UNIVERSITY of RWANDA College of Science and Technology ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

TITLE: DESIGN OF EMBEDDED GENERATION BASED ON PHOTOVLTAIC AT BUSORO HEALTH CENTRE.

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Month and Year: October 2022

Declaration

I declare that this dissertation results from my work and has not been submitted for any other degree at the University of Rwanda or another institution. It has been passed through the Anti-plagiarism system and found the complaint and this is the approved final vision of the dissertation.

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Signed:

Date: 14th October 2022

Dedication

I dedicate this dissertation to my beloved son Dory Blaise HIRWA and my lovely Husband Charles.

Acknowledgment

First and foremost, I would like to give thanks to Almighty God who always walked with me from the starting up to the end of this journey and before. Without the mercy, guidance, and protection of the Lord, this research would barely be a dream.

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Abstract

According to the increase of energy requirements in different fields, there is still a problem with satisfying energy demand for the whole country of Rwanda supplied by the national grid. The big problem high cost of energy due to the location of users, source of energy, or the type of suppliers. Especially health cares located in rural areas or where the national grid is very expensive. This problem can be handled by introducing embedded generation based on renewable energy instead of depending on independent power producers or presumers like distributed generation based on solar photovoltaic (PV) systems. Therefore, this project research focuses on designing embedded generation based on PV for supplying health centers where the grid energy is much cost. The case study is Busoro Health Centre located in the southern province, Nyanza District, Busoro Sector where high solar intensity is obtained. This research is done through the evaluation of the primary load at the health center, working hours per day, and the capacity of PV production. The system of the grid-connected solar system was designed and simulated through the HOMER (Hybrid Optimization Multiple for Electrical Renewables) pro, for achieving the optimal cost of energy. Today energy cost to the health centers is RF186/kWh, proposed cost of energy selling back to the grid in the first scenario is 50% (RF93/KWh) of the energy price where the net present cost from homer becomes RF44 million, LCOE becomes RF113.14/kWh and the grid charge becomes RF372717/ year. In the second scenario, 75% (RF139.5/KWh) of the energy price of the national grid, net present cost becomes RF43.6millions LCOE becomes RF105/KWh and the grid charge will be RF2409/year. To conclude the results according to the purpose of this thesis for minimizing monthly electrical bills, distributed generation is needed for reducing energy bills and for making energy stable due to the source being closed to load.

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List of Abbreviation

HOMER: Hybrid Optimization Multiple for Electric Renewables

NREL: National Renewable Energy Technology Laboratory

iHOGA: improved Hybrid Optimization Genetic Algorithm

NASA: National Aeronautics and Space Administration

EDCL: Energy Development Corporation Limited

EUCL: Energy Utility Corporation Limited

IPP: Independent power production

PSO: Particle Swam Optimization

CSP: Concentrated Solar Power

RES: Renewable Energy Sources

LPG: Liquefied Petroleum Gas

IDP: Internally Displaced Persons

LCOE: Levelised Cost of Energy

HES: Hybrid Energy Sources

CO_2: Carbone dioxide

REG: Rwanda Energy Group

AC: Alternative Current

PV: Photovoltaic

NPC: Net Present Cost

RF: Rwandan Franc

DC: Direct Current

1. INTRODUCTION

Energy demand and energy cost can be managed and promote sustainable energy by increasing renewable energy in the existing network. Due to the high cost of electricity grid extension, renewable energy sources be as the solution for insufficiency or absence of electricity in some regions [1]. RESs are combined with traditional fossil-fuel-powered generators to create hybrid energy systems (HES), which can get beyond the issue of intermittent and unpredictable RES supply[2]. In areas without conventional power networks or with patchy services, renewable energy is a good substitute for traditional sources of energy. These renewable energy sources are significant because they emit less carbon dioxide (CO2) into the atmosphere and are less dependent on the importation and transportation of raw materials for the production of electricity. In the short to medium term, renewable energy is becoming economically competitive[3]. Renewable energy use is encouraged to lower the amount of energy used from the national grid and to counteract the consequences of climate change and global warming. The cost of power decreased when renewable energy was used since fewer resources were required to produce it. In some regions with strong sun irradiation, like Africa, photovoltaic systems are highly preferred as a means of reducing the demand on the grid through self-production Rwanda, there is a problem with electricity access for all population where there is an overload on the national grid, so integration of renewable energy is needed in affecting the sustainable development of the country. Green and clean energy alternatives, such as solar energy, are adopted as renewable energy sources [4]. This study intends to increase knowledge of the role solar energy currently and potentially will play in Rwanda's energy system in terms of cost, a decrease in energy demand from the national grid, and low environmental emissions of greenhouse gases[5]. In the 1950s, PV was initially created to power satellites. Since that time, the PV cell in particular, and the underlying design of PV systems have not altered. The two main elements that affect a cell's output are its temperature and the amount of sunlight it receives.

The potential for variable and altered load profiles by consumers is growing as new decentralized energy technologies develop. Through efficiency enhancements, the utilization of battery and existing non-battery thermal storage, and the use of demand management systems to optimize integration, clean energy supply and demand can be combined at the customers' premises[6]. Demand management and even small amounts of energy storage can increase the value of renewable energy: (especially demand charges based on monthly peak demand when solar output is not always coincident).

- By avoiding exports, which are compensated at lower rates, boosting the capacity to build and utilize renewable energy behind the meter.

- Enabling consumers to take advantage of new energy market opportunities such as off-site renewable energy power purchase agreements with solar and wind farms, network support, auxiliary services, system reserves, and wholesale demand response (by a better matching load to the generator's output profile).

1.1. Background and Motivation

The problems of overdependence on fossil fuels were brought to light by the global oil crisis, which pushed for the development of alternative power resources[7]. 2019 is expected to have a nationwide installed generation capacity of 221MW from a variety of sources, servicing a population of about 12 million people with a 51 percent energy access rate. 37% of networks are grid-connected, whereas 14% are off-grid networks. While grid-connected users are forced to expensive electricity bills and frequent power disruptions, over half of the population lacks access to electricity (blackouts). According to annual electricity production capacity, electrical load, economic viability, feasibility, affordability, carbon footprint, and levels of greenhouse gas emissions for climate change considerations, photovoltaic (PV) solar technology is the best choice for Rwanda's government's goal to reach 512MW of installed power generation capacity through renewable energy penetration in 2023/2024[8]. 71.92% of Rwandan households had access to electricity as of May 2022, and 50.61% of them were wired into the national grid. Over the past ten years, there have been more than ten times as many on-grid connections.

By June 2022, the installed capacity of electricity generation will have increased from 238.052 MW to 345.752 MW. The administration offices, health centers, milk collection centers, water pumping stations, coffee washing stations, schools (pre-primary, primary, secondary, and vocational training centers), markets, telecom towers, tea factories, and IDP model villages can all use solar energy to help them meet their 2024 goals[9]. The government wants to generate 100%

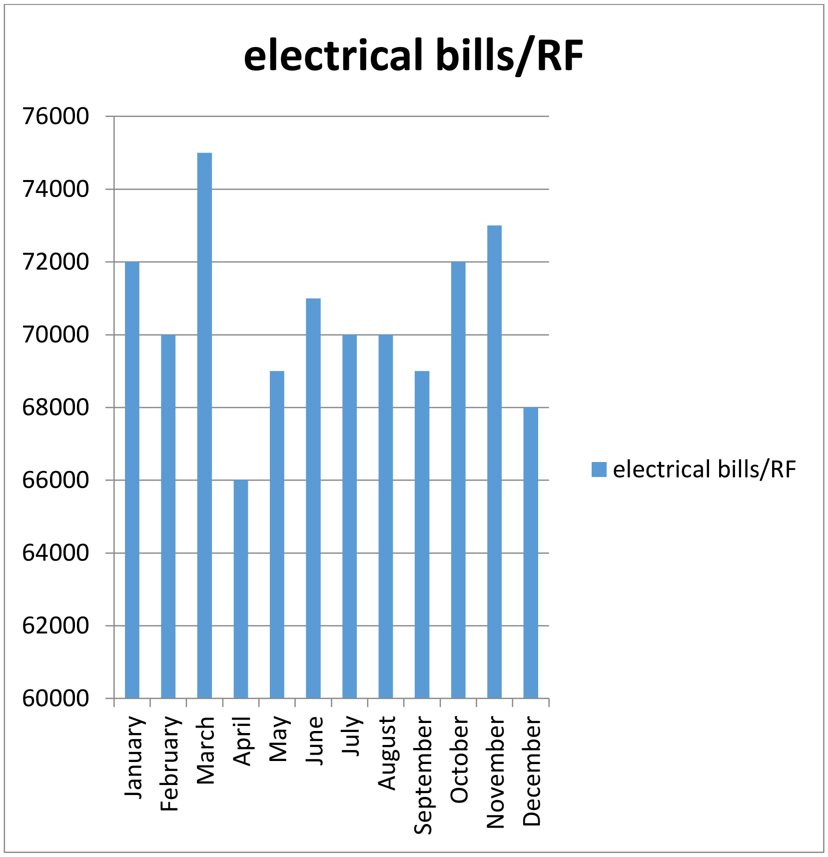
of the nation's electricity by 2024, with 52% of it coming from on-grid sources and 48% from off-grid connections, respectively. The integration of renewable energy into the current energy network will be strengthened to implement the national energy policy and help Rwanda reach its target of 100% electricity availability by 2024[10].

The majority of activities are carried out during the day when solar energy is used without any storage and any excess is sent to the national grid where there is an excessive amount of solar radiation. Energy costs rise when just grid energy or diesel is utilized during a blackout as opposed to when renewable energy is incorporated and self-generation is used. The lack of integration of renewable energy sources into the current power grid results in an overloaded national infrastructure and has detrimental effects on the distribution of electricity throughout Rwanda. A solar PV plant installation can produce enough energy to meet a high load while the excess energy is sent to the utility grid through net metering. The grid-connected solar PV model explores various potentials related to environmental energy production[11].

1.2.Problem statement

Electrical power access plays a vital role in accelerating economic development by improving health and life standards. Electricity in a rural area is not easy to access due to the high cost of transmission lines at several kilometers which cause also electricity to be expensive. The economy can be decreased due to the high cost of energy per Month and it can discourage the user to save money. Commercial, office, and healthcare loads that are close to an electricity grid connection have historically used grid power as their main energy source. However, there is an issue even in grid-connected cities and areas when there are power outages or failures during times of high demand, forcing them to rely on pricey backup generators that burn diesel fuel. When there is a blackout, backup power is also necessary for any medical facilities that perform surgical procedures, manage childbirth, or provide emergency treatment, so backup there is a very expensive diesel generator.

Figure 1-1 shows how electricity was paid in 2021 at Busoro health center where the total annual electrical bill is RF845000.



Months	electrical bills/RF
January	72000
February	70000
March	75000
April	66000
May	69000
June	71000
July	70000
August	70000
September	69000
October	72000
November	73000
December	68000
total	845000

Figure 1-1: Monthly electrical bill at Busoro health center

1.3. Objectives of research

1.3.1. The general objective of the research

The general objective of this research is to design embedded generation based on PV solar at Busoro Health Centre by minimizing the monthly electrical bill. Since electricity from the grid is easily available in this health center but the cost of electricity used per month is too high due to the diesel cost used in a blackout. Photovoltaic technology such as a PV grid-connected system is proposed in terms of cost and efficiency to generate electricity during the day. Due to climatic conditions, the BUSORO sector receives abundant amounts of sunshine all year around. Since solar energy is available only during the daytime, it is very interesting to use solar energy in this health center for reducing the national grid load and minimizing the cost of used electricity. In another hand, this research investigation aims at sizing the solar PV in local load demands at the consumer's level for cost minimization

1.3.2. Specific objectives of the research

The following objectives should be accomplished to achieve the desired goal:

i) Design the PV system connected to the grid which can able to supply the demand of the health Centre when the grid is not available.
ii) Simulate the solar PV grid-connected system in HOMER software.
iii) Sensitivity analysis of electricity cost when the solar is connected to the grid and when electricity is from the grid only.

1.4.Scope of project

This scope of project work is limited to designing and optimizing Grid connected PV system of Busoro Health Center for reducing daily demand on the national grid and reduction of money paid per month on electricity used.

The following assumptions will be considered for getting good results

- The daily load cycles for the health center were collected because the temperature variations at the selected site are approximately fixed and the summer and winter seasons are not different.
- This project life time was estimated based on the guarantee of PV panels which is mentioned to be around 25 years.

- The Annual solar resources input and the primary load profiles are assumed to remain constant throughout the project lifetime.
- It will be simulated by HOMER (Hybrid Optimization for Multiple Electric Renewable) software.

1.5.Significance of project

The significance of this project work is to reduce energy consumption from the national grid due to high demand during the day by integrating renewable energy into the existing network. The PV system is preferable in Busoro health center because of the high solar irradiance in this region.

1.6.Thesis outline

This project is organized as follows with different chapters where chapter 1 is about the introduction of the project. Chapter 2 describes a brief review of embedded generation based on renewable energy integration, types of PV systems connected to the grid, off-grid, and grid only as a source of electricity. Chapter 3 shows data collected in the selected site with a clear presentation of the average daily load profile for Busoro health center. Chapter 4 presents the modeling and simulation of the designed grid-connected PV system of the health center. Chapter 5 shows the conclusion and recommendation

2. REVIEW ON DISTRUSTED GENERATION

2.1. Introduction

There are several researchers in the literature that had investigated the different methods and configurations of renewable energy integration for a particular purpose. As technology improved, Grid-connected, off-grid, or hybrid networks can all be used as different configuration systems. Sometimes, distributed generation is known as an embedded generation.

These different configurations are applied to find the balance of system reliability and cost[13]. Embedded power generation takes place in distribution networks near consumers[14]. Many years ago, high grid overload may arise in electricity grids where distributed renewable energy systems predominate because rising power consumption hasn't kept pace with rising distributed renewable energy system power generation. Both renewable and non-renewable energy sources are available today for maintaining the load demand and the power generated from those different sources to the grid. Energy from renewable sources such as biomass, sun, peat, wind, geothermal, and hydropower are also available[15]. In developing countries, the embedded generation technology was adopted but in African countries independent power producers dominate the embedded generation technology. Because of that and the long distance of grid power, the embedded generation system is proposed to be used as the source of energy for reducing energy drawn from the national grid and the maintenance of power.

2.2. Sources of energy for distributed generation

Energy can be obtained either from Renewable or non-renewable energy sources. Non-renewable energy sources are in short supply, typically because it takes a while for them to regenerate, whereas renewable energy sources have the benefit of an endless supply over an extended period because they can be used in embedded generation systems as the support of energy sources. Renewable energy sources can be solar, wind, water (also known as hydro), biomass (organic matter from plants and animals), and geothermal[16]. In Rwanda, there are many sources of renewable energy but the wind doesn't exist because of its low speed of the wind. Since they are limitless and pollution-free, renewable energy sources (RES) hold the key to the creation of a sustainable energy system like solar energy which is encouraged because of its low cost and environmental friendly.

