Feasibility Study of a Standalone Solar-Wind-Genset with Energy Management System for Rural Electrification in Ethiopia: *(Case Study of Nura Hase community in Bosat district, East Shoa)*

By: Reta Dengesu Haro

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical and Computer Engineering (Specialization in Power Engineering)

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

October, 2019

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Approval of Board of Examiners

We, the undersigned, members of the Board of the Examiners of the final open defense by Reta Dengesu Haro have read and evaluated his thesis entitled **‘’*Feasibility study of a standalone solar-wind-genset with energy management system for rural electrification in Ethiopia: Case study of Nura Hase community in Bosat district, East Shoa*’’** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science (MSc.) in Electrical Power Engineering in the Department of Electrical and Computer Engineering, Adama Science and Technology University.

________________________	________________	_______________
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________________________	________________	_______________
Chairperson	Signature	Date
________________________	________________	_______________
Internal Examiner	Signature	Date
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External Examiner	Signature	Date

DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of materials used for this thesis have been duly acknowledged.

Name: Reta Dengesu Haro

Signature: ______________________

Date of submission: ________________

This MSc thesis has been submitted for examination with my approval as thesis advisor

13/September/2019

Dr. Tefera T. Y. (Assistant professor)

DEDICATION

...to the following Universities and Agencies:-

Bule Hora University, Adama Science & Technology University, Ethiopia Electric Utility agency, Ethiopia Electric Power agency and Ethiopia Meteorology agency

and

....to

All people who have been beside me.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

AC	Alternate Current
COE	Cost of Energy
DC	Direct Current
EEP	Ethiopian Electric Power
EMS	Energy Management System
FDRE	Federal Democratic republic of Ethiopia
HOMER	Hybrid Optimization and Modeling of Electrical Renewable
Kwh	Kilo Watt Hour
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
RES	Renewable Energy Sources Net Present Cost
PLC	Programmable logic controller
PV	Photovoltaic
RF	Renewable Fraction
RES	Renewable Energy Sources
UEAP	Universal Electric Access Program
UNDP	United Nation Development Program

ABSTRACT

It is known that, Ethiopian Electric power utility company uses extension of grids and installation of diesel generator as option for electrification of rural villages. But, grid extension to such area is not practically feasible as these locations are geographically isolated, sparsely populated and have a very low demands. The only use of diesel generators has also harmful effects on environment in addition to higher cost fuel, maintenance and operation. In this thesis, feasibility of solar-wind-genset has been simulated and optimized using HOMER software for the rural community of Nura Hase among the Bosat district, East Shoa, Oromia of Ethiopia. The primary (households, school, healthy centers and churches loads) energy demand of the community is 905Kwh/day with 264Kw peak load and the deferrable (water pumping loads) energy demand of 7.6Kwh/day with 750w peak load was involved during optimal design of hybrid power system. It is also compared the cost of hybrid system with cost required to electrify the villages by extending the grid such that, the net present cost of extending the grid is equal to the net present cost of stand-alone system at the point 9.94km which is breakeven distance. Farther away from the grid, the stand-alone system is optimal and nearer to the grid, grid extension is optimal. Moreover, programmable logic controller (PLC) based energy management system has been incorporated to automate the off-grid system. Accordingly ,solar and wind energy are considered as primary sources to supply electricity directly to the loads and to charge battery bank when there are excess solar and wind energy generation. However, in peak load times diesel generator could also be engaged. The load has been suggested for primary loads(house hold, healthy center,school,churches) and deferrable loads(water pumping and milling).The integration of the hybrid system is to electrify residential houses and their surrounding in order to reduce the need for fossil fuel leading to an increase in the sustainability of the power supply. The study shows that a 50Kw solar, 10*250Kw wind turbines, 55Kw diesel generator and 175 units of 6CS25P batteries with best optimum hybrid system configuration with cost of energy 0.111$/Kwh and net present cost 336,530$ is required for the communities.

Key-words: hybrid power generation, wind energy, photovoltaic energy, HOMER, primary loads, deferrable loads, rural electrification, renewable energy.

CHAPTER – 1: INTRODUCTION

1.1. Background

Now days, solar energy generation and wind energy generation application have grown rapidly to meet friendly environmental electricity demands. An isolated Hybrid solar and wind power generation system becomes a favorable option for power supply to Small electrical loads at remote location where no utility grid power supply is available. Due to high demand of energy and limited availability of conventional energy, nonconventional sources become more popular among researchers.

Ethiopia with landmass of 1.1million square kilometers is the third giant and second populous nation in the Sub-Saharan Africa with estimated population of about 100 million[1].According to the UNDP 2018 report, the human development index increases from 0.283 in 2000 to 0.448 in 2015 and population living below the national poverty line. This puts Ethiopia at a rank of 174th out of 188countries [1]. From January 2012 report of FDRE Ministry of Water and Energy of survey by the Central Statistics Agency (CSA) in 2004 shows about 71.1% of total households use kerosene for lighting followed by firewood (15.7%) and electricity (12.9%).A higher proportion of urban residents use electricity (75.3%) for lighting, while the use of kerosene (80.1%) and firewood (18.5%) are predominant in rural areas .The study by CSA at the country level, suggests that about 81.4 % of the households use firewood, around 11.5 % cook with leaves and dung cakes and only 2.4 % use kerosene for cooking. The majority of rural households use firewood (84.4 %) and few of them (12.7 %) use leaves and dung cakes. The use of modern source of cooking fuel such as butane gas, electricity and kerosene for cooking is uncommon in the rural areas (0.4 %). Use of kerosene is common in urban areas and stands at 13.8 % following firewood (65.4 %). Charcoal (7.7 %), electricity (2.4 %) and leaves (5.3 %) are also used by urban households. On the other hand, only 0.2 % of the households in rural areas are observed to use charcoal for cooking [2]. According to World Bank collection of development indicators 2016 report indicates 42.9% Ethiopian population electrified which is increased from 12.9% in 2004 [3].

EEP has a short and long term plan to increase the existing generation capacity to fill the gap. The generation capacities will be increased to 10GW after constructing new hydropower plants including the Grand Ethiopian Renaissance dam with a capacity of 6000 MW. Although there is high potential in hydro power, vast use of the resource is not implemented.

This is due to the fact that the service giving dams are being affected by climate change and hydrological problems. Additionally, the installation and erection of hydropower system takes long time. Another problem related with this is that, UEAP under EEPCo has planned to electrify majority of the rural community. However, due to capacity constraints and difficult geographical layout of the remote locations, grid connection of remote villages has not been possible. Consequently, rural areas are dependent on local solutions for electricity supply. These areas have been using Kerosene for lighting, diesel for milling and pumping, traditional biomass as source of energy for cooking and dry cells for radio and tape recorders. However, the global price increase of oil and negative effects it imposes on environment has enforced to search for other energy alternatives.

Hence, attention should be given to development and diversification of the power system with renewable energy sources which are cost effective in reaching the remote areas. It is also necessary to increase the current power generation mix to cover increasing power demand and avoid dependence on fuel imports.

The rural area of Nura Hase is among the villages of Ethiopia facing similar problems due to the difficulty of giving electric access by extending the grid. This can be minimized by looking for alternative resources which can be used as a stand-alone to give electric access to the community.

1.2. Study area description

Nura Hase village is one of the Bosat Woreda in East Shoa zone, Oromia, Ethiopia, is located at latitude and longitude of 7°30’ 0’’N and 40°30’0’’E and an elevation of 1606 meters above sea level.

Figure1. 1 Google Map picture of Study area distance from Wolenchit

1.3. Statement of the problem

Depending of rural areas on local solutions, (Kerosene for lighting, diesel for milling and pumping, traditional biomass as source of energy for cooking, dry cells for radio and tape recorders and etc.) on behalf of electricity supply have been brought negative impact on economy of rural villages of Ethiopia due to global price increments. This can be minimized by looking for alternative resources which can be used as a stand-alone to give electric access to the community.

1.4. The significant of thesis

The study of this thesis contribute the electrical power needed by the people those live in this area since they are far from the national grid system and have difficult geographical location which is difficult to connect to the national grid system. The study is also important in the creation of awareness in the peoples and organization in the area with efficient integration of hybrid solar-wind and genset power plant which provide electric power to an isolated area with cleaner energy source.

