UNIVERSITY of RWANDA

College of Science and Technology

ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

TITLE: FEASIBILITY STUDY OF AN OPTIMIZED SOLAR-BIOMASS HYBRID POWER PLANT FOR UNIVERSITY OF RWANDA: CASE STUDY FOR COLLEGE OF SCIENCE AND TECHNOLOGY

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MASTERS OF ELECTRICAL POWER SYSTEMS

Supervisor's Names: **Dr.-Ing Getachew Biru worku**

October 2020

DECLARATION

I, the undersigned, declare that this Msc thesis has been done by myself, and has not been presented for a degree in University of Rwanda or any other Universities. All sources of materials used for this thesis work have been fully acknowledged.

Names: Yvette PEACE

Signature

APPROVAL SHEET

Date of Submission: **18.10. 2020**

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

Dr.-Ing Getachew Biru Worku ……………………………………………………………………………………………

Thesis Advisor Signature

DEDICATION

I dedicate this thesis work to:

- All women in Electric Field
- Family and friends
- UR-CST

ACKNOWLEDGEMENTS

First, I thank **God** for helping me since the beginning of my studies until today. I am grateful.

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ABSTRACT

Rwanda Energy Group intends to increase the capacity of solar power plants to diversify the energy resources and to electrify rural areas by using this available resource so that by 2024 all Rwandan population will have electricity access through both on grid and off grid electricity generation systems. However, solar energy is unpredictable, intermittent and seasonally unbalanced and may not provide the greater security of supply system. The combination of solar energy with wind, biomass and hydro energy provides high portion of electricity demand with reliable and consistent power supply. Hybrid renewable energy system uses more than one renewable energy resource to increase the generation and system efficiency. Therefore, this Thesis work is mainly focused on feasibility study of an optimized hybrid power plant consisting of solar and biomass resources available at University of Rwanda- College of Science and Technology. The main purpose of this research work is to determine the feasible optimum model and performance of a hybrid energy system based on solar and biomass energy sources, which will satisfy the electrical energy demand for the College to replace the conventional grid system by making the college self-sufficient in its electric power need. The college hosts 7000 people including students, staffs, securities and other casual workers. The first part of this this research work was to assess the potential of solar and biomass resources as well as energy demand estimation and forecasting for the college. As per the assessment, the average energy demand for the college is 2230 kWh per day including the future load growth and by considering a minimum solar radiation of G_{min} 4.54 kWh/m^2/day, 8.5ton/day average biomass input produced in the College, a hybrid model was designed and evaluated using Homer software. Various combinations of components have been integrated in the system to find the optimum size for Hybrid Renewable energy system. In the result, different configurations of the system were evaluated according to their net present cost, from the least to the highest and the result having the least net present cost was considered the most feasible. The feasible configuration is found to be the one which contains 160 kW photovoltaic array, 200 kW Biogas generator, 469 Surrette 6CS25P Batteries and 180 kW converter with cost of energy COE $ 0.2001 and total net present cost $ 1,500,807. This system has zero unmet load and zero capacity shortage with electricity excess of 276 kWh/year and it has low COE compared to National tariff. This is the reason why this system has been selected for its Least Cost of Energy.

Key Words: Renewable energy, Hybrid system, solar energy, Biomass, Biogas, COE, NPC, Homer tool

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ACRONYMS

0^{o}	Degree Celicius
AC	Alternative Current
AD	Anaerobic digestion
AD	Daily Autonomy
Ah	Ampere Hour
BC	Battery Capacity
Bp	Battery Connection in parallel
Bs	Battery Connection in Series
C_{Ah}	Storage Capacity of the Battery
COE	Cost of Energy
CST	College of Science and Technology
DC	Direct Current
DG	Distributed Generation
DOD	Depth of Discharge
EL	Daily Load Energy
HOMER	Hybrid Optimization Model for Electric Renewable
HPPS	Hybrid Power Plant System
HRES	Hybrid Renewable Energy System
Isc	Short Circuit Current
kW	Kilowatt
kWh/m2	Kilowatt Hour per Square Meter
LCOE	Levelized Cost of Energy

NASA	National Aeronautics and Space Administration
N_m	Total number of modules
N_p	Number of modules connected in parallel
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
N_s	Number of modules connected in series
PV	Photovoltaic
REG	Rwanda Energy Group
RES	Renewable Energy Sources
Rwf	Rwandan francs
UR	University of Rwanda
V_{OC}	Open Circuit Voltage
η_{bat}	Battery Efficiency
η_{inv}	Inverter Efficiency

1. INTRODUCTION

1.1 Background

Nowadays, Electricity generation utility has started to put many efforts in using clean power generation methods because of high decrease in fossil fuel reserves as well as climate variation. It has become a goal for electricity generation utilities to employ natural energy resources like solar, wind and biomass to become alternatives for conventional/traditional energy sources because they are environmental friendly, associated with low cost and more sustainable [1]. However, natural energy sources are unpredictable, intermittent, and seasonally unbalanced so that the use of one source may not provide the greater security of supply system. Therefore, the utilization of two or more renewable energy sources provide high portion of electricity demand and also reliable and consistent energy supply [1].

Hybrid renewable energy system uses more than one renewable energy resource to increase the generation and system efficiency. The hybrid renewable energy system provides best quality and high reliable energy to electricity consumers compared to a system utilizing only one energy source [1]. Such energy hybridization encounters some limitations because of unavailability of all sources at the same time and these lead to many researches to identify the best combination depending on available resources.

College of Science and Technology is one of University of Rwanda's Colleges located in Kigali City, Nyarugenge District and Nyarugenge Sector. This College hosts 7000 people including students, staffs and other casual workers. It consists of different schools such as the School of engineering, School of Architecture, School of ICT, School of Sciences and School of Mining and Geology. Each school has its own building.

The electricity at the UR-CST is supplied by national grid but it has also some standby diesel fired generators, which supply the campus in case the grid gets disconnected. The campus pays up to 17 000 000Rwf for monthly Electricity consumption to REG but it has also some associated electricity cost paid for the diesel used as input to mentioned standby generators.

This campus has the sources of biomass in terms of human wastes specifically feces and urine not extracted. It has many toilets and for each block there is a feces collection septic tank where the feces from toilets are collected and when the septic tanks are full, the feces are removed and transported out of the campus to provide space for other incoming feces.

Available solar insolation in Rwanda is 5kWh/m2/day with daily five peak sun hours. Referring to this amount of available solar energy and by considering the status of climatic weather in Rwanda, it can be proved that this energy in terms of solar radiations would substantially participate in increasing the national electricity generation once well exploited [2]. This shows that UR-CST has also good solar potential, which can be extracted to generate electricity to different loads of the campus.

The use of hybrid power plant based on solar and biomass resources will help the campus to reduce the dependence in its power supply, as it will generate electricity using its own resources there by reducing the cost of electricity paid by the college to REG. It will also provide a source of income for the campus as the byproducts from digesters while extracting biogas from biomass (Human wastes) through anaerobic digestion will be sold to agricultures for soil fertility application.

The target of this Thesis work is to carry out the feasibility study of an optimized Hybrid Power Plant based on solar and biomass resources, which will make the college self-sufficient in its electric power need. The combination of solar and biomass resources has the advantage that in case there is no sun, the biomass resources keep supplying the energy thereby ensuring the continuity of supply. The performance of the designed system is analyzed using Homer Software.

1.2 Statement of the Problem

Government of Rwanda has a target that by 2024 all Rwandan population will have electricity access through both on grid and off grid electricity generation systems. To achieve this target, people are encouraged to highly use renewable energy sources to generate electricity. College of Science and Technology has 7000 students who use toilets daily. This means that there is a large supply of feces, which can be used in biogas production. The college also has about 5kWh/m2/day solar insolation and daily 5 peak sun hours, which means it is ideal for solar power generation. There is an associated cost related to the electricity consumption for this campus as it is currently supplied by national grid. There is also an associated cost for input to standby diesel fired Generators which provide backup to the grid system. This thesis work proposes the use of solar and biomass hybrid power generation system for supplying the college's electrical energy thereby reducing the cost of electricity paid by the college to National Grid by using the available renewable energy sources.

1.3 Objectives

1.3.1 Major Objective

The major objective of this research is to carry out the optimal design configuration and feasibility study of Solar-Biomass Hybrid Power Plant for University of Rwanda – College of Science and Technology which will use available solar and biomass resources in the college for electricity generation there by making the college self-sufficient in its electric power need.

1.3.2 Specific Objectives

To achieve the main goals, the study has the following specific objectives:

- To study the solar and biogas energy potential of the area.
- To estimate and forecast the electrical load demand of the college of Science and Technology by considering all the basic needs of the college.
- To size appropriate solar modules, battery, biogas generator depending on the energy demand.
- To design and simulate the hybrid renewable energy system to validate its operation.
- Analyze the performance of the designed system by using HOMER tool.
- To evaluate the investment cost of the hybrid system and determine the investment recovery time.
- To compare the cost of designed Hybrid system and the National grid cost.

1.4 Scope of the Study

This study started from assessing the renewable energy resources potentials (solar and biomass only) and the electrical energy demand for UR-CST up to Feasibility study of an optimized Solar-Biomass Hybrid Power Plant. Sizing of hybrid components like PV module, batteries, converter and biogas generator was accomplished. The investment cost of the hybrid system and the investment recovery time was also evaluated and determined.

1.5 Significance of Study

The benefit of hybrid power generation from renewable energy sources to the college is to reduce the cost of electricity consumption paid to REG as well as eliminating the cost for input to standby diesel fired Generators. The combination of the two sources photovoltaic and biomass will increase the amount of energy generated as well as the continuity of supply in case the sun will not be available due to its intermittent property. Therefore, the power generation of such a hybrid system is more constant and fluctuate less compared to a system using a single energy source. Waste products (biomass) biogas production are soil fertilizers, so they can be sold to agricultures there by providing income for the campus.

1.6 Research Methods

To attain the general and specific objectives of the study, the following methods have been applied:

- **Data collection**

The data required for solar radiations were collected online from NASA website using Homer software while data regarding Biomass potential was found in the college based on information collected (through visit done in the college) about total number of people the college host.

- **Load Estimation**

Average daily load consumption for the College was obtained through the self-performed site visit in the College by considering all the basic needs of the College and the monthly electricity cost for the college. Load forecasting for 5 years was carried out for meeting the future load growth and estimation of peak demand for the college was done using Homer tool.

- **Components Sizing**

Sizing of appropriate components including solar modules, battery, biogas generator and converter was performed based on the energy demand for the college.

- **Design and optimization of Solar-Biomass Hybrid System**

Homer Software performed design and optimization of the hybrid renewable energy system.

- **Feasibility Study**

Feasibility studies of the Hybrid system were performed using Homer tool based on the collected data and estimated load. Then the optimal system was selected.

- **Simulation Results and Conclusion**

The simulation result of the optimum configuration was analyzed and conclusions are drawn based on the results.

CHAPTER 2

2. THEORETICAL BACKGROUNG AND LITERATURE REVIEW

2.1 Theoretical Background

2.1.1 Solar Radiation and Solar Energy

Sun is considered the central star of the solar system and solar energy (energy generated by the sun) reaches the Earth in the form of solar radiations. During the process of nuclear reactions inside the Sun, hydrogen undergoes fusion process in which it is converted into helium. During this process, a large amount of energy is released. One portion of this energy reaches on the earth in form of heat and light, and this energy can be converted to electricity through photovoltaic systems [3].

The amount of solar energy reaching on the earth depends on climate conditions, location i.e. latitude and longitude of given area, etc. However, it is stated that at optimum condition, the earth surface receives 1.000W/m^2. The following terms (irradiation and radiation) are mainly used when talking about sunlight and electricity generation through photovoltaic systems and it is necessary to know their meaning as described below:

Irradiation: It is the ratio between the radiated solar power and perpendicular surface of area to the direction of radiation. It is usually expressed in W/m^2 [3].

Radiation: It is the amount of solar radiation energy, which falls on the unit surface of a given area for a given time. It is usually expressed in Wh/m^2 or J/ m^2. Besides expressing it in hourly values, it is often expressed as daily, monthly or yearly radiation depending on the time interval [3].

Fig.2.1. shows how solar energy get generated, 30 0% of solar radiation is assumed to reach on earth surface and remaining portion get colleted by oceans, clouds and land [4].

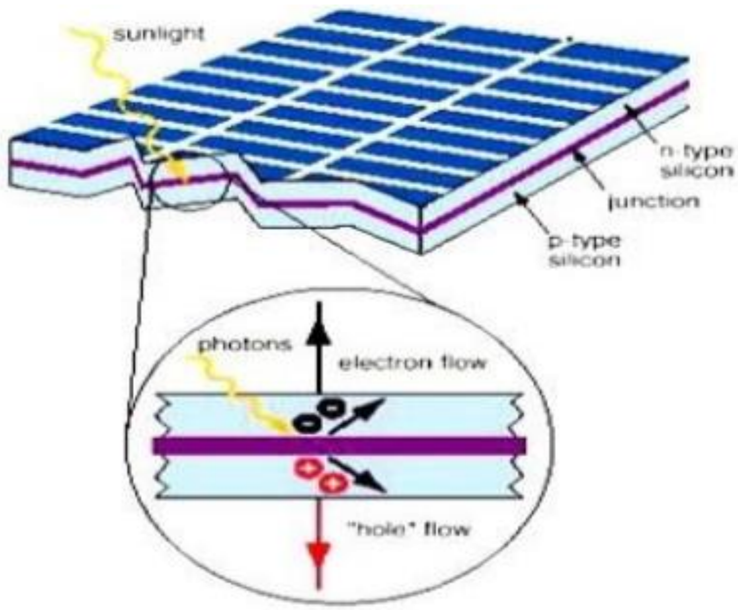


Figure 2.1 Internal of Reaction of Solar energy [4]

The sun radiation affects the operating conditions of photovoltaic (PV) solar modules due to time-to-time variation in solar radiation. The output power from Photovoltaic module rises as the solar radiations increase [5]. Figure 2.2 shows the effect of solar insolation on solar cell.

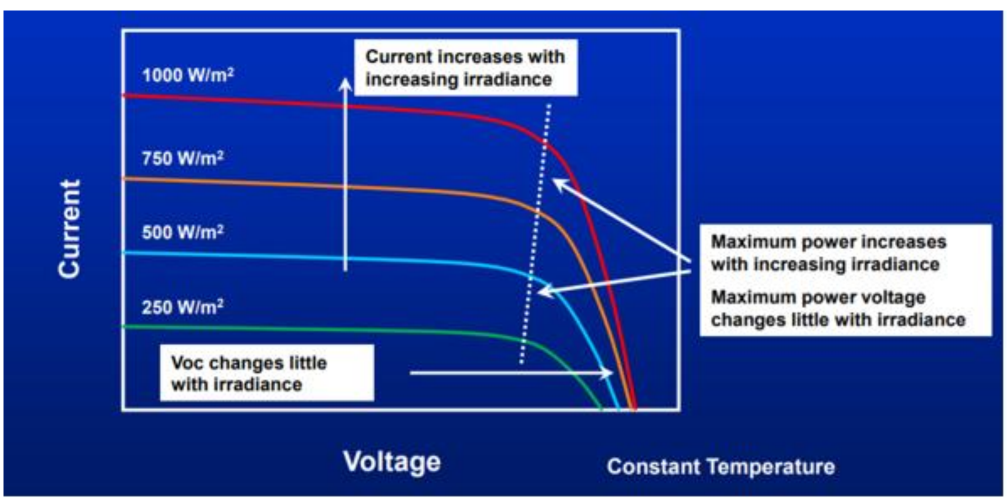


Figure 2.2 PV current and voltages at different insolation levels

2.1.2 Working of Solar Energy System

Photovoltaic cells are used for Converting solar radiations from the sun into DC electricity [4]. Charge regulator controls the power from solar PV to battery and Battery stores electric power, which is used when there is little or no solar radiations (i.e. night). This system is connected to inverter for converting Direct Current (DC) into Alternating Current (AC) [4].

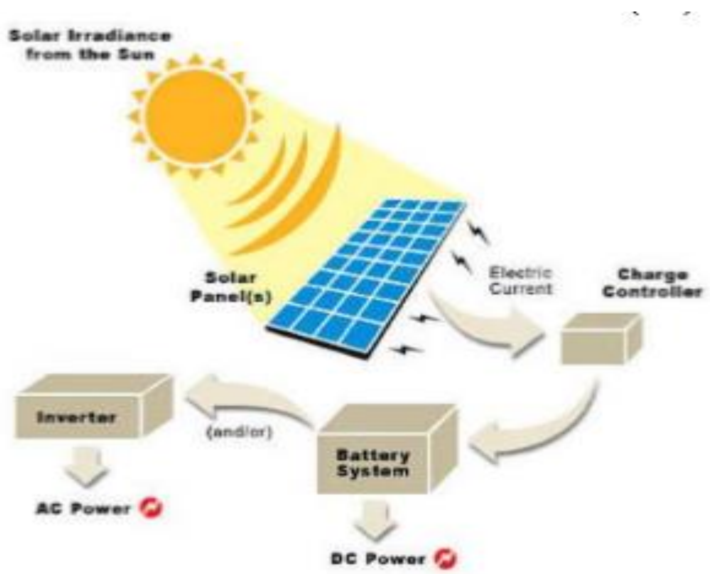


Figure 2.3 Working of solar energy [4]

2.1.3 Photovoltaic Energy Conversion

The conversion of solar radiations into electricity by Photovoltaic panel is the best method of using sun energy [3]. Photovoltaic systems use cells for converting solar energy into electricity. The particles of light are called photons and energy generated from these photons varies with wavelength and frequency. It may also be calculated using Einstein's law shown in equation (2.1) below [3]:

$$h\nu = W_i + E_{kin} \quad (2.1)$$

Where:

$h\nu$: Photo energy

W_i: work out

E_{kin}: Kinetic energy of emitted electrons

Equation (2.1) shows that whenever the photon energy is less than the work out, the electron will be released.

Temperature also affects the flow of electricity in the solar PV through changing the speed of electrons flow [5]. The operating temperature of the module affects more the voltage parameters. The maximum voltage of a solar panel decreases with increasing in operating temperature of the solar module due to an increase in resistance resulted from increase in temperature. In addition, the decrease in operating temperature of the cell leads to cell resistance decreasing. Because of this effect of temperature on solar cell performance, different methods like dust cleaning, cooling the cell to reduce the temperature of the panel using water are used for increasing the performance efficiency of the solar module [5]. Figure 2.4 shows the effect of temperature on solar cell.

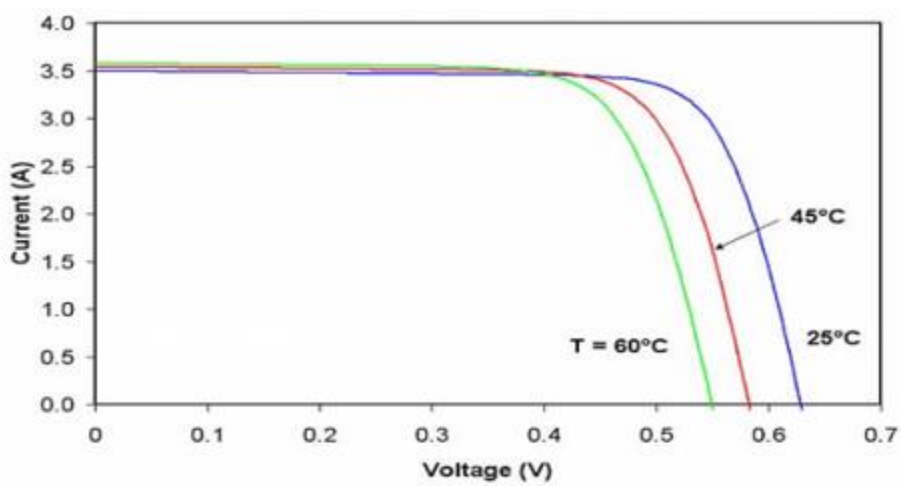


Figure 2.4 The effect of temperature on the performance of a silicon solar module

2.1.4 Modeling of PV Panel

2.1.4.1 Solar Cell

The cells convert energy from the sun in forms of solar radiations directly into electricity and they are formed with different kinds of semiconductor materials. A cell is composed of positive and negative charges and whenever a cell absorbs photons from sunlight, electrons get released there by leading to a flow of electric direct current [4]. Solar cell PV consists of many chemicals.