Small-scale renewable energy has been successfully adopted to encourage sustainable energy use and lower the demand for the domestic energy supply. Solar energy, hydropower, and biomass are examples of renewable energy sources in Rwanda where the distributed generation but solar is very cheaper and easier to install in the distribution network and it is a durable, manageable, and ecologically beneficial energy source recently discovered[17]**.** Due to its benefits, such as reducing reliance on fossil fuels and pollution, renewable energy sources have been expanding quickly on a worldwide scale. As a result, they offer a system that is affordable, dependable, and secure [18]. Solar photovoltaic energy is one of the businesses with the quickest growth rates worldwide (PV). As a result, advancements have been made in several linked disciplines, such as the efficiency of cells, the amount of energy used to produce materials, and the utilization of materials. More focus has been placed on solar photovoltaic (PV) generation technology as a result of the world's growing demand for clean, renewable energy[19]. Since there are no moving parts, the operation is silent, and photovoltaic systems are simple to install, they are a rapidly expanding technology for the generation of electric power around the world. No pollution of the air, land, or water, as well as no need for operating fluid or fuel, make PV power plants environmentally beneficial. Due to the widespread adoption of photovoltaic technology, it may be installed in residential areas, typically on the roofs of homes and businesses, as well as on the ground. It has a durability of over 25 years with very little maintenance, unlike wind power, and can be owned by the average person. It also requires very little skill to maintain[20].

Rwanda's electrical supply is made up of domestic production, electricity imported from neighbors, and regional cooperative power facilities. Hydropower, thermal, solar PV, peat, and methane gas are the main energy sources. Energy imported to the grid (REG) is from MININFRA and the IPP; it is also subdivided into two sub-companies such as EUCL and EDCL. As the aim of 2022 for energy development is to increase a thousand households for access to energy via solar PV systems and mini grids[9], solar PV systems connected to the grid can be implemented in health centers. Figure 2-1represents the percentage of energy sources in Rwanda and their contribution in 2024 and as energy sources in 2019.

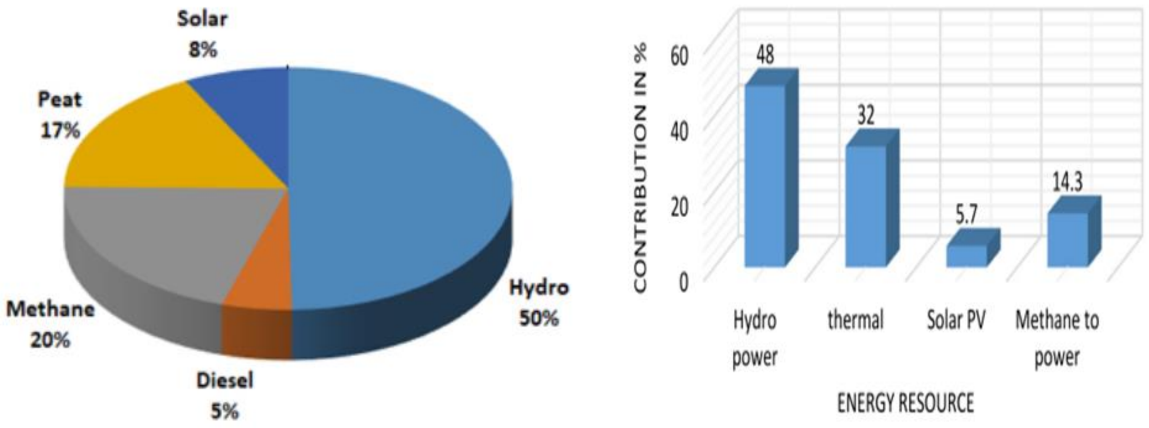


Figure 2-1: Energy mixed in 2024 and 2019

2.2.1. Hydropower

The largest contribution of energy generation in Rwanda is from hydropower plants which contribute over 50% of all energy used in Rwanda. The form of kinetic energy changes to mechanical energy as water turns turbine blades. The generator's rotor, which is turned by the turbine, transforms the mechanical energy into electricity. 123.4MW, or 51.2% of the total power generated, comes from hydropower production (REG, 2022). Where it was 48% in 2019 but its initial cost is very high due to dam construction and it can be also used as distributed generation. The national grid is integrated with around 37 hydroelectric facilities, adding over 120 MW[9].

2.2.2. Thermal energy

Oil, natural gas, and coal can be used as fossil fuels during power generation for meeting the peak load because of their ability to store it to use later. Thermal energy has great air pollution due to sources and it is costly compared to renewable energy or embedded generation system. In Rwanda, thermal has thirty-two percent of the power generated in the country which is second to hydropower but in 2024 the percentage will be reduced to 5% of total energy[9].

2.2.3. Methane gas

Methane gas in Rwanda is extracted from Kivu Lake which borders RDC and Rwanda. The Kivu Lake has large levels of naturally occurring methane gas (CH_4) and carbon dioxide (CO_2), with the maximum levels occurring at depths between 270 and 500 meters over an area of about 2,400 square kilometers. According to estimates, the methane in Lake Kivu has the potential to produce 700 MW of power over 55 years. A little over 350 MW of the overall generation potential belongs to Rwanda, and the balance is split with the Democratic Republic of the Congo[21].

2.2.4. Biomass

More than 90% of the population uses biomass as the source of energy used to cook and light production. These biomass resources are gotten from different activities such as food scraps, crop byproducts, animal dung, and other waste materials. In Rwanda, 83 percent of the rural area population used firewood and charcoal as cooking fuel in 2020 but today that traditional biomass converted into liquefied petroleum gas (LPG), and modern cook stoves were improved[22].

Peat is an additional energy source which is two power plants in Rwanda, YUMN Ltd is building an 80 MW peat-fired power plant in the South Akanyaru prospect in Gisagara District, and the project is to be developed. The government began development of the 15 MW peat power plant in Gishoma, Rusizi District, to reduce the electricity deficit that the country was experiencing and to coincide with the significant growth of electricity demand observed in the region as a result of the expansion of the local cement factory and country development (REG, 2022).

2.2.5. Solar energy

The most of rural area population in Rwanda use solar energy as more energy efficiency where in 2050 solar energy will have around 80% of it because of its lower running cost [22] and cheaper installation. The potential for solar energy deployment in Rwanda is substantial, with average irradiation of 5kWh/m2/day. On-grid and off-grid utilities already use solar energy, which accounts for 5% of the energy added to the system. The energy from the solar can be used in different daily activities where a 3.3 MW plant in Nasho constructed largely to provide irrigation and lighting for the local people, as well as an 8.3 MW project within the Agahozo Youth settlement in the Eastern province, acts as the independent power producer, those power plants were both created in conjunction with Global Gigawatt. Additionally, the 0.25 MW Jali power plant is situated in Gasabo and Ndera with an installed capacity of 1.5MW.

So renewable energy in Rwanda in 2021 was at the good stage where hydro had 75%, solar at 24% and bioenergy was at 1% and there are no wind and geothermal resources in this country [23]. Photovoltaic (PV) systems use converters to generate AC, which is used directly to generate electricity and the excess is delivered into the power grid without being stored in batteries. Being a renewable source integrated into the national grid, this technology will help the nation's deteriorating energy condition while also supplying energy free of toxins and greenhouse gas emissions [24]. The best technology is a photovoltaic system, which should be better, more affordable, and more effective. Due to its favorable effects, it eventually becomes accessible in several nations [25]. In a shared solar energy arrangement, several people rent or buy solar panels or shares (in the form of kilowatts of capacity) in a local solar power project. In circumstances where installations are grid-tied, the energy obtained from the solar garden is utilized to power the homes or establishments of subscribers and may be fed into the national grid, making for the satisfaction of consumers' energy demands as well as the reinforcement of the grid [19].

Concentrated solar power (CSP) in Rwanda is not more considerable but it is a good source of energy that can be suitable in this region[23]. Rwanda is located in East Africa at approximately two degrees below the equator where Solar radiation with the intensity of about 5 kWh/m2/day and peak sun exposure of about 5 hours per day. Governments have always been responsible for providing electricity. However, the enabling environment and laws are typically given by the government. Investors or owners can generate electricity to utilize in their businesses.

Figure 2-2 presents the global solar irradiance in the whole country. Busoro health center is located in the Nyanza district where the solar radiation is too much around 5kWh/m^2 which encourages embedded generation to be adopted in this region as the source of energy close to the user. The Eastern Province of Rwanda has the greatest potential for solar energy production as the legend indicates with 5.4kWh/m^2. In the Southern and Eastern provinces of Rwanda, the daily sun irradiation varies from 4kWh/m^2 but in that figure solar irradiance of Nyanza district is around 5.2kWh/m^2, at Ruhengeri region where the is low solar irradiance in Rwanda around 4kWh/m^2. However, circumstances vary depending on the season, with an average daily irradiation level of 4.5kWh/m^2 in the overcast[24]’

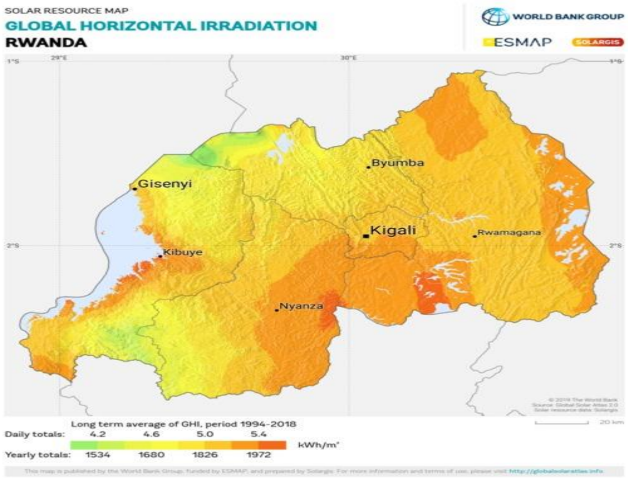


Figure 2-2: Global solar irradiation in Rwanda

Rwanda currently has 12.230MW of installed solar energy that comes from 5 solar power plants, including the Jali power plant, which produces 0.25MW, the Rwamagana Gigawatt, which produces 8.5 MW, the Ndera Solar power plant, which produces 0.15 MW, and the Nasho Solar plant, which produces 3.3 MW. By exporting extra electricity to the grid and lowering energy demand, PV systems can be a good source of income for producers[20]

2.3. Different generation configurations

Generation configurations depend on sources, storage, and how it is connected to the grid but the configuration of distributed generation can be a hybrid or grid-connected system. Off-grid is also a configuration system but it is not distributed configuration. The solar energy source is the best source which includes this distributed generation as a hybrid with solar energy source or grid-connected PV solar system.

2.3.1. Hybrid systems

The photovoltaic generator is installed in hybrid systems along with other energy sources to produce power. These options are intended to be used in circumstances where it is not practical to eliminate fossil fuel-powered generators. A hybrid energy system combines different energy generating and/or storage methods, or it uses a generator that is powered by two or more different forms of fuel. A hybrid energy system is an effective strategy for moving away from economies that rely on fossil fuels. Renewable energy sources, such as the sun, hydro, or wind, are used to produce energy using hybrid energy systems but in Rwanda no wind there. A contribution of energy is gained by the installation of photovoltaic solar panels and wind turbines during times of maximum wind or sun. These systems feature batteries in remote areas for continuous operation and a backup diesel generator set for the electricity supply, which comes on if the energy obtained is insufficient[25].

Figure 2-3 illustrates how different sources of energy can be connected to generate energy like PV solar, wind, batteries, generators, and biomass to supply the load.

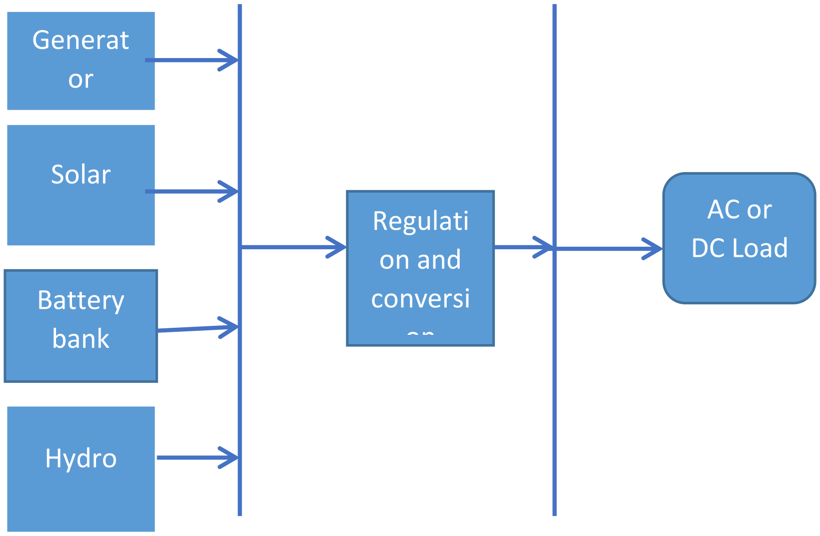


Figure 2-3: Hybrid system

2.3.2. Grid-connected system

On-grid systems are connected to the electric grid but lack a storage system. The most common usage of these systems is in PV power plants to produce electrical energy, which is then delivered to the grid to feed the linked consumers[25]. Due to their use in distributed generation, grid-connected PV systems have gained more popularity than freestanding ones[26]. The solar panels or arrays in a grid-connected PV system are linked to the utility grid by a power inverter unit, enabling them to run in parallel with the electrical utility grid. In other words, residences and businesses with grid-connected PV systems can use solar energy for some or all of their demands while continuing to use the regular electrical mains grid at night or on overcast, gloomy days. Based on various advantages, the utilities and customers built the grid-connected PV systems to work in conjunction with other Distribution Energy Resources and the utility grid. The bi-directional inverter, PV panels, battery system, smart meter, direct current (DC) bus system and alternating current (AC) bus make up grid-connected PV systems. When the power output of the PV system is greater than the power required by the consumers, the bi-directional interface included in the system enables the power generated by the PV panels to supply the loads directly connected to the AC bus system and delivers the excess electricity to the grid[27]. The grid-connected solar PV model investigates several possibilities for producing environmentally friendly electricity that is both affordable and a source of income for producers[11].

Figure 2-4 presents how any source of energy which is solar can produce electricity for use and the excess or total products be injected into the grid at certain agreements between the grid and the independent power producers. Solar panels produce energy from the captured solar irradiance, the power from the panel is DC power and the inverters are needed to convert it into AC power for supplying AC loads. The output from the inverter is passing through the net metering to the grid as the storage.

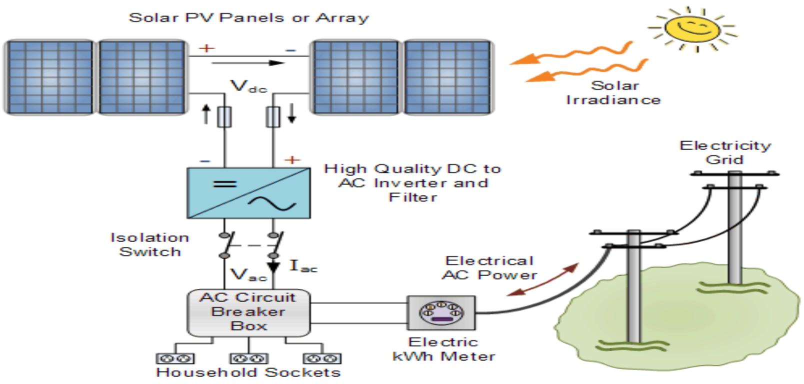


Figure 2-4: grid-connected PV system[28]

The most popular and straightforward solar electric system types that homeowners install are grid-tied systems. When the sun is out and the grid is operating, these complete solar power systems may produce electricity. They are connected to the utility grid. If the system generates more energy than what your home consumes, it sends (sells) the surplus energy back to the grid, offsetting any electricity you would purchase from the utility at night. If you use more energy than your system can produce, the utility will continue to fulfill your extra energy needs as usual. Grid-connected solar power systems are excellent for lowering your energy costs. Examining your electricity bills is the simplest approach to figuring out how much energy you consume annually.