1.5. Scope and limitation of the study

The study has investigated on the efficient integration of solar-wind – genset power plant with energy management to provide efficient energy to the Nura Hase rural area to satisfy their electrical power energy need. The thesis is done by collecting the data and analyzing it to fulfill the energy demand of that specific area. To satisfy the energy supply for the area depending on the gathered information the necessary measures is taken to deliver energy in efficient integration of solar-wind and genset power plant. The thesis is proposed for the 300 households and public service.

During the work of this thesis there are some limitations in

- ✓ Time
- ✓ Resource and
- ✓ Financial money.

Also, limitation on

- ✓ Unarranged data that I collected from different agency, example data from Ethiopian metrology agency.

1.6. Objectives of the study

1.6.1. General objective

The main objective of the thesis is to study feasibility with energy management of solar-wind genset energy system for hybrid electrification of remote villages in Ethiopia, in Bosat district.

1.6.2. Specific objectives

The Specific objectives of the thesis are to:-

- ➢ Study the solar photovoltaic and wind energy potential of the study area
- ➢ Estimate and forecast the energy demand of the Nura Hase village areas for 15 years by considering the basic needs of the people
- ➢ Select appropriate solar modules, wind turbines and batteries depending on the energy demand
- ➢ Model hybrid renewable energy system with energy control for the community in Nura Hase
- ➢ Compare the investment cost of the hybrid system against the cost required to electrify the areas by extending the national grid
- ➢ Continual improvement in energy efficiency
- ➢ Ensure the availability of information and of all necessary resources to achieve objectives and targets.

1.7. Methodology and material used

To achieve the above specific objectives the following methods and materials are conducted.

- ➢ Identifying and site surveying of the village

- Collecting data and feasibility study
- Assessment of resource
- Determine the most appropriate combination of renewable energy resource to be proposed as a hybrid renewable energy system
- Calculating the cost of extending the grid using interlinked Microsoft office excel spread sheet prepared by UEAP
- hybrid system is modeled and simulated using HOMER software based on the data collected to get the best optimization
- Comparing cost of extending the grid with off grid
- Managing, monitoring and controlling the overall system using PLC
- Analysis and interpretation of the result
- Finally make justification of the hybrid system.

1.8. Organization of the thesis

The thesis consists of five chapters and reference with appendixes. The first chapter deals with the introduction part which cover the background, study area description, statement of problem, objective, scope and limitation of study thesis, significance of thesis and organization of thesis. Chapter two covered and discussed literature reviews which are related to works to this thesis and basic theories of solar energy resource, wind energy resource, basic energy management, construction and types together with diesel generator. Chapter three present methodology and materials used, system analysis and load estimation, costs and characteristics of resource components, Hybrid Energy Management System Control using PLC and grid extension cost estimation respectively. Chapter four is all about the result and discussion of optimization and sensitivity and comparing off grid and grid extension cost. Finally, chapter five conclusions and recommendations of the thesis work.

CHAPTER-2: LITERATURE REVIEW

2.1. Hybrid energy system

Hybrid energy system is an excellent solution for electrification of remote rural areas where the grid extension is difficult and not economical. Such system incorporates a combination of one or several renewable energy sources such as solar photovoltaic, wind energy, genset and battery. A hybrid system uses a combination of energy producing components that provide a constant flow of uninterrupted power. Other advantages of the hybrid system are the stability and immobility of the system and a lower maintenance requirement, thus reducing downtime during repairs or everyday maintenance. In addition to this, as well as being indigenous and free, renewable energy resources also contribute to the reduction of emissions and pollution [4].

2.2. Solar energy systems and resources

The sun is the largest energy source of life at the same time it is the ultimate source of all energy (except tidal and geothermal power), even the energy in the fossil fuels ultimately comes from the sun. The sun radiates 174 trillion kWh of energy to the earth per hour. In other words, the earth receives 1.74×10^{17} watts of power from the sun [5].The sun is a typical star with mass 2×1030 kg, beam length 700,000 km and it has roughly 5 billion more years of life. Its surface temperature is about 5800 Kelvin while the internal temperature is approximately 15 million Kelvin. This temperature derives from reactions which were based on the transformation of hydrogen to helium, the process called nuclear fusion, which produces high temperature of the sun and the continuous emission of large amounts of energy. It is calculated that for each gram of hydrogen that is converted to helium sun radiates energy equal to 1.67×105 kWh. The solar energy is emitted to the universe mainly by electromagnetic radiation. Approximately one-third of energy radiated from sun is reflected back. The rest is absorbed and retransmitted to the space while the earth reradiates just as energy as it receives and creates a stable energy balance at a temperature suitable for life[5].

2.2.1. Solar photovoltaic energy

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. PV power generation uses solar panels comprising a number of cells containing a semi-conducting material. As long as light is shining on the solar cell, it generates electrical power. When the light stops, the electricity stops. Many PV system have been in continuous outdoor operation on Earth or space for over 30 yrs. [6].The solar cells that are used on calculators and satellites are photovoltaic cells or modules. This PV module consists of many PV cells wired in parallel order to increase current and in series to produce a higher voltage. When we speak of a PV panel it means any number of PV modules and when we speak of array it means any number of PV panels. Individual PV cells are typically only a few inches in diameter, but multiple cells can be connected to one another in modules, modules can be connected in arrays, and arrays can be connected in very large systems.

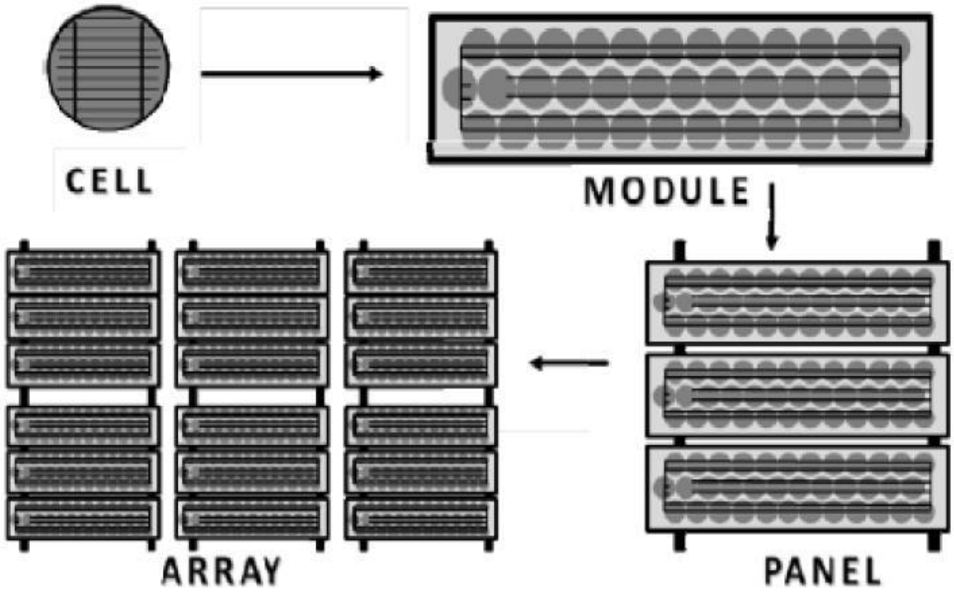

Figure2. 1 PV diagram [7]

PV panel convert sunlight to DC electricity. The PV generated electricity is ‘’silent‶, low in maintenance and does not need in fuel or oil supplies. However, PV energy is available when enough irradiance is accessible.

2.2.2. General working principles of photovoltaic cells

PV cells convert sunlight directly into electricity by taking advantage of the photoelectric effect. Cells are constructed from semiconductor materials coated with light-absorbing materials. When photons in sunlight strike the top layer of a PV cell, they provide sufficient energy to knock electrons through the semiconductor to the bottom layer, causing a separation of electric charges on the top and bottom of the solar cell. Connecting the bottom layer to the top with a conductor completes an electrical circuit and allows the electrons to flow back to the top, creating an electric current and enabling the cycle to repeat with more sunlight (Clean Energy Associates). The following figure illustrates how photovoltaic cells work.