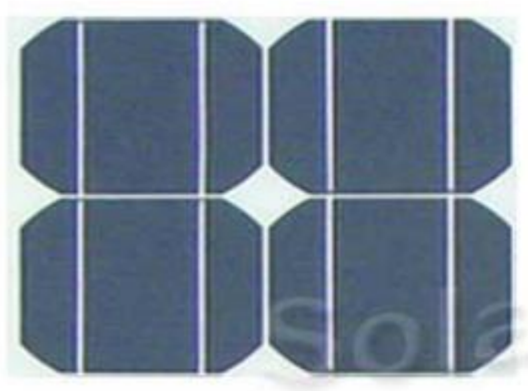


Figure 2.5 Photovoltaic Cell (4 cells) [4]

2.1.4.2 Photovoltaic Panel

Solar panels consist of individual PV cells connected together [4]. Figure 2.6 shows the series connection of PV cells.

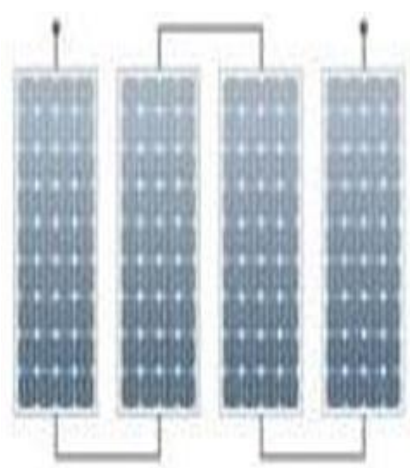


Figure 2.6 Photovoltaic Panel [4]

2.1.4.3 Photovoltaic Module

A Photovoltaic module is a collection of solar cells. Photovoltaic modules are connected in series and parallel during installation to get the energy requirement [4].

Figure 2.7 Photovoltaic Module (Multiple cell) [4]

2.1.4.4 Photovoltaic Array

Photovoltaic Array consists of various amount of Photovoltaic cells connected in series and parallel for increasing voltage and current of an array respectively [4]. This means that as total area of the array increases, the electricity produced from a PV Array will increase too.

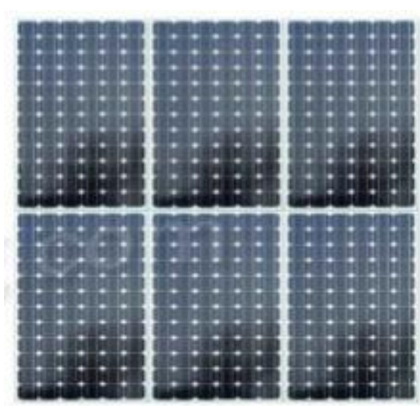


Figure 2.8 Photovoltaic Arrays (Multiple Modules) [4]

2.1.5 Solar PV Technologies

With the growing use of solar power, new technologies are being introduced and existing technologies are developing [6]. There are four types of solar PV cells described below:

- Single crystalline or mono crystalline
- Multi- or poly-crystalline
- Thin film
- Amorphous silicon

Single-crystalline or mono crystalline: Mono crystalline technology is the most available and efficient cell among all cell technologies. It produces more energy from a module. It is called mono crystalline because every cell is formed from a single crystal then further cut into the shape of rectangular cells to increase the number of cells in the solar panel [6].

Polycrystalline cells: Polycrystalline cells are built from similar silicon material but instead of being grown into a single crystal, they are melted and poured into a mold. This forms a square block that can be cut into square wafers with less waste of space or material than round single-crystal wafers [6].

Thin film panels: Thin film panel is the new technology being introduced in solar cell technology. Copper indium dieseline, cadmium telluride, and gallium arsenide are all thin film materials and they are directly deposited on glass, stainless steel, or other compatible substrate materials [6]. Some of thin film panel functions better than crystalline modules in case of low light conditions. A thin film is very thin-a few micrometer or less [6].

Amorphous Silicon: Amorphous silicon is newest in the thin film technology [6]. In this technology amorphous silicon vapor is deposited on a couple of micro meter thick amorphous films on stainless steel rolls and Compared to the crystalline silicon, this technology uses only 1% of the material [6].

2.1.6 Solar Photovoltaic System Components

Solar photovoltaic (PV) energy systems consist of various components each with different specific function in a system. The components are selected based on the type and application of system. For example, a simple Photovoltaic system is made of a solar module or array and the load it powers [7]. If there some AC loads, DC converter (Inverter) will be needed to convert DC power to AC power. In fact, a stand-alone system with energy storage will have more components than a simple Photovoltaic system. Figure 2.9 shows a typical solar PV system.

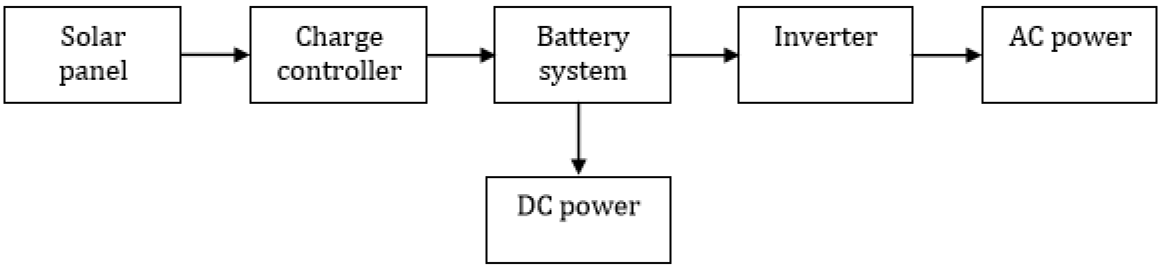


Figure 2.9 Block diagram of a typical solar PV system [6]

2.1.6.1 Solar Panel

A solar panel is made up of interconnected solar photovoltaic cells combined in series, parallel, and is used to generate electricity from sunlight. The cells consists of at least two layers of semiconductor material (usually pure silicon infused with boron and phosphorous) [6]. These two layers have a positive charge and a negative charge respectively. When solar radiation falls on a solar cell, the semiconductor atoms there absorb photons from the light by releasing electrons. These electrons then flow from the negative layer (n-type) of semiconductor to the positive layer (p-type) there by producing direct electrical current flowing in one direction [6].

2.1.6.2 Charge Controller

Whenever there is a battery in a photovoltaic system, a charge controller is required. A charge controller regulates the amount of electrical energy stored in battery. During days with much sun, the solar modules generate more electrical energy, which may break the battery if not well controlled. Therefore, a charge controls the amount of energy to be stored in battery [6].

2.1.6.3 Battery

Battery is used to store energy which will be used in case the energy generated from the sun is not enough to meet the load requirements [7].

2.1.6.4 Battery Banks

If the total voltage required by the system is greater than the capacity of one battery, batteries are interconnected in series and parallel to form a battery bank. For example, two 6-volt batteries connected in series produces a battery bank, which is able to provide up to12 volts of DC energy, and four batteries connected in series produces 24 volts. Battery banks installed to allow loads to operate for more than 1 days during cloudy weather conditions when the array is not able to charge the battery bank [7].

2.1.6.5 Inverter

Energy generated from interconnected photovoltaic modules or a battery bank is direct current (DC). Different DC loads like lights, fans, pumps, motors, and some specialty equipment will use this energy. However, in case of AC load supply requirements, the current needs to be converted from DC to AC. The inverter then performs the conversion of DC energy to AC energy. [7].

2.1.7 Types of Photovoltaic System

Photovoltaic systems are classified into two main groups, which are:

1. Standalone Systems (Off-Grid) or Isolated Systems.

2. Network-connected photovoltaic systems (on-grid).

2.1.7.1 Network-connected photovoltaic systems (on-grid)

The basic components of this system are solar photovoltaic modules, photovoltaic inverter, installed sub frame and measuring cabinet with protective equipment and installation. Photovoltaic modules are used for converting energy generated (solar radiations) from the sun into direct current abbreviated as DC current, while photovoltaic inverter controls the generated energy in a form which can be supplied to the nati onal grid. The AC voltage is supplied to the Grid network the protection and measuring equipment [3]. Figure 2.10 shows the on grid PV system configuration.

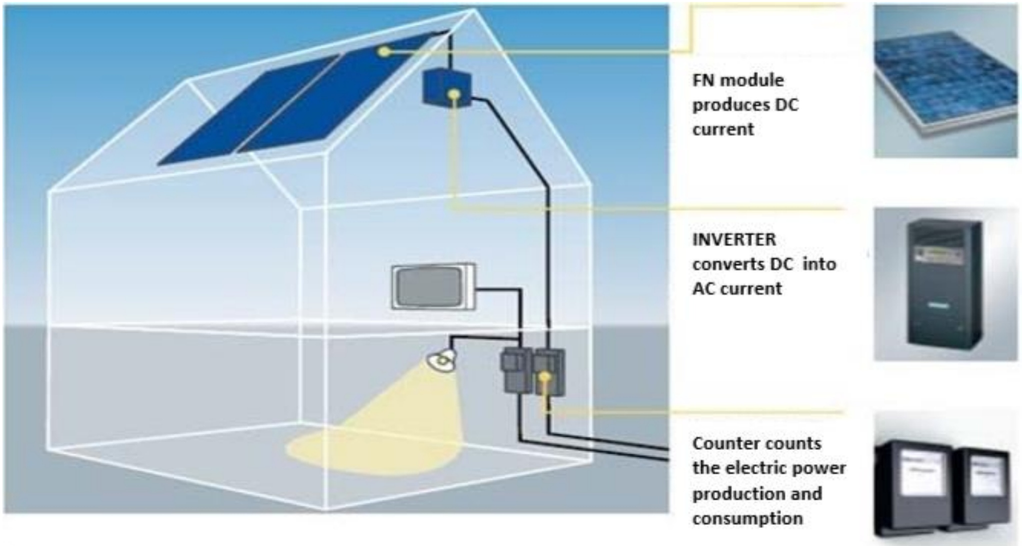


Figure 2.10 Network-connected photovoltaic system [3]

2.1.7.2 Standalone Systems (Off-Grid) or Isolated Systems

Standalone systems are used to provide electricity in rural villages, which do not have electricity access. The systems are installed with a storage of energy (battery) and a charge controller, which regulates the charging and discharging cycles of a battery. The inverter may also be used to convert generated direct current from a solar system into alternating current for electrical equipment and appliances. In fact, typical standalone photovoltaic installation are used to supply electricity in rural areas where there is no electricity network from National grid [3]. Figure 2.11 shows the configuration standalone PV system.

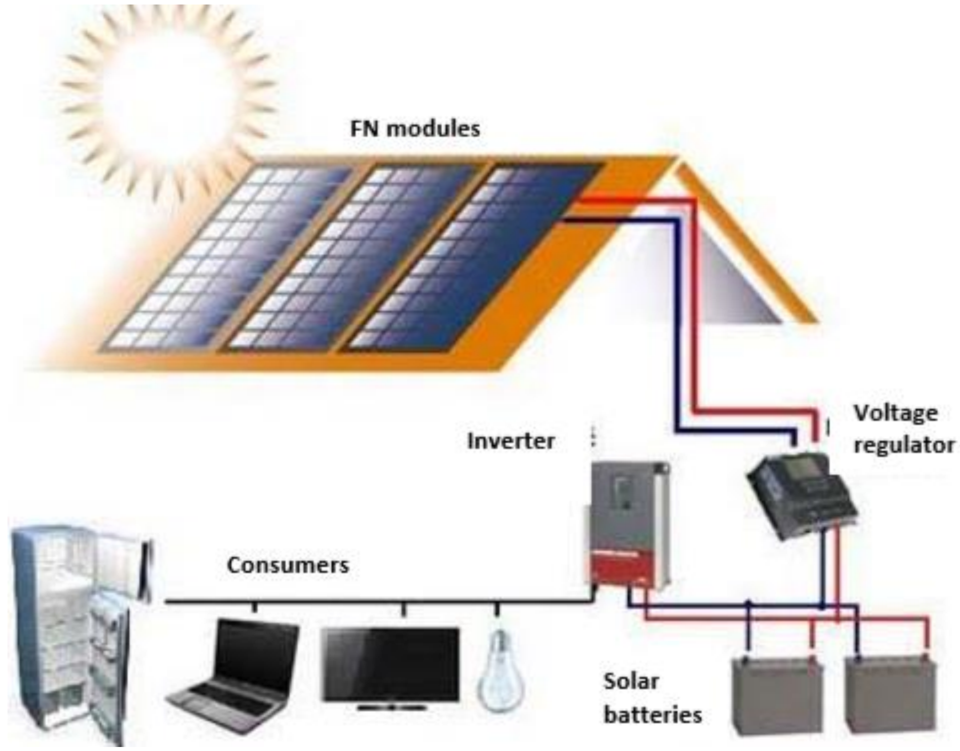


Figure 2.11 Standalone photovoltaic system [3]

2.1.7.3 Hybrid Energy Systems

Solar photovoltaic system requires to be utilized in combination mode with different energy sources like biomass generator, wind turbine, diesel generator, all to ensure a constant and sufficient supply of electricity due to its intermittent property. This means that for cloud days where there absence of the sun, the solar system does not generate electricity and it’s a well-known fact that the need of energy is the same for all days, therefore energy demand must be met from other energy sources like biomass generator, wind energy to compensate for the insufficient energy from the sun there by providing constant energy. The hybrid system can be connected to a network, standalone or as a support network [3]. The hybrid system is used in this study and is based on Solar and Biomass energy resources. Biomass gasifier power plant will produce electricity through biogas-fueled generator. The biogas will be produced through anaerobic digestion of Human waste in terms of fecal matter.

2.1.8 Biomass Energy

Biomass refers to different types of organic matter from fuel wood to marine vegetable. There is numerous convenient way of converting biomass into useful form of energy such as heat and electrical energy. Biomass is a term used to describe all organic matter existing on the earth's surface produced by photosynthesis including all water land-based vegetation, trees, and all waste biomass such as municipal solid waste, municipal bio solids, animal wastes (manures), forestry, agricultural residues and certain types of industrial wastes. The world relied more on fossil fuels for energy generation and Biomass has found to be only other naturally occurring energy resource containing carbon and which can be used as substitute for fossil fuels [8].

2.1.9 Methods of Biomass Energy Extraction

Biomass can be converted to different types of energy using different conversion processes[8]. The methods of biomass conversion are described below:

- **Direct Combustion**

Direct combustion is considered as the simple way of extracting energy from biomass. This is done by burning different types of biomass fuel including wood, agricultural residues, wood pulping liquor and municipal solid waste (MSW) [8]. By doing the biomass combustion, the steam is produced and the produced steam turns the turbine, which also drives the generator there by producing electricity. Due to high quantity of ash produced after biomass combustion, this method is less applicable [8].

- **Gasification**

During Gasification method, solid fuels are broken down by the use of heat with a restricted supply of air to produce combustible gases, which can be used as a fuel for internal combustion engines. The gas produced from this process is composed by carbon monoxide, carbon dioxide, nitrogen, hydrogen, and methane which can be used to drive a high efficiency, combined-cycle gas turbine [8]. Gasification has several advantages over direct combustion. One advantage of this process is that resulted methane among other gases can be used in a similar way as natural gas.

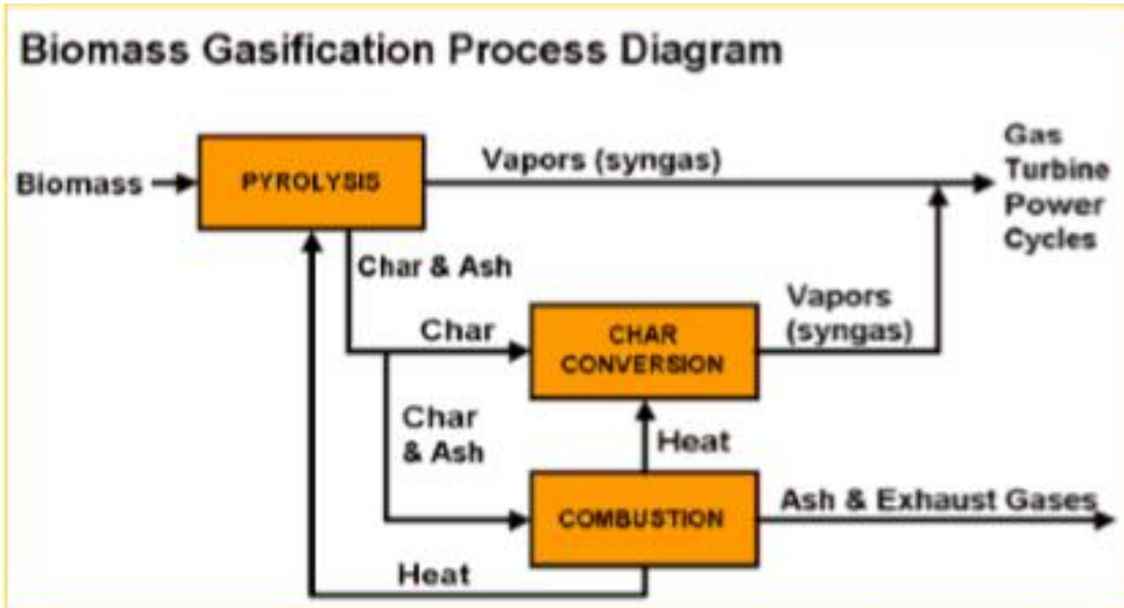


Figure 2.12 Biomass gasification process diagram [8]

Another associated advantage of using gasification is that the fuel produced from its process has few impurities and these results in less environmental pollution problems when burnt. [8].

- **Pyrolysis**

Pyrolysis represents the heating of biomass in the absence either of air, or by the partial combustion of some of the biomass in a restricted air or oxygen supply to remove the volatile matter and leave behind the charcoal. This is general term which describes all processes whereby organic material is heated or partially combusted to produce secondary fuels and chemical products [8].

- **Digestion**

Anaerobic digestion is a technology proved to be commercial and is widely utilized for recycling and treating wet organic waste and wastewaters. It is a type of fermentation that converts organic material into biogas and it is mainly consists of methane (approximately 60%) and carbon dioxide (approximately 40%) [8]. Gas produced from anaerobic digestion can be burned directly for cooking or heating applications after appropriate treatment. It can also be applied in secondary conversion devices like internal combustion engine for electricity generation or shaft work [8].

- **Fermentation**

For centuries, yeasts and other Microorganisms have been used in fermentation of sugar for various plants into ethanol. Producing fuel from biomass by fermentation is just an extension of this process, although a wider range of plant material from sugar cane to wood fiber can be used [8].

2.1.10 Biogas Energy

Biogas is a gas produced after organic materials such as plants and animal wastes decomposition by bacteria in an absence of oxygen through a process named anaerobic digestion. Anaerobic digestion occurs in different places including nature, landfills, and some livestock manure management systems but the process can be controlled and optimized with anaerobic digesters. Biogas contains 50-70 % methane, 30-40 % carbon dioxide, and trace amounts of other gases [9].The liquid and solid digested material called digestate produced after biogas collection is frequently used for soil fertility purpose [9].