If we compare the grid-connected system to the off-grid solar PV system for the same load, the grid-connected system is more cost-effective. This is because, according to simulation results, the on-grid system's NPC (net present cost) is lower than the off-grid system's NPC, despite the latter's use of 100% renewable energy[29].

2.4.Components of grid-connected PV system

The PV panel, inverter, grid, and load components of this design are a grid-connected solar PV system or distributed generation system, or embedded generation system. A grid-tied system depends on the local utility to deliver electricity at night after producing energy for the customer during the day and sending excess to it[30]**.** The bi-directional inverter, PV panels, battery system, smart meter, direct current (DC) bus system and alternating current (AC) bus are all components of grid-connected PV systems. However, occasionally the batteries are not necessary when the excess energy is not stored but instead is directly injected into the grid.

2.4.1. Solar panel

Photovoltaic (PV) cells in large numbers make up solar panels. Solar cells on solar panels absorb photons and the sun's energy packets when sunlight strikes their surface. As a result, the cells become excited and begin to vibrate, producing green electricity. The generated power enters a conductive wire at the panel's edge. The electrical current is carried via the conductive wire to the inverter, which converts it from DC to AC. The panels themselves typically last for roughly 25 years, making maintenance extremely uncommon. The sun is an enormous source of energy, which travels in the form of electromagnetic radiation. The available area, the amount of solar radiation, and the load profile are used to determine the size of a PV array. The peak load value for each panel can be chosen while taking the needed output voltage and area into consideration. Depending on the wavelength of the radiations emitted, these radiations can be classified as light, radio waves, etc. Visible light makes up a very small portion of the sun's radiations that enter the atmosphere of the earth. This visible light creates electrons in solar cells. Different solar cells utilize light with varying wavelengths. Silicon and other semiconductor materials are used to create solar cells, which are used to produce electricity[31].

2.4.2. Bi-directional inverter

A pure sine wave inverter with the ability to connect to the grid and draw power from extra sources like batteries or solar panels is known as a bi-directional inverter. Every solar energy system must have inverters. They provide the function of converting the direct current (DC) generated by the solar panels into the alternative current (AC) that powers your home. Inverters are one of the key elements of on-grid photovoltaic systems because they convert the DC power produced by solar cells into AC power proportionate to the voltage and frequency of the grid and automatically turn off the power when it is not needed. The inverter performs a variety of functions in on-grid solar systems, including changing the current waveform to sinusoidal current, converting DC to AC, and raising the voltage of PV arrays if it is lower than the grid voltage[32].

Additionally, the inverter for home energy serves as a bridge between your house and the electrical grid when a solar-powered home is connected to it. It is referred to as a grid-tie inverter. No matter how much electricity your solar panels are producing, a grid-tie inverter enables your home to have constant power. The photovoltaic inverter can send excess power back into the grid if your solar power system is generating more energy than your home is using. Alternatively, your panels might be generating some electricity but not enough to power your full house, in which case the inverter will combine solar power with grid power. During the increase of renewable energy penetration in the distribution system, inverters have a greater role apart from the power conversion like ensuring that there is effective control of flux of energy without causing power instability in the connected system, control for harmonic distortions, and limiting harmonic levels of current injected to the network[33].

2.4.3. Smart meter

Net metering is a process that examines and presents the imports and exports of your grid, including the amount of power generated by solar panels, how much we used, and how much was exported to the grid. The calculation for your electricity bill will be. The electronic tool used to measure electricity use is called a smart meter. Similar to a standard meter, a smart meter automatically sends its reading to the supplier. Solar panels can assist power your home, but they can only offset the power consumed when the panels are producing electricity if you don't receive net metering credit and have no mechanism to store excess energy[1]. On the other hand, it functions like a conventional meter but measures and logs data on energy use. It is a two-way electricity meter that can track both grid inflows and outflows of electricity. Owners of solar energy systems receive credit for the electricity they supply to the grid through a billing system called net metering. Customers that generate their electricity from solar power for their homes or businesses can use net metering to sell the excess electricity back to the grid. It denotes that a net metering system is dependent on a bidirectional meter to calculate the net charge (or compensation) at the user end and to measure the power import (or export) from (to) the grid[17].

Utilizing net metering in a network has benefits, such as smoothing the demand curve for electricity and enabling utilities to better control their peak electricity consumption. Net metering lessens the load on distribution networks and prevents losses in long-distance power transmission and distribution by promoting generation close to the point of consumption. Self-generation of power and adding additional photovoltaic electricity to the grid are both possible with the integration of a PV system into a residential building[34].

As figure 2-5 presents, the net meter is between the energy source and grid, for measuring energy imports to the grid and energy exports from the grid.

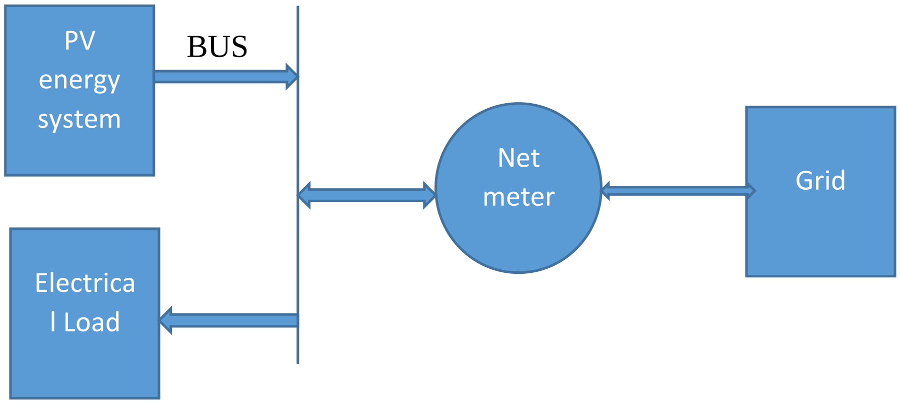


Figure 2-5: system with net metering

When a customer owns or plans to build a renewable energy facility, net metering is a policy that enables them to produce electricity for their own needs and supply the excess to the national grid, offsetting the electricity used during off-peak hours or other times when the production from the RE facility is insufficient to meet the consumer load[35]

2.4.4. Grid

A grid is utilized as a backup power source or an excess power absorber in grid-connected designs. The grid provides energy when RES is unable to meet the demand for the load, and it absorbs energy when there is an excess of it[36].

2.4.5. Bus System

Bus bar systems are a modular method of electrical wiring where electrical devices are put onto an adapter that is directly fitted to a current-carrying busbar rather than having a standard cable wiring to every single one of them. Distribution boards, automation panels, and other types of installation in an electrical enclosure utilize this modular design strategy.

2.5.Working principle of grid-connected PV solar system

An on-grid or utility-intertwined photovoltaic system is another name for a grid-tie solar system. Grid-tied systems use the electrical grid to store energy. The solar panels gather sunlight and convert it to DC (direct current). Direct current (DC) is converted to alternating current via the inverter (AC). A switchboard will be powered by solar energy during the day to power appliances. When solar energy is produced in excess or when electrical appliances are not in use, the extra energy is delivered to the grid and is monitored by the meter box. Retailers of electricity ask for credits in return for energy produced. Power will be extracted from the grid to be utilized when there is no sunshine to generate energy, such as at night, and this can be paid for using earned credits[24].

A grid-connected PV system's simplicity, relatively cheap operating and maintenance expenses, and lower electricity costs are its key benefits. The drawback is that to create the necessary amount of surplus power, enough solar panels must be placed. Most grid-connected designs may do without costly backup batteries since grid-tied systems feed their solar energy directly back into the grid. Additionally, since calculations for solar energy consumption and solar panel sizing are not necessary because this form of the PV system is permanently connected to the grid, a wide range of solutions are available. Use a system as little as 1.0 kWh on the roof to help lower your electricity rates or a much larger floor-mounted array that is big enough to almost eliminate your electricity bills.

Grid-connected, off-grid, and hybrid solar power systems are the three primary types of solar power systems. In truth, there are benefits to adopting a grid-connected PV system for customers because producers can generate energy to use in their activities and they can sell back to the grid for money savings. The grid-connected solar system is the most popular of all the various types of solar systems that have been built around the world.

The more energy you conserve for the electric system and the more money you get from your state government, the less you consume. Since building one off-grid system can cost up to three times as much as installing a grid-connected system, the grid-tied system is less expensive than other systems in comparison. No requirements to purchase pricey battery storage Photovoltaic systems that are connected to the grid are fairly simple to construct and maintain. The most expensive component, the battery, does not need to be purchased, thus there is no need to worry about overcharging or undercharging the battery and harming it. It is for a grid-tied solar system to be very reliable; it must have captured and conserved solar radiation in the utility grid. Consequently, it can give you electricity for your electrical equipment during a power outage. The grid tie solar system configuration uses renewable energy, which means grid-connected solar systems provide electricity with favorable effects on people and the environment.

Because grid-connected solar systems don't need batteries, the environmental damage that batteries cause is reduced, allowing you to breathe cleaner air. You won't need much assistance connecting your solar system to the grid because the installation is simple. It requires a straightforward procedure that you can easily finish over the course of a weekend with a friend's assistance. All you have to do is remember while mounting the panels on your rooftop, that each kilowatt needs at least 100 square feet. Depending on the season, the sun is available during the day in different areas. Due to their savings, grid-connected solar systems are therefore preferred. Some appliances use solar power during the day without batteries, and during the night, the grid serves as a storage facility to supply the load. The grid-tied system will enable you to save more money because it is effective, provides net metering, and only needs little setup and equipment. Batteries, which are frequently pricey, are not necessary. Additionally, because there aren't any batteries, maintenance costs are kept to a minimum. The renewable energy source is installed near the end user because the following reason: To reduce feeder length, reducing feeder load, upgrading existing lines, constructing new lines to share the load, Planning for contingency supply, and Planning for future networks.

2.6. Requirements for grid-connected to PV solar system

Before the energy from the solar to the grid, the current and the voltage at the point of common coupling must be taken into consideration. The total distortion must be less than 5% at this point. The solar power plant shall only be connected to the grid when the frequency and the voltage at the point of common coupling are within acceptable limits[37].

✓ Point of common coupling

The point at which a solar power plant connects to the grid is known as the "point of common coupling (PCC)". It is referred to as the "grid connection point (GCP)" at times. The PCC is often where the high-voltage terminals of the generator step-up transformer link to the grid; it is typically found on the grid side of the isolating switch that connects the solar power plant and the grid. The following technical specifications are typically included in the solar energy grid connection code at the PCC.

✓ Range of voltage

When the voltage at the point of common coupling is within the ranges where the range is $V_g \pm 10$, the grid-connected solar power plant must be able to deliver its actual active power. The solar power plant must also be capable of automatically disconnecting from the grid at predetermined voltages if requested by the transmission system operator.

✓ Frequency range

In the case of a deviation of the grid frequency from its permissible value the acceptable limit is from 47.4Hz to 52Hz, the solar power plant shall perform as follows:

- ❖ If the frequency is less than 50 Hz, the solar plant shall continue injecting active Power until the frequency reduces below 47.5 Hz.
- ❖ When the frequency is between 50 and 50.2 Hz, the solar power plant shall maintain 100% of active power.

- If the frequency is greater than 50.2 Hz, the solar power plant shall inject active power up to 51.5 Hz.

Due to the active current of the grid regulations, the grid-connected PV system must be able to withstand the frequency and voltage deviations at the PCC, and active power can be reduced as little as possible.

2.7. Type of generation configurations at a health centre in Rwanda

Health facilities are an institution where sustainable and reliable energy must be considered by accessing medical technologies and health services. The energy in the health centre is very important for prolonging work time during the night, attracting skilled workers to facilities, quick response for emergency cases like birth children during the night, and access to communication ways[38].

Health centres in Rwanda use energy from the grid even if it is located away from the road which leads energy costs to high according to the distance from the power station. Others use diesel generators which are also expensive to them. Renewable energy technologies are becoming more accessible to health facilities as primary or backup energy sources as their costs decline. This is especially true for solar photovoltaic (PV) power. Community organizations like hospitals place a high priority on having access to sufficient, dependable, and sustainable energy. Access to energy is a crucial prerequisite for having access to medical technologies, which makes it a key factor in determining how well vital health services are delivered.

Numerous life-saving operations simply cannot be carried out without energy. According to research on the availability of electricity in healthcare facilities, a variety of tasks necessitate energy, such as heating water, extending the duration of nighttime service, luring and keeping skilled healthcare professionals in one location, ventilation, and providing quicker emergency response, including for emergencies during childbirth[12]. Instead of storing energy in a battery, direct-drive refrigerators employ solar electricity to operate a cooling system that freezes ice or another phase-change material, as well as thermal energy requirements for food and water heating, sterilizing, space heating, and medical waste incineration. So distributed generation based on solar energy at Busoro health centre and others is very cheap and easy for getting energy and saving money from an excess of energy.

2.8. Energy tariff in Rwanda

In 2020, the energy tariff was presented as shown in table 2-1. The energy price depends on the consumer categories because for residential and non-residential, commercial, and industries the energy consumptions are different[39]. So the price per unit is not the same.

Table 2-1: Rwanda energy tariff 2020

CONSUMER	CONSUMPTION BLOCK	EXISTING TARIFF
Residential consumers	≤ 15kWh/month	89
	]15-50] kWh/month	212
	>50kWh/month	249
Non-residential consumers	≤ 100 KWh/month	227
	>100KWh/month	255
WTP&WPS	All	126
Hotels	All	157
Health Facilities	All	186
Broadcasters	All	192
Small industries ≤22000KWh/ year	All	134
Medium industries]22000-660000]Kwh/year	All	103
Large industries >660000kWh/year	All	94
Commercial data centers	All	179

3. METHODOLOGY

3.1. Overview

Many steps can be employed for achieving the objectives of this research. The solar system technology is applied where there is enough solar irradiance to produce the required energy for the load. The solar system that is connected to the grid was designed using a site visit to the selected case study. The required information can be obtained by data collection on the selected site, documentation, mathematical modeling, and simulation[40].