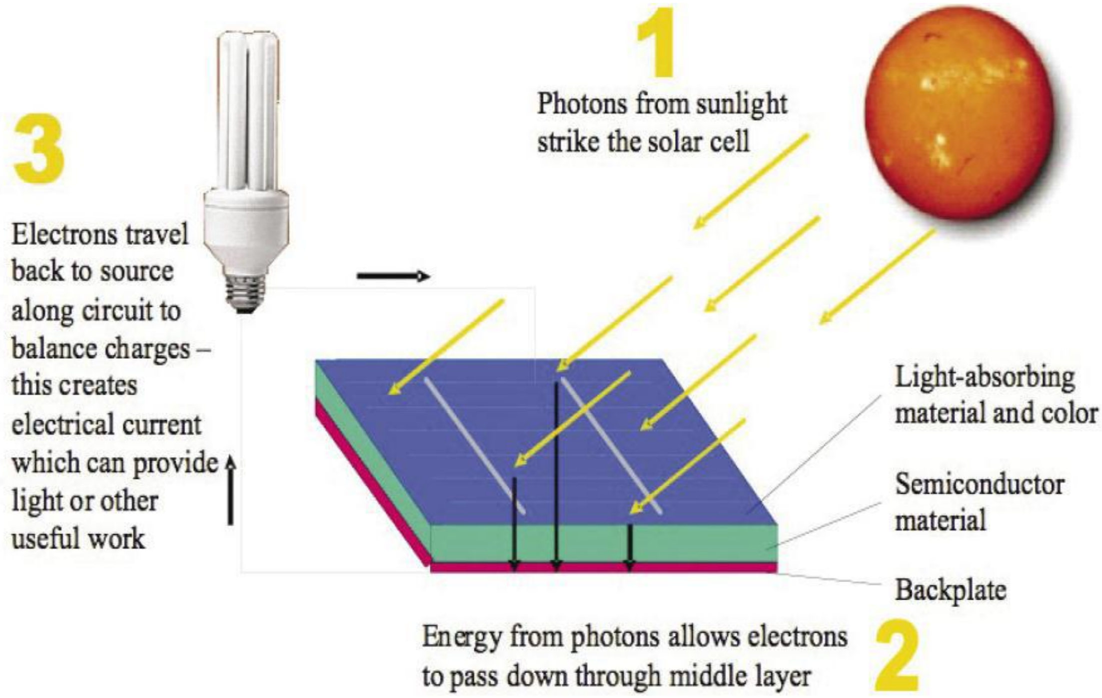

Figure2. 2 How photovoltaic cells work [7]

2.2.3. Main PV cell types

The material that is used widely in the industry for the production of photovoltaic cells is silicon. Based on the structure of the basic material from which they are made and the particular way of their preparation the photovoltaic cells of silicon are categorized into the following four types.

Single-Crystalline Silicon: The basic material is mono-crystalline silicon. In order to make them, silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers to make individual cells. It is the oldest and more expensive production technique, but it's also the most efficient and widely used sunlight conversion technology available. Cells efficiency oscillates between 14% and 18% [8].

Polycrystalline or Multi-crystalline Silicon: The particular cell is relatively large in size and it can be easily formed into square shape which virtually eliminates any inactive area between cells. It has a slightly lower conversion efficiency compared to single crystalline and manufacturing costs are also lower. Cells efficiency oscillates between10% and 13% [6].

String Ribbon: This is a refinement of polycrystalline silicon production. There is less work in its production so costs are even lower. Cells efficiency averages 8% to 10%**.**

Technology which uses thin film solar cells: While the total thickness of a semiconductor is about 1μm. Amorphous or thin film silicon cells are solids in which the silicon atoms are much less ordered than in a crystalline form. By using multiple junctions this kind of photovoltaic cells achieve maximum efficiency which is estimated at about 13% while the installation cost is reduced. The efficiency of this cell oscillates between 6% and 10% [7]. Furthermore the output of an amorphous silicon cell is not decreased as temperature increases and is much cheaper to produce than crystalline silicon. Cells efficiency decreases with increases in temperature. Crystalline cells are more sensitive to heat than thin films cells. The output of a crystalline cell decreases approximately 0.5% with every increase of one degree Celsius in cell temperature. For this reason modules should be kept as cool as possible, and in very hot condition amorphous silicon cells may be preferred because their output decreases by approximately 0.2% per degree Celsius increase [6, 8].

2.2.4. PV module and array

The solar cell is the basic building block of the PV power system. However, it rarely used individually because it is not able to supply an electronic device with enough voltage and power. For this reason, many photovoltaic cells are connected in parallel or in series in order to achieve as higher voltage and power output as possible. Cells connected in series increases the voltage output while cells connected in parallel increases the current. The solar array or panel is a group of several modules electrically connected in series-parallel combination to generate the required current and voltage and hence the power.

A typical photovoltaic system is made of 36 individual 100cm^2 silicon photovoltaic cells and auxiliary devices which are lead-acid batteries with a typical voltage of 12 V. This system has the capacity of producing more than 13V and can charge a 12 V battery.

2.2.5. Equivalent electrical circuit of PV cell

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 2.3.The following parameters call for consideration. The current (I) at the output terminals is equal to the light-generated current I_L minus the diode current I_D and the shunt leakage current I_{Sh}.The series resistance $R_s$represents the internal resistance to the current flow, and depends on the p-n junction depth, impurities, and contact resistance. The shunt resistance R_{Sh} is inversely related to the leakage current to the ground. In an ideal PV cell $R_s = 0$ and $R_{Sh} = \infty$.The PV conversion efficiency is sensitive to small variations in R_s, but insensitive to variations in R_{Sh}. A small increase in R_s can decrease the PV output significantly.

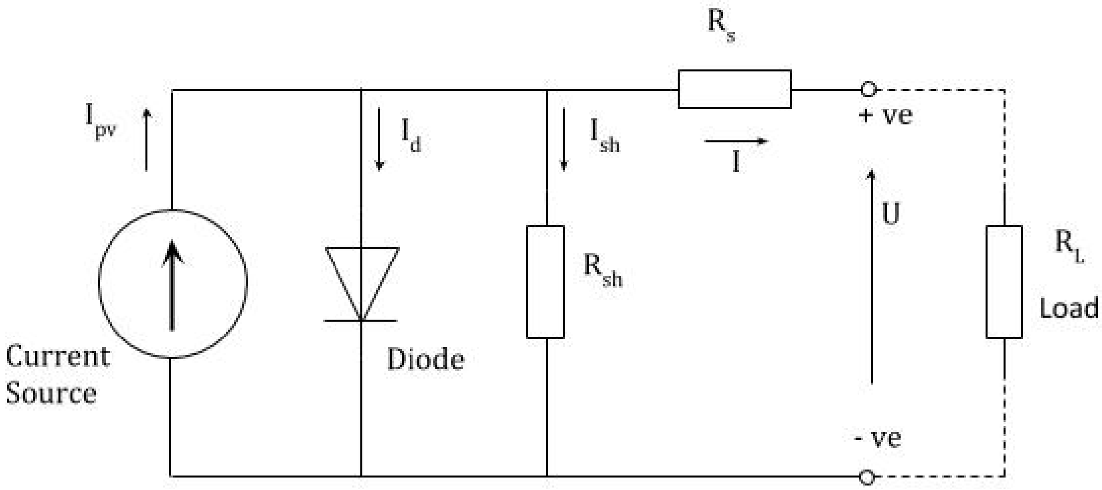

Figure2. 3 APV cell equivalent electrical circuit [9]

2.2.6. I-V curve

The electrical characteristic of the PV cell is generally represented by the current verses voltage (IV) curve. The figure below depicts the I-V curve of typical PV cell. This curve shows the variation of current and voltage when cell resistance varies from zero to infinity. In this curve the point at which the voltage is zero is called the short-circuit current. This is the current we would measure with output terminal shorted. On the other hand the point at which current is zero is known as open-circuit voltage. This is the voltage we would measure with output terminal open. Somewhere in the middle of the two regions, the curve has a knee point.

