compared to other types of power sources.
- **Reduction of harmful gas emission.**

1.6.2 Significant of the Study

Mobile operators are suffering from huge amount that the pay regularly on fuel of diesel generators. Solar is environmental free, efficient, and renewable source of energy which is suitable to reduce the operation cost compared to other types of energy to save energy and to protect the environment.

CHAPITER TWO

2. LITERATURE REVIEW

2.1 INTRODUCTION

The significant increase in the use of renewable energy resources, particularly solar, which is infinite, non-polluting, and has a high potential for use as an alternative energy source have been occurred in recent years. Hybrid energy systems are used for remote systems such as telecommunications sites that are located far from the grid power system[8].

BTS stations consume a significant amount of electrical energy for their operations in the telecommunications industry. The expansion of cellular networks to remote areas has its own set of challenges. There are still many areas from which electricity from normal grid is not available while there is a community that needs telecommunications networks in order to communicate[9]. According to figure 3, the previous system requires the Diesel generator and batteries which is increasing the operation and maintainance cost.

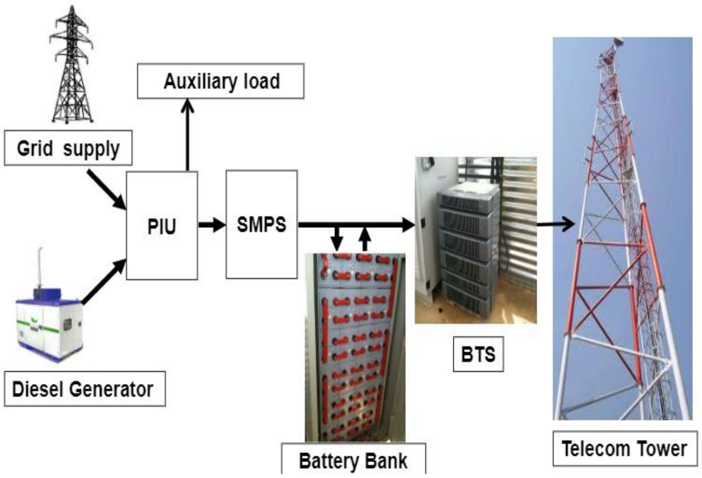


Figure 2. 1 : Schematic of conventional DG base power system [10].

When electricity is supplied from the national electrical grid, the Power Interface Unit (PIU) selects the best phase of the three-phase electrical grid and supplies power to the rectifier or switched mode power supply (SMPS). The SMPS converts 220 VAC to -48 VDC (or, in some cases, 24 Volt direct current), supplying power to the telecom tower equipment as well as charging the batteries [11].

Whenever the electricity from the grid is interrupted, the PIU sends a signal to the diesel generator(DG) to start, and the DG comes online in a matter of minutes.

It meets the entire power demand at the site. The batteries provide the power required by the telecom equipment at the tower during the transition from the electricity grid to the diesel generator, ensuring the telecom site's uninterrupted operation. Tower owners may employ a variety of strategies for transitioning from the electrical grid to DG via batteries.
in order to keep the diesel generator running as little as possible. These cases were not taken into account for the purposes of this white paper [11].

2.2 Solar energy

The energy source generated by sun can be used directly or indirectly, and the energy extracted from it is known as solar energy. Energy from sun is playing a leading role in minimizing environmentally harmful gases produced during electricity generation as a response to environmental pollution .The review for the last twelve years of research and case studies has shown that energy from sun can be a possible solution for the provision of power in the world, specifically to provide electricity in OFF grid site as cost effective solution [12]. Then using solar PV for powering BTS or telecommunication site should be economical. Below is the main architecture of solar energy system.

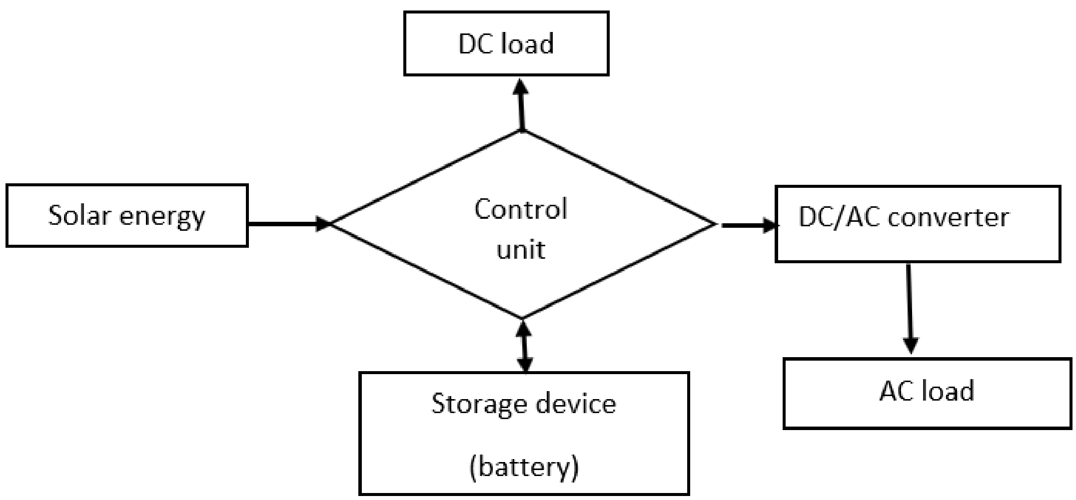


Figure 2. 2 :General architecture of solar energy systems

2.3 Renewable energy as compared with Diesel generator for powering BTS

These non-electrified areas gain access to electricity through grid extension or the installation of a stand-alone system. When the distance between transmission lines increases, particularly in forested, hilly, and island areas grid extension is very cost effective.

However, those hilly areas that are far from the substation and have no electricity access but have sufficient renewable sources are not served by the grid utility solar or wind can be used . Load shedding and power outages are common in remote areas. Although the capital cost of DG is not particularly high, other factors, such as ongoing maintenance and skyrocketing fuel prices, are causing problems for operators. During peak hours, DG are mostly used. These plants have a low capital cost and are always ready to take a load. Because DG has more drawbacks, researchers should shift their focus to new energy generation techniques. Natural resources are abundant all over the world. Rwanda has an abundance of natural resources, but these resources are not being fully utilized due to ineffective strategies However, by making effective use of these natural resources, they can meet the needs of a growing population as well as meet the energy demand [13].

2.4 Base Transceiver Station (BTS) Power Management System

This method will aid in the maintenance of an uninterrupted communication service for mobile users. This smart intelligent system control the battery's undervoltage levels, the alternator's diesel tank float level, and the room temperature. In mobile communication systems, the Base Transceiver Station (BTS) is the radio component that forms the Cell structure. The cell size is determined by the antenna transmitted power, which provides the communication coverage area. An uninterruptible power supply (UPS) is used to provide continuous operation of BTS equipment, resulting in communication along the cell region and call handoff from other BTS Cells[14].

2.5 Related work

2.5.1 AC power utility and generator power source

The system is made up of the power supply from utility grid, which is considered as an AC power source, diesel generator which can be AC or DC in different ratings, ATS, DB, controllers, and chargers, also rectifier once there is AC generator, Batteries arranged in series for backup, circuit breakers and cables. As comparison, positive voltage of the line is more than negative voltage to prevent electrochemical reactions that can damage cables if they became wet[15].

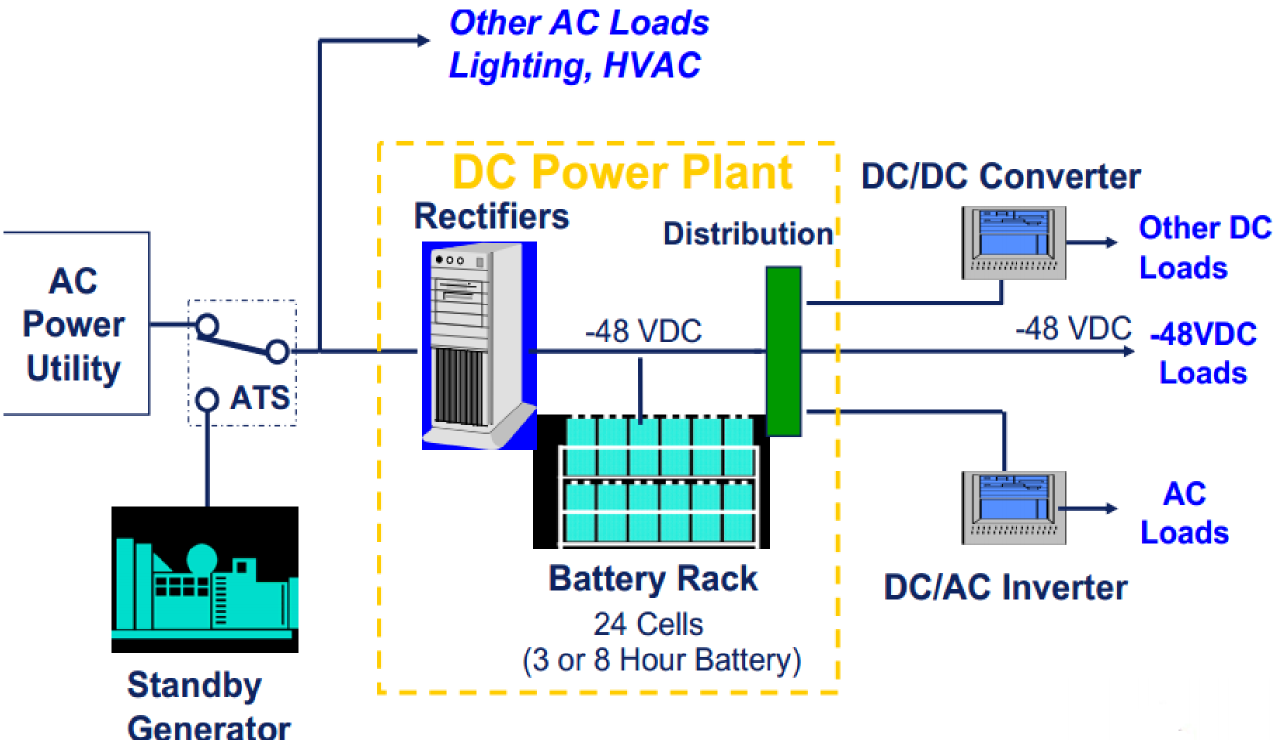


Figure 2. 3 : AC power utility and generator power source [15]

From figure 2.3, When power is available from the electricity network, the PIU selects the best phase of the electrical grid and feeds power to the rectifier through ATS distribution board.