3.2.Data collection

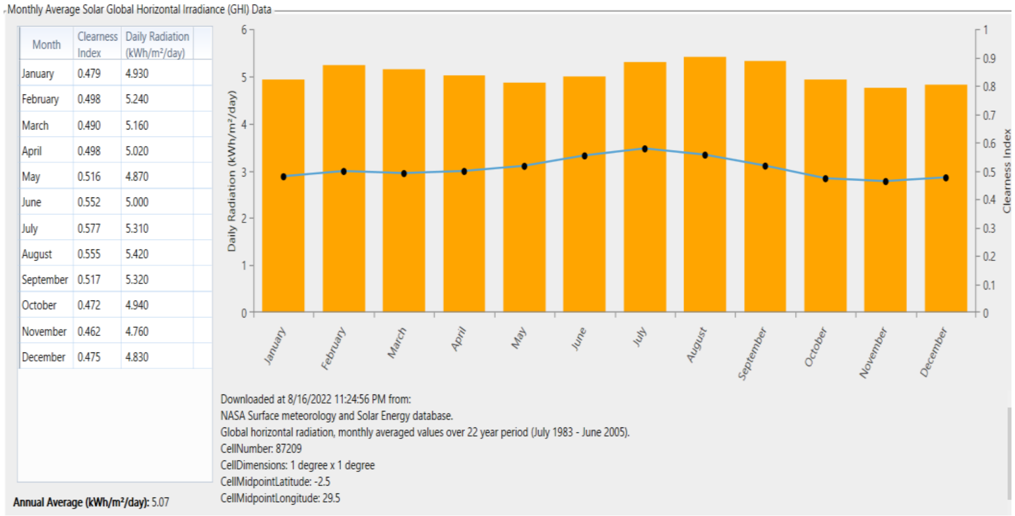
Data collection is the method of getting information used in a certain activity or for another purpose. It is the process of gathering, measuring, and analyzing accurate data from a variety of sites according to the aim through interviews, questionnaires, documentation, or observation. In this research, the observation technique was selected because the site was to observe the power consumption for each appliance in the health centre. The data here must be the primary data where they are found on the site not indirect data. In the design of grid-connected PV systems, more information is needed to make sure that there is under design.

3.3.Documentation

Many researchers studied energy power in the health centre for maintaining energy stability and reliability and also money savings. Dr.Vincent from Nigeria searched for an alternative energy system for health facilities in a rural area for keeping services required in that health centres at low cost and energy stability[38]. In partnership with USAID, studies on how African health centres in rural areas can be powered with renewable energy integration. Results show that due to the lower demand the health posts according to the services provided there. They found that the cost of energy when renewable energy is applied will be low considering the cost of the energy grid even its stability and reliability due to the energy being closer to the load[41].

During the design of an energy system with solar, some information is needed before to make sure that the system will be feasible. The solar irradiance at Busoro health centre is around 5KWh/m^2/day but the average solar global horizontal irradiance data-sheet is 5.07KWh/m^2/day. Figure 3-1 shows the monthly average solar irradiation and the clearness index for the location.

Data indicates that maximum solar irradiation occurs in August with a value of 5.420 kWh/m2 /day and the minimum in December with 4.830 kWh/m2 /day.



Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.479	4.930
February	0.498	5.240
March	0.490	5.160
April	0.498	5.020
May	0.516	4.870
June	0.552	5.000
July	0.577	5.310
August	0.555	5.420
September	0.517	5.320
October	0.472	4.940
November	0.462	4.760
December	0.475	4.830

Annual Average (kWh/m²/day): 5.07

Downloaded at 8/16/2022 11:24:56 PM from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 87209
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: -2.5
CellMidpointLongitude: 29.5

Figure 3-1: Average of monthly solar irradiance from NASA

The clearness index indicates that where there is high solar radiation. As it approaches one, indicating that the high solar radiation can penetrate the atmosphere to fall on the solar PV panels. The solar radiations depend on the cloud conditions.

3.4.Mathematical modeling of an embedded generation system

An embedded generation system is known as the distribution or local generation where any type of individual generation is connected to an electricity distribution network. The mathematical model is the process of using mathematical equations, graphs, or diagrams to present a situation in the real world. The embedded generation here is based on PV solar system where the grid-connected to the solar system was considered. The model of embedded generation can be obtained from the HOMER software during the simulation. The optimization of the power system is done by using HOMER for getting a feasible cost for the designed system. During the design, some formulas are needed for getting the final results.

In this project, PV is modeled before being integrated into the existing system. The size of a PV module is determined by the limitations of the system, such as the permitted unmet load and the size of other renewable portions supplying the system. The output power needed by a PV panel system to meet load demand is therefore determined by the size of the PV system about the required peak load demand[42].

During mathematical modeling, some parameters are required for making equations for calculation. The relationship of parameters makes formulas to calculate energy cost, annual incomes, energy generated in a year, energy generated from PV panels, investment cost, and voltage at the point of common coupling.

3.5.Simulation using the HOMER tool

HOMER means a hybrid optimal model for electrical renewable. It is developed in Canada in 1993 by the national renewable energy technology laboratory (NREL)[43]. There are researchers which use particle swarm optimization (PSO) as the algorithm for obtaining the optimal size of the PV system. For designing and simulating a hybrid power system, a software tool is needed but there is a large number of software tools in designing, analyzing, and optimizing energy systems. Some of them are HOMER from Canada, RETScreen from Canada, PVsyst from the University of Switzerland, and iHOGA from the University of Zaragoza in Spain[43]. From this software, HOMER is software that provides a more accurate solution for a hybrid power system technically optimal and maximally cost-effective. During the design, engineering and economic skills are needed for selecting an optimal design. The most popular simulation tool, HOMER, is used to design and analyze grid-connected and standalone HESs with a variety of conventional sources, including cogeneration, PV, hydroelectric, wind turbines, biomass, batteries, fuel cells, and other inputs. This software permits the users to judge the HES's viability from a techno-economic and environmental standpoint throughout a specific project lifetime[2]. In addition, HOMER is frequently used to measure, assess, and evaluate the performance of PV grid-connected systems. This software is also computer simulation software which is developed by the National Renewable Energy Laboratory in the United States where the different types of renewable resources and components are used to design the system. There are three primary activities of this software such as simulation, optimization, and sensitivity analysis [44]. Through the simulation process, this software determines the lifecycle cost and the feasibility of the designed power system.

It can be used to calculate the cost of energy and other financial metrics like net present value. After the simulation, the results will be shown and analyzed. The energy cost will be shown on a monthly and annual basis when embedded generation is used when the grid is the only source of power to provide the load. Homer uses the input to run the model to describe the resource's availability and cost components. HOMER can simulate a system for 8760 hours in a year, and a portion of that time involves balancing the system's energy over the year. After the simulation, it displays a list of the configuration, which aids in making the best choice by comparing lists and results. In addition to lists, it also displays or simulates results in graphs and tables for assessing them according to their technical and financial merits[29]. Simply Homer software is selected to use in this research because of the following advantage: it presents results in graphical and tabular form, hourly handling capacity, access to it is free, easy to understand, computation time is very and the results can be imported in user's documents.

4. DATA COLLECTION RESULTS FROM THE SITE

4.1 Overview of site

Utility-size solar PV technology has conditions for installation in the partial region like land and solar irradiation per year which is very high for providing sufficient energy. An investigation must be conducted to know if the site is suitable and feasible for a particular purpose[45]. The site visit is conducted at Busoro Health Centre located in BUSORO Sector, Nyanza, Rwanda. The coordinates of the Busoro Health Centre are Latitude: -2.2893982. Longitude: 29.9304418 known as Mayage in Nyanza district, southern province. Figure 4-1 illustrates the locations of Busoro health centre on the geographical map.

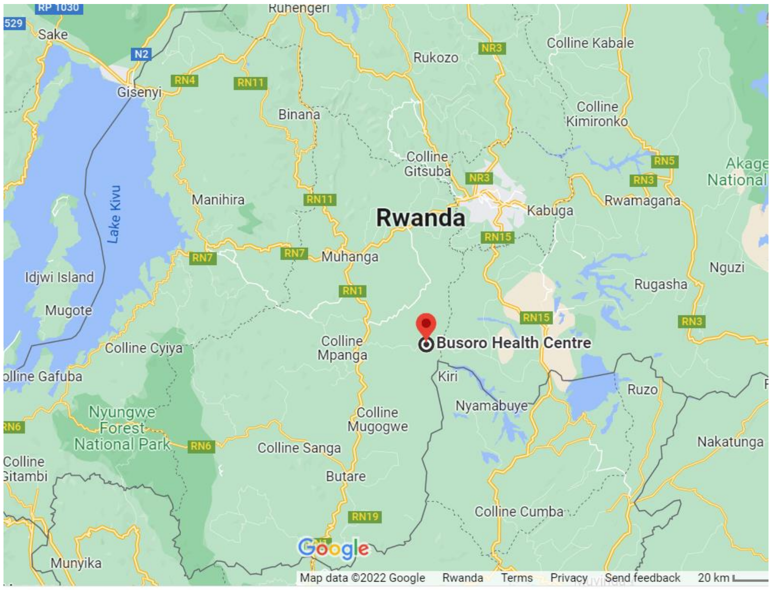


Figure 4-1Geograthical location of Busoro health centre [geographic map]

Sit visit will be conducted by finding the total load at Busoro health center, working hours, an area where the panels will be installed, and the yearly electrical bill. It was conducted by evaluating each appliance with their energy consumption per day and its working to get the total load. Every device has fixed power consumption that can be found on its nameplate details and this data from all the devices that are going to be used should be retrieved.

4.2. Busoro health centre load profile

There are many services conducted at the health centre where access to electricity is needed like lighting during the night time, heating water freezing, recording using computers, refrigerators, and other activities that require access to electrical energy. Table 4-1 presents the Busoro health center appliances which consume energy per day, the rated power, and its working hours per day.

Table 4-1: the daily load of Busoro health centre

Items	Quantity	Power(W)	Total power (W)	Working hours (h)	Energy consumed(Wh)/Day
Refrigerator Medicine	1	165	165	24	3960
Lab refrigerator	1	250	250	24	6000
Computer Desktop	13	250	3250	8	26000
Printers	6	50	300	8	2400
Sysmex (XP-300)	1	3	3	8	24
Laptops	8	100	800	8	6400
Humalyzer primus	1	100	100	0.5	50
Bulmer	1	1800	1800	0.1	180
Microscope	1	30	30	6	180
Centrifuge	1	40	40	0.5	20

Distillation water	1	2000	2000	0.4	800
LED lamps	30	9	270	12	3240
Fluorescents bulbs	20	15	300	12	3600
Mobile phone	18	5	90	6	540
32’LED television	1	70	70	15	1050
Photocopier	1	400	400	6	2400
total daily energy			9863		56844

The total daily energy consumption at Busoro Health Centre is 56.844 kWh. The total energy consumed during one year is 20748.06kWh/year, where the daily power required is 9863 W.

Figure 4-2, presents how the daily load is formed with power consumption with time. During the day, energy consumption is high due to electrical types of equipment requiring energy and during the night energy use decreases because of lamps and some equipment.

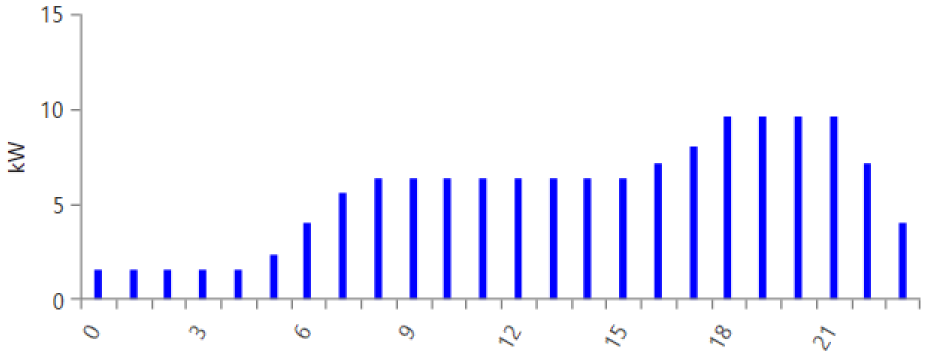


Figure 4-2: Daily load profile of Busoro health centre

Figure 4-3 indicates how energy in the month and how can be consumed. In July is where high power is needed because some equipment is used like ventilation for cooling space due to the high temperature in this region.

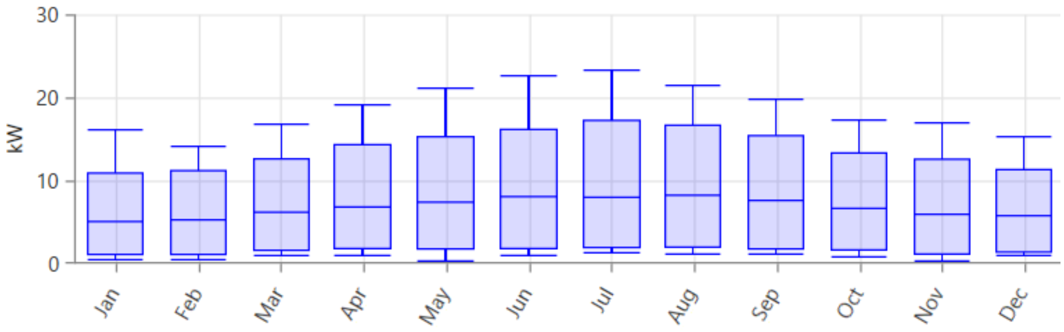


Figure 4-3: monthly load profile

Figure 4-4, presents the year profile, the horizontal axis presents the days of the year from one to 365 and for vertical axis presents the hour from 0 to 24 on the left and different colors assigned by scale situation on the right side. Blue color presents power from 0 to 5KW as the base load in the year. It means that from the first day to the last day of the year at 0 to 6h the power required is the same. From 6 to 18h, the load rises in the whole year from 5to10kW. The green color presents energy from 10to15kW which is required from 18to24h and from 15 to 20kW is from ninety to two hundred seventy days.

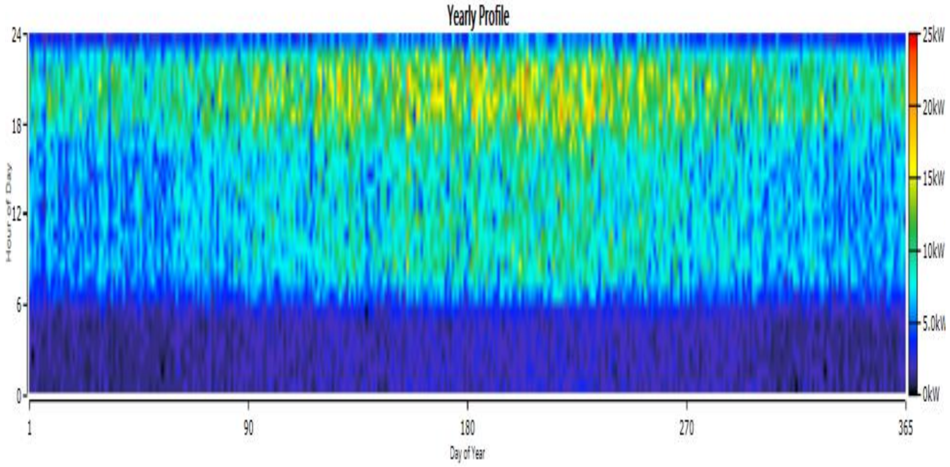


Figure 4-4: Yearly load profile of Busoro health centre

5. MATHEMATICAL MODELING OF EMBEDDED GENERATION

5.1. Model of grid-connected to PV in homer

The system proposed in this research consists of a PV module, inverter, and the grid as power storage or supply to load where is needed. The system is to supply the health centre which consumes 56.844kwh/day. The PV system can supply it or can inject the excess power into the grid or energy can be a drawback from the grid when there is no power from solar. Figure 5-1, illustrates the grid-connected PV system components where PV power output is DC and converted into AC by using the inverter to supply the AC load, or the grid can store the excess energy from the PV system or supply the Load.