After biogas is captured and stored, it can be used in different applications like heat production, input fuel for engines, in micro turbines and fuel cells for electricity generation. The advantages of using stored biogas is that it can produce a clean, renewable, and reliable source of base load power to replace fossil fuels [9]. Utilizing stored biogas limits the amount of methane which could be released into the atmosphere and also reduce dependence on fossil fuels [9].

There is also associated climate benefits through the use of anaerobic digestion because it reduces the charges associated with waste remediation and also building biogas systems in a given area could add temporary construction jobs and permanent jobs there by contributing to unemployment problem reduction [9].

2.1.11 Biogas Production Process

Anaerobic digestion (AD) is the process where different organic materials are decomposed by bacteria without any presence of oxygen. The resulting products from anaerobic digestion are biogas and bypass product also called digestate [10]. The anaerobic digestion takes place in 4 steps discussed below:

- **Hydrolysis**

Hydrolysis is the initial stage of anaerobic digestion where non soluble organic matters such as proteins, fats, lipids and carbohydrates get converted into soluble organic compounds such as amino acids, fatty acids, monosaccharaides and other simple organic compounds [11].

- **Acidogenesis**

Acidogenesis is the second step where soluble compounds produced in the first stage are further degraded resulting in the production of carbon dioxide (CO2), hydrogen (H2) gas, organic acids, alcohols and some organic Sulphur compounds [11].

- **Acetogenesis**

Acetogenesis is the third stage during which lactic acid, alcohols and glycerol are converted by the acetogenic micro-organisms into acetic acid, hydrogen and carbon dioxide [11].

- **Methanogenesis**

Methanogenesis is the last stage where fermentation products such as acetate and hydrogen are converted to methane and carbon dioxide [11].

2.1.12 Factors affecting anaerobic digestion process

- **Temperature:**

Anaerobic digestion methodology operates efficiently for all climatic conditions but its efficient reduces with decrease in temperature. For temperatures below 15°C, the digestion does not operate satisfactorily. To compensate for cold climates or season, heating systems and insulation can be applied for providing optimal digestion temperatures. However, this requires additional investment costs and fuel costs for heating there by making this biogas production system economically unviable [10].

- **Hydraulic Retention Time**

The Hydraulic Retention Time refers to the period taken by organic matter in the reactor to be completely digested. The necessary HRT needed to complete anaerobic digestion reactions is affected by applied technologies, temperature and waste type [10].

- **Inhibition**

When planning and running a biogas plant, different factors that might inhibit the anaerobic process have to be considered. Some compounds at high concentrations may be toxic to the anaerobic process. Generally, inhibition depends on the concentration of the inhibitors, the composition of the substrate and the adaptation of the bacteria to the inhibitor. The following are various types of inhibition factors: Oxygen, hydrogen sulphide (H2 S), organic acids, free ammonia, heavy metals, et al. hazardous substances like disinfectants (from hospitals or industry), herbicides, insecticides (from agriculture, market, gardens, and households) and antibiotics [10].

2.1.13 Anaerobic Digestion Technologies for Bio waste

Biogas technology refers to the use of biogas digesters for converting different input biomass into biogas. Biogas digesters are the constructed vessel in which biomass in terms of animal waste and other bio-degradable materials are broken down by bacteria in complete absence of oxygen to produce biogas [11]. Biogas generation commonly utilizes the organic waste such as cattle manure, food waste, agricultural waste, and human waste. Utilization of raw material such as human waste (human excreta) is beneficial in terms of the process because it does not require additional starter (microorganisms seed), and a supply of microorganisms occurs continuously during the feeding of raw materials. This directly supports the sustainability of the production of biogas [12].

There are many types of digesters that are used in anaerobic digestion process to produce biogas but the main 3 types used are: fixed-dome type, floating-drum type and tubular type [10]. Even though the designs differ in detail, each digester has three common parts descried below:

Digester: where input biomass (slurry) is injected and broken down by bacteria to produce biogas.

Biogas holder: A place where collection and storing of biogas takes place and which could be part of the digester.

Displacement tank: where removing of fully digested slurry and prevention of over pressurization of biogas takes place [13].

2.1.13.1 Fixed-dome type digester

This digester consists of three main parts as discussed above. The digester has a shape of dome, the gasholder is static, inlet feed stock, and displacement tank are located in opposite position. A schematic diagram of Fixed –dome digester is given in Figure 2.13. Biogas from the digester is collected in the upper part of the reactor [10].

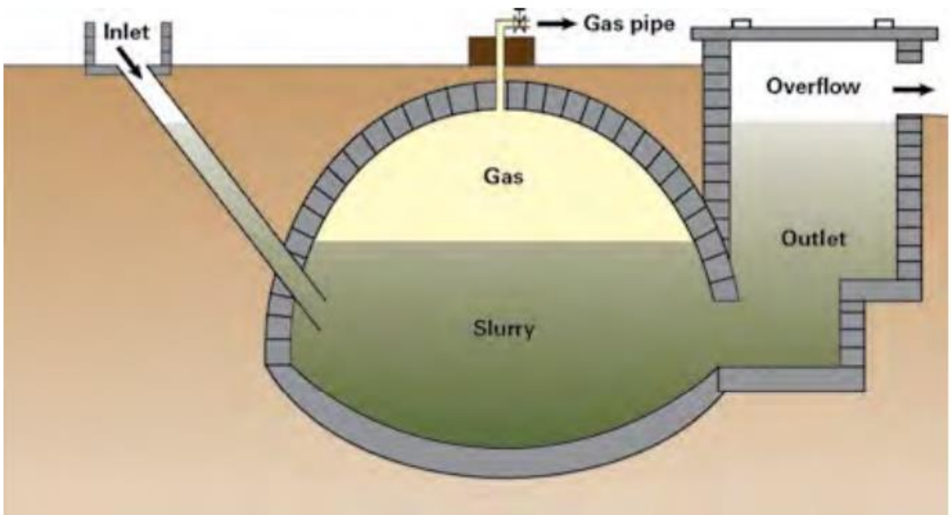


Figure 2.13 Scheme of fixed-dome digester [10]

Advantages of fixed dome type digester

- Simple design
- Inexpensive
- Doesn’t need regular maintenance as there are no moving parts, Long life

Disadvantages of fixed dome type digester

- Variation in gas pressure
- Requires skills people to construct it

2.1.13.2 Floating-drum type digester

This type biogas digester is composed by three main parts. The digester shape is cylindrical, Gas holder also called drum is movable, input feedstock and output are located at opposite sides as shown in Figure 2.14. The digester is made of bricks and it is constructed underground whereas the drum is above ground [10].

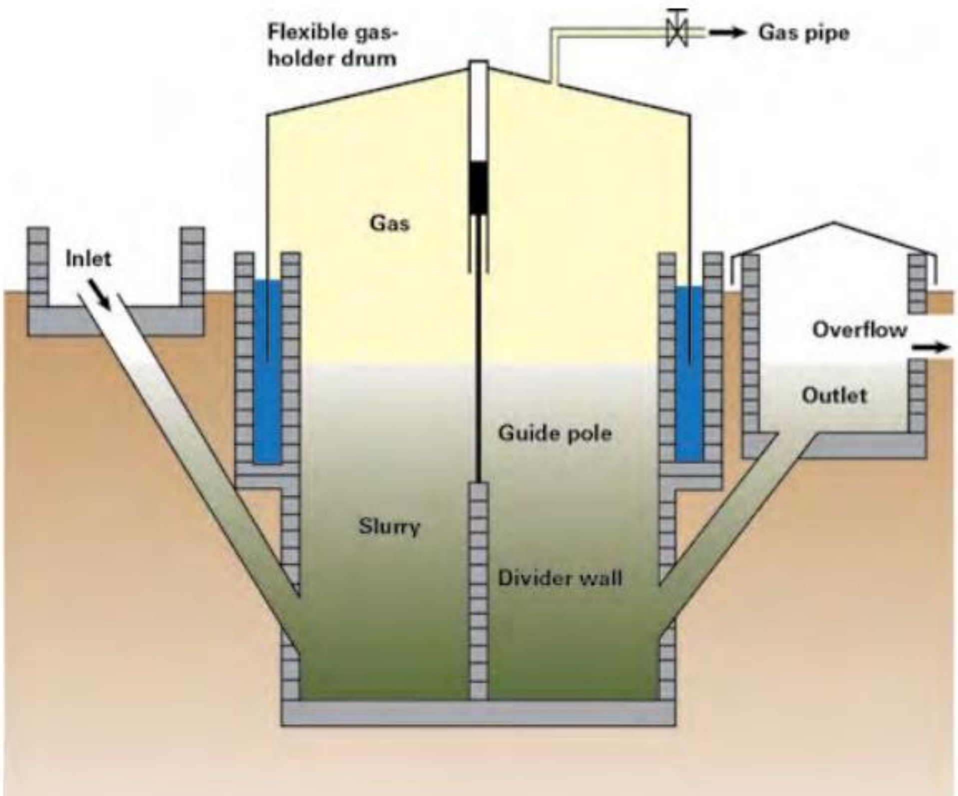


Figure 2.14 Scheme of floating-drum digester [10]

Advantages of floating-drum type digester

- Constant gas pressure
- Shows Cleary the quantity of gas collected

Disadvantages of floating-drum type digester

- Expensive
- Corrosion problems due to steel drum
- Requires regular maintenance due to moving parts

2.1.13.3 Tubular or Balloon Digester

It is made of three main parts as shown in Figure 2.15. The digester is a plastic or rubber bag with balloon shape and it acts as digester and gasholder in one. Both input feedstock and outlet of this digester are directly attached to the skin of the balloon. The pressure of produced gas can be increased by placing weights on the balloon but with much attention to avoid its damage, as it is plastic. shows a schematic representation of a typical tubular digester [10].

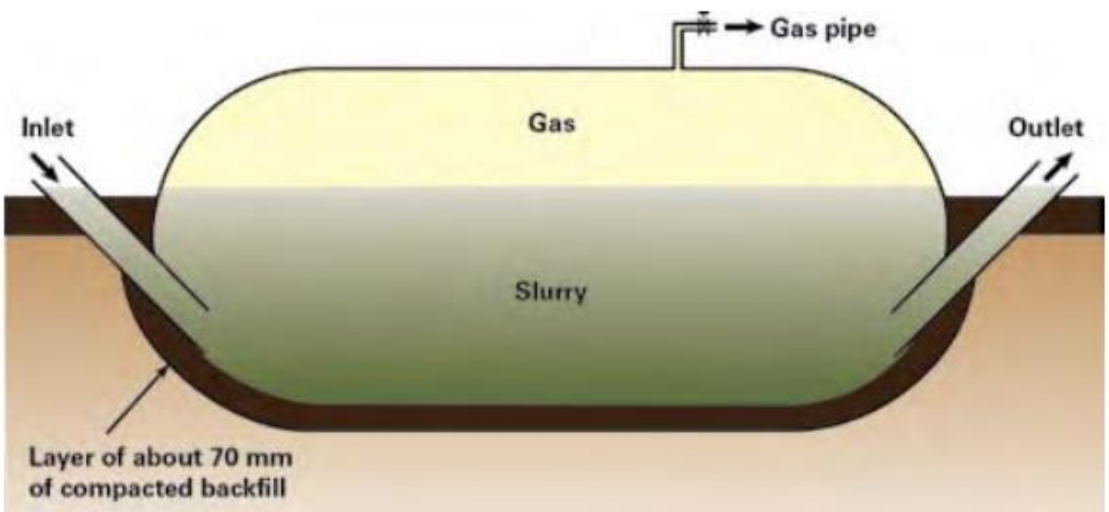


Figure 2.15 Scheme of balloon digester [10]

Advantages of tubular or balloon type digester

- Simple design
- Easy and quick to construct
- Transportable
- Inexpensive

Disadvantages of tubular or balloon type digester

- Variable gas pressure
- Difficult to clean
- Easily damaged
- Structurally unstable
- Short life span

2.2 Literature Review

Many research works have been carried out either in the use of renewable energy sources used alone or in hybrid system. Hybrid systems have been designed as either stand-alone or grid connected. Some of papers has been reviewed and their results are discussed below:

2.2.1 Literature Review on Single Energy Source Systems

Eunil Park, Sang Jib Kwon and Angel P. del Pobil in [14] paper proposed the potential configuration of renewable energy production facilities for Chiang Mai University in Thailand to utilize local renewable resources and to reduce the electricity dependency on the national grid connection and greenhouse gas emissions and based on the simulation results from HOMER software, the potential configuration organized by PV panels, batteries and converters was proposed. The chosen configuration was found to have 100% of the renewable fraction with $0.728 of the cost of energy but it shows high initial cost. However, if they could think of using hybrid system by combining solar system with another renewable energy resource like biomass, the cost of storage would have been minimized there by reducing the mentioned heavy initial capital costs.

Samuel Bimenyimana, et al. [2] used the HOMER software for modeling the optimal, sustainable, reliable, and affordable photovoltaic solar technologies as energy solutions for all (off-grid and on-grid users) in Rwanda. For off-grid users who have no access to electricity, photovoltaic solar technologies were modeled via the standalone solar system and solar minigrid technology solutions. The system completely used renewable energy technology (100%renewablefraction) with 4129% maximum renewable penetration, US$ 0.6155 LCOE (levelized cost of electricity, and zero hydrocarbon and greenhouse gas emissions [2]. Referring to the computational simulation and optimization results from the HOMER software, supplying electricity through solar-operated minigrid technologies have been found to be a better solution to increase electricity access to the population. Therefore, for the offgrid users, solar photovoltaic technology with storage was recommended but this system presented a high cost of energy compared to grid cost, unmet load and capacity shortage. For on-grid users who have access to the electricity from an unreliable grid characterized by frequent blackouts, either of the two hybrid grid-PV system technologies with or without storage was recommended because their LCOEs were below the normal tariffs of electricity in Rwanda [2]. However, if in both off grid and on grid cases they could combine solar energy with another renewable energy source like biomass the generation would have been increased there by increasing the electricity access to the population and minimizing the cost of production as the size of storage would have been minimized too.

W. Lamula et al. [15] presented a technical and economic feasibility study for designing cost-effective and sustainable biomass-based energy generation system for a South African farm and neighboring community in the Free State province. Different system configurations with or without energy storage were studied and compared with respect to their optimum system architecture, cost-effectiveness, energy security and emission levels using HOMER [15]. Option of standalone biomass-based generating system without energy storage system was found to be the most economically and technically feasible system configuration as it was found to have the total Net Present Cost of $27 503, Cost of Energy of $0.186 and it has excess of electricity of 31 kWh. This research has shown that having local biomass-based generating system has benefits such as reduced implementing & operational costs, reduced environmental emissions and independency from the centralized grid but because of this excess energy they conclude that the biomass-based generating system can be hybridized with other intermittent renewable energy resources. [15] South Africa has the best solar resources in the World, average daily solar radiation varies between 4.5 and 7 Kwh/m^2. [16] From this solar potential in South Africa the hybrid system based on solar and biomass energy resources can be a solution.

2.2.2 Literature Review on Hybrid Systems

The Paper [1] presented design optimization of hybrid renewable energy system based on solar and biomass energy resources. The optimization has been carried out using HOMER software to get the best and optimal operation system. The optimum sizing of the Hybrid Renewable Energy System (HRES) was determined based on optimization and sensitivity analysis in order to get the best combination or solution of the proposed development. The optimization of HRES considered components selected, its sizing and operational strategy to provide the reliable and efficient system. The excess energy generated by the HRES was also evaluated. It considered on minimizing the excess energy of the HRES. Data of solar radiation and biomass resources was analyzed and simulated in HOMER to assess the proposed HRES. The results obtained from simulation of the proposed HRES consist of solar and biomass energy resources show that the system can meet the IPPH, UPM's load demand. The cost of energy (COE) was found to be only $0.214/kWh with the excess electricity only 46.4 kWh/year[1]. The result shows that the hybrid renewable energy system (HRES) has low for electricity generation and recommended the IPPH, UPM to apply their result for designing the HRES for their own use to supply the electrical load.

The Author in paper [17] presented and simulated a hybrid biomass-solar renewable energy for rural settlements in Nigeria for Unwana community as a case study. Homer software was used to identify the optimum HRES, which will satisfy the electrical energy, needed for the selected study location. The results show that the system was feasible to meet the electricity demands of the study location using this designed system given the available biomass and solar resources. The most economic configuration of the plant was found to have 93.7% of the total electricity produced from biomass (sum of the 43.8% and the 49.9% produced by the 10kW and 20kW biogas generators respectively) and the remaining 6.3% derived from solar. However, Further studies is required be conducted to compare the economics between generating with this renewable energy system and conventional means of generation using grid extension in order to determine whether the system is cost effective as feasibility accounts for cost too.

The Author in paper [18] described the design of a hybrid electric power generation system utilizing both solar and biogas biomass energy for supplying remote areas of Bangladesh. Basic Electric load requirements of the rural areas such lighting, fan, a television and a refrigerator was suggested. Simulations and design was performed using the HOMER tool for optimization. The deployment of renewable energy resources has been proposed in order to solve the energy crisis issues in Bangladesh as it was experiencing an acute shortage of electric power .The work started by assessing solar and bio energy potentials of the desired site, compiling data from different sources and analyzing it using Homer software. The proposed hybrid system was designed for both on grid and off grid operation to reduce dependency on the national grid for electrical supply and the system consists of PV generators, biogas, biomass, battery bank, battery charge controller and the dump load [18].The results shows that the system was an excellent, cost effective and also a reliable solution to mitigate the existing power crisis but didn't show the electrical properties of the system like unmet load percentage, capacity shortage, excess electricity and contribution of each system to meet the load.

In paper [19], entitled "Micropower optimization model" a renewable energy-based micro grid system based on solar-biomass hybrid system has been designed for the electrification of the city of Sharjah. The micro grid hybrid system was designed based on solar PV and biogas generators integrated with batteries and converters to meet the desired electric loads of Sharjah city. Simulations, optimization, and economic analysis were performed to test the performance and the cost of the proposed hybrid micro grid system. The results show that the solar-biomass hybrid system can provide up to 14% of the total yearly electrical demand in the city of Sharjah where the percentage shared by PV panel was 74% and 26% by the biogas generator. Biomass resources input has increased the cost of system as they needed to be transported from rural area to town and the cost of supply of the proposed renewable energy based electricity (0.328 $/kWh) was not cost effective and was less attractive to the users [19]. If they could choose the available resources, which are close to the selected site, the cost of the system would have been minimized. Therefore, energy resources availability needed to be well explored (like by including the fecal matter from urban people) to increase the penetration of renewables in the energy mix and for reducing the cost of power generation from renewable energy systems.

CHAPTER 3

3. DATA COLLECTION AND ANALYSIS

3.1 Data collection

3.1.1 Primary Data Collection

Primary data are those data that researchers collect directly from the main sources and happen to be original in character. These data have a big impact on the outcome of the results therefore; care must be taken when collecting them. There are several methods of collecting primary data and main ones are Observation method, Interview method and Questionnaire.

The data has been collected in the campus of the College of Science and Technology, University of Rwanda. The primary data for this study include different kind of electrical loads and their usage time, the total connected load of the college, numbers of transformers which supply the college and their ratings, number of standby generators and type of fuel input to these generators, monthly energy cost of electricity and total number of students, staffs and casual workers in the College.

3.1.2 Secondary data

Secondary data are the information that have been collected in the past through primary sources and made them available for researchers to be used in their own research.

Secondary data for this study include solar radiation, biomass quantity generated per day from human excreta and cost of different equipment used in Hybrid system. These data have been found through some literatures and different websites.