The switched mode power supply converts 220 volts alternating current to -48 volts direct current, supplying power to tower equipment, and charging the batteries, as well as floating them in care they charged in full.

When the power from the grid unstable, the Power Interface Unit sends a command to start the generator set, and it comes online to meet the site's power needs.

During the transition from electrical grid to DG, the storage batteries supply the power needed to the site equipment at the tower to ensure the BTS operates continuously. Tower companies can employ a variety of strategies for transitioning from the national grid to diesel generators. The automatic transfer switch is mostly used for this switching function.

2.5.2 Diesel consumption comparison

The hybrid system, which consists of a solar panel, a battery, and a diesel generator, runs for 4.57, 16.7, and 2.8 hours, respectively. The combination of diesel generator and battery bank, on the other hand, increases the running hours of the diesel generator to 15.6 hours. This increase is caused by the lack of solar energy, as shown in the table below [16].

Table 2. 1:Diesel consumption comparison [16]

Power supply topology	Working hours for Solar	Working hours for Battery	DG running hours	Diesel Consumption rate
Solar-DG (hybrid)	4.570	16.70	2.80	6.860
Diesel Generator	0.0	10.080	15.60	38.220

2.5.3 Telecommunication base stations in remote rural area with optimal solar power system

The solar PV can supply the necessary energy to the load. However, if the solar panels fail, resulting in an inability to provide the required energy to the load, the battery bank compensates for the energy shortage. If the battery bank reaches its maximum depth of discharge (DOD) or exit voltage and is no longer capable of supplying the required energy to the load, the backup diesel generator supplies power to the LTE macro base station.[17].

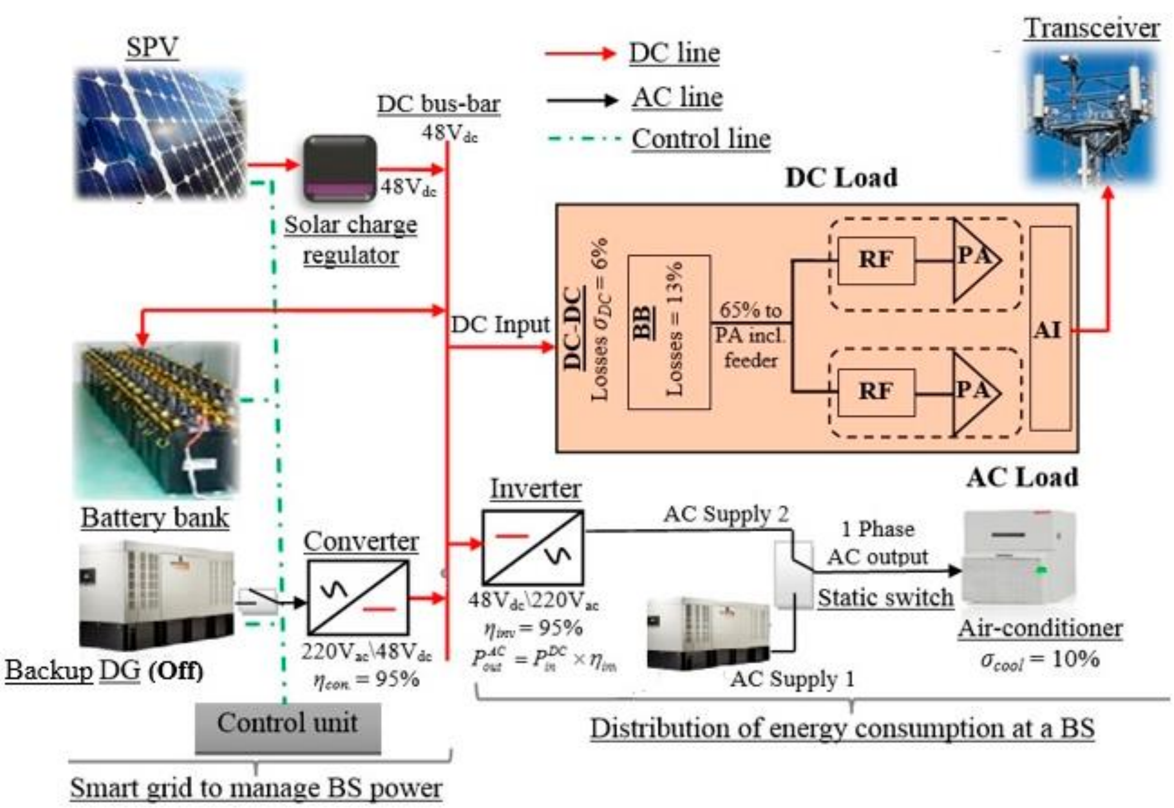


Figure 2. 4 : A solar energy system integrated with an LTE-macro base station model [17].

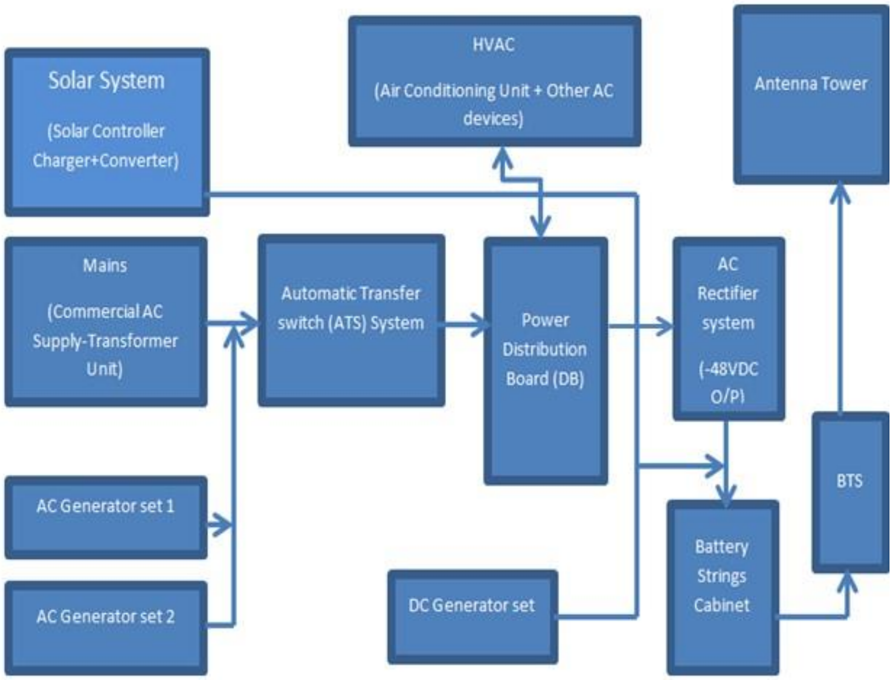


Figure 2. 5 : Integrated power supply system layout [15]

2.5.4 STORAGE DEVICES

The proposed hybrid system requires the use of a storage system. The model stipulated that the energy generated by solar panels could be stored in a battery and used whenever solar radiation was low or when the solar cells' electricity generation was insufficient. This condition is common on cloudy or rainy days. In addition, the battery can be used as an energy source during the night, as well as a storage device for excess energy [18].

2.5.5 Converter/Inverter Parameter

The converter is critical in the design or model of the power system setup.. A converter contains both an inverter and rectifier. The rectifier transforms the alternating current (AC) from the power source such as the grid and the diesel generator into a required amount of direct current (DC) to power the telecom electronic equipment. On the other hand, the inverter converts the direct current produced from the renewable source such as the Photovoltaic (PV) array into alternating current (AC)[19].

2.5.6 Characteristics of load

The BTS tower is made up of several devices, including a radio antenna, a transmission antenna, and a module that acts as a transmitter and receiver, providing services to a mobile station or a mobile phone.

Because BTS Devices have DC voltage characteristics, using AC voltage from the utility grid necessitates the use of a rectifier. The BTS requires a minimum of 1.5kwh of operating power[5]. The power consumption of a BS varies depending on the cellular generation [20].

Table 2. 2:Power consumption for 6/6/6 and 2/2/2 BTS sites area

POWER CONSUMPTION FOR GSM MACRO BTS		
Configuration type	6/6/6	2/2/2
Baseband accessory	300 W	200 W
TRX 40W power amplifier with eff. 35%	2200 W	700 W
BTS consumption	2500 W	900 W
Another accessory	100 W	100 W
AC-DC power conversion	370W	130W
Power consumption at site	3000 W	1130W
Cooling system, consumption around 30%	700 W	300 W
Power consumption with cooling system	3700W	1430W

2.5.7 Details of the installation

The system is designed to ensure the telecommunications site's continuous power supply, 1600W/48V. The emergency generator's display is used to calculate the total power of instant telecommunications equipment (power generated). Because telecommunications equipment operates 24 hours a day, this power is constant throughout the day[21].

PV-Grid-Battery

This study proposed a model for overcoming the national power shortage and ensuring service continuity. PV-Grid-Battery is the proposed hybrid model. The Grid and PV module are the primary components for meeting demand, with the battery serving as a backup energy source. Because PV is inherently unreliable due to the fact that solar irradiance is intermittent and the grid may be disrupted, a battery is used as a storage device that can deliver power when there is a shortage of energy for load. The PV module and batteries generate DC power, which is routed to the DC link[22].