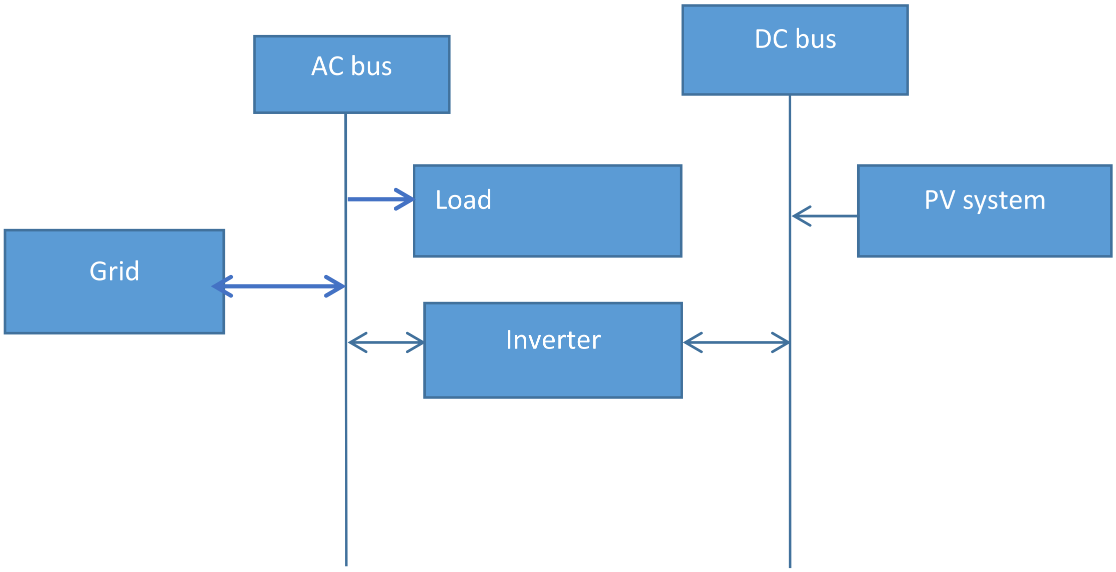


Figure 5-1: the model of grid-connected PV in homer

5.2. PV energy model

Energy consumed per day (E_{day}) for the selected site can be calculated by using the following formulas:

$$E_{day}=\sum_{n=0}^{n} \frac{Ui*Pi*n_i}{1000} (kWh) \qquad (5, 1)$$

Where, i is the index of each type of load like a fan, desktop,…, Ui is the working hour of load, Pi is the power rating of load type and n_i is the number of device type i. when the embedded generation system includes the PV energy, the output of PV array can be also calculated. The output of a PV panel can be calculated by using the equation, Homer uses the equation to calculate the power output of PV solar and becomes,

$$P_{PV} = E_{pv}.\ F_{pv} (G/G_{STC}) [1+ \alpha_P (T_e-T_{STC})] \qquad (5, 2)$$

Where, P_{PV} = is the rated capacity of the PV array [kW], fpv= is the derating factor [%], G = is the solar irradiation on the PV [kW/m2], G_{STC} = is the incident irradiation at standard test conditions [1kW/m2], α_P = is the temperature coefficient of power [%/°C], = is the PV cell temperature [°C], T_{STC} = is the PV temperature under standard test conditions [25 °C]. Or simply can be calculated as follow if the temperature effect is negligible. In terms of voltage and current[24], the output of the PV array becomes Eq (3, 4, 3) in terms of resistances

$$I=I_L-I_{SC} \left(exp^{\frac{q(V+IRs)}{n*K*T}} - 1\right) - \frac{V+IRs}{R_{SH}} \qquad (5, 3)$$

Where, I_L is the current of the photoelectric effect, I_{SC} is the short circuit current, q is the elementary charge 1.6x10-19 Coulombs, k is a constant of value 1.38x10-23J/K, T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias)

$$P_{PV}= \frac{E_{day}}{S_d*d}(kW) \qquad (5, 4)$$

Where s_d is average solar radiation, and d is the derating factor which is influenced by the efficiency effects such as lost wires, shadows, aging, and so on. System efficiency is the efficiency of the inverter and cable efficiency. Where cable E_{ff} =98% and an inverter with an efficiency of about 95%[46]. The number of panels for the system can be also calculated and its equation becomes,

$N_{panel}=P_{PV}/P_O$ (5, 5)

Where, the P_o is the power output capacity of the panel.

5.3. The objective function of the system

The objective function of this project depends on the goal of this research which is to minimize the energy cost and maximize energy generation. As is mentioned in the problem statement, the energy cost in the health centre is high which causes the high electrical bill to be paid. The main objective is to maximize the net present cost for improving the profitability of the system and minimizing monthly electrical bills. Two main objective functions are being optimized. The energy cost can be minimized according to the investment, operation and maintenance cost, and the energy production of the system in its lifetime. When the energy production is increased from solar, the saving to the producer will be increased due to high power injected into the grid, and also the LCOE of energy be reduced[47]. One objective function can be used with the binary number where linear programming is used as the algorithm. This equation 5.6 shows that if binary a is zero, the objective function maximizes energy and if the a is equal to 1, the objective function is minimizing LCOE as is shown in this equation

$$X(C, E)_{min}\,[(\frac{C_C(x)+C_M(x)}{E_{Total}(x)})*a-(1-a)*(P_{plant}(x)*n_s*EAF) \quad (5, 6)$$

Where n_s is the PV plant operational lifetime, EAF is the energy available factor, C_c is capital cost, and C_M is maintenance cost. Eq (5.7) presents what a is, and it is a binary number. The objective function can be expressed as,

$$a=\begin{cases} 1, X_{min}(\frac{Cc+Cm}{E_{Total}}) \\ 0, X_{max}\,(P_{plant}*n_s*EAF) \end{cases} \quad (5, 7)$$

During the PV grid-connected system, constraints are considered to account for different parameters in the system. The following expressions show the variable limits required[48],

$V_{min} \leq V_{pv} \leq V_{max}$ (5, 8)

$P_{min} \leq P_{pv} \leq P_{max}$ (5, 9)

$0 < P_{pv} \leq P_{max}$ (5, 10)

5.4. Economic mathematical model

The net present cost is used to evaluate the investment status of the project over a period of time. It shows the difference between the present worth of cash inflows and the present worth of cash outflows. If NPC is positive, the project is profitable but if NPC is negative the project is not profitable. So the net present cost be calculated as follows

$$F(t) = \text{MaxNPC} \quad (5, 11)$$

$$NPC = \sum_{i=1}^{t} \frac{C_i - C_f}{(1+r)^i} - I_0 \quad (5, 12)$$

Where the I_0 is an initial investment, t is the period, r is the discount tax, and C_i is the sum of the total annual income and what the system brings to the users. It is the sum of the cost of energy selling to the grid and the energy saving. C_f is the sum of energy purchased from the grid ($C_{e\text{-}purch}$), ($C_{O\text{-}System}$) cost of operation system, and cost of replacement in the system ($C_{c\text{-}rep}$) as shown in Eq (5, 13).

$$C_f = C_{e\text{-}purch} + C_{O\text{-}System} + C_{c\text{-}rep} \quad (5, 13)$$

$$C_{e\text{-}purch} = Pg * Cg \quad (5, 14)$$

$$C_{O\text{-}System} = C_{O\text{-}PV} * t_{PV} + C_{inv} * t_{inv} \quad (5, 15)$$

$$C_{c\text{-}rep} = C_{rep\text{-}PV} * t_{PV} + C_{rep\text{-}inv} * t_{inv} \quad (5, 16)$$

$$I_0 = C_{PV} * t_{PV} + C_{inv} * t_{inv} + C_{SYST} \quad (5, 17)$$

Where the C means the cost and the t means the time of the element

$$C_i = \sum_{j=1}^{365} [\sum_{k=1}^{24} ((Ps(k) * Cesell) + \left(Pload(k) - Pg(k)\right) * Cg] \quad (5, 18)$$

Where, P_S, P_{laod}, and P_g are power injected into the grid, load power demand, and power taken from the grid respectively. $C_{e\text{-}sell}$ and C_g are respectively the prices of 1KW selling to the grid and what is taken from it in Eq (5, 18).

As the PV module is connected to the DC bus and the demand is connected to the AC bus, an inverter is necessary to be added to the system to convert the power generated by the PV into the AC bus to supply the required load[49]. The loss factor, which is 1.3, multiplies the load power to determine the inverter size, which is then equal to the size of the module. The input rating of the inverter for grid-tied or grid-connected systems should match the rating of the PV array to enable safe and effective operation.

Grid-tie solar system inverters are simply sized to maximize the output of the sun. When an output of AC power is required, an inverter is utilized in the system. The inverter's input rating should never be less than the sum of its input watts, and its size should be 25–30% greater than the sum of its input watts. It's crucial to remember that inverters don't have to be the same size as solar panels. The inverter's capability then rises to about 75kW. For calculating energy costs and net present costs during the power generation process, additional formulas are needed. The system's lifetime installation and running costs, system cost at Eq (5,19), payback period, and Levelized cost of energy are all included in the system's net present cost [50] also be calculated in the following formula:

$$C_{System}= C_{pv}+C_{inverter} \tag{5, 19}$$

Where C_{system} is the cost of the system, C_{PV} is the cost of PV, and $C_{inverter}$ is the cost of the inverter

Simple payback time (PBP) is defined as the number of years when money saved after the renovation will cover the investment. In another hand, the payback period is the time it will take for a business to recoup an investment. It is calculated as follows in eq (5,20):

$$PBP= \frac{initial\ investment}{cash\ inflow\ per\ year} \tag{5, 20}$$

The net present cost of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime in eq (5, 21).

$$NPC= \sum_{t=0}^{n} \frac{Rt}{(1+i)^t} - initial\ investment \tag{5, 21}$$

Where, Rt: net cash-inflow - cash outflows during a single period t, i: discount rate, t: number of periods

Levelised cost of energy (LCoE) is a measurement used to assess and compare alternative methods of energy production. The LCOE is a fundamental calculation used in the preliminary assessment of an energy-producing project as it is in Eq (5, 22). It can be used to determine whether to move forward with a project or as a means to compare different energy-producing projects

$$\text{LCOE}=\frac{I_0+\sum_{t=1}^{n}\frac{Mr+Ft}{(1+r)^t}}{\sum_{t=1}^{n}\frac{Et}{(1+r)^t}} \qquad (5, 22)$$

Where,

I0: is the Investment Cost, Mt: is the Operations and Maintenance Cost in year t, Ft: is the Fuel cost in year t (if applicable), Et: is the Electricity generation in year t, r: is the Discount rate and n: is the Life of the system.

5.5. Voltage and current at PCC

The voltage and current at the point of common coupling must be controlled by an inverter before injected into the grid from the solar PV as it is shown in Eq (5, 23), where the v_{pcc} and i_{pcc} present the voltage and current at the PCC respectively[33]. The voltage at the PCC is expressed in terms of current and impedance which is given as,

$$V_{PCC}=Ri_{PCC}+L\frac{di_{PCC}}{dt}+V_g \qquad (5, 23)$$

Where, R is resistance, L is inductance and V_g is the voltage at the grid.

6. SIMULATION

This chapter focuses on the simulation of t design of the designed PV system connected to the grid and is based on the daily load of a health centre in Homer pro, where the extra solar energy will be fed into the grid by daily electricity usage. To improve the overall quality of the power flow of the grid-connected solar PV system, accurate forecasting of solar PV output is crucial. The load demand and sun irradiation of the site location must be gathered to generate an accurate estimate for solar PV electricity[18].

When solar energy is used during the day and excess energy is sent into the grid, the system is developed by estimating the monthly demand of electrical energy consumed at BUSORO Health Center's monthly electricity bill. Systems that are connected to the grid are designed to run independently of an electric utility. This system's benefits include lower running costs, good health, and environmental considerations[51]. Several DC-to-AC inverters are used in an on-grid photovoltaic system to convert the output DC voltage from the PV modules to the grid's AC voltage[32].

During the simulation in homer, the location and daily demand are needed to get information from the internet like solar radiation and it depends on where the project is being conducted. The types of load like residential, industrial, or community are also needed. The Source of energy to supply the load must be inputted to get the results.

6.1. Grid-connected PV system modeling in HOMER

This design process begins by putting input data that demonstrate the technical specifications, resources data, and costs that are relevant for designing the entire system in the HOMER tool. Figure 4.1 shows the general design of the system which is made of two bus bars connected to the PV array and the grid itself. A converter playing at the same time the role of inverter and rectifier is also connected in bi-directional mode to the bus bar. Finally, the bus bar is connected to the load in unidirectional mode to supply the required electricity. Figure 6-1 indicates the grid-connected or on-grid system configuration which consists of a PV array, converter, and grid for the backup system in the homer. The total energy consumption per day is 56.844kWh/day and the peak load is 8.00KW

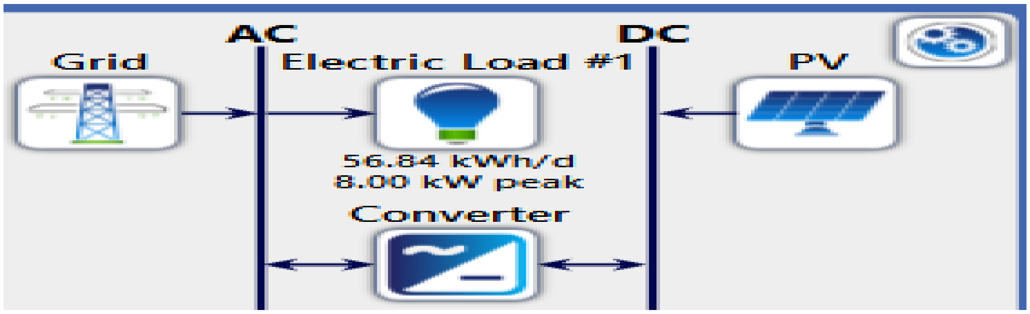
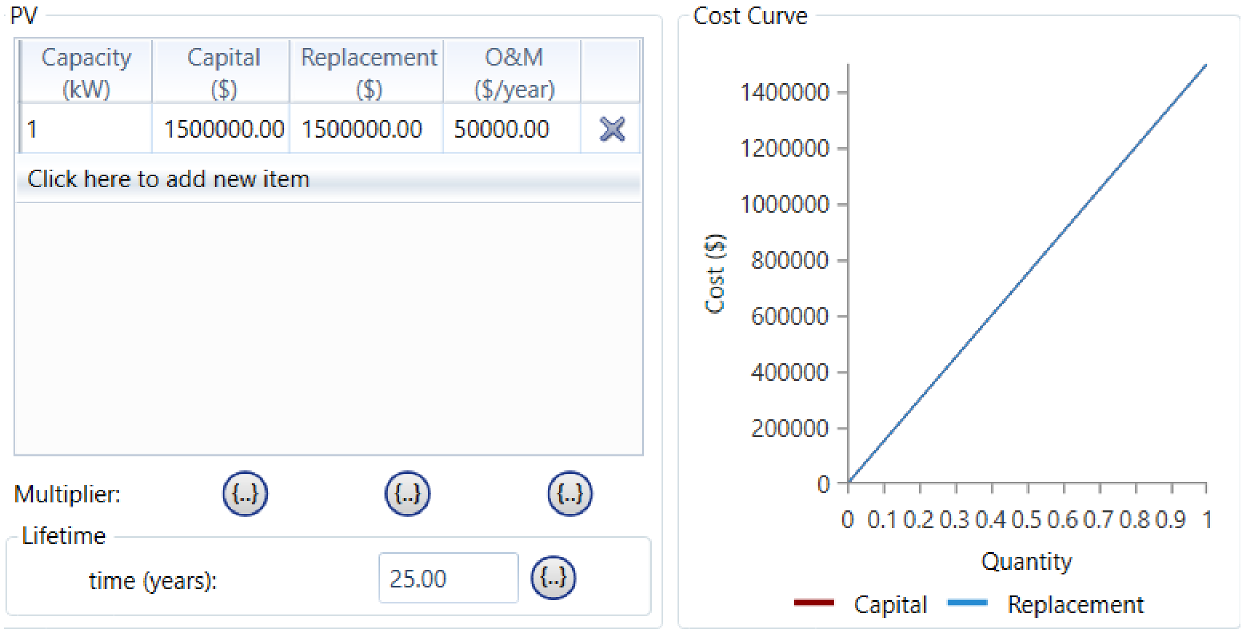


Figure 6-1: input model in homer with a load and a source [homer]

6.2. PV modeling

After introducing the load in HOMER, PV was modeled according to the solar irradiance and temperature from NASA and the cost of PV depends on the size where RF1500000/KW including installation and transport costs. The total Power from the solar system depends on the capacity of the panel. Capital replacement and operation and maintenance cost introduced in HOMER where the cost of replacement is the same as capital cost and maintenance cost is RF150000/KW, and Operation and Maintenance cost is RF 50000/year. The solar panel used is generic flat plate PV with a lifetime of 25 years as shown in figure 6-2. This curve of cost is a straight line because the replacement cost and the capital cost are equal.