3.2 Resource Assessment

Hybrid power plant, which uses renewable energy sources, requires evaluation and estimation of available renewable energy resources in the selected area. Solar and Biomass resources have been assessed more in details and below are the results found for each of renewable energy resource.

Global Horizontal solar radiation, clearness index and Temperature monthly averaged values over 22 year's period was found from NASA website. Biomass quantity generated from Human excreta was obtained from published papers.

3.2.1 Biomass Resource Potential

The waste converted into biogas is not only the waste from nature such as agricultural waste, food waste, or cattle manure; but can also be human waste also known as human excreta. The utilization of human waste for biogas production is important both in the terms of process and environment. It is also used in energy production there by reducing environmental problems caused by uncontrolled human waste disposal [12].

The biomass input to Solar-Biomass system is in form of Human Excreta from students, staffs and other casual workers. Studies and research show that human feces is the raw material with the high potential both in terms of quality and quantity in the production of biogas [21]. Literature states also that the biogas from human feces has the highest percentage of methane around 67.6% [21]. Table 3.1 shows the comparison of biogas production and percentage of Methane for different feedstock.

Table 3.1 The comparison of biogas production and percentage of Methane [21].

Feedstock	Biogas production (m^3/kg-VS)	CH_4 Content (%)
Pig slurry	0.50	61
Cow slurry	0.30	55
Chicken slurry	0.60	60
Broiler chicken waste[16]	0.57	56
Human faces	0.59	67.6

The most important component of biogas from the calorific point of view is methaneCH4 [22]. The high portion of methane content in biogas (above 45%) makes biogas more flammable. Therefore, the high portion of methane in biogas implies higher energy generated from biogas [10]. Therefore, from these data, it is shown that Human feces is the best biomass input for electricity generation from Biogas.

To know the quantity of biogas generated from the college, firstly the total quantity of biomass generated per day was calculated. This quantity of biomass is then used as an input in HOMER to find the amount of biogas produced per day.

Researchers indicated that an average adult can be expected to produce 1-1.3kg of urine and 0.2-0.4kg of feces per day [13]. From [13] data, if we assume that one person is expected to produce 1.2 kg of urine and 0.3 kg of feces per day and having the total number of people in the campus equivalent to 7000, the total quantity of biomass can be calculated.

Total quantity of urine: 7000 x 1.2 kg = 8400 kg

Total quantity of feces: 7000x 0.3 kg = 2100 kg

The total quantity of biomass produced daily is 10500 kg but as Homer accepts input in tons per day, the maximum quantity of biomass generated is converted to 10.5 ton/day. The quantity of biomass produced daily is not constant for all months as the College does close for students' holiday and this lead to a decrease in quantity of biomass produced monthly which is the reason why we have to make a hybrid system of solar and biomass so that solar will complement the biomass system in case of low generation from biomass energy system. Table 3.2 shows the quantity of biomass generated per day in each month.

The maximum quantity is expected from September up to end of November, as in December around 8% of students use to go home for Christmas celebration then back in January. Again, in April around 12% of students get a short break for Memorial week events. From June up to end of August, there is a great reduction in biomass quantity since there is a holiday for all students but the quantity doesn't get to zero because staffs and some casual workers still remain in the campus. This data is used as an input in HOMER for biogas quantity calculation and biogas generator selection. Table shows the daily quantity of Biomass produced daily in UR-CST.

Table 3.2 Monthly average biomass data for UR-CST.

Month	Available Biomass (tones/day)
January	9.5
February	10.5
March	10.5
April	9
May	10.5
June	5
July	3
August	3
September	10.5
October	10.5
November	10.5
December	9.5
Average	8.5

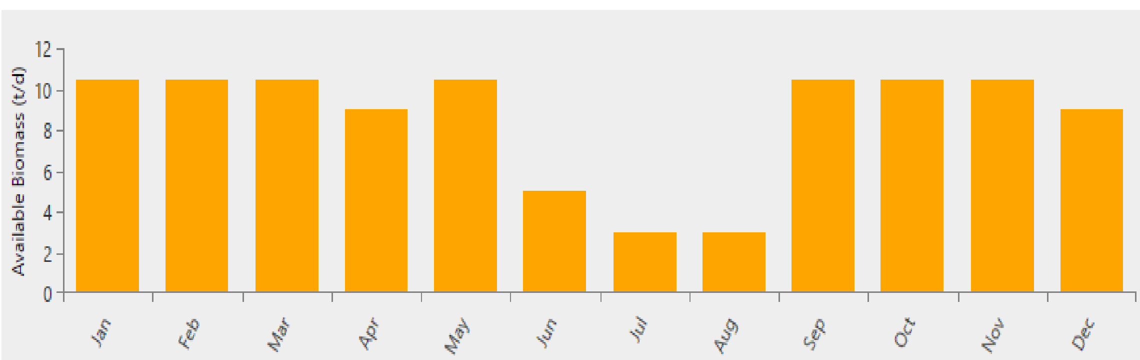


Figure 3.1 Chart of Monthly average biomass data for CST

3.2.2 Solar Resource Potential

When carrying out the design of solar PV system, it is very important to determine insolation (solar radiations) of the specific location in which the system will be installed. 22 years' monthly average solar radiation and clearness index of the college are obtained from NASA metrology at Latitude of 1.5^{o} and Longitude of 30.5^{o} where solar radiations monthly values vary from 4.54 in November to 5.22 in February with an average of 4.88 kw/m^2/day. Because of these variations in solar radiation, the energy generated from solar will vary also from January to December and therefore the biomass energy will support the energy generation during this time. The average solar radiation, clearness index and temperature data of the campus for 22 years is shown in Table3.3 as well as their pictorial representation.

Table 3.3 Solar radiation, clearness index and temperature for CST from Homer

Month	Clearness index	Temperature (^{o}c)	Daily radiation (kwh/m^2/day)
January	0.480	19.850	4.930
February	0.496	20.680	5.220
March	0.473	20.180	4.970
April	0.479	19.720	4.830
May	0.498	20.620	4.710
June	0.532	21.130	4.830
July	0.556	21.260	5.140
August	0.519	22.040	5.090
September	0.491	21.680	5.070
October	0.448	19.960	4.680
November	0.442	19.200	4.540
December	0.451	19.260	4.570
Annual Average		**20.47**	**4.88**

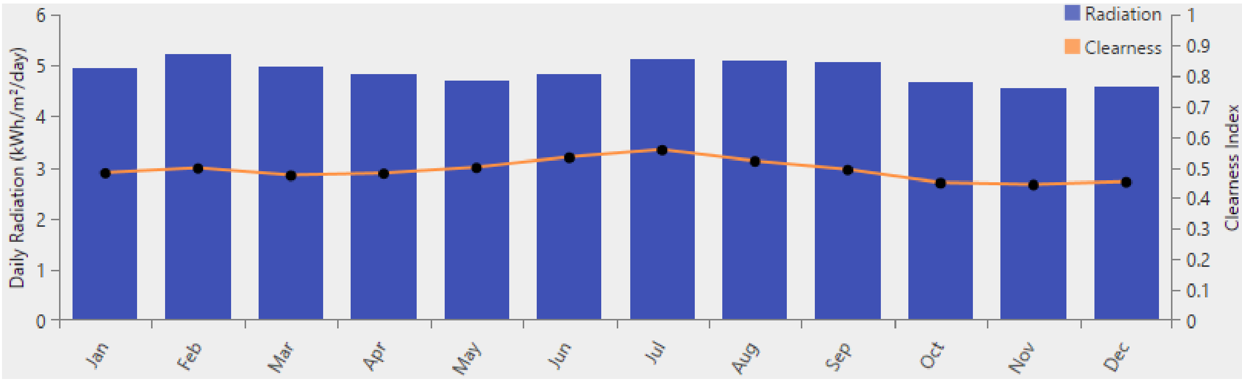


Figure 3.2 Chart of Solar radiation, clearness index for UR-CST from Homer tool

Clearness index (CI) shows the portion of solar radiation from the sun which reaches in a given area of the earth. CI varies from around 0.8 during sunny days to near zero during cloudy days [20]. Clearness index (CI) varies from 0.442 in November to 0.556 in July in the college.

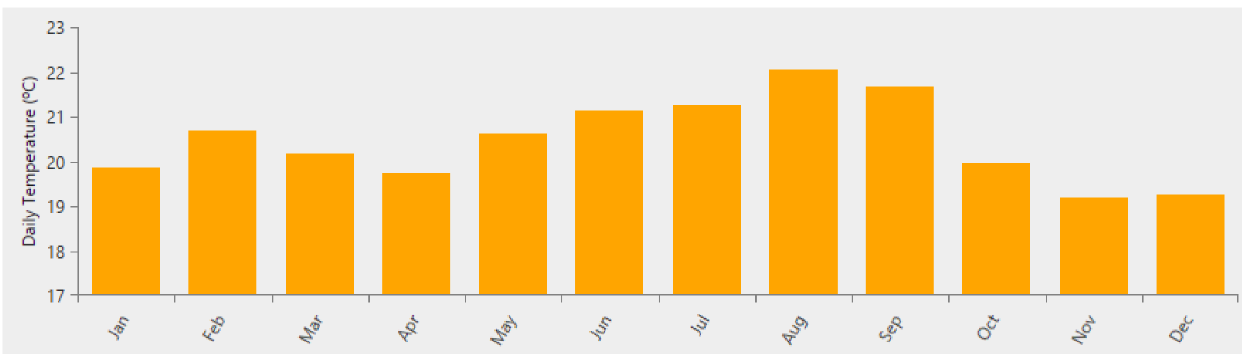


Figure 3.3 Chart of Temperature for UR-CST from Homer tool

Solar irradiance and temperature have been analyzed because they have a big impact on the power generated by solar PV as discussed in chapter 2.

3.3 Load Estimation and forecasting for UR CST

College of science and Technology is currently supplied by National grid. It has 3 transformers with 650 KVA, 650 KVA, 800 KVA ratings respectively. The main electrical loads of the college are the following: Electrical lights (Projectors and Fluorescent lamps), electrical motors for pumping systems, computers, projectors, workshops, computer laboratories and air conditioners. The total connected load for the college is 1200 kW. It has also 2 standby diesel fired generators with 500 kVA rating used for back up purpose.

The monthly electricity cost paid to the National Grid by the college is between 3 500 000 Rwf (when students are in holiday) and 17 000 000 Rwf when all students are in the college. The cost of Electricity as shown on Rwanda Energy Group Website is 255 Rwf/ kWh. Having the electricity cost per month for the college and the cost for one unit of electricity, the quantity of daily, monthly and annually electricity consumption was calculated. During load estimation, the nature of load has been thoroughly analyzed to come up with amicable energy forecast over the season.

- **Load calculation and forecasting**

Based on monthly electricity cost and the cost for one unit of electricity from electricity tariff in Rwanda, the daily energy demand was estimated and was found to be 1747 kWh but to meet the future load demand, 5% of load growth for the college was used to forecast the load demand for 5 years based on the formula given below:

Future value = present value of energy$(\mathbf{1} + \% \ \mathbf{growth})^n$**,** where n is the number of years. The present value is 1747 kWh, percentage growth is 5% and n = 5 years.

Therefore, the energy demand for the campus after 5 years is given by $1747(1+0.05)^5$ =2229.66 kWh which is rounded to **2230 kWh.**

For designing an electricity generation system, one has to design based on the peak load in order to meet the load requirement there by achieving system reliability. Therefore, Homer was used to estimate the peak demand for the college by considering random variabilities. Homer tool estimates the annual average load, the peak load and the load factor depending on the values inserted during each hour of the day [5]. To get a more realistic load profile in HOMER, adjustment with random variabilities is performed [20].The selected day-to-day and time step variabilities are 10 % and 15 % respectively.

The peak demand for the college was then found to be **313.18 kW** with a load factor of 0.3. This scaled peak load demand includes the random variabilities (day-to-day and time step) and operating reserve for load growth.

Metric	Baseline	Scaled
Average (kWh/day)	2,112.1	2,230
Average(kW)	88.01	92.92
Peak (kW)	296.64	313.18
Load factor	.3	.3

Time Step Size: **60** minutes

Random Variability

Day-to-day (%):	10
Timestep (%):	15

Figure 3.4 Scaled peak load for CST in HOMER tool

The baseline column shows the real load values without any added variables but the scaled column values include the random variabilities.

The load profile for the College was estimated in Homer and the chart representing the load variation of the campus is shown in Figure 3.5 shown below:

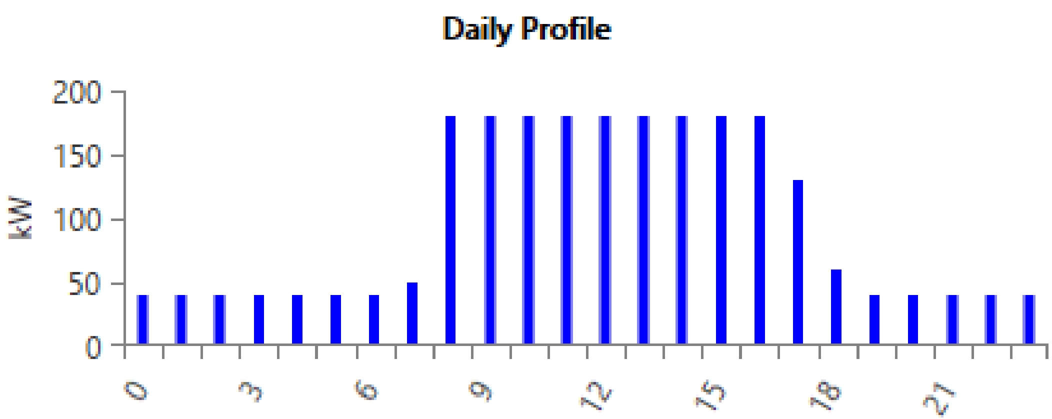


Figure 3.5 Daily load profile for CST from Homer tool

From 0.00 - 5.00 A.M., the load is low, because only the public lights are on for security purpose and almost all people are sleeping.

From 6.00 -7.00 A.M., the load increases a bit, as students use lamps, connecting some kettles and others ironing their clothes.

From 8.00 A.M. the load start to increase to the maximum up to 5 p.m. as computers, air conditioners, projectors are connected and some lamps in offices are on.

From 6.00 - 11.00 P.M. then the load decreases as air conditioners and projectors, office lamps get off and computer labs are closed.

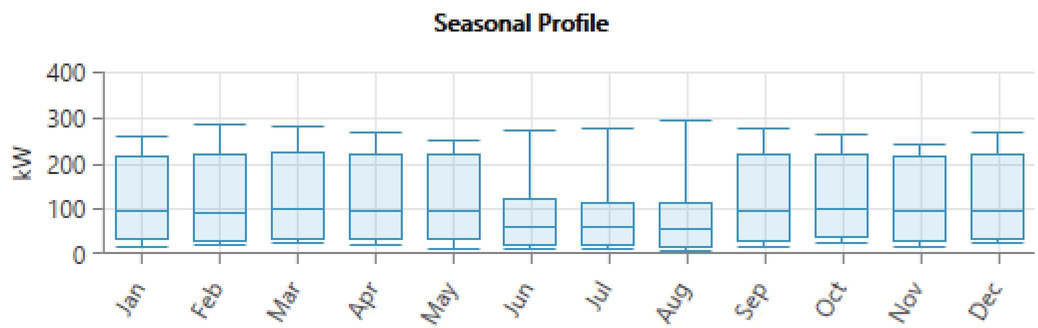


Figure 3.6 Seasonal load profile for CST from Homer tool

As stated above, the load demand is low from June to August as the college close up for student holiday. However, the demand does not reach to zero as staffs still use to come at work and some other casual workers remain in the campus and use electricity in different activities like computer and phones charging.

CHAPTER 4

4. DESIGN AND OPTIMIZATION OF HYBRID SYSTEM

Once all inputs have been gathered together, the next step is the design and optimization of the Hybrid Power Plant. The Design and Optimization has been performed using HOMER Software.

4.1 Hybrid Power Plant Design and Optimization

The design aims at selecting appropriate power generating and storage components that will use the available solar and biomass resources to satisfy the load demand of the college of science and technology. The design of Solar-Biomass Hybrid Power Plant was done using HOMER tool.

4.1.1 Overview on HOMER Software

HOMER is an abbreviation of Hybrid Optimization of Multiple Energy. HOMER is the main tool used in this research work for carrying out simulation and optimization process of the hybrid system. HOMER is very useful in carrying out various technologies including PV, boilers, wind, hydro, biomass, fuel cells, and loads which may be AC/DC, thermal and hydrogen where it is carries out optimization and decide the feasible system configuration [5]**.**

The performance of HOMER is a bit robust and is carried out in **three stages** to generate a clear analysis of the system as well as technical and financial details of design selections. **The three stages carried out in Homer are simulation, optimization, and sensitivity analysis** [5]**.**

During **simulation process,** the hourly working operation of a given power system configuration is modeled yearly to determine its technical feasibility and life-cycle cost [18].

During **optimization** process, it carries out different configurations for finding out the optimum one i.e. the configuration, which meet the load requirements at minimum cost. Homer performs optimization by using different quantities and sizes of system components [20].

During **sensitivity analysis process**, HOMER carries out many optimizations buy consideration a range of assumptions due to uncertainty or changes in inputs parameters like fuel prices, component efficiency etc. [20].

Input data of daily load values for different hours are inputted in Homer and then Homer extrapolates the load profile for the year [5]. To make the load more realistic the random variabilities are added to inputted load values to account for day-to-day load change. In fact, Homer is more attractive when carrying out evaluation of many system components and resource options on different number of constraints with much effectiveness and high efficiency[5].

These above explanations about HOMER Software working principle are the main reasons why Homer was used in different research works for system design and optimization since it easy to get an optimum system configuration which meet the load requirement at least cost of energy.