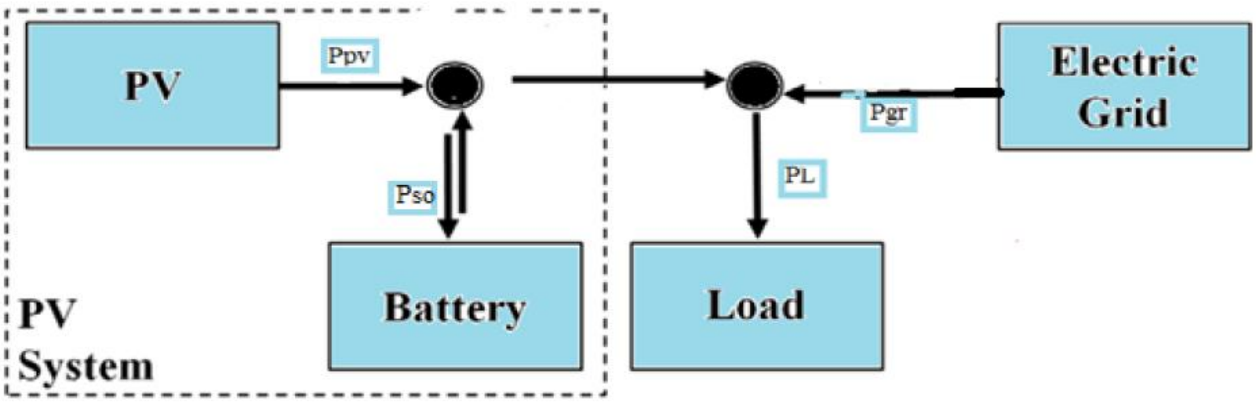


Figure 2. 6 :PV-Grid-Battery model [22]

When the suggested system is activated, the grid, PV array, and battery work in one of the following ways to meet the power demand:

- When the total power generated by PV arrays and utility Grid are greater than the load demand, the surplus energy will be stored in the batteries. However, when the battery becomes full, the remaining energy will be either dumped or can be sold to the utility.

- When the total power generated by PV arrays and/or Grid are less than the load demand, the battery will be used as a backup source.

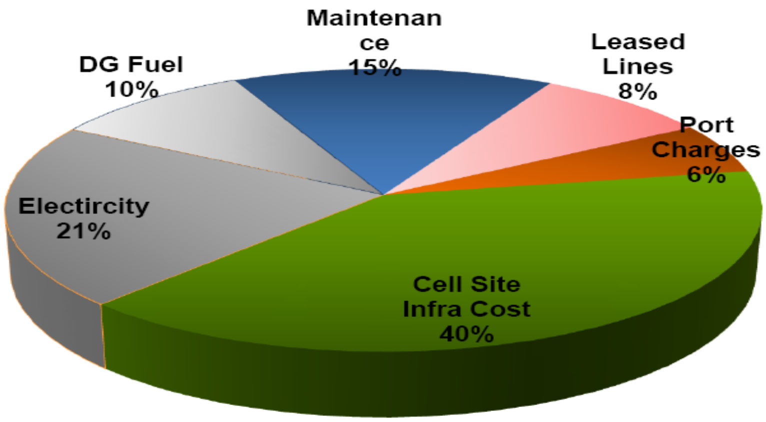


Figure 2. 7: Expenses on telecom tower [23]

2.6 Literature gap

- In Rwanda, only few sites have solar panels and the study was not well done for example, sites located in Musanze, Burera and so on.
- Diesel consumption rate of telecommunication sites is high which increases the operation cost
- Failure of generator cause the site to go down which affect communication and internet connectivity.
- Diesel generator running causes destruction of environment.
- Some remote rural sites are still using battery bank and generator topology in Rwanda
- Another challenge is unavailability and stability issues of power supply.
- Low voltage and intermittent supply of electricity renders battery ineffective and battery doesn't gets fully charged due to unreliable supply of grid.
- Telecom Operators depend mainly on Battery & Standby DG

So alternative, cheaper, and sustainable energy sources is required. My project will focus on the introduction of solar panels on all sites because in Rwanda as the solar energy is available.

Chapiter three

3. RESEARCH METHODOLOGY

Documentary techniques:

In this study, electronic sources were used by visiting various websites. The internet was a useful tool for gathering information in this case. We accessed different Publications and e - books through electronic sources, which contributed to improving the idea we had about our study. Lecture notes, papers, books from department library, search on internet and data collection from different BTS sites.

Interviews have been used to improve the quantitative analyses to receive enough knowledge of the conditions to develop solar energy on BTS sites in Rwanda. Different BS sites have been visited to analyze insolation, power consumption, generator running hours, loads. Different field engineers have been contacted In this study we have shown all the steps involved for designing PV system.

The process of determining the size of each component of a photovoltaic power system in order to meet the load requirement is known as PV system design. The following steps are taken to complete the design:

Step 1: site survey or site inspection

Step 2: load requirements determination

Step 3: sizing of PV module

Step4: sizing of charge controller

Step5: sizing of battery bank

Step 6 Sizing of inverter

Step 7: cable sizing

Step 8: evaluation of the cost

3.1 Research steps

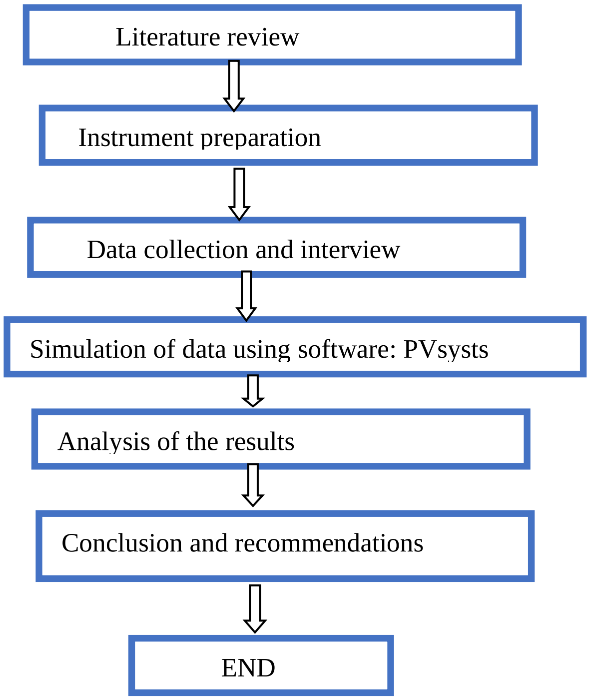


Figure 3. 1: Steps of research

The importance of solar PV as source of renewable energy for BTS has been discussed in this research project. Furthermore, PVSYST7.2 simulation software was used to find estimated cost of energy from PV for BTS and also to find other parameters like the number of modules, batteries, and inverters required for design consideration and powering BTS.

3.2 DATA COLLECTION.

The data has been collected in Telecom Service Provider (TSP) company in Rwanda. It is a Specialist Technology and Telecommunication Services company with a network of 15 Global Offices. It is a company that can Design, Build, Power and Manage telecom infrastructures anywhere in the world. Below are sample questions that I used to ask field engineers.

Table 3. 1:some questions and answers on questionnaire

No	Some questions	Some answers
1	What is the load at BTS site?	The load of BTS site depends on the site location. Urban sites have higher load compared to rural sites because urban sites have a lot of traffic. Example given is Nyabugogo site in Rwanda that has a load of 122.4Ampere and uses 48V, thus power is 122.4*48= 5.8752KW. While Kageshi located in rural area has a load of 30 Amperes, with 48V, the total power was 1.440KW
2	What are the elements of BTS site	Transmission radio, Rf antenna, Rectifier, Lighting lamps, Aviation light, cooling system, batteries, generators, grid system
3	Catalogue of equipment's	Only few equipment's have catalogue
4	What are the current challenges of telecom operators?	-Ful consumption issues - Increased competition - Churn in the market
5	What is the average fuel consumption and the cost per month?	Fuel consumption depends on the load of the site. The average fuel consumption is 2.5 liters per hour but it increases depending on the load. The cost depends on the fuel consumption per month
6	Generator capacity	Generator capacity ranges from 13Kva 14kva,16kva, 18,20,22,25,30,33kva and so on depending on the load of the site. The generator cost depends on the supplier.
8	What are the challenges of renewable energy?	It is not reliable High initial cost Needs a lot of space Dc equipment are expensive

9	What are the challenges of using solar energy?	The cost of purchasing a solar system is high at first. Weather-dependent. Although solar energy can be collected on cloudy or rainy days, the efficiency of the solar system decreases. Solar energy storage is costly. It takes up a lot of room.
10	What are the additional elements that consume power at the site?	Cooling systems, lighting, monitoring
11	Generator maintenance cost	The average cost of generator maintenance depends on the capacity of the generator. The bigger the capacity the more it cost and vice_verser. Mainly maintenance cost includes Oil filters Fuel filters Fan belts Engine oil Engine coolant Radiators Just mention but few So when determining the cost, you must consider all the above.

BATIMA SITE POWER
Batima site has been visited and below data have been recorded.
AC power:
Mains Supply Circuit Breaker Size :3 Phase.
Amperes: 63A
Static Generator Type: FG WILLSON

DC power supply
Main DC DB CB Rating:63
Rectifier Module Quantity :17
Rectifier Battery Type: GEL BATTERY
Rectifier Battery Quantity :12

Data collected on Muyumbu site and their observation

PV system design

By considering all load to be DC, AC Loads should be air conditioner and, in this design, we will consider small inverter.

Transmission radio 7.2kwh/day

Rf antenna. 7.2

1800MHzRRU. 7.2

900 MHz RRU. 7.2

Rectifier. 2.1

Lighting lamps. 0.9

Aviation light. 0.3

Other accessories: 7.2

Figure 3. 2: Muyumbu site view

Figure 3. 3: Diesel Generator

Figure 3. 4: Batteries backup

Table 3. 2:Characteristics of another visited telecommunication site(Ntarama site)

Equipment	Rated Power	working voltage	Mode of voltage	Time of Operation
Telecommunications site	1.65KW	48V	Continue	24h

3.3 Analysis of data collected at Muyumbu site and Rusoro.

Two among the visited sites are Muyumbu and Rusororo sites. The total energy and power have been calculated.

After collecting basic data and making simple calculation, Total approximated energy is 39.3KWh per day depending on the traffic and this will be considered for software simulation and design.

60 sites are OFF grid and they use battery bank and generators. 600 sites are grid-generator

Table 3. 3:Sample load

Equiment	**Energy per day(kwh/day)**
Transmission radio	7.2
Rf antenna.	7.2
1800MHzRRU	7.2
900 MHz RRU	7.2
Rectifier	2.1
Lighting lamps	0.9
Aviation light	0.3
Other accessories	7.2
Total	**39.3**

CHAPITER FOUR

4. DESIGN AND SIMULATION

The design for these parts will consider the manual and software for both two case OFF grid and ON grid. Below key points have been analyzed.

4.1 OFF grid site:

Analyzing generator running hours for Muyumbu site.