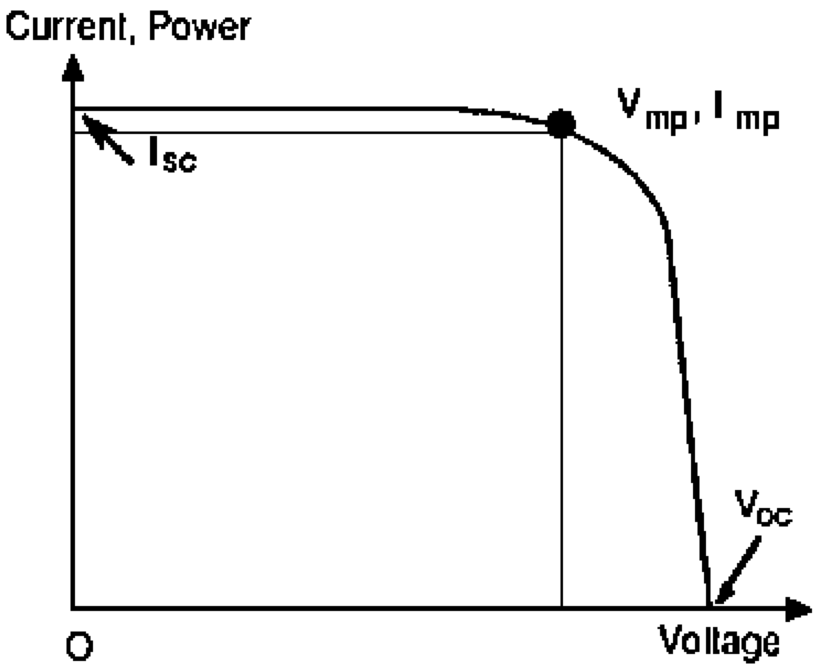

Figure2. 4 I-V curve of a typical silicon PV [10]

The power output of the panel is the product of the voltage and current outputs. Note that the cell produces no power at zero voltage or zero current, and produces the maximum power at the voltage corresponding to the knee point of the I-V curve. This is why the PV power circuit is always designed to operate close to the knee point with a slight slant on the left-hand side. The PV circuit is modeled approximately as a constant current source in the electrical analysis of the system.

Finally in order to measure the photovoltaic cells output power the following standard test conditions are established internationally. The irradiance level is $1000 {}^{W}/_{m^2}$, with the reference air mass 1.5 solar spectral irradiance distributions and cell or module junction temperature of 25°C.

2.2.7. Solar radiation estimations

For any solar based system design, the most important factors are the position of the sun in the sky, the slope and orientation of a collecting surface, and obstruction and reflection properties of neighboring structures. The below figure shows the geometry describing orientation of a collector and position of the sun in the sky. A point on the earth's surface is expressed by its latitude and longitude. The angle between the collector surface and the horizontal is called slope, β (with 00<β <900 for a surface facing towards the equator; 900< β <1800 for a surface facing away from the equator). Surface azimuth angle, y is the angle between the normal to the surface and the local longitude meridian, projected on the horizontal plane. In either hemisphere, y equals 00 for a surface facing due south, 1800 due north, 00 to 1800 for a surface facing westward and 00 to - 800 eastward. For a horizontal surface, y is always 00.

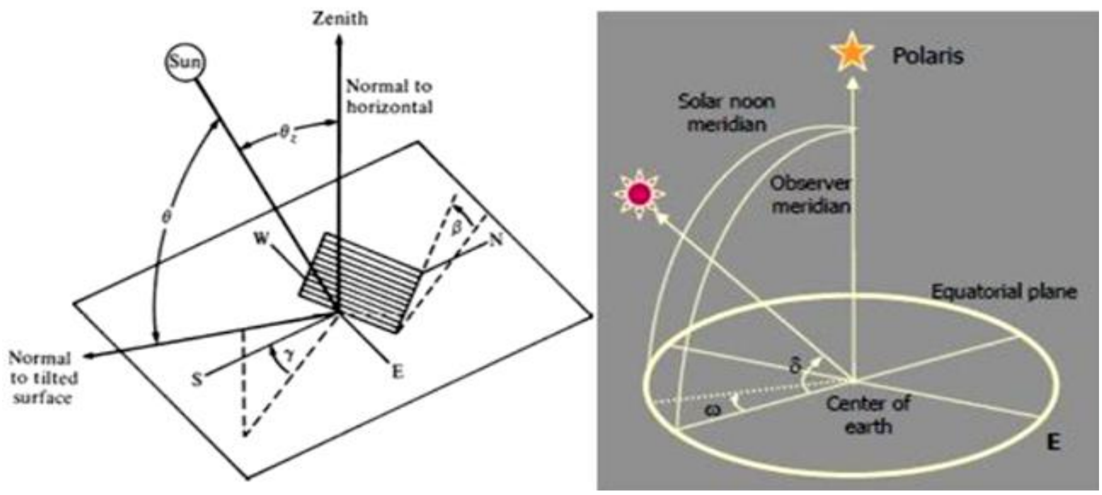

Figure2. 5 Geometry of solar collector and location of sun relative to Earth [11]

Location of the sun in the sky relative to a point on the ground can be defined in terms of two angles: - the solar altitudeα_s (or its complement the solar zenith angle θ_z) and the solar azimuth $\gamma_{s.}$ Solar altitude α_s angle of solar beam to the horizontal. Solar azimuth θ_z is the angle between the solar beam and the longitude meridian projected on the horizontal plane. Sign convention is the same as for surface azimuth angle (γ). Solar altitude and solar azimuth are functions of location (latitude θ), time of the year (declination angle δ) and time of the day (hour angle ω).Solar declination angle (δ) is the angle between the earth's equatorial plane and the earth sun line. Solar hour angle ω is the angle Earth has rotated since solar noon [9, 11 and 12].

Ideally, the data required to predict the solar potential of any site are several years of measurements of irradiance on the proposed collector plane. These are rarely available, so the required data have to be estimated from meteorological data available either (i) from the site, or (ii) from some nearby site having similar irradiance, or (iii) from an official solar atlas or database [11].

2.2.8. Solar energy resource in Ethiopia

Ethiopia receives 4.55 to 6.5 kWh/m^2/day annual average of solar isolation throughout the country [13]. This varies significantly during the year, ranging from a minimum of 4.55kWh/m^2 in July to a maximum of 6.55kWh/m^2 in February and March. Other literatures describe the yearly average radiation to be in the range from 4.25 kWh/m^2 in the areas of Itang in the Gambella regional state (western Ethiopia), to 6.25 kWh/m around Adama in the Oromia regional state (Central Ethiopia) [14].

2.2.9. Solar energy assessment of Bosat district

The assessment of the potential for solar radiation of the selected area is done by taking data from different sources. These are National Metrological Service Agency of Ethiopia (NMSA), NASA and SWERA. The monthly average solar radiation of Bosat district for the data taken from NMSA is shown on the Table 2.1. Year of 2013-2017 data.

Table2. 1 The daily solar radiation and clearance index

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.08	6.57	6.52	6.31	6.36	5.77	5.23	5.36	5.84	6.31	6.27	6.08
0.66	0.67	0.63	0.60	0.61	0.56	0.51	0.51	0.56	0.63	0.67	0.68

2.3. Wind energy systems and wind energy resources

Winds are produced by uneven solar heating of the earth's land and sea surfaces. Thus, they are a form of "solar" energy. On average, the ratio of total wind power to incident solar power is on the order of two present, reflecting a balance between input and dissipation by turbulence and drag on the surface. It happens at all scales, from local breezes created by heating of land surfaces that lasts some minutes, to global winds caused from solar heating of the Earth. Wind power is the transformation of wind energy into more utile forms, typically electricity using wind turbines [15].

2.3.1. Historical uses of wind

Wind energy is one of the oldest sources of energy used by humankind, comparable only to the use of animal force and biomass [16]. Some 5000 yrs. ago wind was used to sail ships in the Nile. Many civilizations used wind power for transportation and other purposes: The Europeans used it to accomplish some mechanical works such as grind grains and pump water in the 1700s and 1800s. The first wind turbine used to generate electricity was installed in U.S in 1890 [16]. However, for much of the twentieth century there was small interest in using wind energy other than for battery charging for distant dwellings. These low-power systems were quickly replaced once the electricity grid became available. The sudden increases in the price of oil in 1973 stimulated a number of research, development and demonstrations of wind turbines and other alternative energy technologies in different countries [17].

2.3.2. Distribution of wind speed

The distribution of wind is expressed by Weibull distribution over a certain period of time at a particular site [18].

2.3.3. Wind turbines

A wind turbine is a machine that converts the kinetic energy from the wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator [15].