4.1.2 Hybrid Power Plant System Technological Configuration

The Hybrid Power Plant components supply both DC and AC Electrical energies. Solar PV Panel and Storage battery generate DC Power. By using the combination of these components with a converter, AC energy can be obtained and supplied to the different College's loads. The converter can be used alternatively or in parallel with the Biogas generator. The HPPS is therefore designed in HOMER using both AC and DC bus couplers hybrid system configuration as shown in Figure 4.1 below:

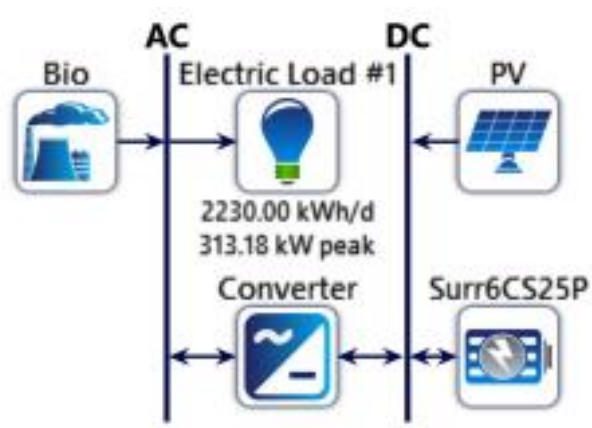


Figure 4.1 Solar-Biomass Hybrid System Configuration

4.1.3 Input Data to Homer Software

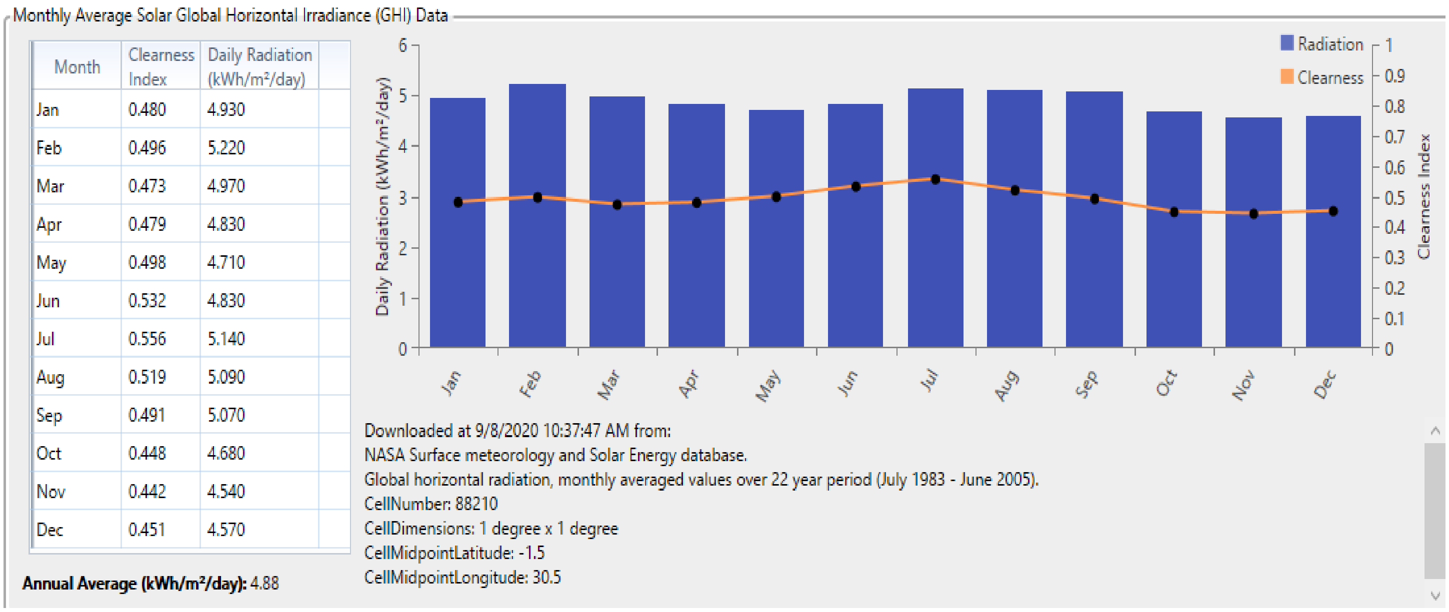
Input data are the required for Homer to carry out design and optimization. Therefore, the input data used in Homer during design of Solar-Biomass Hybrid Power Plant are given below:

Resources: A resource in Homer terms means any external inputted parameter that can be used by a component to generate electricity or heat [5]. In this thesis development, the solar radiation and biomass have been taken as the main energy resources required for optimum performance of selected Hybrid power plant configuration. Solar resource depends strongly on geographical location (Longitude and Latitude) and climate while biomass resource depends on local biological productivity. Therefore, Solar and Biomass resources have been inputted and analyzed in Homer tool.

Load: The electrical load for the College needs to be supplied by the Hybrid system without any unmet load. The input data for load was inputted in homer to estimate the daily, monthly and yearly load profile.

Components: The data including technical specification, quantity and cost of components have been inputted in Homer. The components used include PV solar panels, batteries for storage, power converter, and biogas generator. The design aimed at selecting appropriate power generating and storage components that will utilize the available solar and biomass resources to meet the load demand [17]. The input data for Resources, Load and Components are described below:

Resource inputs

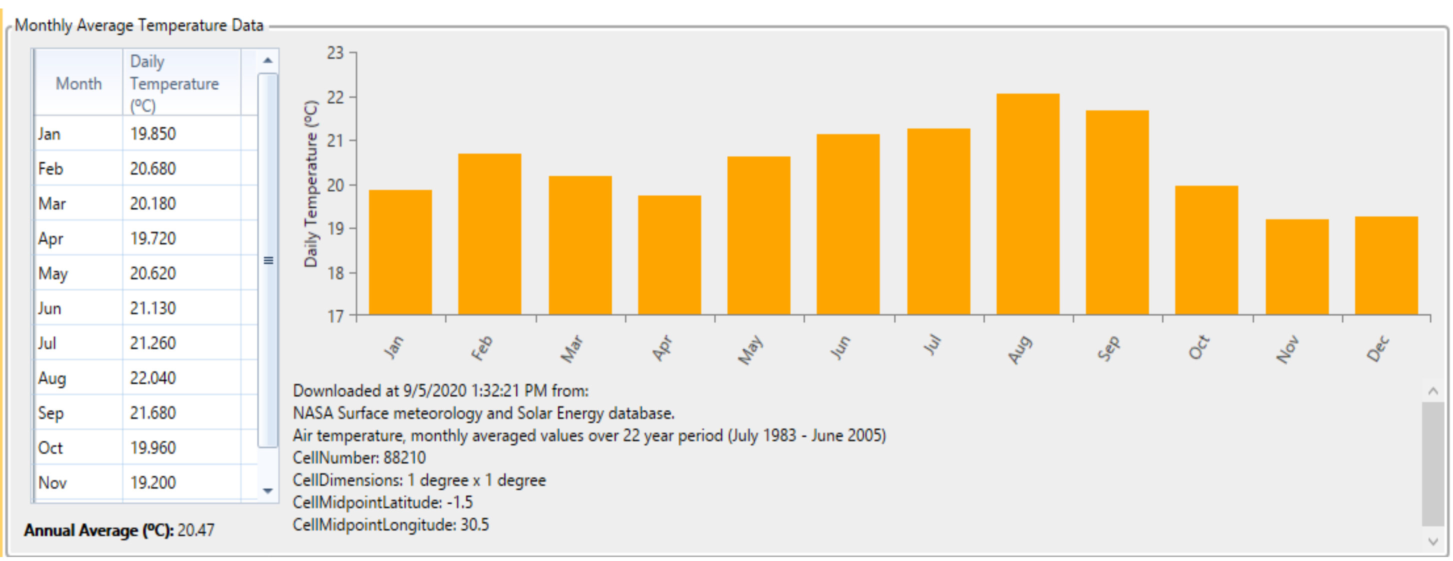

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.480	4.930
Feb	0.496	5.220
Mar	0.473	4.970
Apr	0.479	4.830
May	0.498	4.710
Jun	0.532	4.830
Jul	0.556	5.140
Aug	0.519	5.090
Sep	0.491	5.070
Oct	0.448	4.680
Nov	0.442	4.540
Dec	0.451	4.570

Annual Average (kWh/m²/day): 4.88

Downloaded at 9/8/2020 10:37:47 AM from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 88210
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: -1.5
CellMidpointLongitude: 30.5

Figure 4.2 Homer input window for solar resource


Monthly Average Temperature Data

Month	Daily Temperature (ºC)
Jan	19.850
Feb	20.680
Mar	20.180
Apr	19.720
May	20.620
Jun	21.130
Jul	21.260
Aug	22.040
Sep	21.680
Oct	19.960
Nov	19.200

Annual Average (ºC): 20.47

Downloaded at 9/5/2020 1:32:21 PM from:
NASA Surface meteorology and Solar Energy database.
Air temperature, monthly averaged values over 22 year period (July 1983 - June 2005)
CellNumber: 88210
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: -1.5
CellMidpointLongitude: 30.5

Figure 4.3 Homer input window temperature

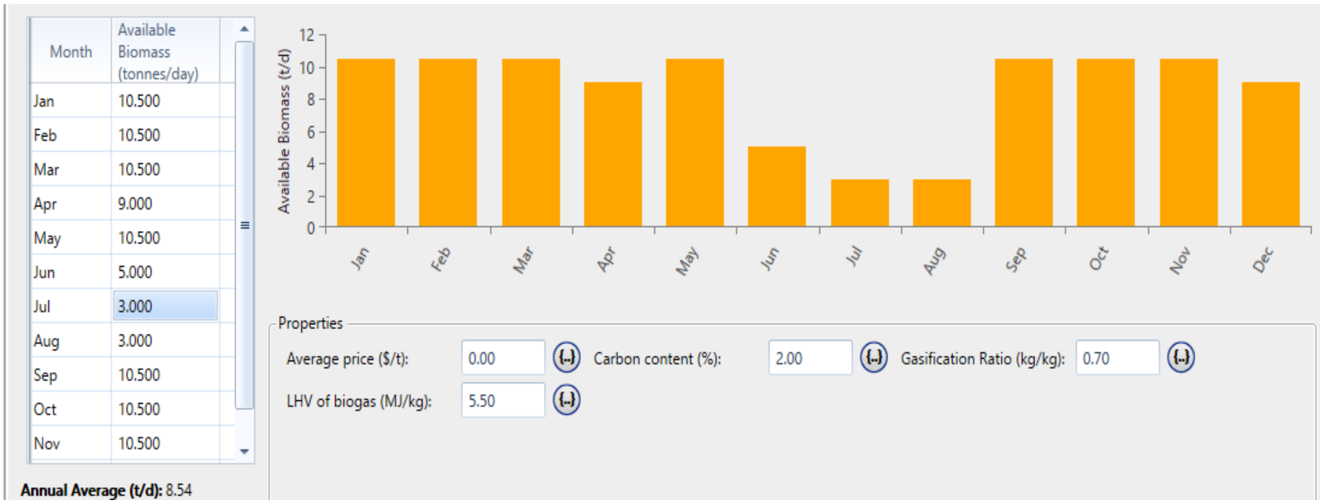


Figure 4.4 Homer input window biomass resource

Load inputs

The daily and monthly energy consumption was estimated depending on monthly electricity cost and the unit cost of energy from REG. Therefore, the values obtained have been inputted in homer to estimate the energy required for College of Science and Technology. Random variabilities are included in estimation of load demand for the college for having a more realistic electrical load profile. The electrical load profile estimated for CST in Homer is shown in Figure 4.5.

Figure 4.5 Homer input window for primary load profile for CST

2112.1 kWh gives the baseline energy values for the electrical load/ day while scaled energy values which include random variabilities is given by 2230 kWh/day. Baseline load values don't consider random variabilities [20].The baseline annual peak demand is 296.64 kW which increases to 313.18 kW by employing the random variabilities.

Component inputs

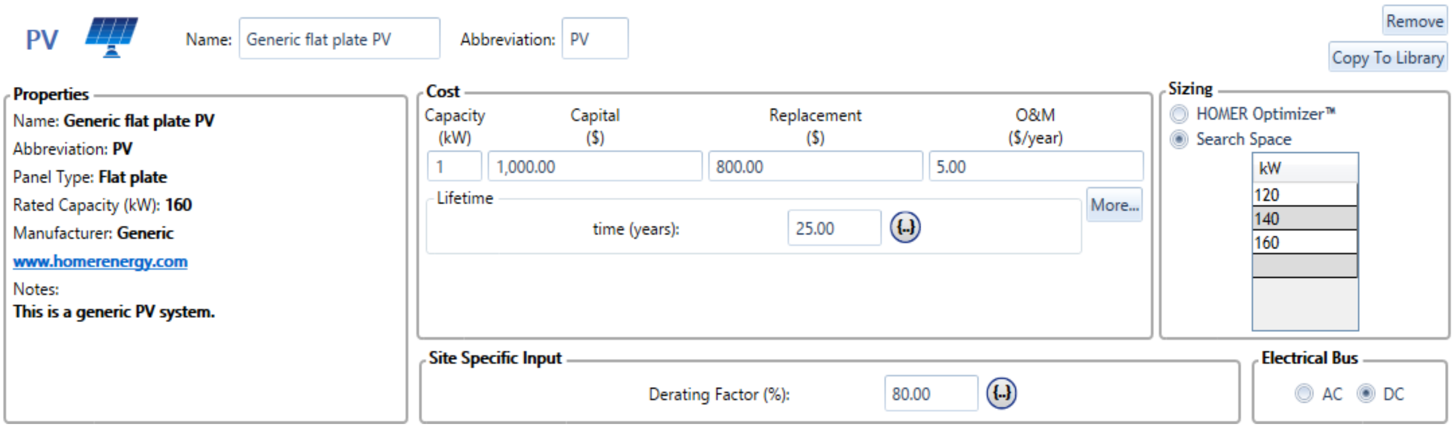


Figure 4.6 Homer input window for Solar PV

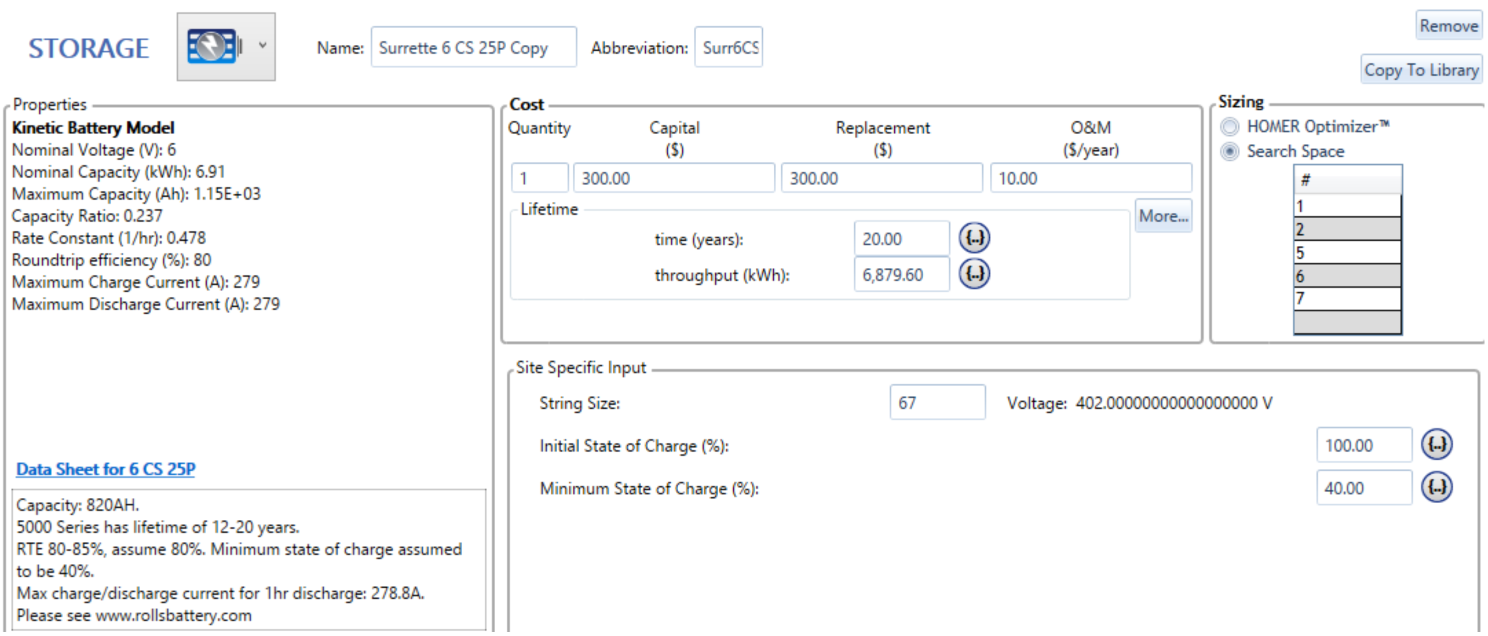


Figure 4.7 Homer input window for Storage Battery

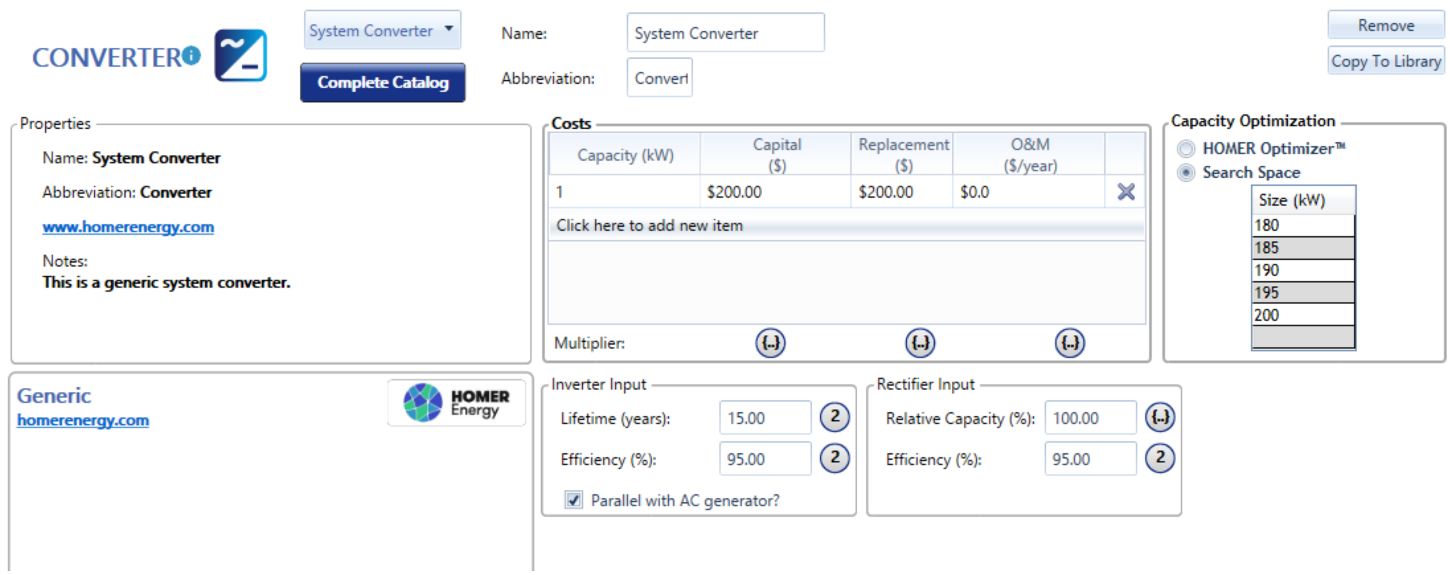


Figure 4.8 Homer input window for converter

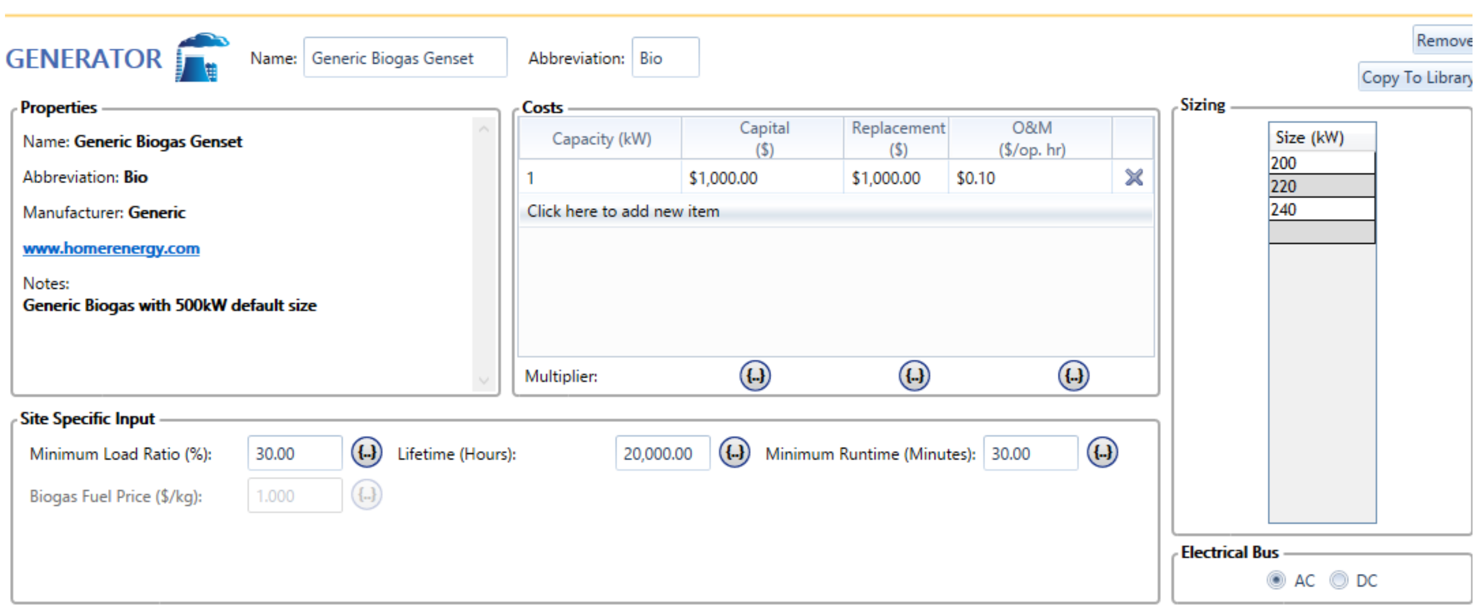


Figure 4.9 Homer input window for Biogas Generator

4.1.4 Simulation Options

HOMER software used in modelling of different Hybrid systems performs simulations based on configuration arrangement of selected components to determine the optimum size and performance of a system. The optimum System is determined based on optimization and sensitivity analyses [1].Different simulation options are described below:

- **Search space**

Optimum variables are chosen in HOMER and inserted in search space worksheet. In search space, optimization is carried out through variation of capacity and number of the different system components [20].Therefore, in each component's Homer input window search space is provided for optimization purpose i.e. one may give different sizes and number of equipment for Homer to carry out the optimization there by selecting the optimum system

- **Sensitivity Variables**

Different number of optimizations is carried out by considering different input assumptions. A sensitivity analysis shows how selected optimum system configuration is likely to change due to variation in input parameters like fuel prices, components efficient,… [20]. In this study, the main sensitivity variables used during Homer optimization are:

Varying input of **nominal discount rate:** 3%, 6%, 9%, 12% have been inputted in Homer. In addition, varying **Converter efficiency** from **90**% to 95% has been carried out in Homer.