Analyze the fuel consumption per month

Analyze the cost of fuel per month

Solar irradiance at site

Compare the cost before and after solar PV integration

Checking if the integration of solar energy is beneficial

Analyzing challenges of some sites that currently are using solar

4.2 ON grid site

Analyze the energy needed per month

Analyze the total cost of energy per month

Checking if the integration of solar energy is beneficial

4.3 MANUAL DESIGN

Total energy is 39.3KWh per day depending on the traffic

Selected system voltage **= 48V**

1. Total amount of energy required to run the appliance from the PV modules =39300Wh/day x1.3 =**51090wh**

The total watt-peak rating needed to power the appliances equals the total PV energy required from the panel divided by the panel generation factor.

$$2. \textit{The total watt} - \textit{peak rating} \text{ required} = \frac{\textit{total PV energy required}}{\textit{panel generation factor}} = \frac{\mathbf{51090wh}}{3.43} = 14895Wp$$

The solar panel generation factor is 3.43

From the above we can use peak sun hour=5h

$$3. \boldsymbol{The\ total\ watt - peak\ rating}\ \textbf{required} = \frac{\boldsymbol{total\ PV\ energy\ required}}{\boldsymbol{panel\ generation\ factor}} = \frac{\textbf{51090wh}}{\boldsymbol{5h}} = \boldsymbol{10218Wp}$$

When calculating the size of a PV system, the panel generation factor is used. It is a variable factor that depends on the climate of the site location.

PV modules depend for the system = = Total watt-peak rating required to run the appliance divided by the watt-peak of the PV module you have available. **I decided to select this panel**

PV module: Longi Solar

Model: LR5-72 HPH 550 M

Unit Nom. Power: 550 Wp

Voltage at Maximum Power (Vmpp): 41.95

Vocmax: 50.60V

Isc: 13.98 Amps

From the above we can calculate according to the highest values.

$$N_m = \frac{\text{1module} * \text{total watt peak rating}}{\text{rated output of the PV module}} = \frac{1 \times 10218}{550} = 19 \text{ modules}$$

N_m= Number of PV modules

The required number of PV panels is 19 PV panels. The system will perform better and the battery life will be extended if more PV modules are installed. As a result, this system should be powered by at least 19 550 Wp PV modules.

To get the number of modules in series shown in the equation below.

$$\boldsymbol{N_{ms}} = \frac{\boldsymbol{V_{system}}}{\boldsymbol{V_{module}}} = \frac{\mathbf{48}}{\mathbf{41.95}} = \mathbf{1.144}\ \boldsymbol{by\ approximation}\ = \ \mathbf{2}\ \boldsymbol{modules}$$

The number of parallel blocks is determined by dividing the designed array output.$P_{PVarray}$ by the output power of the chosen module P_{module} and modules number in series N_{ms}

$$\boldsymbol{N_{mp}} = \frac{\boldsymbol{N_{mt}}}{\boldsymbol{N_{ms}}} = \frac{\mathbf{19}}{\mathbf{2}} = \mathbf{10}\ \boldsymbol{modules}$$

Hence the overall number of required modules is 20 units

I pmax: 13.120 amps and Isc : 13.98 amps

Sizing of Batteries

When selecting the basic components of an off-grid solar PV system, one of the most important considerations is the size of the solar batteries.

To determine the number of required PV system batteries, we must first determine the storage capacity of the batteries, which can be calculated using the following equation.

$$C_a = \frac{DO_A * E_L}{\eta_{out} * \ DOD_{max} * V_{system}} = \frac{3.5 * \mathbf{39300}}{0.97 * 0.8 * 48} = 3692.8Ah$$

Size of a battery bank Narada, AcmeG 12V 200, Cb = 200 Ah, Vb = 12 V, Ddisch = 80% battery module Battery efficiency (b) = 0.97. Number of Autonomy Days (Daut) = 3.5 Days

Were,

C_a = Battery bank capacity required

DO_A =Day's autonomy

E_L = Approximated load energy in Wh

DOD_{max} Maximum depth of discharge (select 0.8)

η_{out} =Battery loss

V_{system}=System voltage

The minimum number of days of autonomy is 0.5 (assumed value) and the maximum allowable depth of discharge is taken as 80% The battery bank capacity required (Cx) is given by;

Renogy Deep Cycle AGM Battery 12 Volt 100Ah for RV, Solar Marine and Off-grid

The battery selected has a capacity of 100Ah and a nominal voltage of 12V.

The number of batteries required ($N_{\ Total}$) is;

$$N_{\ Total} = \frac{C_a}{C_{seleted}} = \frac{3692.8Ah}{200Ah} = \ 19 \ batteries$$

Batteries number in series (N_{bs}) is given by

$$N_{bs} = \frac{V_{system}}{V_{battery}} = \frac{48}{12} = 4batteries.$$

Batteries number in parallel (N_{bp}) is given by

$$N_{bp} = \frac{N_{\ b-req}}{N_{bs}} = \frac{19}{4} = \mathbf{5} \ \boldsymbol{batteries}$$

of course, the total batteries required would be 4x5=**20 batteries**

Solar charge controller sizing

The charge controller is the photovoltaic system's brain. It allows for the protection and control of the battery bank.

The charge controller serves two purposes: it serves to protect batteries from overloads and deep discharges and it improves energy transfer from PV array to load.

The solar charge controller must match the voltage of the PV array and batteries before determining which type of solar charge controller to use. It must also have enough capacity to handle the current from the PV array.

To select the capacity of the charge controller, we must first determine the maximum current produced by the PV modules, which is calculated as follows.

$$I_{cc} = \frac{Power_{\ PV\ array}}{U_{PV\_system\_voltage}} = \frac{\mathbf{10218}Wp}{48V} = \mathbf{212.875A}$$

Once we selected the Rating of charge controller to be 3200W and 48V, the number of charge controller will be $= \frac{\mathbf{10218}}{3200} = \mathbf{4\ charge\ controllers}$

The best voltage regulator should be handling the maximum current coming from PV and the load current at maximum.

$$I_{rated} = N_{mp} * I_{SC} * f_{safety}$$

I_{rated} = Rated current of chage controllers

N_{mp} = Number of module in pallel

I_{SC} = Short circuit currrent of module = 13.98 Amps

f_{safety} = Safety factor =1.3

$I_{rated} = 10 * 9.57 * 1.3 = \mathbf{124.41A.}$

4.4 SIMULATION USING PVSYST. Software

4.4.1 OFF GRID SITE

Site location:

The site is located at Muyumbu sector in Rwamagana district in Rwanda.

Latitude: -1.97^{0}S, longitude:30.25^{o}E, altitude:1554m and time zone is UTC+2

Availabity of energy is 39.3 kW/Day.

Available Energy: 18088 kWh/year

Energy used :14348 kWh/year

Meteo and incident energy at Muyumbu site

Table 4. 1:Muyumbu Meteo and incident energy

Month	GlobHor	DiffHor	T_Amb
	kWh/m²	kWh/m²	°C
January	185.8	71.4	22.2
February	140.9	73.5	19.6
March	149.1	81.5	19.2
April	141.6	74.0	19.5
May	154.9	71.2	19.0
June	157.0	59.6	18.7
July	189.5	59.7	20.5
August	163.7	73.3	21.4
September	167.6	73.5	22.1
October	154.0	78.2	21.4
November	148.6	69.6	20.1
December	142.9	73.6	19.4
Year	1,895.5	859.0	20.3

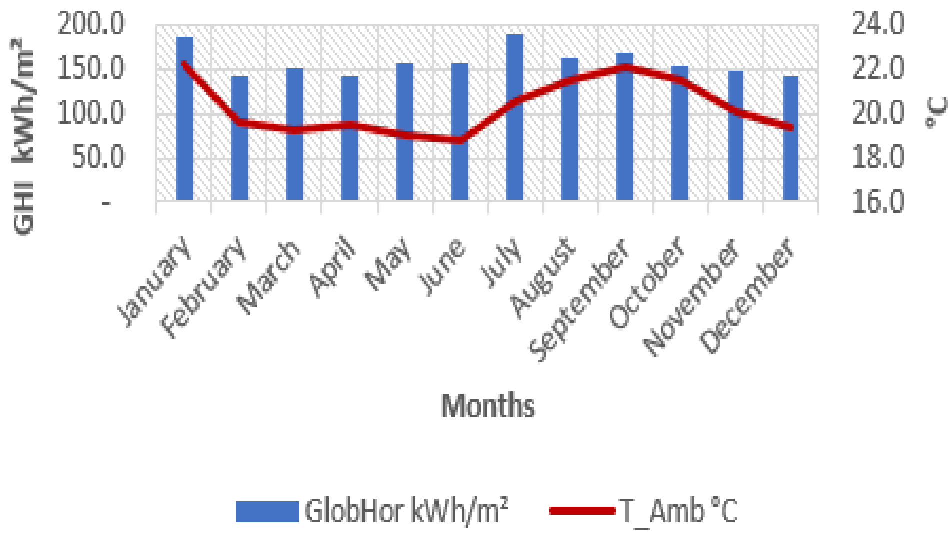


Figure 4. 1 : Muyumbu BTS Monthly meteorological data

4.4.2 PV Array Characteristics

PV module: Longi Solar

Model : LR5-72 HPH 550 M

Unit Nom. Power: 550 Wp

Number of PV modules: 22 units

Modules: 11 Strings x 2 in series

Battery characteristics

Manufacturer: Narada

Model: AcmeG 12V 200Ah

Technology: Lead-acid, sealed, Gel

Nb. of units: 2 in parallel ×4 in series

Voltage:48V

Nominal Capacity:400 Ah

Converter characteristics

Maxi and EURO efficiencies: 97.0 / 95. 0%

DC Input voltage: 76.9V

Back-up genset

Nominal power:20KW

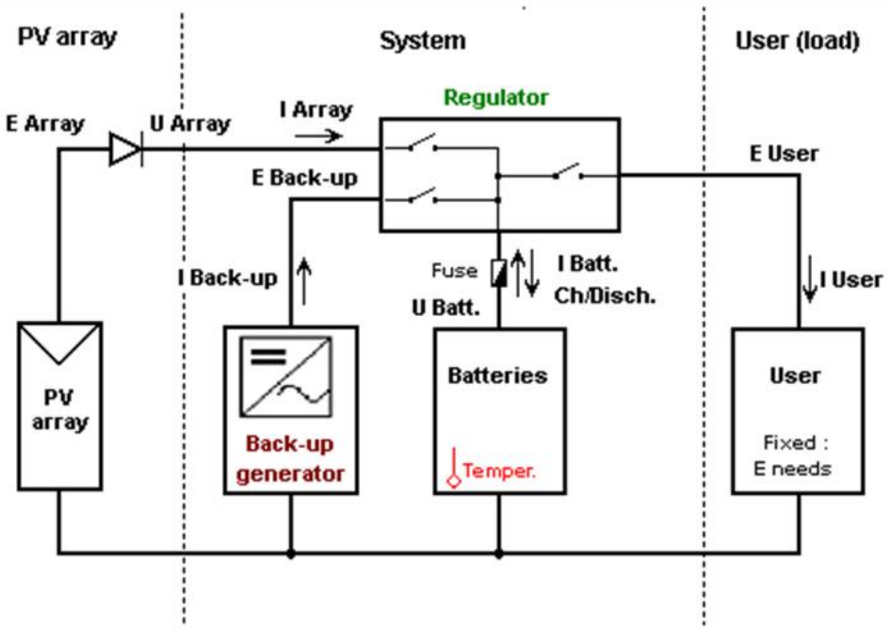


Figure 4. 2: System

WORKING PRINCIPAL

- When solar is available it is the primary source of power. Here solar system can supply the load while charging batteries bank.
- When it is at night or when it is cloudy , the battery bank can supply the load until the exit voltage(46.9V).
- When the battery bank reaches the exit voltage, the controller system sends the command to the generator, and it is starts running and supplying the load. Note that the Generator is not supposed to charge battery bank in order to reduce the load.