There are a number of different wind turbine types available. The horizontal axis turbine, HAWT the most common type of turbine. They come in two different types: the upwind, which face the wind (tower behind rotor) and the downwind arrangement that works away from the wind (tower in front). Another kind of turbine is the vertical axis, VAWT arrangement that uses drag and lift as the driving forces; the horizontal also uses drag and lift, but in other proportions. The advantages with upwind turbines are that the tower does not act as an obstacle for the wind hitting the rotor. Despite this, the flow behind the passing blade is affected by the tower and causes a slight drop in power. When the blade passes the tower it also decreases the drag on the construction which can cause an on/off bending process causing fatigue stress. This has of course been taking into account when designing the turbine. The upwind design needs a control system that helps the nacelle turn straight to the wind. In downwind turbines, the tower shades a rotor blade each time it passes by and causes greater power losses compared to the upwind design. An advantage with downwind turbines is that the nacelle is self-adjusting and is not in need of a control system. One drawback with this is the problem with untwisting the cable inside when the nacelle has turned same direction repeatedly. The VAWT´s are not as commercial and economically competitive as the HAWT´s. Some of the VAWT types suffer from low efficiency due to design difficulties as well as the problem with operation close to the ground. Parts of the vertical turbines will therefore receive low quality winds causing power losses. To keep the construction upright it also needs to be supported with guy cables attached to the ground. The vertical turbine is not in need of yaw control, which of course is an advantage and the wind always hits the turbine tangentially [19].

The modern wind turbine is a sophisticated piece of machinery with aerodynamically designed rotor and efficient power generation, transmission and regulation components. The size of these turbines ranges from a few Watts (Small Wind Turbines) to several Million Watts (Large Wind Turbines). The modern trend in the wind industry is to go for bigger units of several MW capacities in places where the wind is favorable, as the system scaling up can reduce the unit cost of wind-generated electricity. Most of today's commercial machines are horizontal axis wind turbines (HAWT) with three bladed rotors.

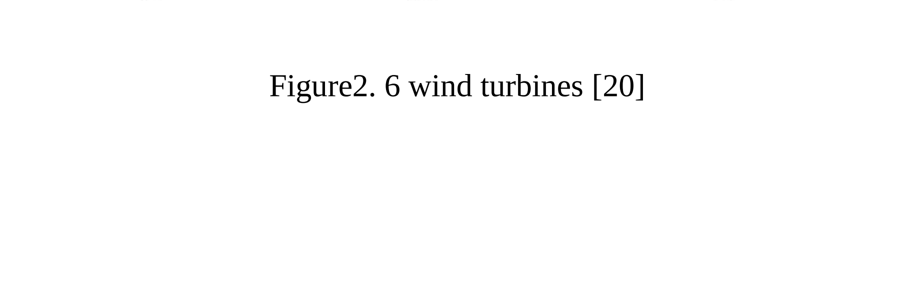

Figure2. 6 wind turbines [20]

HAWT are either upwind machine or down wind machines:

(a) Upwind machine (b) or down wind machines (c) Vertical axis wind turbines (VAWT) accept wind from any direction [20].

2.3.3.1. Wind turbines components

The most common turbine type is the horizontal axis wind turbine. A cut-view (below figure) helps the reader to get familiar with the components of a wind turbine.

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Hub: Hub is the connection point for the rotor blades and the low speed shaft.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes specially for small scale wind turbines.

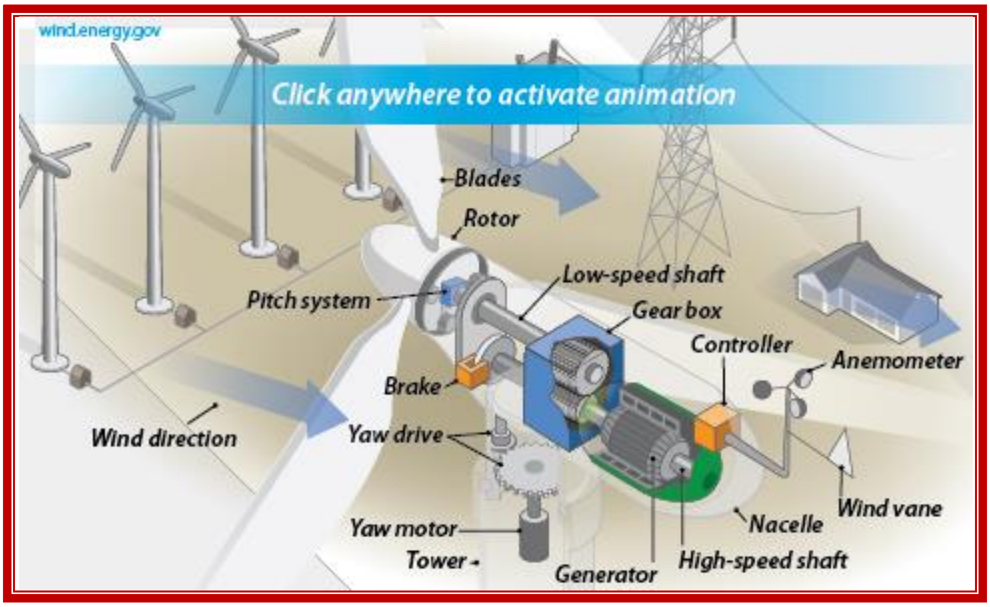

Figure2. 7 Cut-view wind turbine [7]

Generator: The generator is connected to the high-speed shaft and is the component of the system that converts the rotational energy of the shaft into an electrical output.

Tower of wind power generation: The tower is used to support the nacelle and rotor blades and typically made of rolled, tubular steel, and built and shipped in sections because of its size and weight. Common tubular towers incorporate a ladder within the hollow structure to provide maintenance access. Small -scale towers range in height from 24-35m and its weight depends on the material from where it is manufactured.

Nacelle: The rotor attaches to the nacelle, which sits top the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 3.5 to 7.2 meters per sec (m/s) and shuts off the machine at about 30 m/s.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rpm.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.

Yaw motor: Powers the yaw drive.

Electronic equipment: Such as controls, electrical cables, ground support equipment and interconnection equipment.

2.3.3.2. Workings principles of wind turbines

The blade, using aerodynamic lift, capture energy from wind in order to turn the shaft. In small wind turbines the shaft usually drives the generator directly. The generator converts the mechanical energy into electricity. The shaft power causes coils to spin past alternate poles of magnets allowing electric current to flow. If a permanent magnet device is being used the opposite occur: current flow as magnets spin past coil windings. Most small wind turbines use a permanent magnet alternator. Large wind turbines usually use either induction generator or a synchronous generator. In addition, in large wind turbines the shaft connected to the generator via a gearbox those steps up the rotational speed for the generator.

2.3.3.3. Wind energy extraction by HAWT

The energy of wind is extracted by using appropriate wind turbine. The wind energy is tapped by the wind turbine which converts the kinetic energy of the wind into mechanical shaft energy. The rotational energy is converted into electrical energy through the transmission system. The transmission system consists of the rotor shaft with bearings, brake(s), an optional gearbox, as well as a generator and optional clutches.

Energy conversion from free-flowing fluid streams is limited because full energy extraction implies decrease of fluid velocity (decrease of kinetic energy of the stream), down to zero which is impossible. Some fluid may not pass through the turbine and may simply flow around it (bypass it).

The power coefficient and efficiency of wind turbines vary greatly from manufactures to manufacturers. As a result, the power output of wind turbines vary from turbine to turbine and is given by power curve which plots the output power of a turbine against wind speed (see Figure 2.8).