- **Dispatch Strategy**

Systems, which include a battery storage and generator, require a dispatch strategy, which means set of regulations governing how the battery will be charged by the system. There are two dispatch strategies carried out by Homer, which are Load-following (LF) strategy and Cycle-charging (CC) strategy. During Load- Following strategy, only the generator (Biogas generator in this study) supply the primary load while other renewable power sources like solar charges the batteries. Under Charging-Circle strategy, the generator may charge the battery too in case its generation is than required to serve the load [20]. In this system, Homer Cycle Charging dispatch strategy is used to mean both solar and biogas generator will supply the load for the college.

- **Economics**

During evaluation of economic viability for a given Hybrid system, analysis of cost of energy for each optimum system is carried out. Renewable energy systems are associated with high initial cost but low Operation and Maintenance cost within a given system lifetime. By comparing with fuel-based energy, these systems are associated with low capital cost but high Operation and Maintenance costs. Therefore, LCOE for a given system is used to make comparison of various energy system configurations in order to select the most the economic Hybrid system. The optimization of the system using Homer is therefore performed based on Levelized Cost of Energy (LCOE) analysis whereby system with least cost is considered to be the optimum one [20].

- **Net Present Cost**

Net present cost of a given system is calculated by taking the present value of all costs required by the system over its lifetime subtracting the present value of all the revenue gained over its lifetime. Following costs are considered and include: capital, replacement, operation and maintenance and fuel costs [20].

- **Levelized Cost of Energy**

HOMER software calculates the Cost of Energy (COE) which represents the mean cost per kWh of electrical energy generated by the system [20]. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total electric load served using the following equation:

$$LCOE = \frac{Cann,tot - Cboiler\ Hserved}{Eserved} \quad (4.8)$$

Where:

$Cann, tot$ = total annualized cost of the system [$/kWh]

$Cboiler$ = boiler marginal cost [$/kWh]

$Hserved$ = total thermal load served [kWh/yr]

Because there is no thermal load considered in the designed system, $CboilerHserved$ is ignored and can be equalized to zero. Therefore, the final equation for LCOE is calculated using equation 4.9 given below:

$$LCOE = \frac{Cann,tot}{Eserved} \quad (4.9)$$

The total annualized cost of the system **abbreviated as Cann, tot include the total cost of all equipment used in Hybrid system including solar PV, battery, converter, biogas generator costs required to meet the electrical load requirements.**

4.2 Sizing of Hybrid Renewable Energy System Components

As per simulation results shown in HOMER, for the Hybrid power plant to operate at optimum (to meet the estimation total load at minimum cost of CST) the PV system will contribute 25.5% of the total load demand while 74.5 % will be contributed by biogas power plant depending on solar and biomass sources availability in College of Science and Technology.

4.2.1 Sizing of Solar System Components

The solar system used in this study consists of Solar PV Panel, Battery and voltage Converter components. Solar PV Panel is used in the system to convert energy from the sun into electricity. The electrical load for the college is AC type and it requires a 3-phase energy supply system. Therefore, in this design, arrangement of solar modules and batteries is done based on required input voltage range for DC-AC voltage converter. The voltage level for a 3-phase AC system is 380 V, so a DC-AC converter with 400 V DC input and 380 V AC output voltage has been selected. Converter is connected to DC bus and therefore a DC bus voltage level of 400 V DC has been used in this system design. The sizing of Solar system components is shown in details below:

- **PV sizing**

Solar system is expected to cover 25.5 % of the total load.

The total energy electrical load energy required per day = 2230 kWh/ day.

25.5 % is covered by solar, i.e. (25.5 x 2230) /100 =568.65 kWh/ day.

Considering the PV derating factor (Which is a measuring factor expressing how the produced power from the solar PV array will be reduced due to dirt, snow or other foreign matter falling on the solar PV surface), the output energy required from PV system is given by:

E_{pv} = 568.65/0.8= 710.81 kWh/day.

Considering the minimum solar radiation denoted as G_{min} and standard operating irradiance, which is equal to 1000 W/m2 at optimum condition, the output power from solar PV panel, is calculated.

The power from PV system = (E_{pv}/ G_{min}) x 1000 W/m^2, Gmin = 4.540 kW/ m^2/day from solar data resource

P_{pv} = (710.81/ 4.54) x 1000 = 156.56 kW Round up next whole number, **P_{pv} = 160 kW**.

As mentioned in chapter 2, modules can be installed in parallel and series for increasing the total current and voltage of the system respectively. The selected module has 290 W, 8.99 A, 32.3 V rating peak power, current and voltage respectively.

Total number of modules denoted by N_m is given by equation 4.1 given below:

$$N_m = \frac{\text{PV array size (kW)}}{\text{Rating per module}} \quad (4.1)$$

As the maximum power for the selected module is 290 W, the total number of modules will then be given by:

$N_m = \frac{160}{290}$ = 551.7, Round up to next the whole number =552 modules.

Modules are connected in series to meet the system voltage level. Therefore, by using 400 V DC system voltage, the number of modules required per string to provide this voltage can be calculated using equation (4.2.) below:

$$N_s = \frac{\text{System voltage}}{\text{Module operating voltage}} \quad (4.2)$$

Hence, $N_s = \frac{400}{32.3}$ = 12.38, Round up to next the whole number = 12 modules.

Finally, the number of modules in parallel is given below as:

$$N_p = \frac{\text{Total number of modules}}{\text{Number of modules per string}} \quad (4.3)$$

Hence, $N_p = \frac{552}{12}$ = 46 modules.

Total number of modules is given by, N_P x N_s = 46x 12 = **552 modules.**

4.2.2 Sizing of Storage Battery

Battery is used in this system to store energy from solar panels, which will be used for supplying the load when the energy generation from solar panel becomes less than the required. The capacity and size of battery depends on the daily energy consumption (kWh/day) and the required days of autonomy. Days of autonomy are the number of days a battery system will supply a given load without being charged by a PV array, or another source. Maximum depth of discharge of the battery is another important factor to consider when carrying out the battery sizing; it represents the limit of energy, which will be discharged from the battery. Most systems have been designed for regular discharges of up to 40 to 80 percent [5].

In this study 6V, 820Ah Surette 6cs25p was selected and it has and 60 % allowable rate of discharge.

Batteries are connected in parallel and series to increase the total current and voltage of the system respectively and the calculations are shown below:

The storage capacity of battery denoted by C_{Ah} is given by equation (4.4)

$$C_{Ah} = \frac{E_{L*}AD}{\eta_{inv}*\eta_{batt}*V_n*DOD} \quad (4.4)$$

Where:

E_L: Daily energy demand = 568.65 kWh/ day

DA: Days of Autonomy = 2 days

η_{inv}: Inverter efficiency = 95 %

η_{batt}: Battery efficiency = 80%

V_n: System nominal voltage = 400 v

DOD: Depth of discharge = 60%

Replace each element by its value, $C_{Ah} = \frac{568.65*2}{0.95*0.8*0.4*0.6} = 6228.1$ Ah

Number of battery connected in parallel B_p is given by equation (4.5) as follow,

$$B_p = \frac{C_{Ah}}{B_c} \tag{4.5}$$

$B_p = \frac{6228.1}{820} = 7.59$ batteries but for optimum operation Homer chooses 7 batteries from search space input number of strings during optimization.

Number of battery connected in series B_s is given below as follow,

$B_s = \frac{400}{6} = 66.6$ but for optimum operation Homer chooses 67 batteries.

Total number of batteries is given by, B_p x B_s = 67 x 7 = **469 batteries,** by considering 2 days of Autonomy.

4.2.3 Converter

The need of converter for a hybrid system is to carry out the energy conversion between DC and AC electric power. A converter is an electronic power device, which has an inverter and a rectifier for the conversion of power from DC to AC and AC to DC respectively. Different factors like efficiency of the inverter, waveform requirement of the load, Grid connected or off grid system, affect the appropriate size of converter to be used in a given energy system. For a given PV system to operate at optimum condition the size of converter must be a bit greater than the capacity of the system as shown from equation 4.7 below [20]

$$R_S = \frac{P_{PV,\ rated\ (kW)}}{p_{inv},\ rated\ (kW)} \tag{4.6}$$

Where P_{pv} and P_{inv} present the rating of Solar PV and inverter input power, respectively. For optimum condition, sizing ratio (Rs) must be in between 0,8 and 1,8 [20].

Considering PV capacity of 160 kW, then Homer selects Converter size equivalent to **180 kW.** The specifications of selected converter are: Input DC voltage ranges from 220v to 400v, output AC voltage range varies from 220 V to 480 V and current ratings from 100 A to 1400A.

4.2.4 Biogas Fueled Engine or Biogas Generator

Biogas production is not constant during the day; it varies with change in inputs and ambient temperature. Therefore, biogas needs to be stored in gas holder and used for electricity generation when required [10].

The next step after biogas production is the combustion of biogas in biogas-fueled generator to generate electricity. The biogas generator is needed in case solar energy and the stored energy don't satisfy the energy required by different electrical loads [20].

As simulation results shown in Homer, the biogas generator will supply 74.5% of energy demand.

75.5 % of total energy demand = (74.5 * 2230)/100 = 1681.42 kWh/ day required from Biogas generator.

The average biomass produced per day from the college is estimated to 8500 kg/day, assuming 8% loss which represents unconverted biomass, the quantity of biomass which will be converted into biogas will be given by (8500 * 92)/100 = 7820 kg= 7.820 ton/day.

The gasification ratio of digester is 0.7, so the quantity biogas produced will be 7.820*0.7 = 5.48 ton/day.

The quantity of Biogas produced yearly is (5.48 * 365) = 2000 ton/yr.

From this quantity of biogas produced, a Biogas generator with 3451 hours of operation per year and 665371 kWh electrical production per year (i.e. 1823 kWh/ day) was selected to satisfy the load demand. The power rating of Biogas generator is (665371/ 3451) = 192.8 kW but for optimum operation Homer chooses **200 kW**. The details about selected Biogas generator are shown in simulation results.

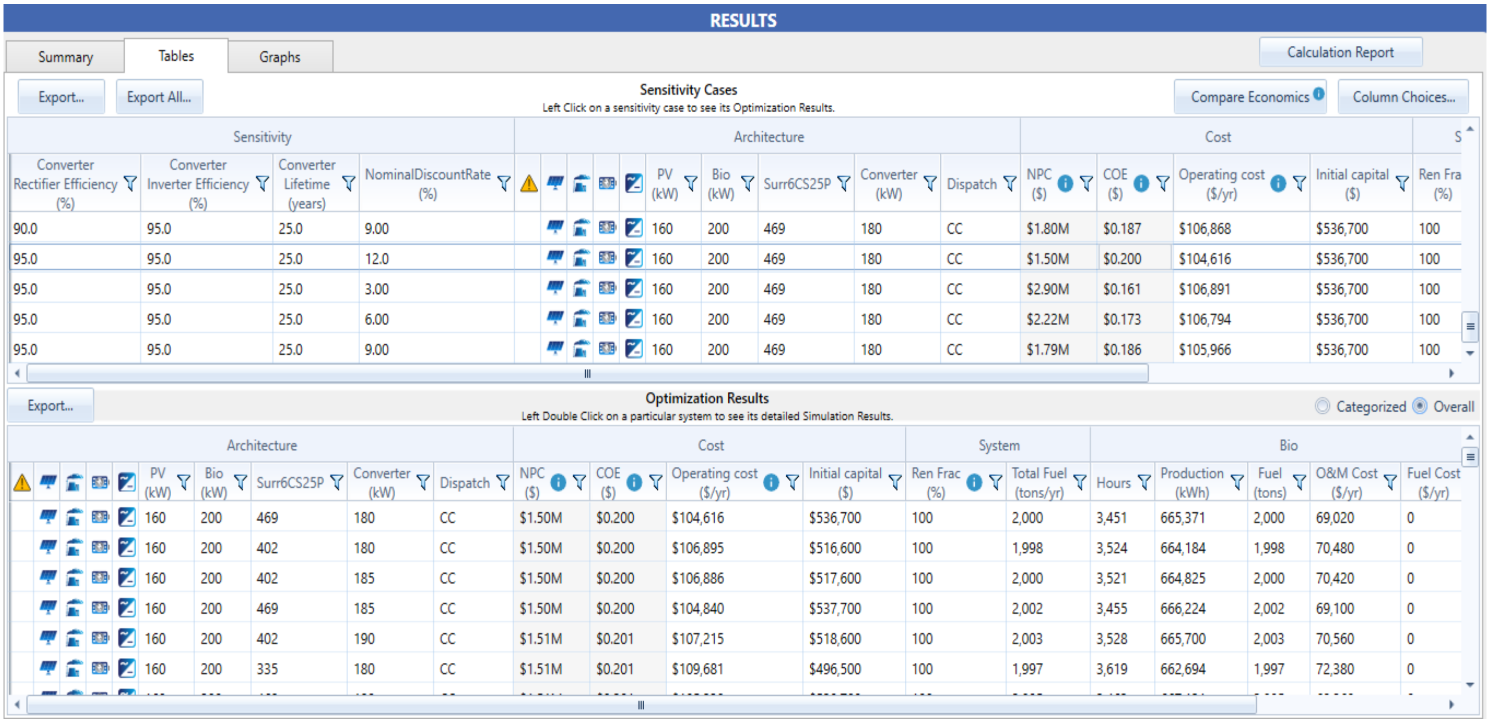
CHAPTER 5

5. SIMULATION RESULTS AND DISCUSSION

This part of thesis work discusses about the optimal simulation results for designed Solar-Biomass Hybrid Power Plant for College of Science and Technology using Homer software. The simulations were carried out in Homer based on input data entered in Homer which include solar and biomass resources, primary load and Hybrid system components specification like PV, Battery storage, Converter and Biogas generator. The design and optimization was carried out with the objective of finding the Hybrid Power Plant configuration which will meet the energy demand for College of Science and Technology at minimum possible cost (least cost of energy) using the available solar and biomass resources. Homer identifies the optimum solutions for different system configurations by varying variables that affect an output. The variables that have direct effect on the output result are: PV array size, quantity of batteries, system converter size etc. The optimum conditions depend mostly on how much will the system meet the load, quantity of electricity excess generated from the system, capacity shortage and the Levelized Cost of Energy. Therefore, an optimum system is the one, which meet the load at 100 %, without capacity shortage and with no or less electricity excess and at low cost of energy.

Different combinations of components have been carried out in Homer to find the optimum size for Hybrid Renewable energy system components. This was done by varying the capacity of solar PV and Biogas Generator, the size of converter and number of battery depending on available energy resources and load demand. Search space was used as discussed in chapter 4 to facilitate the evaluation of different sizes and quantity.

In the simulation, different feasible configurations of the system are given and arranged according to their net present cost, from the least to the highest. System configuration means how components are arranged in the system and quantity or size of components used. The result having the least net present cost is considered the most feasible [17]. Figure 5.2 shows the optimization results from Homer simulations. Different configurations were made by variating the number of Batteries, Solar PV capacity and Biogas generator sizes.



Sensitivity				Architecture					Cost				
Converter Rectifier Efficiency (%)	Converter Inverter Efficiency (%)	Converter Lifetime (years)	NominalDiscountRate (%)	PV (kW)	Bio (kW)	Surr6CS25P	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Fra (%)
90.0	95.0	25.0	9.00	160	200	469	180	CC	$1.80M	$0.187	$106,868	$536,700	100
95.0	95.0	25.0	12.0	160	200	469	180	CC	$1.50M	$0.200	$104,616	$536,700	100
95.0	95.0	25.0	3.00	160	200	469	180	CC	$2.90M	$0.161	$106,891	$536,700	100
95.0	95.0	25.0	6.00	160	200	469	180	CC	$2.22M	$0.173	$106,794	$536,700	100
95.0	95.0	25.0	9.00	160	200	469	180	CC	$1.79M	$0.186	$105,966	$536,700	100

Architecture					Cost				System		Bio				
PV (kW)	Bio (kW)	Surr6CS25P	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (tons/yr)	Hours	Production (kWh)	Fuel (tons)	O&M Cost ($/yr)	Fuel Cost ($/yr)
160	200	469	180	CC	$1.50M	$0.200	$104,616	$536,700	100	2,000	3,451	665,371	2,000	69,020	0
160	200	402	180	CC	$1.50M	$0.200	$106,895	$516,600	100	1,998	3,524	664,184	1,998	70,480	0
160	200	402	185	CC	$1.50M	$0.200	$106,886	$517,600	100	2,000	3,521	664,825	2,000	70,420	0
160	200	469	185	CC	$1.50M	$0.200	$104,840	$537,700	100	2,002	3,455	666,224	2,002	69,100	0
160	200	402	190	CC	$1.51M	$0.201	$107,215	$518,600	100	2,003	3,528	665,700	2,003	70,560	0
160	200	335	180	CC	$1.51M	$0.201	$109,681	$496,500	100	1,997	3,619	662,694	1,997	72,380	0

Figure 5.1 Overall Optimization Results

From Figure 5.1 the overall feasible solutions, the best cost effective system is the one, which has the lowest total net present cost as discussed in chapter 4. Therefore, 160 kW photovoltaic array, 200 kW Biogas generator, 469 Surrette 6CS25P batteries and 180 kW converter system configurations was selected because it meets the load at minimum life cycle cost.

Figure 5.2 and Figure 5.3 shows details about cost summary for the system configuration of the study village and yearly cash flow summaries by component cost type.