The position of solar panels are in West-Est posing in order to reduce the shading around the tower as shown on below

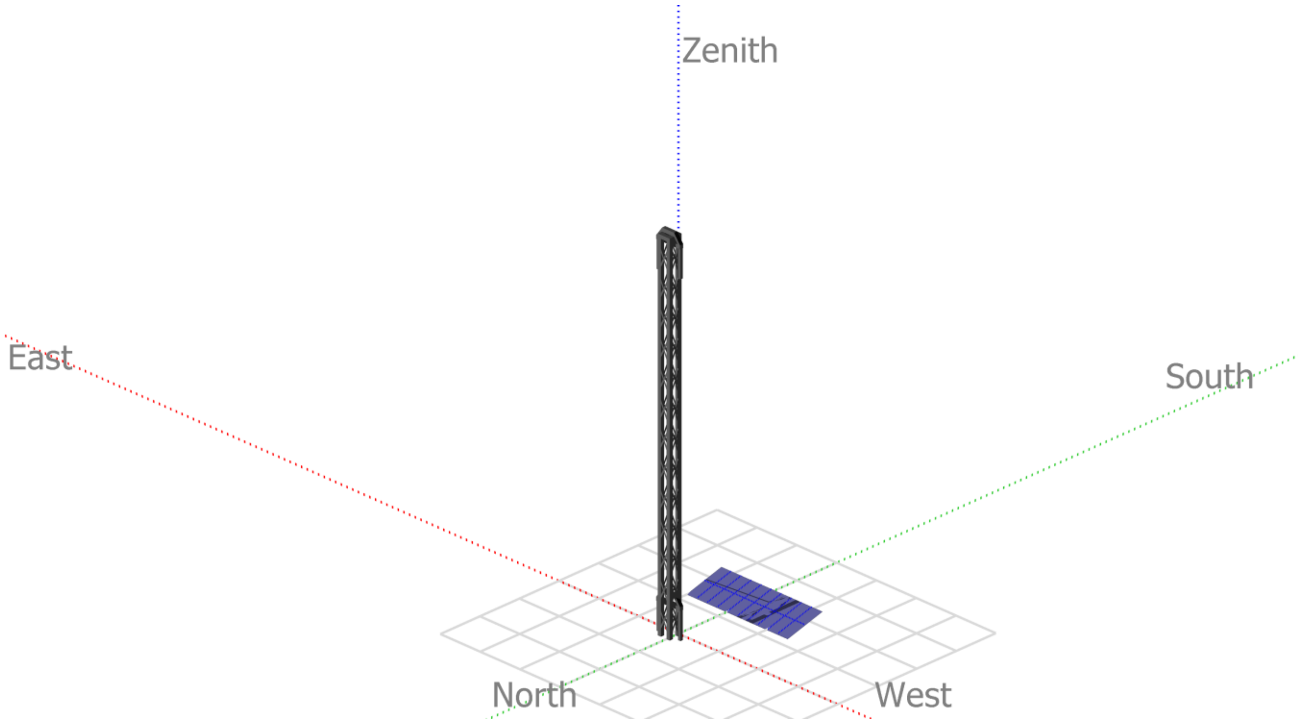


Figure 4. 3 : Perspective of the PV-field and surrounding shading scene

4.4.3 System Production

Available Energy: 18088 kWh/year

Used Energy:14348 kWh/year

Fuel Consumption: 2190 liters/year

Table 4. 2:Balances and main results

Month	E-Avail in kWh	E-User in kWh	E-Array in kwh
January	1,610	1,218	1,681
February	1,301	1,101	1,362
March	1,440	1,219	1,508
April	1,413	1,179	1,478
May	1,568	1,219	1,636
June	1,599	1,179	1,667
July	1,916	1,219	1,994

August	1,628	1,219	1,699
September	1,630	1,179	1,705
October	1,417	1,219	1,489
November	1,317	1,179	1,385
December	1,248	1,219	1,313
Year	**18,088**	**14,348**	**18,917**

4.4.4 Cost analysis on OFF grid site (generator-battery bank topology)

This analysis was conducted at MUYUMBU site that uses generator and battery bank as backup.

The data has been recorded in 24 hours (a complete day) from 5th, August 2021 at 10:04 PM up to 6th, August at 11:29 PM.
The total generator running hours for this day is 17 hours as shown in table 1.17.

Table 4. 3:DG running hours per day at MUYUMBU OFF grid site.

Start Time	End Time	Duration
8/5/21 10:04 PM	8/5/21 11:43 PM	1:39
8/6/21 12:56 AM	8/6/21 2:43 AM	1:47
8/6/21 4:04 AM	8/6/21 5:59 AM	1:55
8/6/21 6:57 AM	8/6/21 8:43 AM	1:46
8/6/21 9:41 AM	8/6/21 11:27 AM	1:46
8/6/21 12:21 PM	8/6/21 2:03 PM	1:42
8/6/21 2:53 PM	8/6/21 4:33 PM	1:40
8/6/21 5:23 PM	8/6/21 7:01 PM	1:38
8/6/21 7:39 PM	8/6/21 9:12 PM	1:33
8/6/21 9:55 PM	8/6/21 11:29 PM	1:34
Total DG running hours		**17:00**

The total fuel consumption for MUYUMBU site in 2020 is **22,345** L and the same fuel is expected in 2021. The generator consumes 3.5 liters per hour. The generator running hours per month has been obtained by taking fuel consumed per month divide by 2.51.

The average value of diesel from 31-May -2021 to 30-August-2021 is 1054 Rwanda Franc per litre which is equal to 1.047USD/litre[24].

$$\text{The total fuel cost without PV per year } = 1.047\text{USD} \times 22{,}345 = 23{,}395\text{USD per year}$$

$$\text{The total fuel cost with PV per year} = 1.047\text{USD} \times 219 = 2{,}293 \text{ USD}$$

The fuel cost reduction=23,395USD-2,293USD=21,100USD

$$\text{Rate of fuel cost reduction} = \frac{100 \times 21{,}100}{23{,}395} = 90.19\%$$

The fuel cost has been reduced by 90.19 % after integration of solar PV

Table 4. 4:Fuel consumed and Generator running hours in 2020

Month	Fuel consumed per month in liters without PV	Generator running hours Without PV	Fuel consumed per month in liters with PV	Generator running hours With PV
January	2,050	586	186	74
February	1,820	520	168	67
March	1,930	551	186	74
April	1,800	514	180	72
May	1,760	503	186	74
June	1,900	543	180	72
July	1,890	540	186	74
August	1,875	536	186	74
September	1,820	520	180	72
October	1,890	540	186	74
November	1,810	517	180	72
December	1,800	514	186	74
Year	**22,345**	**6,384**	**2,190**	**876**

Table 4. 5:Cost of fuel with and without PV

Month	Fuel consumed by month in liters	Generator running hours	Fuel cost with PV in USD	Fuel cost without PV in USD
January	2,050	586	194.7	2,146.4
February	1,820	520	175.9	1,905.5
March	1,930	551	194.7	2,020.7
April	1,800	514	188.5	1,884.6
May	1,760	503	194.7	1,842.7
June	1,900	543	188.5	1,989.3
July	1,890	540	194.7	1,978.8
August	1,875	536	194.7	1,963.1
September	1,820	520	188.5	1,905.5
October	1,890	540	194.7	1,978.8
November	1,810	517	188.5	1,895.1
December	1,800	514	194.7	1,884.6
Year	**22,345**	**6,384**	**2,293**	**23,395**

For MUYUMBU site, refueling is done twice per month. That is 2nd August 2021 and 12th 2021,for the first refueling,1,600L was put in the tank and for the second refueling 1,500L was put in the tank as shown in below figure 4.4.