PV

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)	
1	1500000.00	1500000.00	50000.00	✕

Click here to add new item

Multiplier: {..} {..} {..}

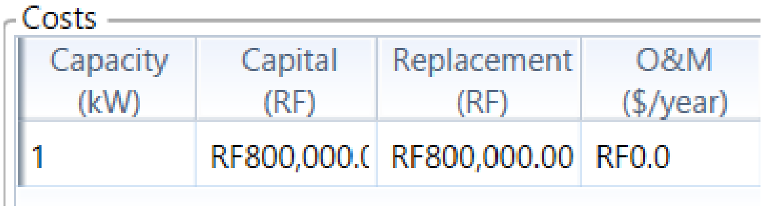
Lifetime

time (years): 25.00 {..}

Figure 6-2: PV input model in homer with capital cost

6.3. Inverter modeling

Due to the connection of the PV module to the DC bus, the inverter is needed to convert DC power to AC power for supplying AC load. Figure 6-3 presents the capital cost of the inverter per kilowatt is RF800000 and the inverter capacity must be 1.2 multiple of peak load.



Costs

Capacity (kW)	Capital (RF)	Replacement (RF)	O&M ($/year)
1	RF800,000.(	RF800,000.00	RF0.0

Figure 6-3: Inverter cost in homer

6.4. Simulation of system design at the selling back cost of 50% for grid cost

6.4.1. Grid modeling

Table 6-1 presents the cost of power from the grid which is RF186/kWh and the selling back cost of excess energy to the grid is half of the grid cost which is RF93/KWh. According to the selling back agreement between the producer and grid, the Levelized cost net present value, payback period, and other parameters will change due to the sellback cost to the grid.

Table 6-1: sell back to the grid cost agreement

Grid price (RF /KWh)	Agreement for sellback cost(RF/KWh)
186	93
	139.5

Table 6-2 presents the simulation from the grid-connected to solar PV configuration where the cost of selling back the energy to the grid is half of the grid energy price and the output of PV solar is 13.88kw, and the energy cost becomes RF113.14/kWh.

Table 6-2: Energy production of PV at RF93/kWh

Architecture/PV (kW)	Architecture/Grid (kW)	Cost/COE (RF)	Cost/NPC (RF)	Cost/Operating cost (RF/yr)	Cost/Initial capital (RF)	PV/Capital Cost ($)	PV/Production (kWh/yr)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)
13.88206	999999	113.141	4.40E+07	1256617	2.80E+07	2.08E+07	20552.36	11517.46	9695.584
	999999	186	4.93E+07	3859139	0			20748.06	0

6.5. Simulation of system design at the selling back cost of 75% of grid cost

Table 6-3 shows the production of PV with capital cost and net present cost when the agreement of grid and producer becomes 75% of grid energy cost in tariff. The power from PV solar is 15.4kWand the cost of energy becomes RF105.6/kWh.

Table 6-3: energy production and power price at 139.5/kWh

Architecture/PV (kW)	Architecture/Grid (kW)	Cost/COE (RF)	Cost/NPC (RF)	Cost/Operating cost (RF/yr)	Cost/Initial capital (RF)	PV/Capital Cost (RF)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)
15.4375	999999	105.6086	4.36E+07	984374.4	3.11E+07	2.32E+07	11308.34	11583.17
	999999	186	4.93E+07	3859139	0		20748.06	0

6.6. Optimization Results

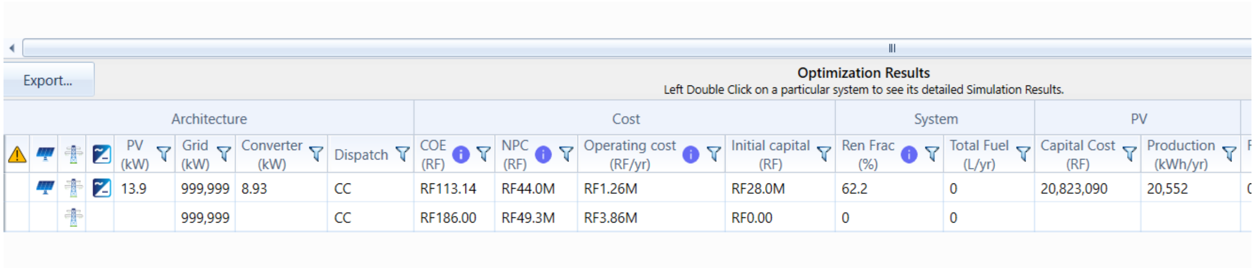
The results in tables 6-2 and table 6-3 present the optimal results for different agreements to the sellback cost of energy for excess energy from solar PV to the grid. The scenario case is for different agreements for excess energy generated by PV panels per month where the cost of energy for sellback can be 50% of the purchase price or 75% of the power price.

The optimization results present the optimal design of the system and at which one with lower net present cost or lower energy cost with the ability to supply energy at desired load without the deficit and there is the integration of renewable energy. There are two scenarios situation where the cost of energy from the grid to the community is RF186/KWh but the sellback cost to the grid is RF93 and RF139.5/KWh in the first and second scenarios respectively.

6.6.1. The Sellback energy cost to the grid is half of the energy cost which is RF 93/kWh

When the agreement to sell back energy excess from the PV via the monthly net metering is half of the energy cost which is RF93/KWh, the results from the homer become as follows in table 6-4, the power from the PV system is 13.9kW.

Table 6-4: Optimal results of System at RF93/KWh of sellback



Export...

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

Architecture				Cost				System		PV	
PV (kW)	Grid (kW)	Converter (kW)	Dispatch	COE (RF)	NPC (RF)	Operating cost (RF/yr)	Initial capital (RF)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (RF)	Production (kWh/yr)
13.9	999,999	8.93	CC	RF113.14	RF44.0M	RF1.26M	RF28.0M	62.2	0	20,823,090	20,552
	999,999		CC	RF186.00	RF49.3M	RF3.86M	RF0.00	0	0		

The net present cost (NPC) and cost of energy (COE) for half of the energy cost of sellback to grid cost are RF44.0M and RF113.14 respectively as table 6-4 is shown that the capital cost of generic Flat PV is RF 20823090, with operation and maintenance cost becomes the RF 28 million. The cost spend on the grid is RF 4764573, for the system converter, the cost is RF 9570658.

Figure 6-4 presents the cost of generic flat plate PV cost, the cost of the grid system, and the cost of the system converter. The cost of PV is very high compared to the other components.

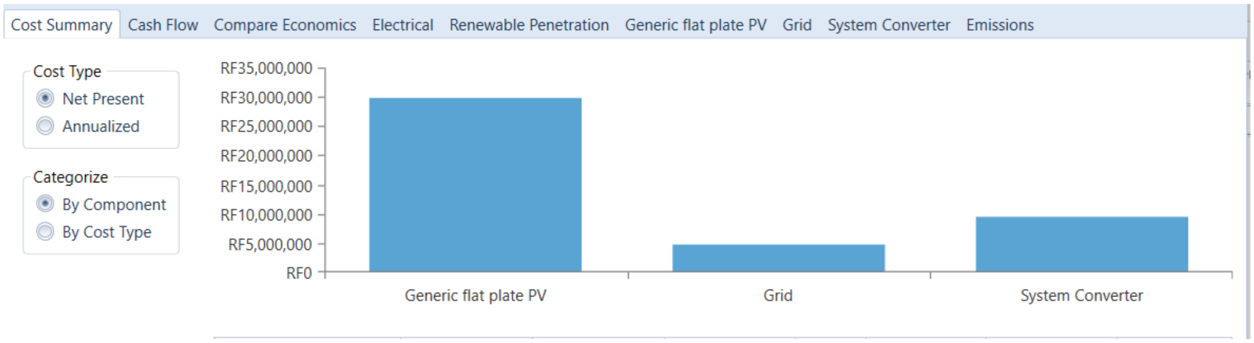


Figure 6-4: system components cost

The system becomes expensive due to the high cost of equipment used in system design. The total PV panel cost is RF29.7 million, for the grid is RF 4.7 Million, and the system converter cost is RF9.57 million in table 6-5.

Table 6-5: components system cost

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic flat plate PV	RF20.8M	RF8.87M	RF0.00	RF0.00	RF0.00	RF29.7M
Grid	RF0.00	RF4.76M	RF0.00	RF0.00	RF0.00	RF4.76M
System Converter	RF7.14M	RF0.00	RF2.98M	-RF554,880	RF0.00	RF9.57M
System	RF28.0M	RF13.6M	RF2.98M	-RF554,880	RF0.00	RF44.0M

Figure 6-5 shows us that the maximum sun during the day is from 9 AM to 3 AM as the color presents. The maximum power is 13.9kW at noon of day and during the one year and the working hour is 4380 hours in one year. From 0 to 7 and from 17 to 24h there is no power generated as it is shown by black color. The mean power output from the grid is 2.35kW and the average energy per day is 56.3 KWh/day.

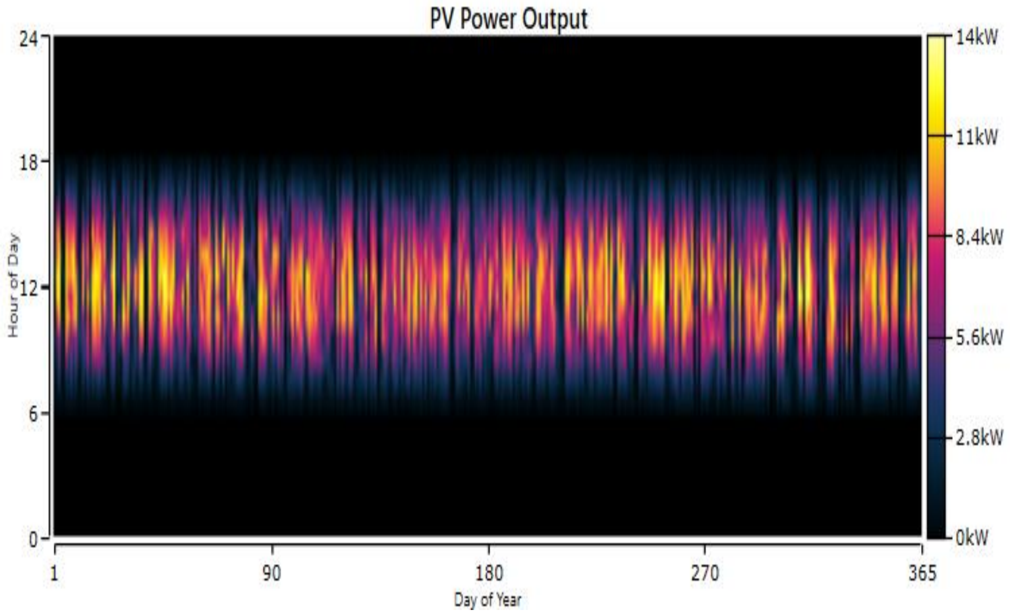


Figure 6-5: yearly PV power production

In Figures 6-6, we see the capital cost, operating, salvage, and replacement cost of solar connected to the grid at Busoro health centre. The high capital cost with the green color with a value of RF28.0 million, each year there is operating and maintenance cost which is not much the inverter will be replaced after 15 years as their lifetime and after 25year, the salvage will be obtained

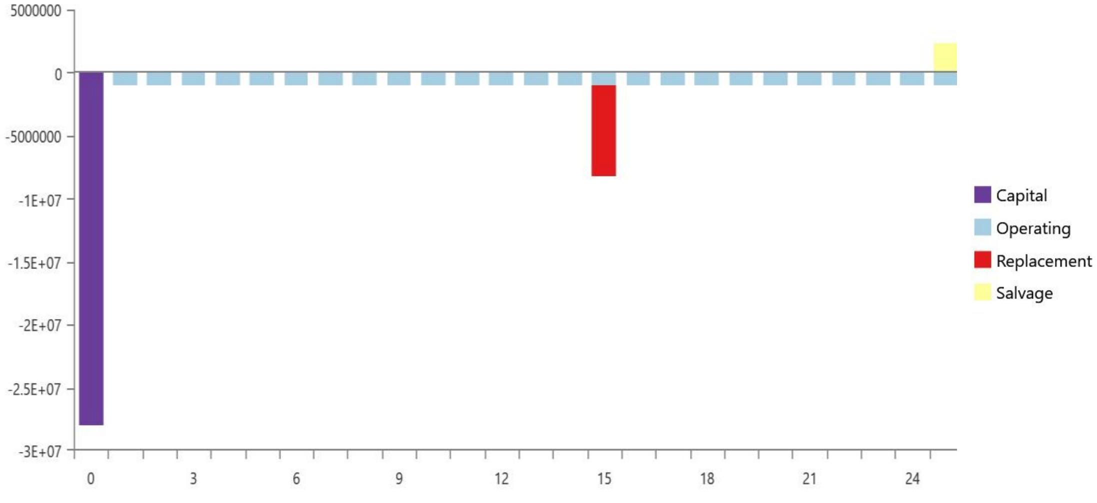


Figure 6-6: Cash flow of the system

Figure 6-7, illustrates the cash flow of components in the system at normal cost. The components considered in this system are generic flat-plate PV, grid, and the system converter.