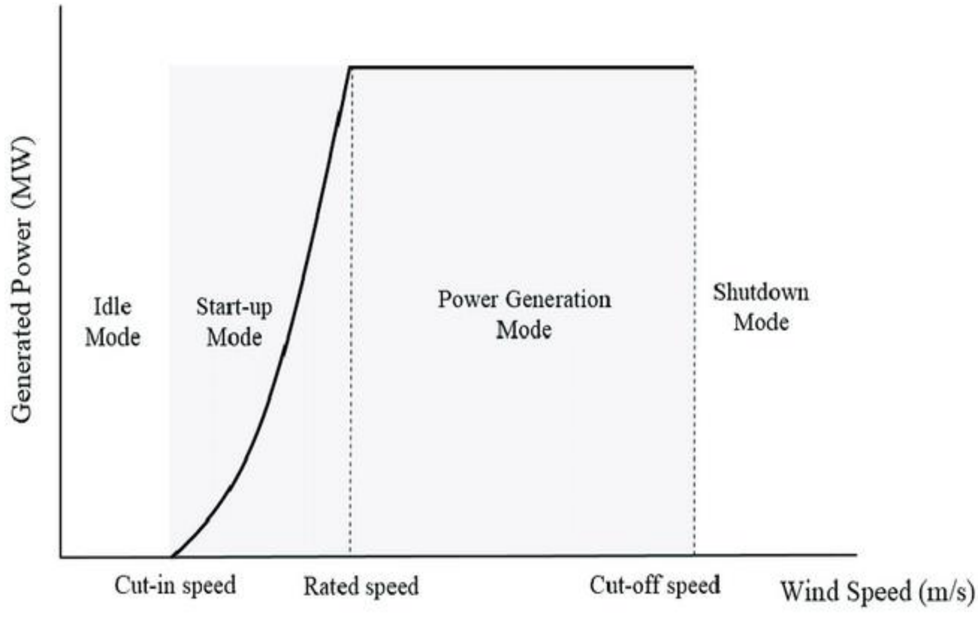

Figure2. 8 General Power curve of wind turbine [14]

The wind speed at which wind turbine starts generating electrical power is called the cut- in speed. The rated wind speed is the wind speed at which the turbine operates at its maximum efficiency of energy conversion. Rated power is the power output at the wind speed which is equal to, or above, the rated speed. The cut-off speed is the wind speed at which the turbine maybe shut down to protect the rotor and drive train machinery from damage, or high wind stalling characteristics.

2.3.3.4. Wind turbines power control mechanism

All wind turbines are designed with some sort of power control. There are different ways to control aerodynamic forces on the turbine rotor and thus to limit the power in very high wind speeds in order to avoid damage to the turbine. There are three commonly used types of power control in the industry [22].

- Stall Control
- Pitch Control
- Active stall regulation

The simplest, most robust and cheapest control method is the stall control (also called passive control), where the blades are bolted onto the hub at a fixed angle. The fixed-blade pitch is chosen so that the turbine reaches its maximum or rated power at the desired wind speed. The design of the rotor aerodynamics causes the rotor to stall (lose power) when the wind speed exceeds a certain level which limits the aerodynamic power on the blades.

Another type of control is pitch control, where the blades can be turned out or into the wind as the power output becomes too high or too low, respectively. Generally, the advantages of this type of control are good power control, increased energy capture, assisted startup and emergency stop. The pitch change system has to act rapidly. From an electrical point of view, good power control means that at high wind speeds the mean value of the power output is kept close to the rated power of the generator. The extra complexity arising from the pitch mechanism and the higher power fluctuations at high wind speeds can be mentioned as the demerits of this control scheme.

The third possible control strategy is the active stall control, in which the stall of the blade is actively controlled by pitching the blades. At low wind speeds, the blades are pitched similar to a pitch-controlled wind turbine, in order to achieve maximum efficiency. At high wind speeds, the blades go into a deeper stall by being pitched slightly into the direction opposite to that of a pitch-controlled turbine. The active stall wind turbine achieves a smoother limited power, without high power fluctuations as in the case of pitch-controlled wind turbines. This control type has the advantage of being able to compensate variation in air density and inherits the advantages of both pitch and stall control mechanisms.

2.3.4. Wind energy resources

Wind resource is the most important element in determining turbine performance at a given place. The energy that can be extracted from a wind stream is proportional to the cube of its velocity. In addition, the wind resource itself is intermittent. It varies with year, season, and time of day, elevation above ground, and form of terrain. Proper choice of site which is free from large obstructions, improves wind turbines performance.

2.3.5. Wind speed measurement

The wind speed is measured with an instrument called an anemometer. These instruments come in several types. The most common type is a cup anemometer which has three or four cups attached to a rotating shaft. When the wind hits the anemometer, the cups and the shaft rotate. The angular speed of the spinning shaft is calibrated in terms of the linear speed of the wind. Normally, the anemometer is fitted with a wind vane to detect the wind direction. A data logger collects wind speed and wind direction data from the anemometer and wind vane respectively.

It is very important that the measuring equipment is set high enough to avoid turbulence created by trees, buildings or other obstructions. Readings would be most useful if they have been taken at hub height where the wind turbine is going to be installed [15].If the measurement of wind speed was not made at the wind turbine hub height (in this case it is 10 m) it is important to adjust the measured wind speed to the hub height. This can be done using either the logarithmic law, which assumes that the wind speed is proportional to the logarithm of the height above ground, or the power law, which assumes that the wind speed varies exponentially with height.

Table2. 2 Friction coefficient α of various terrains [16]

Terrain Type	Friction coefficient α
Lake, ocean, and smooth, hard ground	0.1
Foot-high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

2.3.6. Wind resource in Ethiopia

Ethiopia has exploitable reserve of 100 GW wind energy with an average speed of 3.5 – 5.5 m/s, flowing for 6 hours/day. There are two basic zones with homogenous periodicity separated by the rift valley. In the first of these, covering most of the highland plateaus, there are two well-defined wind speed maximal occurring, respectively, between March and May and between September and November. In the second zone, covering most of the Ogaden and the eastern lowlands, average wind velocity reaches maximum values between May and August [22, 25]. Currently two projects are constructed; one Ashegoda wind park (near Mekele) of 120MW and the other Adama Wind Park of nearly 51MW and Adama Wind II Park 153 MW.

2.3.7. Wind potential assessment in the study area

The resource assessment for the wind potential is done by taking the data's only from NASA. This is because of the absence of full data regarding wind speed in the National Metrological Service Agency of Ethiopia and in SWERA. Therefore, the annual average wind speed for Bosat, which is located at latitude and longitude of 7°30' 0''N and 40°30'0''E and an elevation of 1606 meters above sea level, is found to be 4.2 m/s at a height of 10m. This value is used as an input to the wind resource in modeling the hybrid system. Year of 2013-2017 data.

Table2. 3 Monthly averaged wind speed of the village

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.73	4.36	4.03	3.84	4.04	4.51	4.30	4.07	3.79	3.75	4.30	4.67

2.4. Converter

A converter is an electronic power device that is required in a hybrid system to maintain the energy flow between AC and DC electrical components. It has an inverter and a rectifier to do the conversions from DC to AC and vice versa. The converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The rectifier capacity, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity has been specified. The final physical properties of the converter are its inversion and rectification efficiencies, which are assumed to be constant. The economic properties of the converter are its capital and replacement cost in dollars, its annual O&M cost in dollars per year, and its expected lifetime in years.

2.5. Inverter

An inverter is an electrical device that converts DC power to AC power at a desired output voltage or current. Its typical application is to convert DC power from a battery or PV array into AC power for use with conventional, utility-powered household appliances. Basically, there are three kinds of DC-AC inverters; square wave, modified sine-wave, and pure sine wave inverters. Among the three, the square wave type is the simplest and least expensive, but with the poorest quality output signal. The modified sine wave type is suitable for many load types and is the most popular low-cost inverter. Pure sine wave inverters produce the highest quality signal and are used for sensitive devices such as medical equipment, laser printers, stereos, etc. The working principle of most inverters is to use a low DC voltage input and to first step-up the voltage to a level corresponding to that of the peak value of the desired AC voltage and then generate the desired AC voltage by using a full-bridge or half bridge electronic circuit configuration. The output voltage of the inverter is controlled by electronic circuitry.