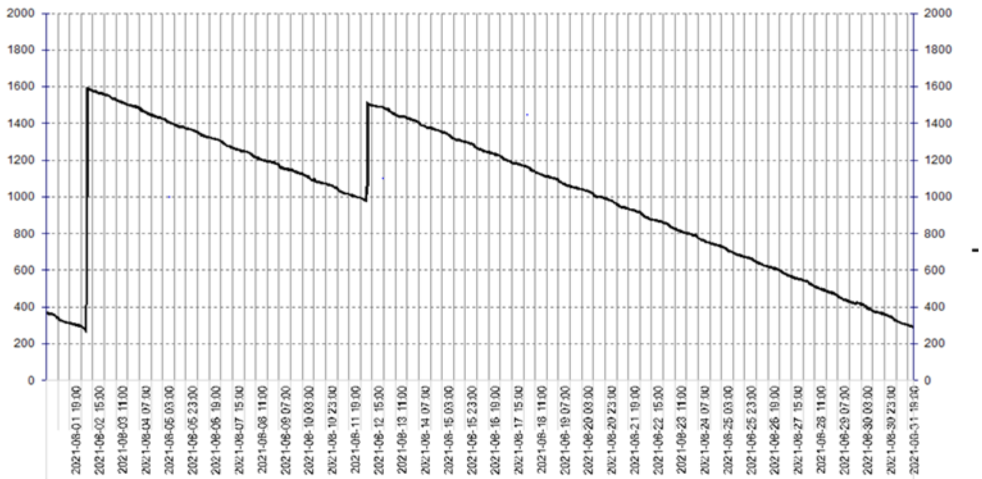


Figure 4. 4 : Fuel consumption graph in August 2021

4.5 COST OF THE SYSTEM

Table 4. 6 :Installation costs

Item	Quantity units	Cost USD	Total USD
PV modules: LR5-72 HPH 550 M	22	260.00	5'720.00
Supports for modules	22	15.00	330.00
Controllers	**4**	**560.00**	**-2'240.00**
Accessories, fasteners	1	10.00	10.00
Wiring	1	50.00	50.00
Combiner box	4	1.00	4.00
Monitoring system, display screen	1	650.00	650.00
Surge arrester	1	100.00	100.00
Global installation cost per module	22	258.50	5'687.00
Global installation cost per inverter	4	635.25	2'541.00
Shipment	1	3'000.00	3'000.00
Total **Depreciable asset**			**15'852.00** **3'820.00**

Table 4. 7 :Operating costs

Item	Total USD/year
Cleaning	200.00
Provision for battery replacement	625.00
Fuel for Back-Up generator	5'474.31
Facilities insurance	1'000.00
Total (OPEX)	**7'299.31**

Table 4. 8: System summary

Total cost of installation	15'852.00 USD
Costs of operation	7'299.31 USD/year
Excess energy (battery full)	0.0 Wh/year
solar energy used	14.3 MWh/yea
Cost of energy used	0.594 USD/kWh

4.6 FINANCIAL ANALYSIS

Simulation period

The project time is 25 years and start year is 2022. The discount rate is 6.5%/year

The project is profitable after one year.

Table 4. 9:Detailed economic results (USD)

	Run. costs	Self-cons. saving	Cumul. profit	% amorti.
2022	7'299	16'213	-6'938	56.2%
2023	7'299	16'213	1'975	112.5%
2024	7'299	16'213	10'889	168.7%
2025	7'299	16'213	19'803	224.9%
2026	7'299	16'213	28'716	281.2%
2027	7'299	16'213	37'630	337.4%
2028	7'299	16'213	46'543	393.6%
2029	7'299	16'213	55'457	449.8%
2030	7'299	16'213	64'371	506.1%
2031	7'299	16'213	73'284	562.3%
2032	7'299	16'213	82'198	618.5%
2033	7'299	16'213	91'112	674.8%
2034	7'299	16'213	100'025	731.0%
2035	7'299	16'213	108'939	787.2%
2036	7'299	16'213	117'853	843.5%
2037	7'299	16'213	126'766	899.7%
2038	7'299	16'213	135'680	955.9%
2039	7'299	16'213	144'594	1012.1%
2040	7'299	16'213	153'507	1068.4%
2041	7'299	16'213	162'421	1124.6%
2042	7'299	16'213	171'334	1180.8%
2043	7'299	16'213	180'248	1237.1%
2044	7'299	16'213	189'162	1293.3%
2045	7'299	16'213	198'075	1349.5%
2046	7'299	16'213	206'989	1405.8%
Total	**182'483**	**405'324**	**206'989**	**1405.8%**

According to the net profit in one year, the figure below provides the variation of profit in different period. During the starting there is no profit due to the investment period as shown on figure 4.5. in the appendices.

4.7 RUSORO ON GRID SITE

4.7.1 Site location

For the ON grid site, the selected site is Rusororo, in Gasabo district, Rusororo sector.

The latitude is -1.97 ^{0}S and the longitude is 30.22 ^{0}E

4.7.2 PV Array Characteristics

PV module: Longi Solar

Model : LR5-72 HPH 550 M

Unit Nom. Power: 550 Wp

Number of PV modules: 22 units

Modules: 2 Strings x 6 in series

Total number of PV modules: 12 modules

Rusororo BTS Monthly meteorological data

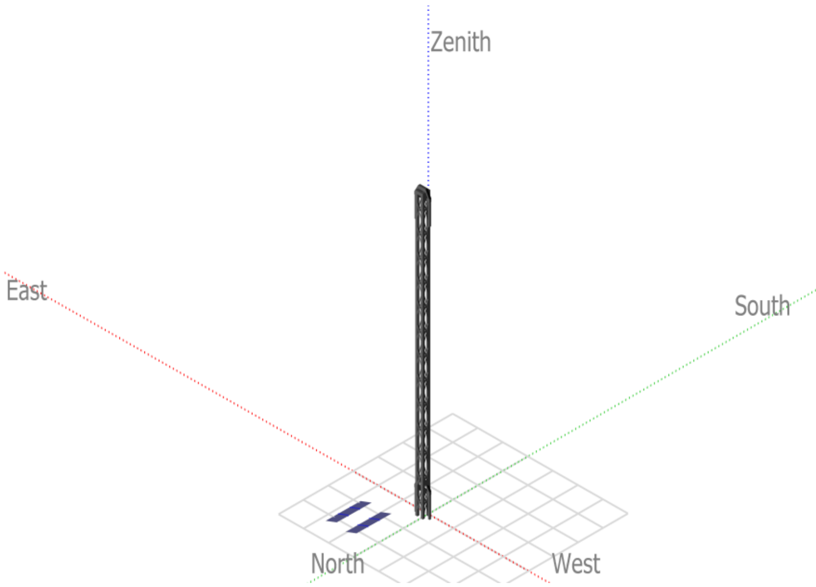


Figure 4. 5 :Perspective of the PV

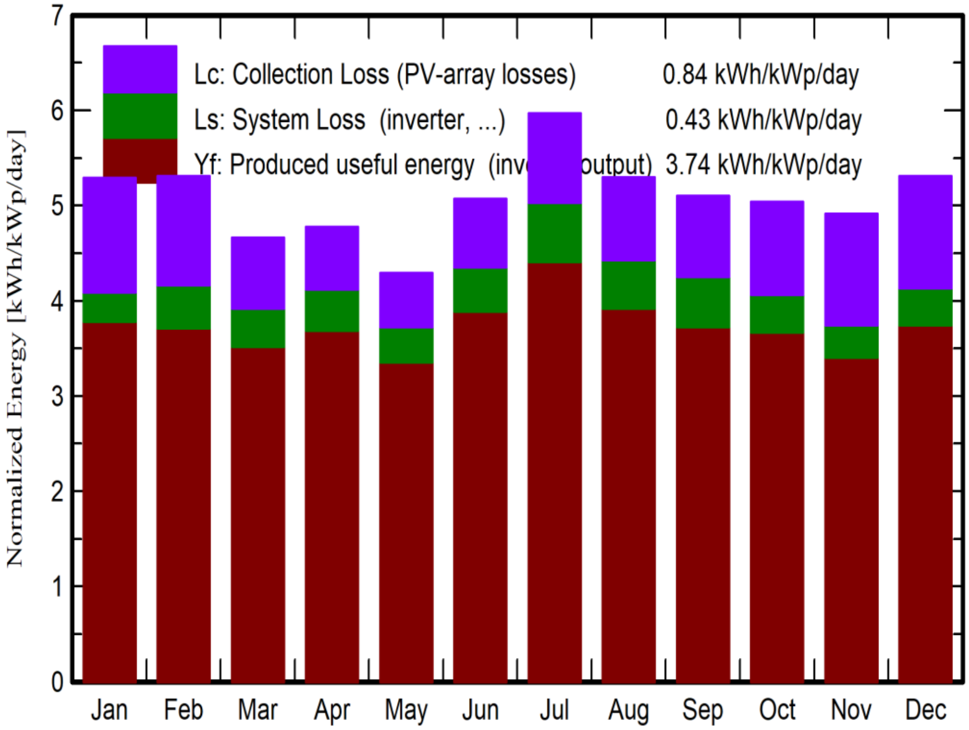


Figure 4. 6 :Normalized productions (per installed KWP)

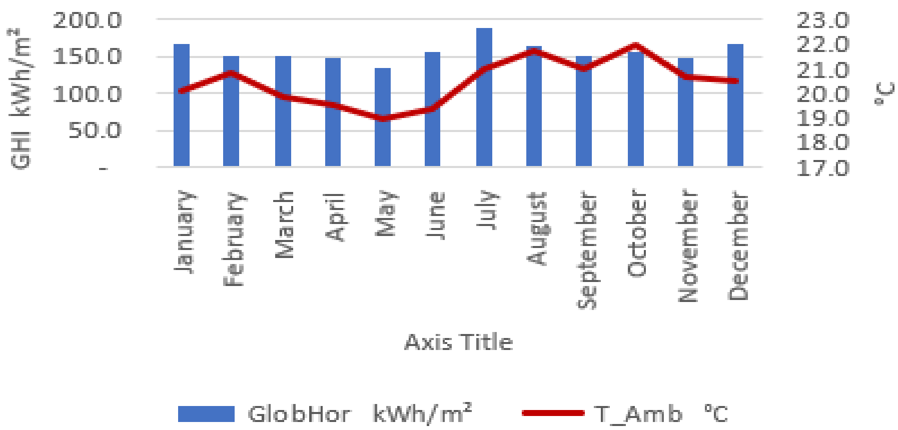


Figure 4. 7 : Rusororo BTS Monthly meteorological data

Table 4. 10 :Balances and main results

Month	EArray	E_User	E_Solar	Eunused	EfrGrid	EavailB	EdirUse	EArray	E_User
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
January	837	1219	773.8	3.33	444.8	777.1	478.7	837	1219
February	770	1101	686.1	14.92	414.6	701	436.5	770	1101
March	802	1219	720.2	10.98	498.4	731.2	458.5	802	1219
April	816	1179	730.1	14.33	449.2	744.5	472.2	816	1179
May	762	1219	687.3	5.15	**531.4**	692.4	452.8	762	1219
June	862	1179	770.5	16	408.8	786.6	470.5	862	1179
July	1030	1219	902.8	37.78	**315.8**	940.6	540.5	1030	1219
August	906	1219	801.9	31.42	416.7	833.3	514.5	906	1219
September	842	1179	738.3	27.97	441	766.2	476.4	842	1179
October	832	1219	750.7	9.49	467.9	760.2	475.4	832	1219
November	741	1179	674.1	0	505.2	674.1	443.9	741	1179
December	846	1219	766.1	1.87	452.5	768	498.9	846	1219
Year	10047	14348	9002	173.24	5346.2	9175.2	5718.7	10047	14348