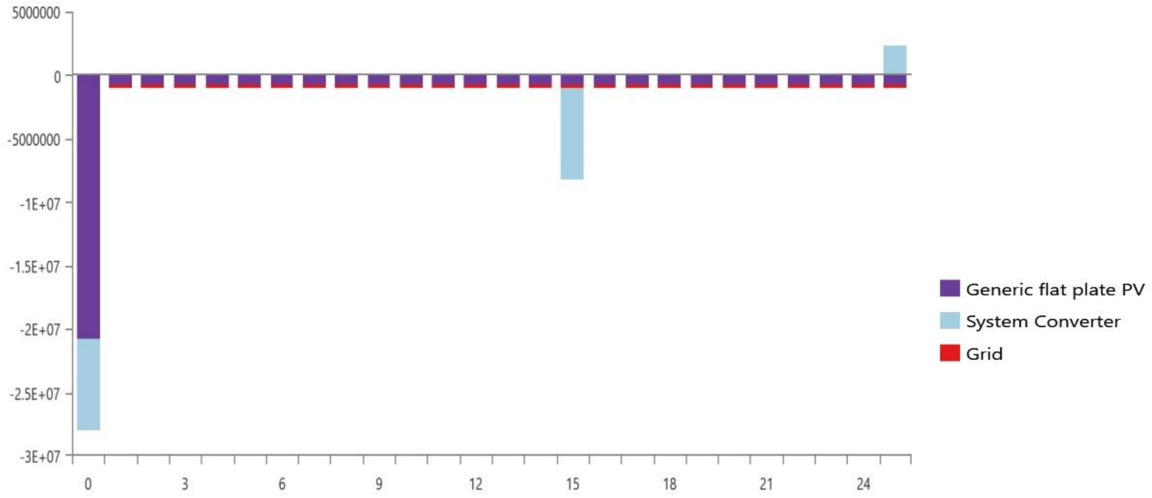


Figure 6-7: component system cash flow

The monthly average electricity produced is demonstrated in figure (6-8) where the power of grid and PV production is shown. The total energy generated by generic flat plate PV per year is 20552KWh and the energy purchased from the grid is 11517Kwh/year. The energy sold to the grid is 9696kWh/year and the excess power during the generation in a year is 1.96% of the total energy produced. The energy production from solar PV per year is 20552 kWh which is 64.1% of the energy needed by the load during the year. The energy purchased from the grid by the load is 35.9% which is 11517 kWh per year.

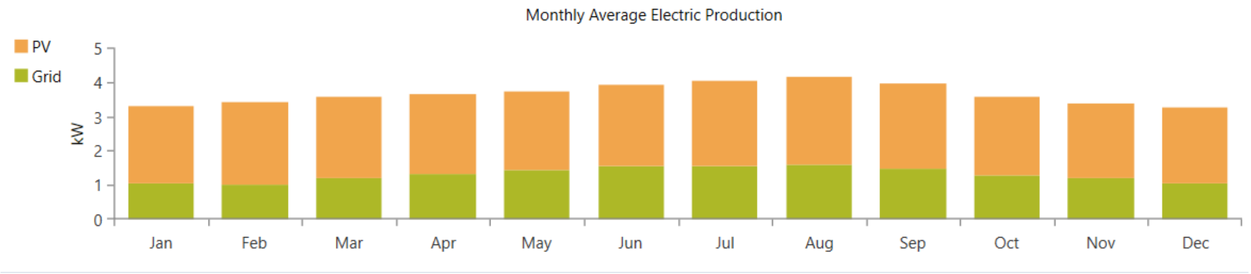


Figure 6-8: grid and PV energy production

Table 6-6 represents that the energy from the PV is more than the energy purchased from the grid. Energy sold and energy purchased is also shown in the table. The peak demand is 8kW; net energy purchased per year is 1822kWh, energy sold is 9696kWh and energy purchased is 11517kWh/year. The energy charge of the grid is RF372717 per year which is low compared to the charge when there is no renewable energy integration.

Table 6-6: energy sold and purchased of the grid at RF93/kWh

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Energy Charge
January	788	907	-119	-RF11,071
February	686	862	-176	-RF16,384
March	887	889	-2.24	-RF208.09
April	943	805	138	RF25,672
May	1,074	747	326	RF60,693
June	1,128	705	424	RF78,794
July	1,146	783	362	RF67,419
August	1,187	784	403	RF74,936
September	1,062	788	274	RF51,043
October	951	789	162	RF30,212
November	873	777	95.7	RF17,795
December	792	859	-66.5	-RF6,185
Annual	11,517	9,696	1,822	RF372,717

Energy purchased from the grid (kW) in a year is presented in figure 6-9 where energy is purchased every day for the year. From 18 to 24 hours is where high energy is purchased from the grid with power between 2.5 to 5kW.

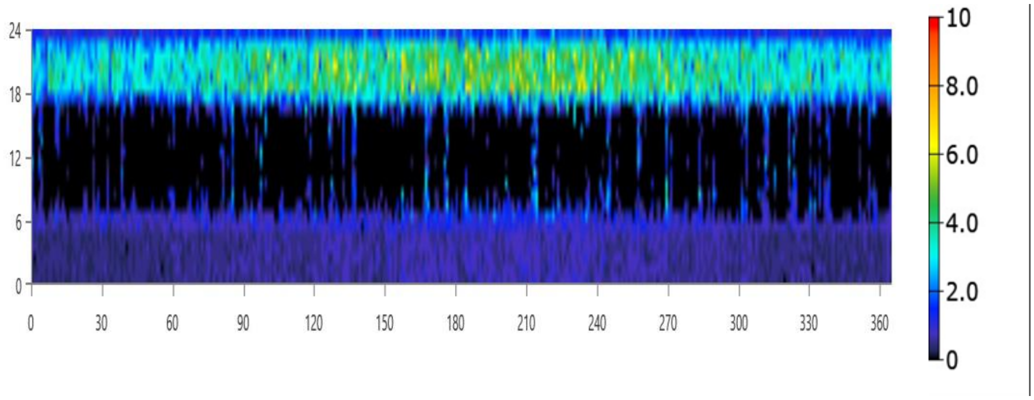


Figure 6-9: energy purchased from the grid

Figure 6-10 illustrates the energy sold to the grid from the solar PV system when the excess energy is available. During the day, the sun can be much or few which is the source of energy and when solar energy is high, there is energy sold to the grid otherwise purchased. The power sold to the grid occurs from 7 to 15 hours when there is high energy produced from PV due to high solar radiation. The power is approximately between 3 to 7kW.

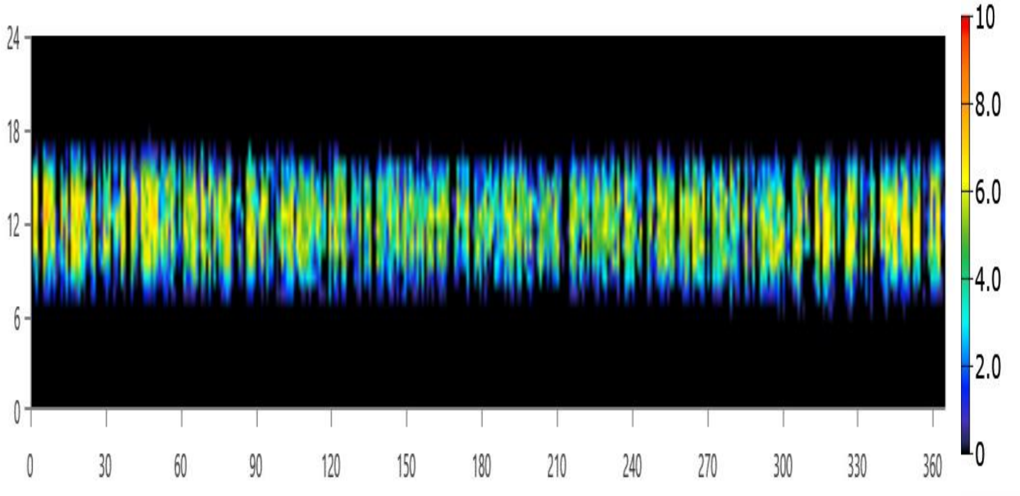


Figure 6-10: energy sold to the grid (KW)

Figure 6-11 illustrates that during the day, power produced by solar is used while during the night or when there is no sun available, the grid supply to the load. From 9:00 pm to 3:00 am, the load is supplied by the PV solar system otherwise the grid supplies the load. So as the solar is produced due to the sun, there are grid sales at a maximum of 3.9KW but as there is no power from the grid, there are grid purchases at 4.46KW maximum power.

It also indicates the power output of PV and AC Primary load where the maximum power from the sun is 6.46KW and the power needed by the primary load is 2.75Kw. It means that during the day, there is excess energy injected into the grid. During the night and in a cold situation, the grid supplies the AC Load.

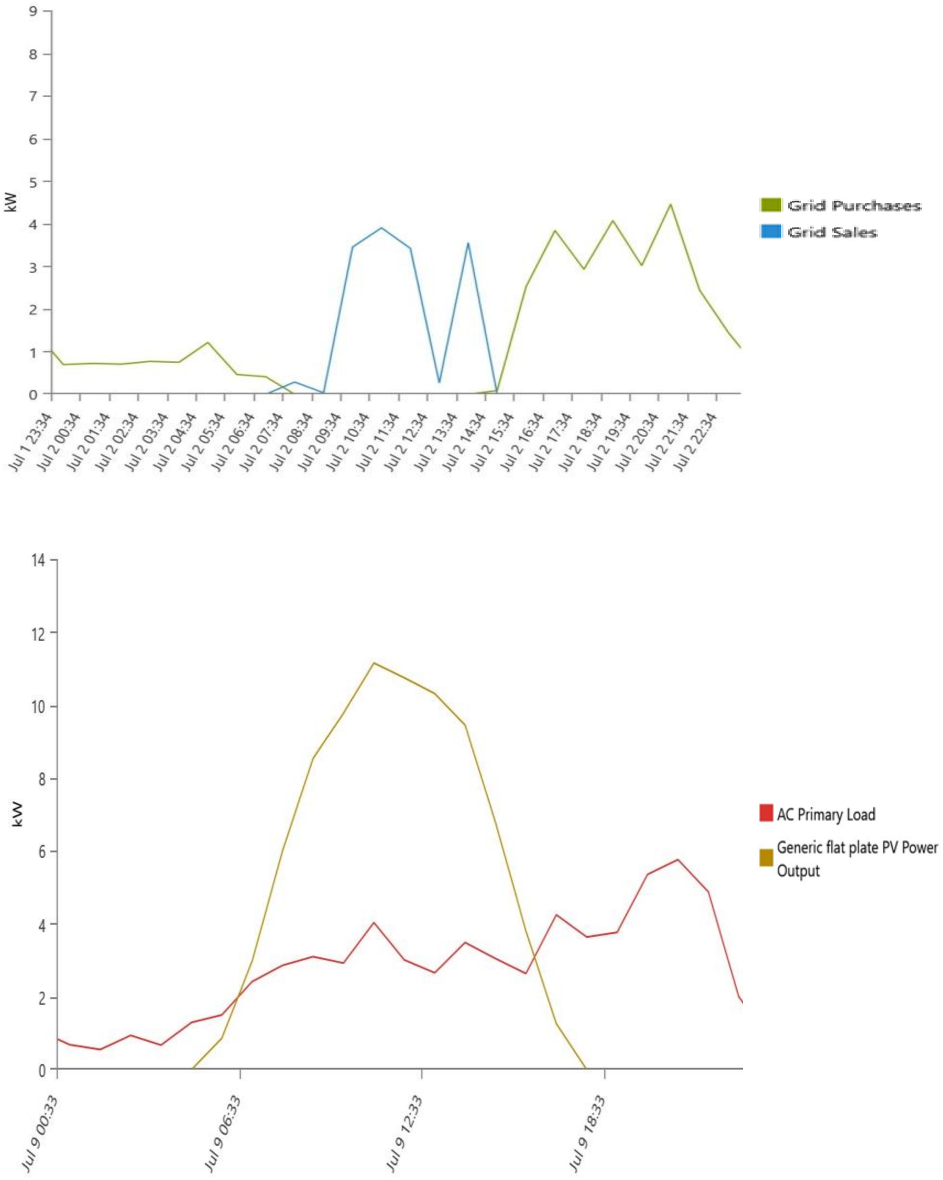
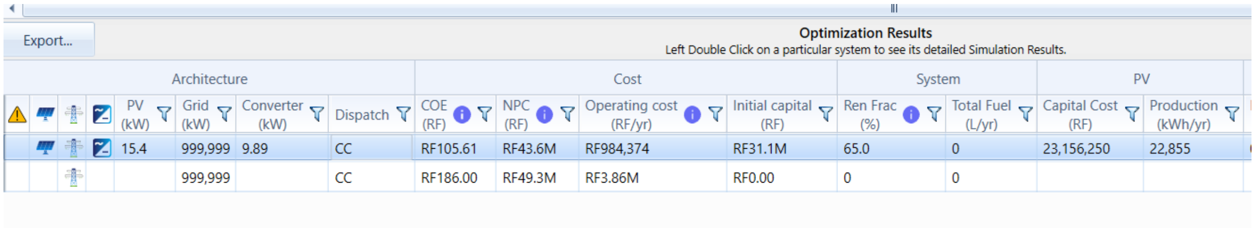


Figure 6-11: PV output, AC primary load, energy sold and purchased

6.6.2. Sellback of energy from the PV to the grid at 75% of energy cost

When the agreement for sellback energy excess from the PV via the monthly net metering is 75% of energy cost from the grid which is RF139.5/KWh, the results from the homer are shown in table 6-7.

Table 6-7: the optimal result at 75% of power price for sellback



Optimization Results

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

Architecture								Cost				System		PV	
⚠				PV (kW)	Grid (kW)	Converter (kW)	Dispatch	COE (RF)	NPC (RF)	Operating cost (RF/yr)	Initial capital (RF)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (RF)	Production (kWh/yr)
				15.4	999,999	9.89	CC	RF105.61	RF43.6M	RF984,374	RF31.1M	65.0	0	23,156,250	22,855
					999,999		CC	RF186.00	RF49.3M	RF3.86M	RF0.00	0	0		

The monthly average electricity produced is demonstrated in figure (6-12) where the power of grid and PV production is shown. The energy generated from generic flat plate PV is 22855kWh/year, grid purchases 11308kWh/year, grid sales 11583kWh/year, and the energy excess in a year is 726kWh/ year.

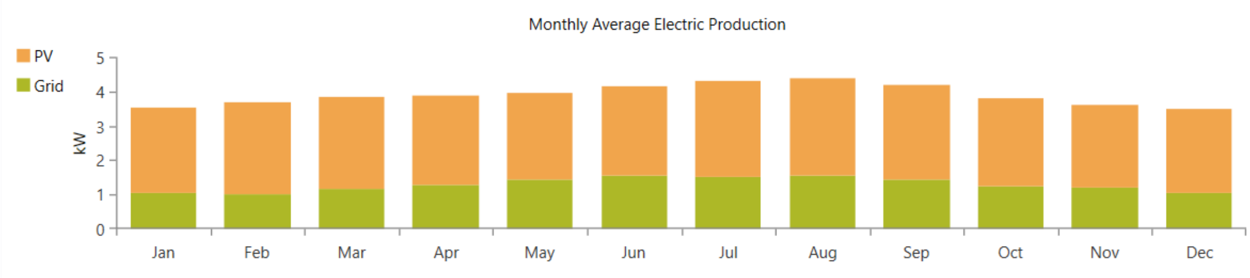


Figure 6-12: PV and grid output at RF 139.5/KWh of sellback

The energy production of PV panel is 22855kWh/year with 66.9% and the grid purchases to the health centre is 11308kWh/year with 33.1%; the excess energy of this designed system is 726kWh per year.

The power generated by PV only is illustrated in figure 6-13 where the rated power capacity is 15.4KW and the mean energy per day is 62.6kWh and the total energy of PV is 22855kWh/year. The working hour of PV is 4380hours during the year.