2.6. Battery

Batteries are a key component in a stand-alone renewable energy system. Basically, a battery is a device that stores energy for later use. It is a combination of electrochemical cells that can store chemical energy that has the potential to be converted into electric voltage or, to put it simply; it is a device that converts chemical energy directly to electrical energy. Lead-acid battery is the type of battery commonly used in stand-alone power systems. Batteries can be classified in two ways: by their application (the way they are used) and their construction (how they are built). The major construction types are flooded (wet), gelled, and AGM (Absorbed Glass Mat). The construction aspect is beyond the scope of this work. With regard to their applications, the major ones are automotive (starting), marine, and deep-cycle. Deep-cycle batteries are used in renewable energy applications. In terms of the automotive (starting) type, it is designed to provide a large amount of current for a short period of time. To achieve a sufficiently large amount of current, car batteries use thin plates in order to increase the surface area. Such batteries are not suitable for storing the energy that PV or hybrid systems produce. On the other hand, Deep Cycle batteries are designed to be discharged as low as 80 % and recharged over and over again and therefore have much thicker plates. It is important to note that companies recommend that hybrid system batteries should not be discharged beyond 50% of their capacity. Deep Cycle batteries deliver a consistent voltage as the battery discharges. The Marine type is usually hybrid and falls somewhere between the starting and deep-cycle battery types. The plates may be composed of lead sponge, but it is coarser and heavier than that used in starting batteries. With regard to the effect of temperature on batteries, the battery capacity is reduced as the temperature goes down, and is increased as the temperature goes up. The standard rating for batteries is

25 0C. Battery Ah capacity drops to 50% at approximately -27 0C. At freezing (≈0°C), capacity is reduced by 20%.

2.7. Diesel Generator

A diesel generator is simply a normal electric generator driven by a diesel engine (prime mover). An electrical generator is an electromechanical system that converts mechanical energy into electrical energy through the interaction of electromagnetic and electrostatic fields within the system. Below figure shows the per-phase equivalent circuit of a synchronous generator driven by a prime mover, which in this case is the diesel engine. T is the mechanical torque of the prime mover, $E_a$is the internal voltage generated, $I_a$is the armature current, R_a+ j$X_s$is the synchronous impedance, and $V_a$is the load voltage.

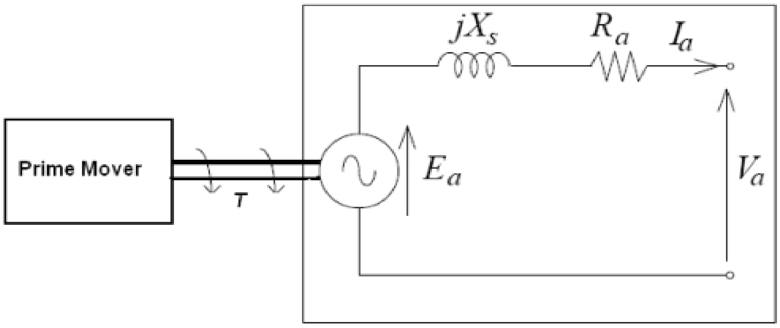

Figure2. 9 The Per-Phase equivalent circuit of a synchronous generator driven by a diesel generator (prime mover) [23].

2.8. HOMER tool

HOMER is a user-friendly micro-power design tool that was developed by NREL in the U.S.A to assist the design of power systems and facilitate the comparison of power generation technologies across a wide range of applications [24]. HOMER is used to model a power system physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life time. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

2.9. Energy basics and management

Energy is the ability to do work and work is the transfer of energy from one form to another. In practical terms, energy is what we use to manipulate the world around us, whether by exciting our muscles, by using electricity, or by using mechanical devices such as automobiles. Energy comes in different forms-heat (thermal), light (radiant), mechanical, electrical, chemical, and nuclear energy. It is difficult to imagine spending an entire day without using energy. We use energy to light our cities and homes, to power machinery in factories, cook our food, play music, and operate television.

2.9.1. Energy management and energy audit

The term energy management means the judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions [25].The fundamental goal of energy management is to produce goods and provides services with the least cost and least environmental effect. The objectives of energy management are to achieve and maintain optimum energy procurement and utilizations throughout the organization, to minimize energy costs/waste without affecting production and quality, and to minimize environmental effects [25].

Energy audit is the key to a systematic approach for decision –making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Energy audit is defined as "the verification, monitoring, and analysis of use of energy include g submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption [25].

2.10. Programmable logic controller

A PLC or Programmable logic controller is a microprocessor-based controller with multiple inputs and outputs. Also it is a solid state member of the computer family, using integrated circuits instead of electromechanical devices to do control functions. It uses a programmable memory to store instructions and carry out functions to control machines and processes. They are capable of storing instructions, such as sequencing, timing, counting, arithmetic, data manipulation and communication to control industrial machines and processes.

The PLC performs the logic functions of relays, timers, counters and sequencers. It has the following advantages:

- ✓ Low cost
- ✓ Reliability
- ✓ Reprogram ability

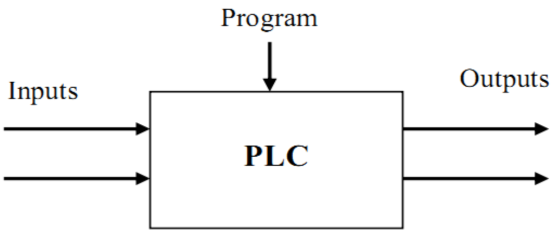

Figure2. 10 PLC conceptual application diagram [26]

2.11. Operation of programmable logic controller

The operation of a programmable logic controller is simple. The input/output (I/O) system is physically connected to the field devices that are encountered in the machines or that are used in the control of a process. These field devices may be discrete or analog input/output devices such as limit switches, pressure transducers, push buttons, motor starters, solenoids; etc. The I/O interfaces provide the connection between the CPU and the information providers (inputs) and controllable devices (outputs) [26].

CHAPTER-3: MATERIAL AND METHODOLOGY

3.1. Site survey

As it is described in chapter one introduction the rural area where this thesis handled is Nura Hase village which located in Ethiopia, Oromia, East-Shewa, Bosat district at latitude and longitude of 7°30’ 0’’N and 40°30’0’’E facing hard problems of giving electric access by extending the grid problems due to the difficulty geographical layout of the remote locations.

3.2. Electric load estimation

One of the basic inputs to HOMER is the load profile of the system. The term loads refers to a demand for electric energy. Two types of loads are modeled using HOMER: - primary load which is electric demand that must be served according to a particular schedule and deferrable load which is electric demand that can be served at certain period of time, the exact timing is not important.

According to Bekele G. [22], electric load in the rural villages of Ethiopia can be assumed to be composed of lighting, radio and television, water pumps, health post and primary schools load.

In this study, electricity for flour mills is added to the load together with radio receiver and health post is upgraded to health clinic with additional medical equipment. Water pumps are considered as deferrable loads while the others as primary loads. As introduced earlier, the communities understudied with equipped primary school, church and a health clinic has 300 households with an average 4 members per family.

3.2.1. Electric load estimation of study area

The total power generated by the hybrid solar-wind-genset system is given as the addition of the power generated by the solar panel, power generated by the wind turbine and diesel generator. To decide the power generated by the system, the number of households and the appliances they use in their home and the electricity need for public services must be known.

3.2.1.1. Primary loads

The total watt-hour energy required for primary loads by the village is the sum of energy hours used by all households (domestic loads), health center, churches and school

.3.2.1.1.1. Domestic loads

The home appliances used by each of household are given in the table 3.1 with their power rating.

Table3. 1 The home appliances used by households

Home Appliance	No of loads to another	Power consumption per load (W)	Total Power consumption per house hold (W)	Total Power consumption Loads per 300 households (KW)	Operating hours/day	KWh/day (daily usage)
Internal lighting	3	15	45	13.5	18:00-23:00	67.5
Radio/Tape	1	4	4	1.2	8:00-10:00 12:00-14:00 18:00-20:00	7.2
TV set	1	100	100	30	8:00-9:00 18:00-21:00	120
Mobile charger	1	4	4	1.2	6:00-8:00	2.4
Electric oven	1	1000	1000	300	12:00-12:20 19:00-19:20 06:00-06:20	300
External lighting	1	15	15	4.5	19:00-6:00	49.5
Total						546.6

As shown in households table the watt-hour energy required on average is 546.6 KWh/day.

For the community three flour machines of 12.5kw capacity each working from 9:00-12:00, 7:00 to 8:00 and 13:00 to 18:00 are assumed and daily used Kwh/day energy for three machines is 337.5 KWh/day.

3.2.1.1.2. Healthy center loads

The electric energy needed by the health center of the village is given in the table 3.2.