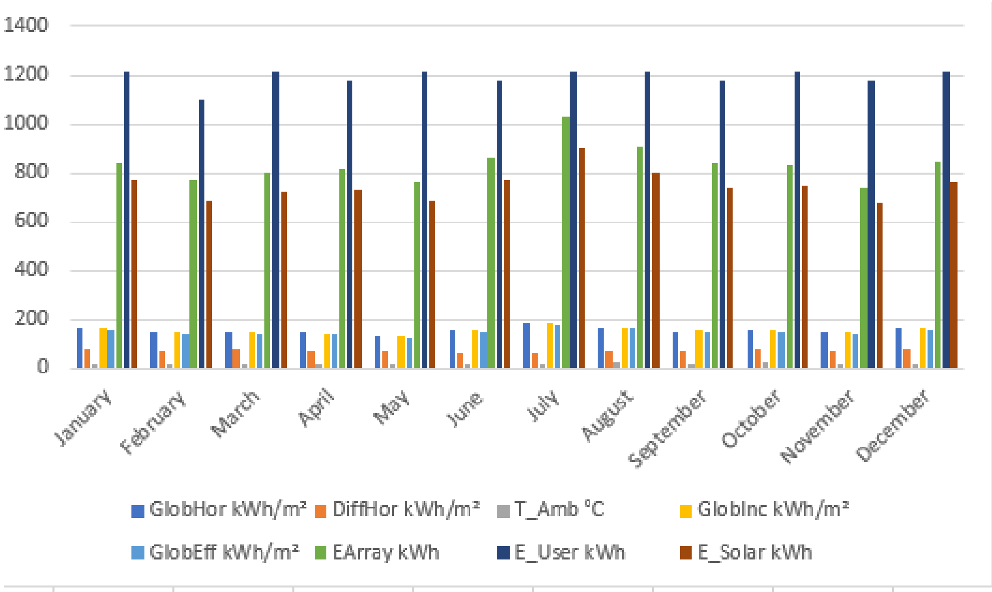


Figure 4. 8 :Balances and main results

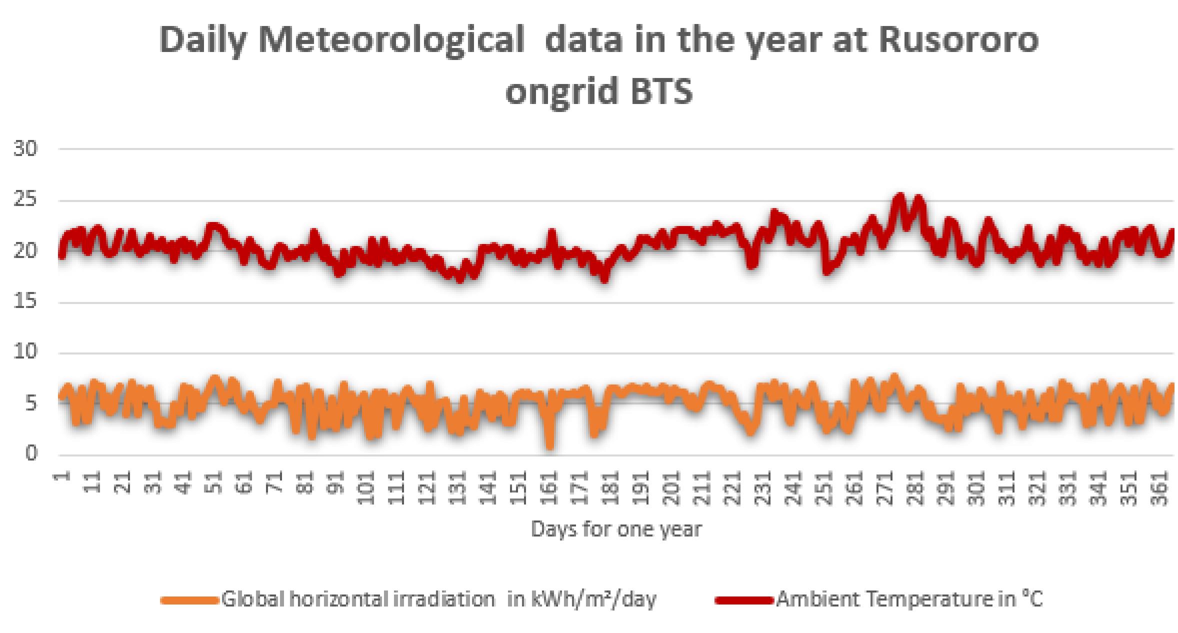


Figure 4. 9 : Daily meteo data

Table 4. 11:Detailed economic results (USD)

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit	% amorti.
2022	0	700	403	0	0	-700	1'809	-11'873	8.5%
2023	0	700	403	0	0	-700	1'809	-10'763	17.1%
2024	0	700	403	0	0	-700	1'809	-9'654	25.6%
2025	0	700	403	0	0	-700	1'809	-8'544	34.2%
2026	0	700	403	0	0	-700	1'809	-7'435	42.7%
2027	0	700	403	0	0	-700	1'809	-6'326	51.3%
2028	0	700	403	0	0	-700	1'809	-5'216	59.8%
2029	0	700	403	0	0	-700	1'809	-4'107	68.4%
2030	0	700	403	0	0	-700	1'809	-2'997	76.9%
2031	0	700	403	0	0	-700	1'809	-1'888	85.5%
2032	0	700	403	0	0	-700	1'809	-779	94.0%
2033	0	700	403	0	0	-700	1'809	331	102.5%
2034	0	700	403	0	0	-700	1'809	1'440	111.1%
2035	0	700	403	0	0	-700	1'809	2'550	119.6%
2036	0	700	403	0	0	-700	1'809	3'659	128.2%
2037	0	700	403	0	0	-700	1'809	4'768	136.7%
2038	0	700	403	0	0	-700	1'809	5'878	145.3%
2039	0	700	403	0	0	-700	1'809	6'987	153.8%
2040	0	700	403	0	0	-700	1'809	8'097	162.4%
2041	0	700	403	0	0	-700	1'809	9'206	170.9%
2042	0	700	0	0	0	-700	1'809	10'315	179.5%
2043	0	700	0	0	0	-700	1'809	11'425	188.0%
2044	0	700	0	0	0	-700	1'809	12'534	196.6%
2045	0	700	0	0	0	-700	1'809	13'644	205.1%
2046	0	700	0	0	0	-700	1'809	14'753	213.6%
Total	0	17'500	8'060	0	0	-17'500	45'235	14'753	213.6%

Total energy per day =39.6KWh

Total energy per month=39.6KWh×30=**1188KWh**

From Rwanda Utilities Regulatory Authority annual report 2019-2020(rura_annual_report_2019-2020), the tariff of electricity for telecom towers is 201 RWF/KWH as shown in the below **table 4.12.mu.**

Table 4. 12 :Electricity end user tariffs

CUSTOMER	Block	New tariff (FRW/kwh)
Residential	[0-15]	89
	]15-50]	212
	>50	249
Non-Residential	[0-100]	227
	>100	255
WTP & WPS	All	126
Telecom towers	**All**	**201**
Hotels	All	157
Health Facilities	All	186
Broadcasters	All	192

Small industries	All	134
Medium Industries	All	103
Large industries	All	94
Commercial data Centers	All	179

Industrial customers are those registered as industries by Rwanda Development Board (RDB). Industrial customers are classified based on their level of consumption.

Rwanda energy sector has mission objectives of energy policy summarized as follow (MININFRA, 2015 as follow:

- Make sure sufficient, and affordable energy supplies are available to all the population in Rwanda
- Set up and promote an enabling environment for increased private sector participation in energy supply and service provision,
- Encouraging and incentivizing more rational, efficient use of energy in public institutions, and amongst industrial and household end-users.
- Ensuring the sustainability of energy exploration, extraction, supply, and consumption so as to prevent damage to the environment and
- Promoting safe, efficient, and competitive production, procurement, transportation, and distribution of energy,
- Developing the requisite institutional, organizational, and human capacity to increase accountability, transparency, national ownership, and decentralized implementation capacity for sustainable energy service delivery.

CHAPITER FIVE

5. RESULTS AND DISCUSSION

Renewable energy solar power solutions are the best alternative for BTS sites beyond the reach of the electricity grid & Electric supply not reliable/poor quality. According to the results from manual design and software design as shown from tables above.

The total fuel consumption for MUYUMBU site in 2020 is **22,345** L. The generator consumes 3.5 liters per hour. The generator running hours per month has been obtained by taking fuel consumed per month divide by 3.5.

The average value of diesel from 31-May -2021 to 30-August-2021 is 1054 Rwanda Franc per litre which is equal to 1.047USD/litre[24].

$$\text{The total fuel cost without PV per year } = 1.047\text{USD} \times 22{,}345 = 23{,}395\text{USD per year}$$

$$\text{The total fuel cost with PV per year} = 1.047\text{USD} \times 219 = 2{,}293 \text{ USD}$$

The fuel cost reduction=23,395USD-2,293USD=21,100USD

$$\text{Rate of fuel cost reduction} = \frac{100 \times 21{,}100}{23{,}395} = 90.19\%$$

The fuel cost has been reduced by 90% after integration of solar PV.

This means that any OFF grid site where solar energy can reach should use solar panels.

About cost

People generally prefer diesel generators over solar powered ones due to the initial cost of installation. But if one can sit and think about the future expenses that would be in store, the individual would, without doubt, prefer solar generators.

Diesel generators would need a constant supply of fuel that would cause the investment to pay back itself, owing to the ever increasing price of fuel. Add to that the amount of time each day or week spent making sure the generator does not run out of fuel, and additional savings can be realized.

Pollution

The solar PV not only conserves power but also reduces pollution.

The diesel generator would produce continuous noise, whereas the pv does not.

Diesel generator also causes air pollution.

CHAPITER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 conclusion

Referring manual calculation and simulation by using pvsyst.7.2 software it is clear that the integration of solar panel in the system powering BTS site is feasible and it is not costly. For OFF grid site, the solar PV is profitable for the first year while for ON grid site, the solar PV is profitable after 10 years. For OFF grid, the cost for fuel has been reduced by 90.19%, therefore the project is feasible technically and economically.