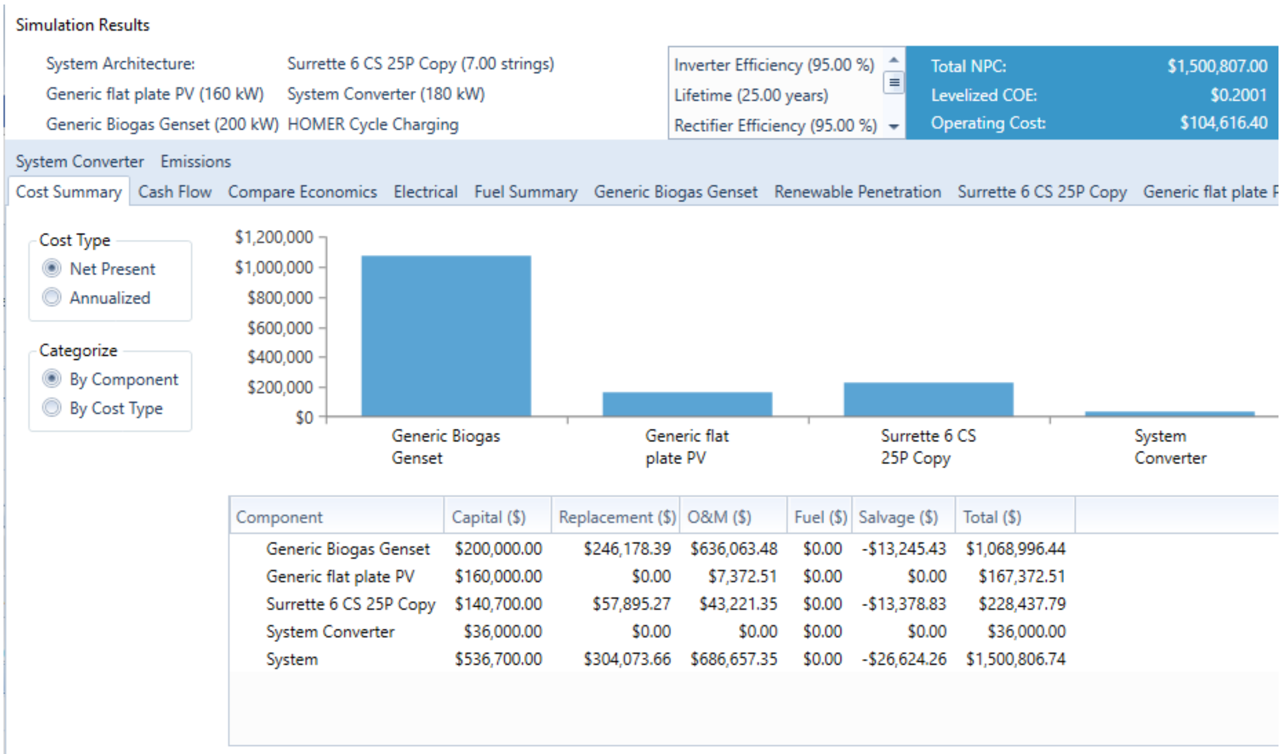


Figure 5.2 Cost summary of selected hybrid system for CST

From the cost summary results, Generic biogas Genset has high cost compared to other system components (Generic flat plate PV, Battery bank and system Converter) and this is because biogas generator will contribute high portion of energy demand.

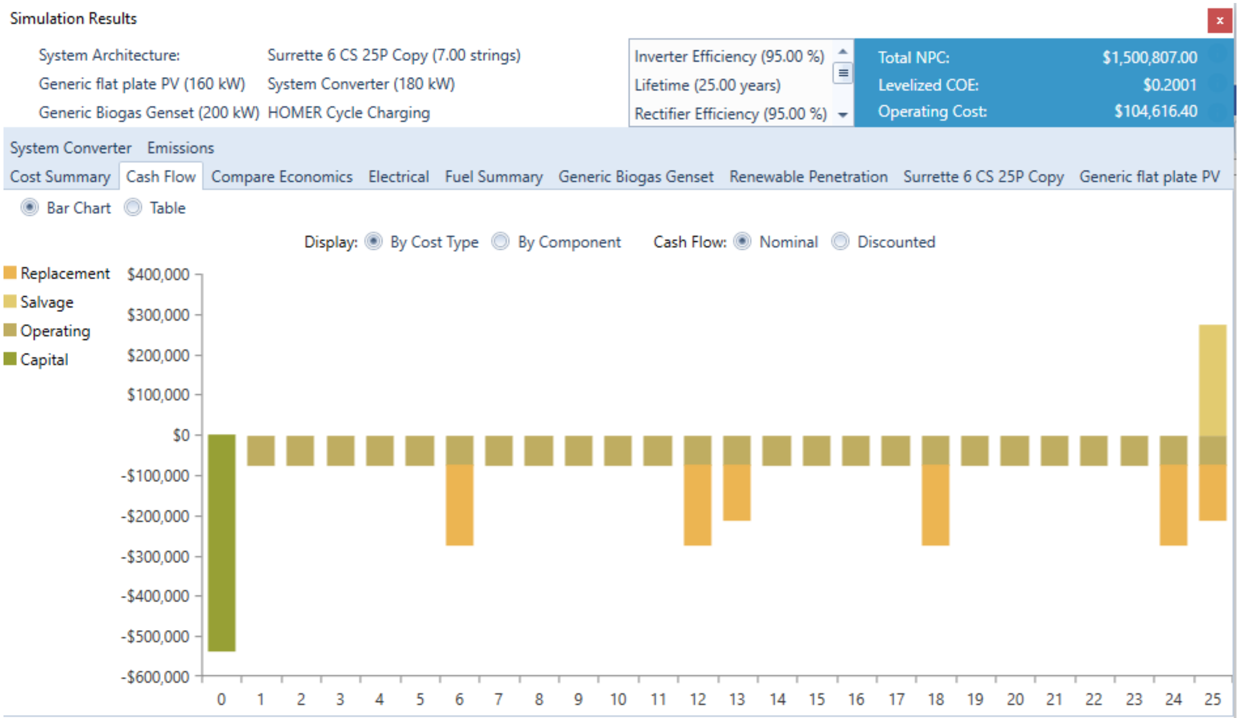


Figure 5.3 Cash flow summary of selected hybrid system for CST

From cash flow summary results of the hybrid system, it is shown that initial cost for the system is high compared to operating and maintenance cost. This is because the renewable energy resources (solar and biogas) are available free.

Figure 5.4 given below shows the electrical (actual net energy) production of the Selected Hybrid system.

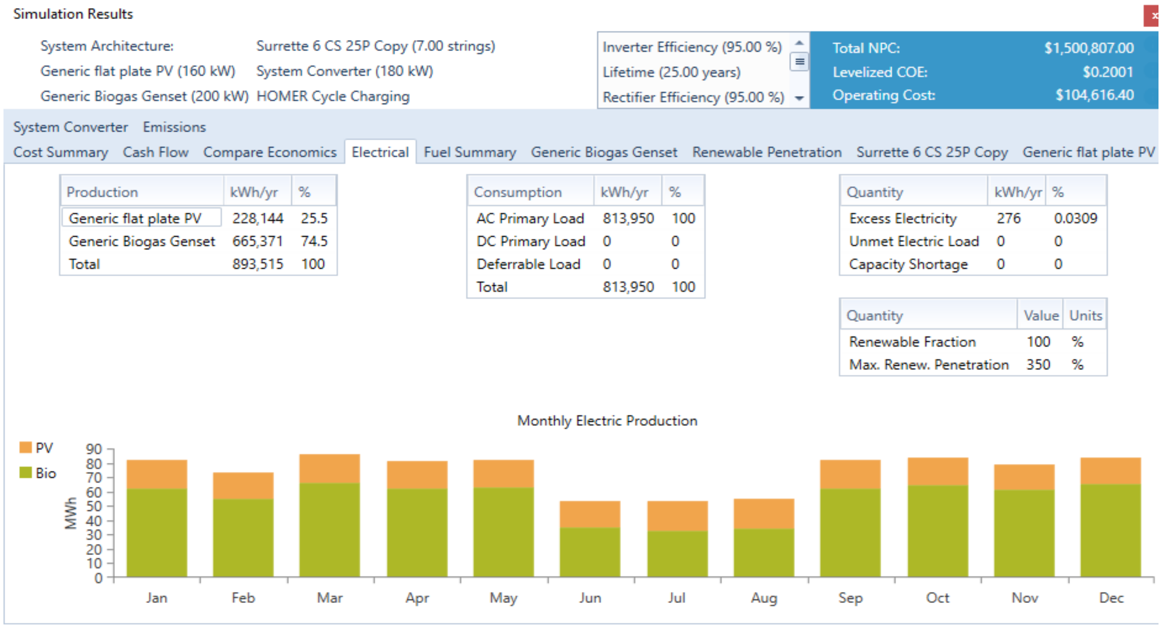


Figure 5.4 Electrical output summary of selected hybrid system for CST

As shown in Figure 5.4 and 5.5 respectively, the solar PV will contribute 25.5 % of the energy demand while biogas generator will generate 74.5% of the load demand. The system has zero unmet load and zero capacity shortage with few electricity excess. This is the reason why this system has been selected for its Least Cost of Energy.

These electrical properties are summarized in Figure 5.5 shown below:

Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	276	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
Generic flat plate PV	228,144	25.5
Generic Biogas Genset	665,371	74.5
Total	893,515	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	813,950	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	813,950	100

Figure 5.5 Electrical summary of selected hybrid system for CST

The details also for other simulations results, which include biogas generator, solar PV, battery and converter, are also described below with different figures below:

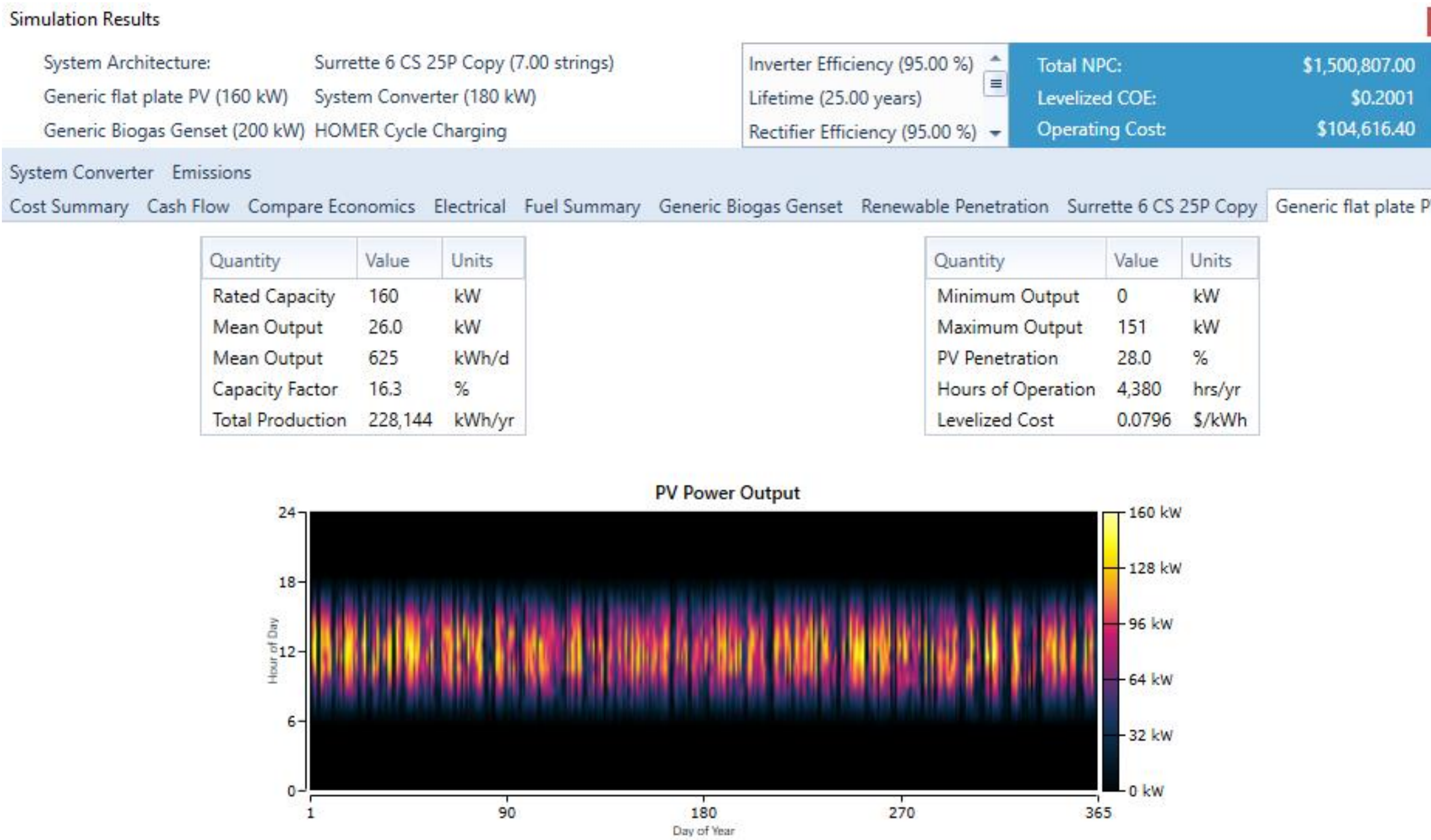


Figure 5.6 Simulations results of selected solar PV

From simulation results shown, a 160 kW was found to be the optimum size for solar PV and more details are shown in in Figure 5.6 given above.

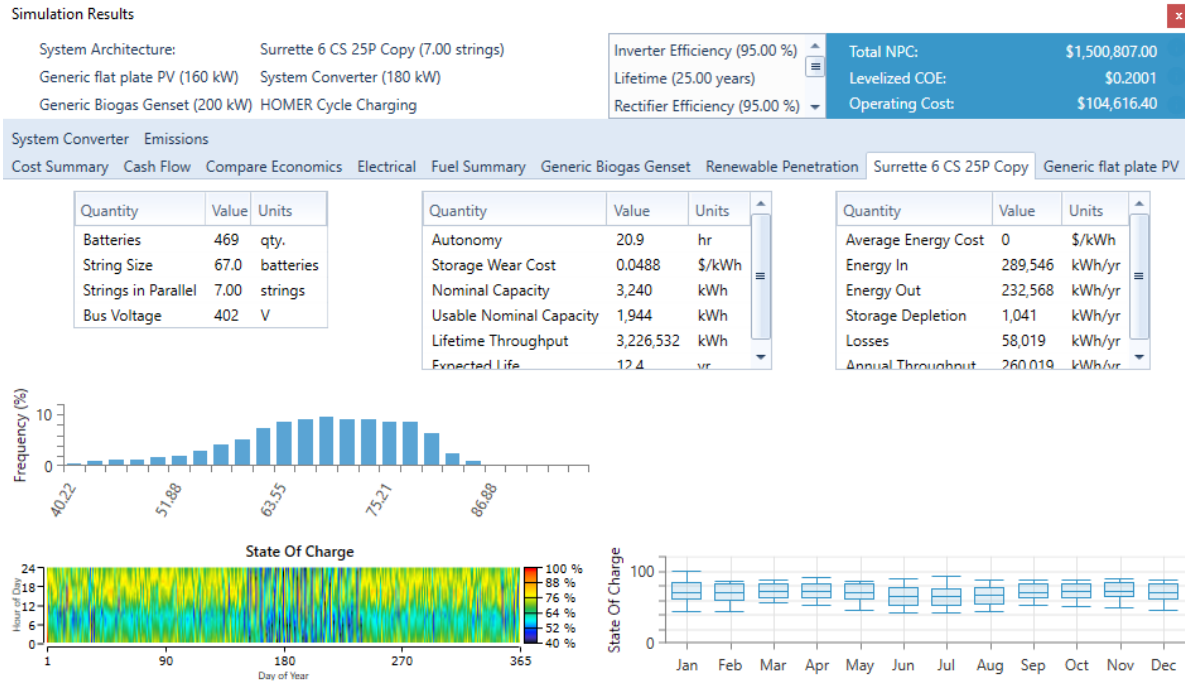
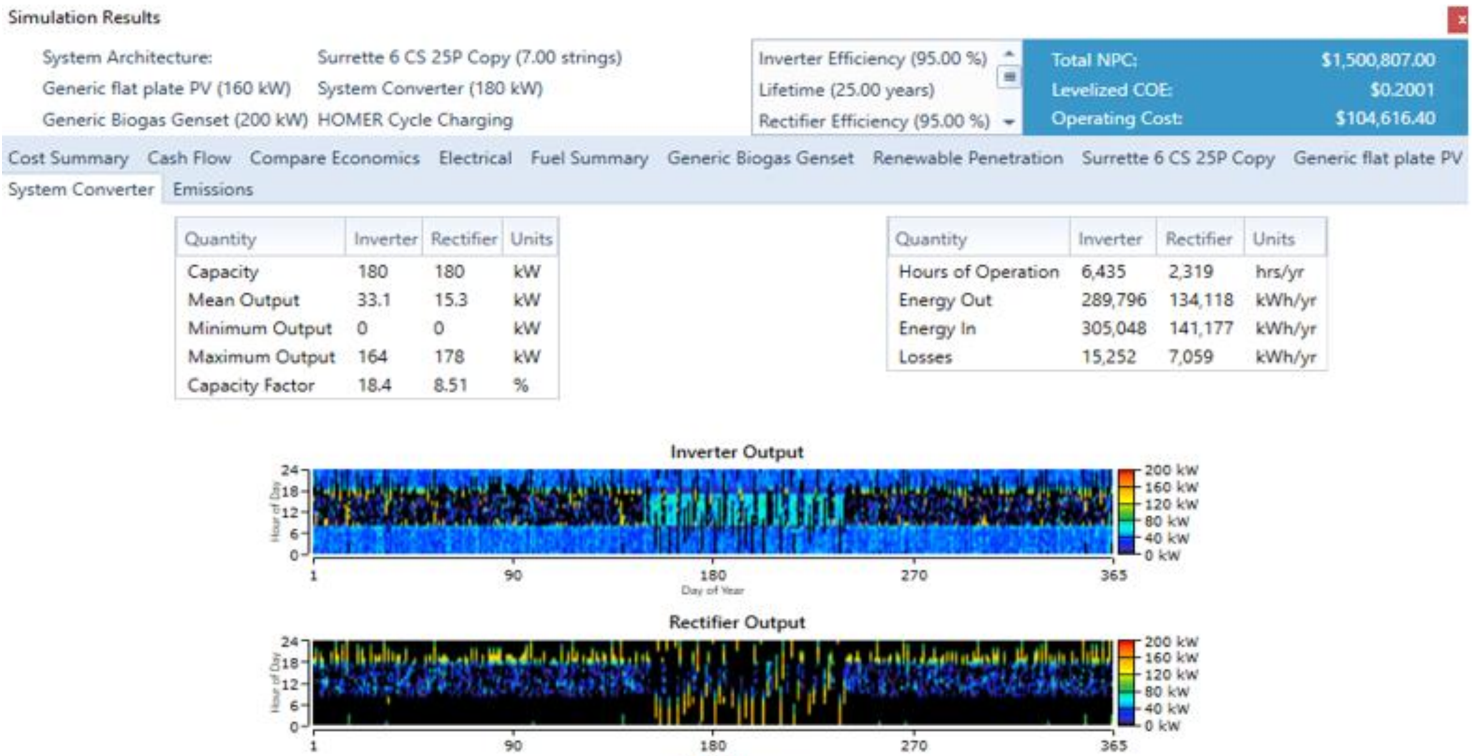


Figure 5.7 Simulations results of selected battery storage

From simulation results of the selected battery storage system, it is shown that for the hybrid power plant to operate at optimum, the total number of batteries equal to 469 is required with 7 strings connected in parallel and 67 batteries connected in series for each string.