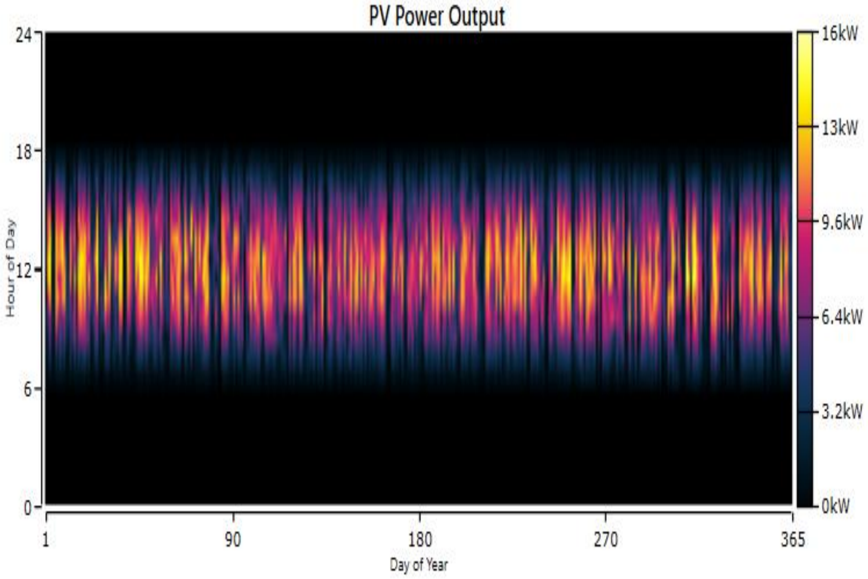


Figure 6-13: Yearly power production of PV

Figure 6-14 indicates the cash flow of each year of the project where the cash will flow out likes capital which is a high investment, operating and maintenance cost, and salvage and replacement cost of components.

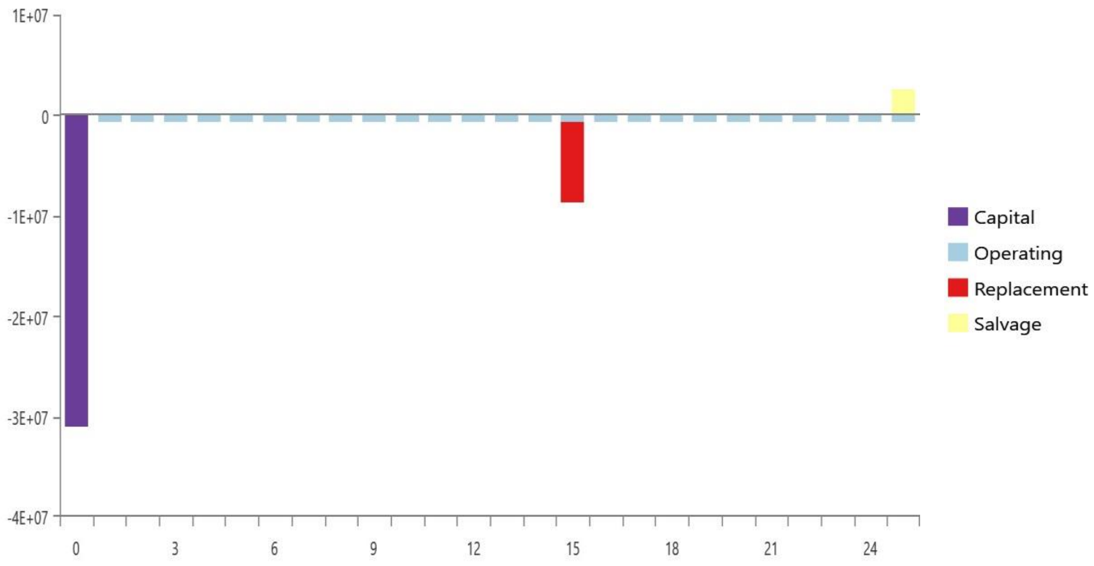


Figure 6-14: Cash flow of system without discount

Cash flow for components in the system designed is shown in figure 6-15, where the PV is very costly, and the system converter is replaced after 15 years.

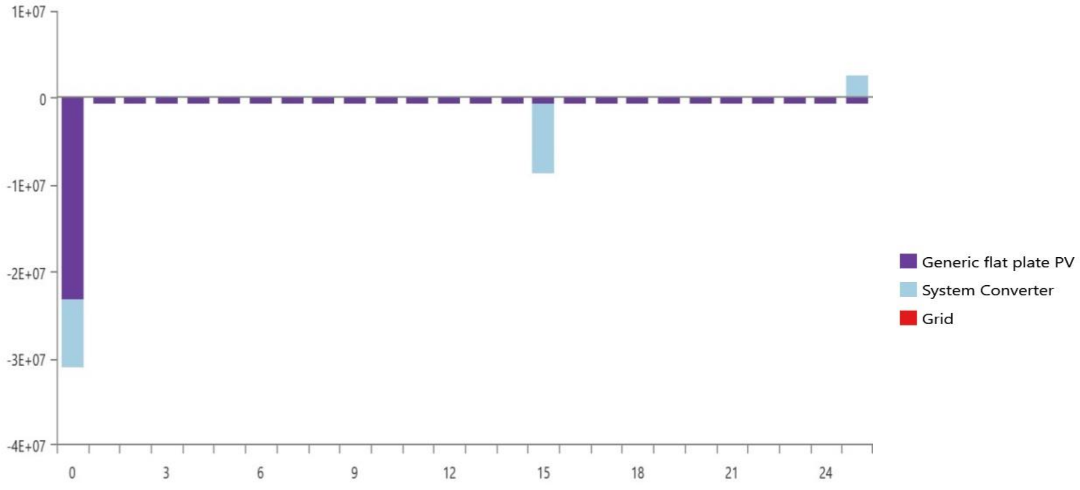


Figure 6-15: cash flow at RF139.5 of sellback to grid

Table 6-8 indicates the energy purchased and energy sold from and to the grid, net energy purchased and energy charged in each month, and total annual energy. The total energy purchased is 11308KWh/year; the energy sold is 11583 KWh/year.

Table 6-8: energy purchased and sold at 75% of power price sellback

Month	**Energy Purchased (kWh)**	**Energy sold (kWh)**	**Net Energy Purchased (kWh)**	**Energy Charge**
January	774	1,060	-286	-RF39,939
February	674	1,012	-338	-RF47,090
March	872	1,054	-182	-RF25,353
April	928	964	-36.8	-RF5,129
May	1,055	905	150	RF27,987
June	1,107	859	247	RF45,968
July	1,124	953	171	RF31,783
August	1,163	952	212	RF39,361
September	1,042	946	96.2	RF17,896
October	935	947	-12.0	-RF1,680
November	856	918	-61.8	-RF8,621
December	778	1,013	-235	-RF32,774
Annual	11,308	11,583	-275	RF2,409

Figure (6-16) illustrates that the primary load is satisfied by power generated by PV during the day while during the night and when there is no sun; AC primary load gets energy from the national grid. The maximum power from the PV is 7.22KW but the primary Load is 2.75KW. It also indicates the amount of power generated by PV solar at a particular time where the maximum in July is at 11:40 AM and the power is around 10kW.

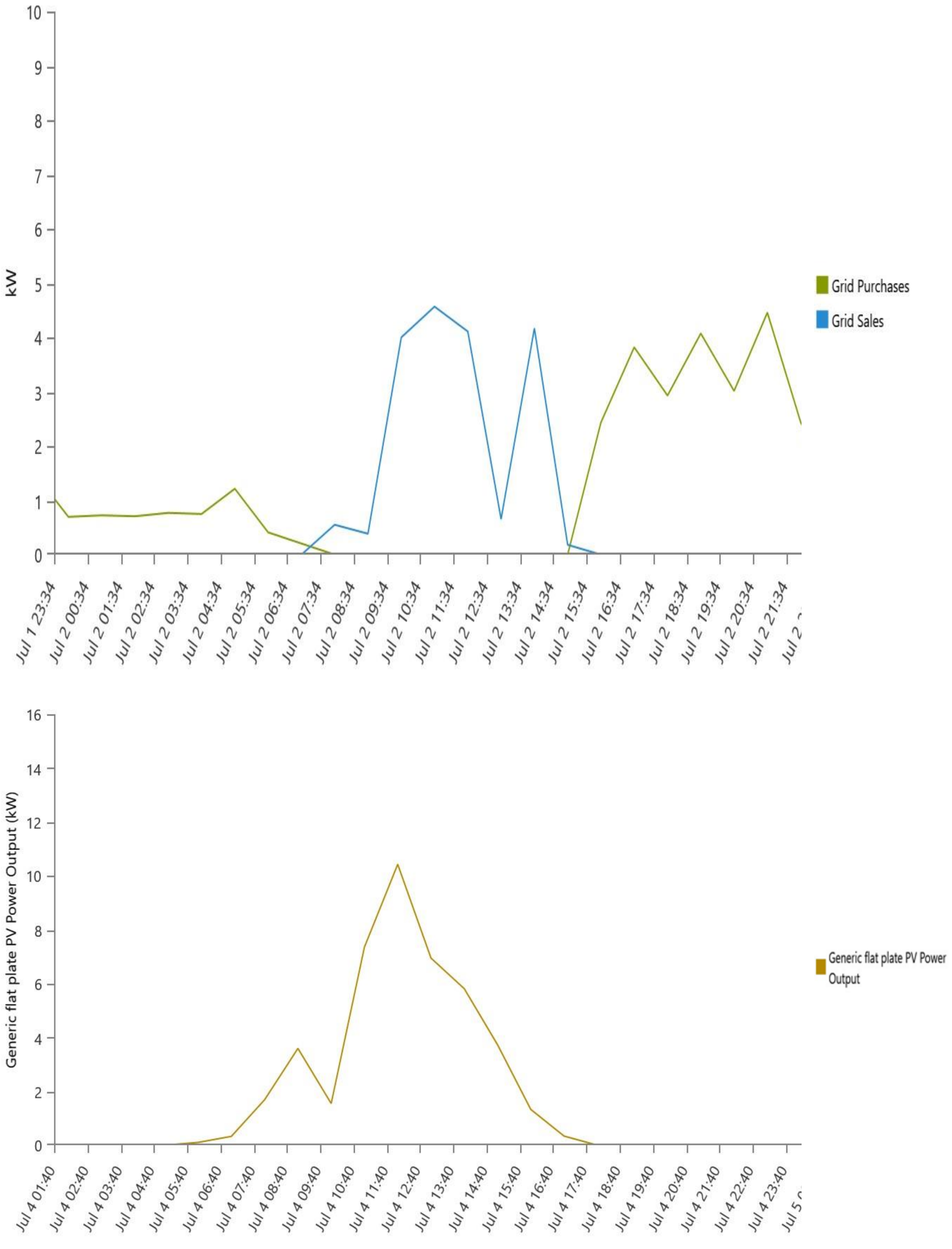


Figure 6-16: Energy from PV, Energy sold and purchased at RF139.5/KWh

According to the cost of selling back excess energy from PV to the grid agreement of the project, the payback period, return on investment, and intern rate of return are presented in table 6-9 where those parameters are closer to being the same.

Table 6-9: economic comparison of different sell-back prices

Economic parameters	**Sellback of RF93**	**Sellback of RF139.5**
Present worth	RF55684555	RF 5301463
Annual worth	RF 444684	RF 414716
Return on investment	5.3%	5.3%
Internal rate of return	7.9%	8.0%
Simple payback period	10.07 years	10.02 years
Discounted payback period	18.94 years	18.77ears

6.7. Sensitivity analysis

Sensitivity analysis was also conducted for getting the effect of some parameter changes in the system. The effects of solar system components cost, cost of energy sells back to the grid, and energy produced by PV solar system. But as table 6-10 shown, according to the agreement of selling back excess energy to the grid, power production changed. If the sellback cost of energy is RF93/kWh, the energy generated by the PV system per year is 20552KWh with a PV power of 13.9KW, and the LCOE becomes RF113.14/kWh. When the sellback cost is 75% of the grid power price which is RF139.5/kWh, the power generated by the PV system is 22855kWh/year, and LCOE becomes RF105/KWh. This is when the panel cost is RF15000000/KW and the inverter cost is RF800000/KW.

Table 6-10: sensitivity analysis results at a higher cost of components

Sellback price of excess energy(RF/KWh)	Architecture/PV (kW)	Cost/COE (RF)	PV/Production (kWh/yr)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)	Energy charge(RF) /Year
93	**13.88206**	113.141	20552	11517.46	9695.584	372717
139.5	**15.4375**	105.6086	22855	11308.34	11583.17	2409

As the power generated by PV solar increases, the cost of energy decreases accordingly. When the power production from the solar is low, energy sold to the grid also is low and the energy charge or energy consumed from the grid increases as it is RF372717/year. If the power is high, the energy sold back to the grid is high, and the energy charge from the net meter record becomes low like power production per year is 22855KWh, and the energy-charged per year becomes RF2409.

For components costs like the cost of solar panels and converters can make the cost of energy changed and the amount of the electrical bill of the health centre varies. When the cost of the panel changed to RF1000000/kW and the inverter cost became the same as the panel cost, table 6-11 indicates the effects on money saving and cost of energy. When the cost of components is low, the cost of energy becomes low. At the sellback cost of energy of RF139.5/kWh, energy sold to the grid is higher than energy drawn from the grid. So there is the amount of money the health centre as a producer will get per year for their excess of energy injected into the grid which is RF411356.

Table 6-11: sensitivity analysis result at the low cost of components

Sellback price of excess energy(RF/KWh)	Architecture/PV (kW)	Cost/COE (RF)/KWh	PV/Production (kWh/yr)	Grid/Energy Purchased (kWh)	Grid/Energy Sold (kWh)	Energy charge(RF) /Year
93	**15.5**	96.26	22894	11305	11008	133850
139.5	**17.8**	85.62	26316	11053	14006	-411356

7. CONCLUSION AND RECOMMENDATION

This project work aimed to design the embedded generation based on PV solar system which is connected to the grid at Busoro health centre located in the Nyanza district. The total load needed at this health center is 20748kWh/year. The work was achieved by considering the global horizontal radiation from NASA at Busoro sector and the primary load at this selected site obtained by data collection for a site visit for reading energy consumption for each electrical appliance and its working hours per day. Basic knowledge of energy resources is needed to select the suitable region according to the types of renewable energy sources. As the research shows, the Nyanza district is one of the southern provinces which has high intensity of solar radiation around 5kw/m^2/day which can attract producer to generate their electricity without using grid energy or generator due to the high cost of energy.

Grid-connected PV solar system was designed and simulated in a homer at the different agreement of selling back excess energy to the grid during the day. Those two scenarios presented that there is an amount of money that can be saved from what they paid where only energy from the grid is used. The first scenario is to sell back to the grid at RF93/kWh where the net present value and cost of energy became RF44 million and RF113.14/kWh respectively while sellback to the RF139.5/kWh, the Net Present Cost and the energy cost became RF43.6million and RF105/KWh. As the energy cost agreement increased, the energy charge was reduced because, in the agreement of 75%, the energy charge was RF2409 per year, but when the energy cost for selling back is RF93/kWh, the energy charge per year was RF372716.

This project found that as the energy produced from the PV increases, the energy charge to the grid as the monthly bill decreases due to the energy sellback via the net meter. As a recommendation, the energy from the grid is costly compared to the energy from the energy integrated with renewable energy sources. So the use of energy today is required as much as possible if all of the users draw energy from the grid without injecting it back into the grid, the cost, stability, and reliability will be an effective problem in the energy network. So embedded generation based on renewable energy is required instead of presuming dominance.

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