6.2 Recommendation

According to the results as shown from the software, the owner of the company should integrate the renewable energy sources for powering BTS specifically PV solar system for proper cost reduction. I recommend to put solar PV system on all OFF grid BTS sites where solar energy can reach. I also recommend to telecom companies to do sites maintenance regularly because by analysis, different surveys show that some solar sites sometimes fail due to poor maintenance.

REFERENCES

[1] A. Musa and B. S. Paul, "Analysis of Solar and Fossil Fuel Powered Base Transceiver Stations," *IEEE AFRICON Conf.*, vol. 2019-Septe, 2019, doi: 10.1109/AFRICON46755.2019.9133826.

[2] M. H. Alsharif, "Comparative analysis of solar-powered base stations for green mobile networks," *Energies*, vol. 10, no. 8, 2017, doi: 10.3390/en10081208.

[3] "GSM Network Architecture | GSM System Architecture | Electronics Notes." 2014, [Online]. Available: https://www.electronics-notes.com/articles/connectivity/2g-gsm/network-architecture.php.

[4] L. Olatomiwa, S. Mekhilef, A. S. N. Huda, and K. Sanusi, "Techno-economic analysis of hybrid PV – diesel – battery and PV – wind – diesel – battery power systems for mobile BTS : the way forward for rural development," pp. 271–285, 2015, doi: 10.1002/ese3.71.

[5] W. W. Wibowo, Y. D. R. W. Astuti, and C. Hudaya, "Solar-Powered Base Transceiver Station," *Proc. - 2018 2nd Int. Conf. Green Energy Appl. ICGEA 2018*, pp. 108–112, 2018, doi: 10.1109/ICGEA.2018.8356275.

[6] "Renewable Energy Potential – GET." .

[7] S. Goel and S. M. Ali, "Cost analysis of solar/wind/diesel hybrid energy systems for telecom tower by using HOMER," *Int. J. Renew. Energy Res.*, vol. 4, no. 2, pp. 305–311, 2014, doi: 10.1234/ijrer.v4i2.1165.g6281.

[8] S. L. Trazouei, F. L. Tarazouei, and M. Ghiamy, "Optimal design of a hybrid solar -Wind-Diesel power system for rural lectrification using imperialist competitive algorithm," *Int. J. Renew. Energy Res.*, vol. 3, no. 2, pp. 403–411, 2013, doi: 10.20508/ijrer.76830.

[9] P. Nema, S. Rangnekar, and R. K. Nema, "Pre-feasibility study of PV-solar / wind hybrid energy system for GSM type mobile telephony base station in Central India," *2010 2nd Int. Conf. Comput. Autom. Eng. ICCAE 2010*, vol. 5, pp. 152–156, 2010, doi: 10.1109/ICCAE.2010.5451496.

[10] G. Sea, "Back ground ALTA ENERGY," 2012.

[11] B. T. S. Site, C. Calculations, and O. Calculations, "The True Cost of Providing Energy to Telecom Towers in India Whitepaper Contents," pp. 1–10, 2012, [Online]. Available: https://www.gsma.com/membership/wp-content/uploads/2013/01/true-cost-providing-energy-

telecom-towers-india.pdf.

[12] R. K. Akikur, R. Saidur, H. W. Ping, and K. R. Ullah, “Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electri fi cation : A review,” *Renew. Sustain. Energy Rev.*, vol. 27, pp. 738–752, 2013, doi: 10.1016/j.rser.2013.06.043.

[13] M. Usman, “HOMER Analysis for Integrating Solar Energy in Off-Grid and On- Grid SCO Telecommunication Sites,” *2019 1st Glob. Power, Energy Commun. Conf.*, pp. 270–275, 2019.

[14] I. Conference and C. Networks, “A Smart BTS Power Management System,” no. Sim 300, 2010, doi: 10.1109/CICN.2010.97.

[15] N. K. Pal and B. J. Ifeanyi, “TECHNICAL OVERVIEW OF ALL SOURCES OF ELECTRICAL POWER USED,” no. August, 2019.

[16] L. J. Olatomiwa, S. Mekhilef, and A. S. N. Huda, “Optimal sizing of hybrid energy system for a remote telecom tower: A case study in Nigeria,” *2014 IEEE Conf. Energy Conversion, CENCON 2014*, pp. 243–247, 2014, doi: 10.1109/CENCON.2014.6967509.

[17] M. H. Alsharif and J. Kim, “Optimal solar power system for remote telecommunication base stations: A case study based on the characteristics of south Korea’s solar radiation exposure,” *Sustain.*, vol. 8, no. 9, pp. 1–21, 2016, doi: 10.3390/su8090942.

[18] Y. Yin and S. Hosoe, “A H YBRID S YSTEM C ONTROL A PPROACH Abstract :,” vol. 2, no. 6, pp. 1–10, 2008.

[19] S. M. Kyei, “Optimization of Electricity Supply to Mobile Base Station with Design of PV Systems: A Case Study in Accra Metropolis (MTN selected cell sites) Optimization of Electricity Supply to Mobile Base Station with Design of PV Systems: A Case Study in Accra Metr,” 2018.

[20] M. H. Alsharif, J. Kim, and J. H. Kim, “Green and sustainable cellular base stations: An overview and future research directions,” *Energies*, vol. 10, no. 5, 2017, doi: 10.3390/en10050587.

[21] M. Abdallah and M. Khatir, “Study and Sizing a Photovoltaic Generator intended to a Telecommunications site,” no. November, 2017.

[22] R. Mohammed, N. Advisor, and S. Abebe, “Optimal Sizing of Grid-PV Hybrid System for ethio telecom Access Layer Devices and Its Economic Feasibility,” no. June, 2017.

[23] S. Prasad, “Renewable Energy in Telecom,” 2012, [Online]. Available: http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/06/Bharti_Infratel_1011.pdf.

[24] "Rwanda gasoline prices, 06-Sep-2021 _ GlobalPetrolPrices." .

Appendices

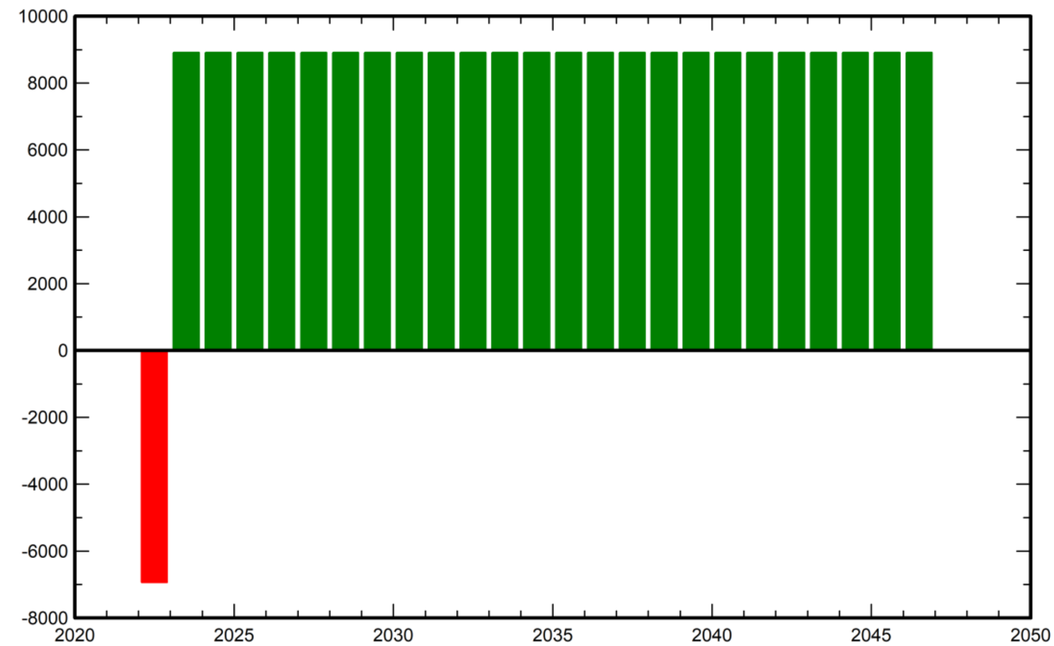


Figure 4. 10 :Yearly net profit (USD)

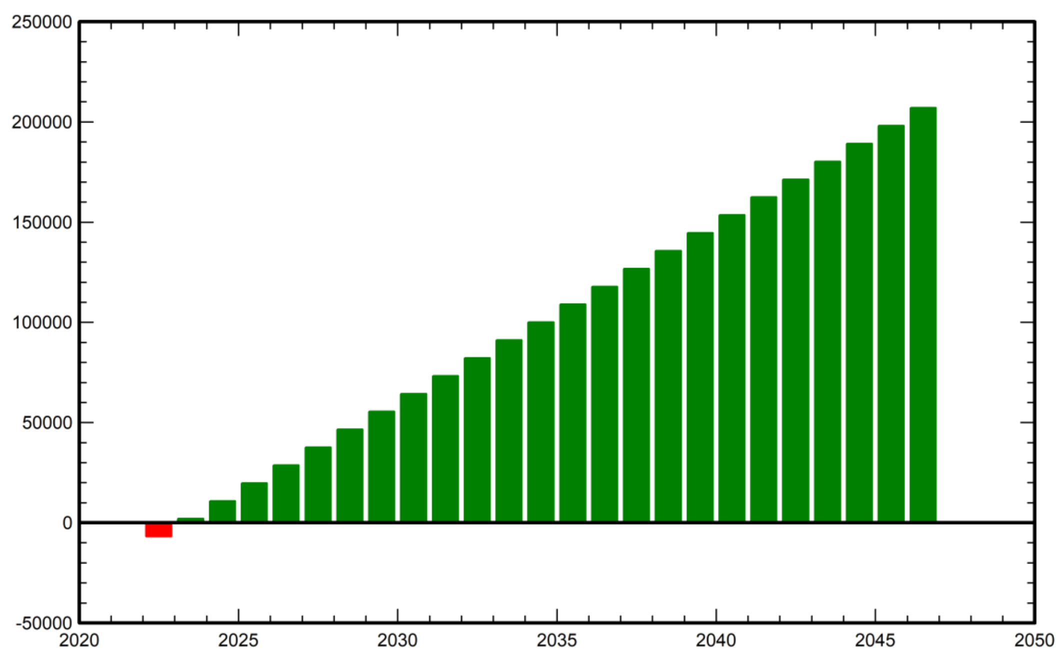


Figure 4. 11: Cumulative cashflow (USD)