Simulation Results

System Architecture: Surrette 6 CS 25P Copy (7.00 strings)
Generic flat plate PV (160 kW) System Converter (180 kW)
Generic Biogas Genset (200 kW) HOMER Cycle Charging

Inverter Efficiency (95.00 %)
Lifetime (25.00 years)
Rectifier Efficiency (95.00 %)

Total NPC: $1,500,807.00
Levelized COE: $0.2001
Operating Cost: $104,616.40

Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | Generic Biogas Genset | Renewable Penetration | Surrette 6 CS 25P Copy | Generic flat plate PV | System Converter | Emissions

Quantity	Inverter	Rectifier	Units
Capacity	180	180	kW
Mean Output	33.1	15.3	kW
Minimum Output	0	0	kW
Maximum Output	164	178	kW
Capacity Factor	18.4	8.51	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	6,435	2,319	hrs/yr
Energy Out	289,796	134,118	kWh/yr
Energy In	305,048	141,177	kWh/yr
Losses	15,252	7,059	kWh/yr

Figure 5.8 Simulations results of selected system converter

Figure 5.8 given above shows the details of selected system converter, for optimum condition of designed hybrid power plant, a 180 kW converter was selected and more details about this converter are given in the Figure 5.8.

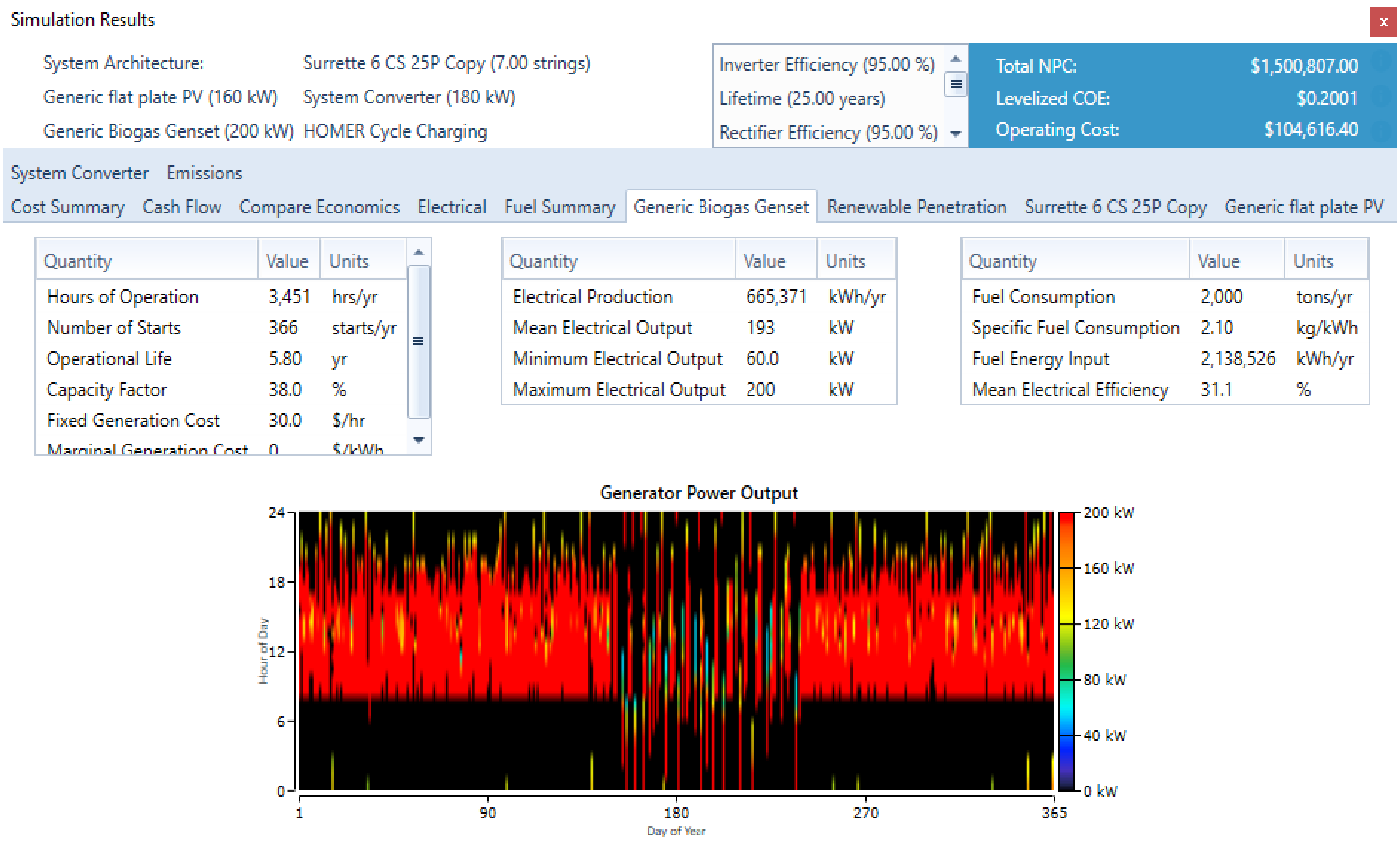


Figure 5.9 Simulations results of selected Biogas generator

Figure 5.9 given above shows the details of selected biogas generator for the system to operate at optimum. As shown, the fuel consumption for this generator is 2 tons per year with specific fuel consumption of 2.10 kg/kWh. The minimum power that can be generated by biogas generator is 60 kW and maximum power generated is 200 kW.

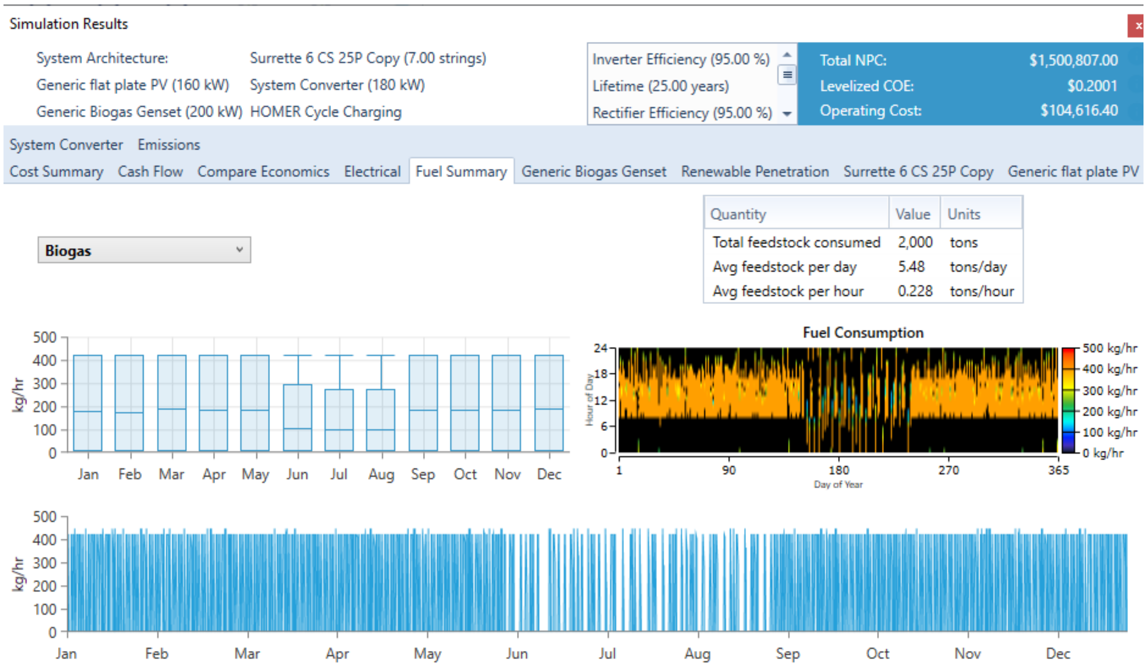
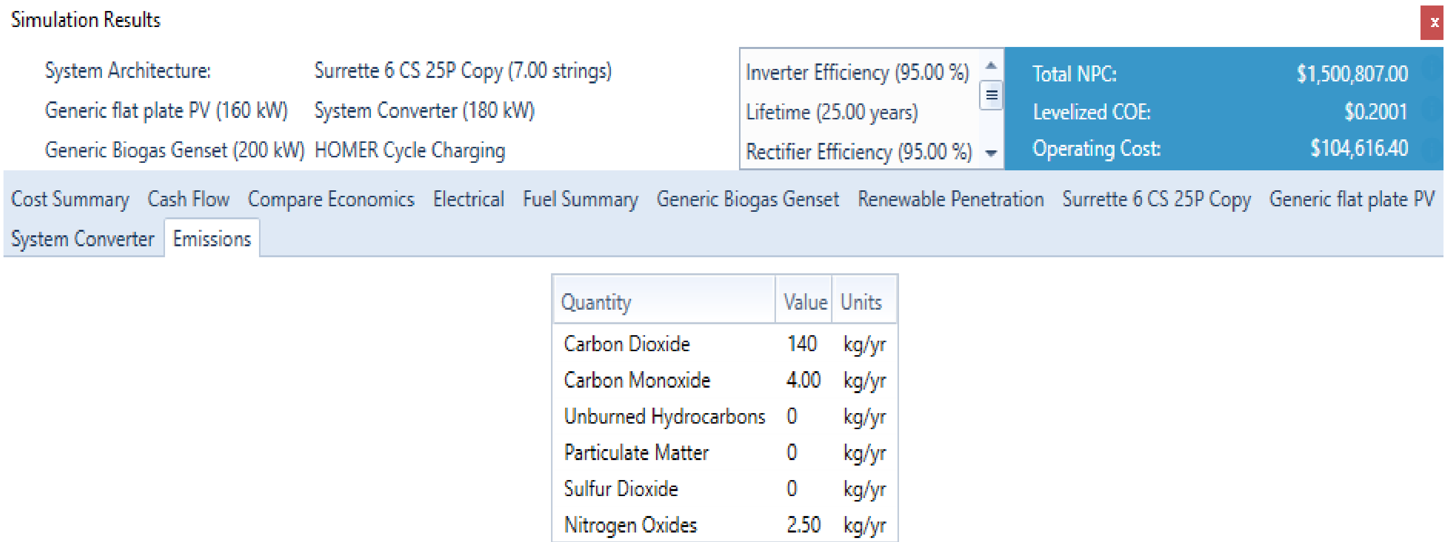


Figure 5.10 Simulations results of fuel summary

Figure 5.10 shows the details about biogas consumption by the generator. The total feedstock consumed per year is 2000 tons and average feedstock per day is 5.48 tons per day.



Quantity	Value	Units
Carbon Dioxide	140	kg/yr
Carbon Monoxide	4.00	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	2.50	kg/yr

Figure 5.11 Simulations results of Emissions

As result shows in Figure 5.11, the selected hybrid system configuration has good emissions results, as the emissions quantity is low. Carbon Dioxide, Carbon Monoxide and Nitrogen Gases are produced due to biogas combustion in biogas generator. These gases have a little effect on the environment according to the result.

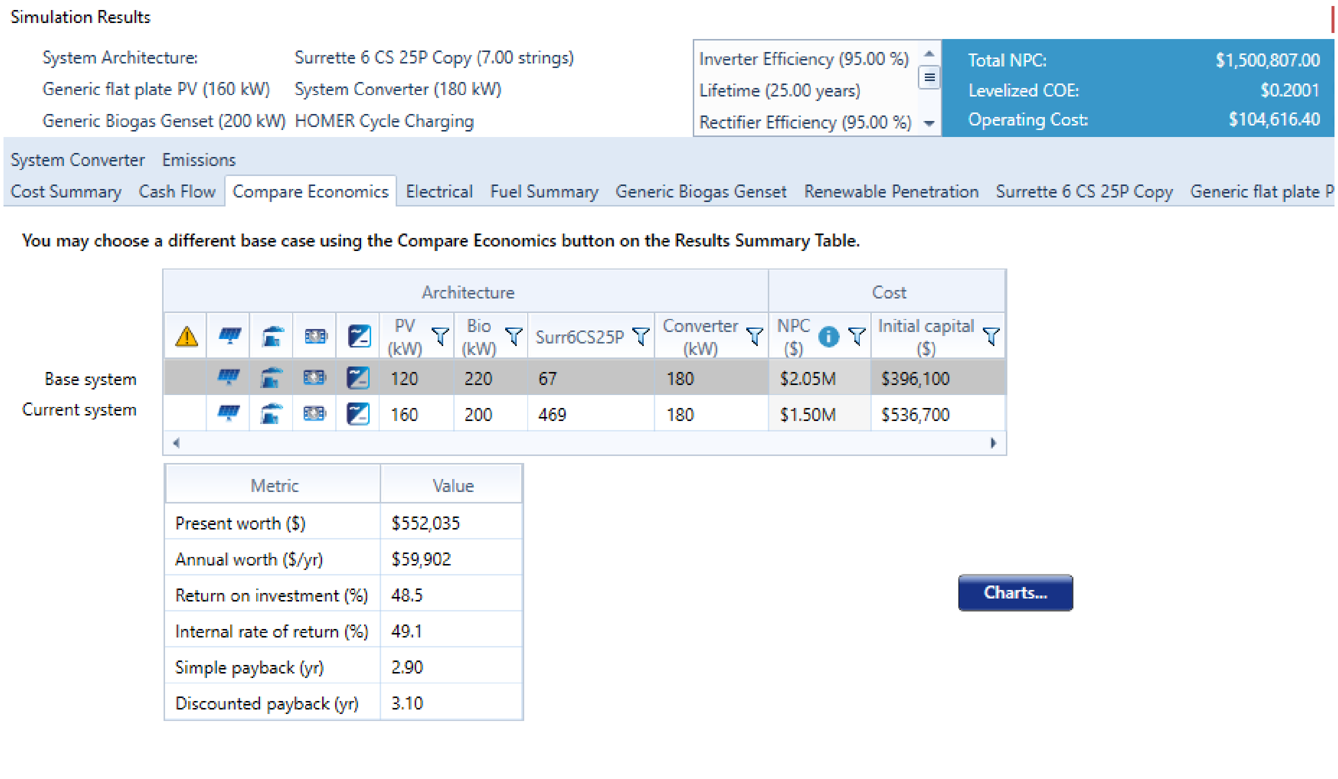


Figure 5.12 Simulations results about investment recovery

From results shown in Figure 5.12 above, the Return on investment is 48.5%, this means that the system returns the invested money with return on investment of 48.5 % and the payback period is 2.9 years, this means that 2.9 years is required for the College to get back the investment.

Cost comparison

The cost comparison of the designed Hybrid Power plant for College of Science and Technology and the cost of energy for the Rwanda National Grid is presented in Table 5.1 given below:

Table 5.1 Cost comparison of HRES with National Grid

Range of energy (kWh) consumption	Designed Hybrid System COE (Rwf)	National Grid COE in 2020 (Rwf)
> 100	194	255

To date the exchange rate of Rwandan franc in USD is given below:

1$ = 970 Rwf, the COE of the designed hybrid power plant is 0.2001$ which is equivalent to (970 x 0.2001) this gives 194 Rwf as shown in table 5.1 above. From this difference in prices for National Grid and Hybrid system respectively, let us determine how much the College will save by using Hybrid system.

Estimated Energy demand per year is 813950 kWh as shown in figure 5.6 above, so by having the cost for one kWh the total cost can be found. The total costs of enegy in one year for both systems is calculated below as follows:

Annual total cost paid by college to Grid = 255 x 813950 = 207557250 Rwf.

Annual total cost paid by college if it uses Hybrid system = 194 x 813950 = 157906300 Rwf.

By comparing these costs, the designed hybrid system is more cost effective for electricity generation as it has less cost compared to Grid cost. By using the Hybrid Power plant in the college the amount of money that the college will save is given by the difference between the Grid cost and Hybrid system cost and is calculated as:

Money that college will save annually using the Hybrid system is equal to: 207557250 Rwf - 157906300 Rwf = 49650950Rwf. But also the residues generated after extracting biogas from biomass can be used for soil fertility purpose in agriculture. Therefore, as the college doesn't have any farm, it may sell those residues (digestate) to agricultures there by providing income to the campus.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this thesis work, a feasibility study of an optimized hybrid power plant model which uses solar and biomass energy resources was conducted at UR-CST. The aim of this research work was to determine the optimum design model, operation of a hybrid power plant composed of solar, and biomass energy sources, which is able, satisfy the electrical load demand for the College to replace the conventional grid system by making the college self-sufficient in its electric power need.

The first step in this study was the assessment of renewable energy resources potential (solar and biomass), estimation and forecast of electricity consumption based on load demand for the college. The 22 years monthly average solar radiation and clearness index of the college was obtained from NASA metrology at Latitude of 1.5^o and Longitude of 30.5^o. The quantity of biomass was estimated depending on total number of people hosted in the college. The average monthly values for daily solar radiation vary from 4.54 in November to 5.22 in February with an average of 4.88 kw/m^2/day and the total quantity of biomass produced daily is 10500 kg, which is equivalent to 10.5 ton/day.

Electrical Load profile for the college was determined by referring to the electricity cost per month for the college and the cost for one unit of electricity from REG tariff and from this, the quantity of daily, monthly and annually electricity consumption was calculated. During load estimation, the nature of load has been thoroughly analyzed to come up with sustainable energy demand satisfaction since electric load vary time-to-time and seasonal bases. During design, the load was forecasted in the range of 5 years to satisfy the future load demand growth. The daily energy demand was then found to be 2230 kWh, peak power demand of 313.18 kW and a load factor of 0.3.

Then, after Homer tool was used to perform optimal sizing, feasibility study and economic analysis of the proposed Hybrid Power Plant for the college. In the result, different feasible configurations of the system was then given and arranged according to their net present cost, from the least to the highest. The result having the least net present cost was considered the most feasible. Therefore, from simulation Results shown in HOMER, for the Hybrid power plant to operate at optimum (to meet the estimation total load of CST at minimum cost) the PV system contributed 25.5% of the total load demand while 74.5 % was contributed by biogas power plant depending on solar and biomass sources availability in College of Science and Technology and the power generation capacity of the resources. The optimal HRES components have the following capacities: 160 kW photovoltaic array, 200 kW Biogas generator, 469 Surrette 6CS25P batteries and 180 kW converter with cost of energy COE $ 0.2001 and total net present cost $ 1,500,807. This system has zero unmet load and zero capacity shortage with few electricity excess (276 kWh/year) and this electricity excess will cover the future energy demand.

Finally, the comparison between Grid connected and Hybrid system was carried out and the results show that generation of electricity using HRES for the college is cheaper compared to National Grid. Therefore, UR-CST can consider these results as a base research and construct the HPPS for their own use there by becoming independent from National Grid.

6.2 Recommendation

As stated in introduction, Rwanda has a target to increase the electricity access to 100% by 2024. To achieve this goal, people was encouraged to use solar energy systems for electricity generation but as solar is intermittent, Hybrid system can be more advantageous. So far, in Rwanda, few feasibility studies were carried out in Hybrid Systems and they are mainly based on Micro Hydro and Solar or Solar and Wind renewable energy resources. This study is done based on University of Rwanda -College of Science and Technology using solar and biomass. Therefore, next research studies should extend this research in other potential sited areas to contribute to the government goal especially in rural areas where the electricity access is still low.

UR-CST can consider these results as a base study for developing the HPPS for their own use there by becoming independent from National Grid.

In order to get a better performance of the Hybrid system, the overall power management for coordinating and controlling energy sources using intelligent energy control mechanism is suggested.

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