Table3. 2 The electric energy needed by the health center of the village

Appliances	Quantity	Power consumption per load (W)	Total Power consumptions (W)	Total load in (kW)	Operating hours/day	kWh/day (daily usage)
Internal lighting	11	15	165	0.165	17:00-1:00	1.32
TV set	2	100	200	0.2	8:00-12:00 14:00-16:00 18:00-20:00	1.6
Vaccine Refrigerator	2	60	120	0.12	0:00-24:00	2.88
Microscope	2	15	30	0.03	10:00-12:00 14:00-16:00	0.12
Computer	2	60	120	0.12	9:00-12:00 20:00-22:00	0.6

Ceiling Fan	10	75	750	0.75	11:00-12:00 13:00-18:00	4.5
External lighting	10	15	150	0.15	19:00-6:00	1.65
Total						12.67

Total watt-hour energy required by health center of the village on average is 12.67 KWh/day.

3.2.1.1.3. Churches loads

The energy used by the churches at the villages is given in table 3.3.

Table3. 3 The energy used by the churches at the village

End use appliances	Quantity	Power consumption per load (W)	Total Power consumptions (W)	Total load in (kW)	Operating hours/day	kWh/day (daily usage)
Internal lighting	10	15	150	0.15	18:00-20:00 4:00-6:00	0.6
Ceiling Fan	10	75	750	0.75	11:00-12:00 13:00-18:00	4.5
External lighting	6	15	90	0.09	19:00-6:00	0.99
Megaphone	6	15	90	0.09	6:00-9:00	0.27
Total						6.36

As depicted in churches table the watt-hour energy required by churches at the village on average is 6.36 KWh/day.

3.2.1.1.4. School loads

The energy used by the school at the villages is given in table 3.4.

Table3. 4 The energy used by the school at the village

Home Appliance	Quantity	Power consumption per load (W)	Total Power consumptions (W)	Total load in (kW)	Operating hours/day	kWh/day (daily usage)
Internal lighting	15	15	225	0.225	18:00-21:00	0.675
Microscope	2	15	30	0.03	10:00-11:00 14:00-15:00	0.06
Computer	6	60	360	0.36	9:00-12:00 20:00-22:00 7:30-8:00	1.8
Megaphone	2	15	30	0.03	12:15-12:45	0.06
Radio/Tape	3	4	12	0.012	7:30-8:00 12:15-12:45 17:30-18:00	0.036
Ceiling Fan	10	75	750	0.75	11:00-	4.5

					12:00 13:00-18:00	
Vaccine Refrigerator	3	60	180	0.18	9:00-12:00 13:00-18:00	1.44
External lighting	10	15	150	0.15	19:00-6:00	1.65
Total						10.221

The school watt-hour energy required by school on average is 10.221 KWh/day. The total watt-hour energy required for primary loads by the village is the sum of energy hours used by all households, flour mills, health center, churches and school which is 913.351 kWh/day which are primary loads.

3.2.1.2. Deferrable loads in target area

Deferrable load is the load that should be fulfilled after the primary load demand is supplied except in especial cases when water tank left empty below the required level, regardless of the time. The aim is for providing water to the community in order to satisfy their water supply demand. In this Thesis 5 water pumps, one for health center & school and the rest four water pumps are assumed for households use. Each water pump has a 150W power rating, with capacity 10L/min and pumps supply 30000 l/day for the 300 families (100 liters per family); and 3000 l/day for the school and clinic. The average deferrable load (total consumption of electricity by the pumps) is calculated to be 7.5kWh/day for the households and 0.75kWh/day for the school and health post, totally 8.25kWh/day. The peak deferrable load (rated power of the pumps) is 0.6 kW for the households and 0.15 kW for the school and health post. A sufficient water storage capacity for 4 days is assumed and the corresponding electricity storage capacity is 30kWh for the households and 3 kWh for the school and health post.

Exceptions: In the weekends it is assumed that flour mills are not working because of religious concern and evening classes are conducted at day time. In the rainy season from

15% to 30% deferrable load can be expected to decrease because water consumption from the pumps is expected to be shared by river and rain water ponds [23]. 15% deferrable load decrease for June and September while 30% for July and August are assumed. There are no classes in July and August (annual break) and in January (semester break).

Table3. 5 Energy used by deferrable loads

Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
8.25	8.25	8.25	8.25	8.25	7.01	5.78	5.78	7.01	8.25	8.25	8.25

The total watt-hour energy required by the village is the sum of watt-hour energy required for primary loads and watt-hour energy required for deferrable loads, i.e.913.351kWh/day+91.586kWh/day =1004.937kWh/day and for the future load demand 25.063kWh/day as reserve. So the total watt-hour energy demand including the reserve is 1030kWh/day.

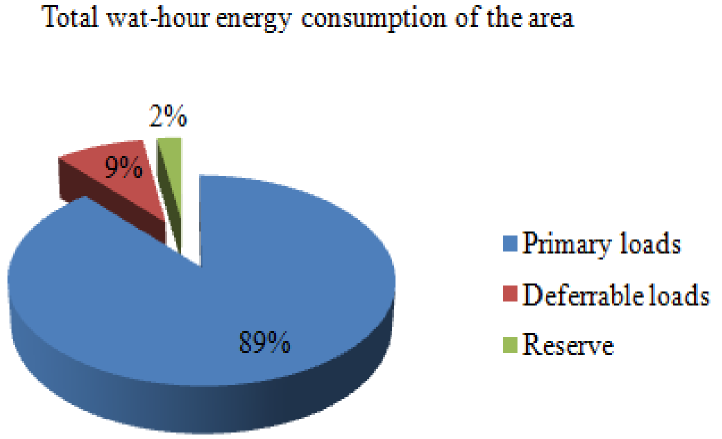

Figure3. 1 Total watt-hour energy consumption of the area

Table3. 6Hourly demands of primary loads

Hour	Demands
00:00-01:00	5.175
01:00-02:00	5.01
02:00-03:00	5.01
03:00-04:00	5.01
04:00-05:00	5.16
05:00-06:00	5.16
06:00-07:00	101.41
07:00-08:00	38.952
08:00-09:00	31.61

09:00-10:00	39.68
10:00-11:00	38.54
11:00-12:00	40.76
12:00-13:00	101.362
13:00-14:00	41.25
14:00-15:00	40.31
15:00-16:00	40.28
16:00-17:00	40.05
17:00-18:00	40.227
18:00-19:00	45.56
19:00-20:00	150.45
20:00-21:00	49.38
21:00-22:00	19.155
22:00-23:00	18.675
23:00-00:00	5.175

3.3. Electric load forecasting of the study area

A forecast of electricity demand of the village is made based on a method known as energy approach. In this approach the annual energy for residential customers are forecasted using appropriate growth rates such as population growth rates, customer growth (market penetration) and growth rates of consumption per connection which are described in the sections below [28].

Population Growth Rate: First year population figure is projected by an annual growth rate of 3%, until the end of the forecast period. This population figure is converted to total number of households using an assumed average number of occupants per household [7, 28].

Residential Consumption: The number of potential residential customers is changed to annual residential consumption by assuming an average per household consumption, which starts with 1030kWh on the first year. This average consumption per household is made to grow at a rate of 2.57% per year for the whole forecast period [7, 28].

Market Penetration (Customer Growth): At the first year of electrification, all households are assumed to be connected. Therefore, market penetration rate is necessary. After the first year of interconnection, 5% market penetration rate (MP) is taken to change the total number of households to potential residential customers until the end of forecast [7, 28].

Table3. 7 Energy forecast for the study area

Year	Average consumption rate increase	Number of Household	Yearly energy consumption (KWh)	Daily energy consumption (KWh)
2018	1030	300	309000	846.58
2019	1056.47	315	332788.05	911.75
2020	1083.62	331	358678.22	982.68
2021	1111.47	348	386791.56	1059.70
2022	1140.04	365	416114.6	1140.04
2023	1169.34	383	447857.22	1227
2024	1199.40	402	482158.8	1320.98
2025	1230.22	422	519152.84	1422.34
2026	1261.84	443	558995.12	1531.49
2027	1294.27	465	601835.55	1648.86
2028	1327.53	488	647834.64	1774.89
2029	1361.65	512	697164.8	1910.04
2030	1396.64	538	751392.32	2058.61
2031	1432.53	565	809379.45	2217.48
2032	1469.35	593	871324.55	2387.19
2033	1507.11	623	938929.53	2572.41

The above Table shows the forecasted yearly and daily energy consumption of the community for 15 years using energy approach method. This method is employed as the HOMER software used. But, didn't take in to account the forthcoming variation of energy consumption of the community. This is taken as a fundamental draw back or limitation of the software.

3.4. Resource assessment

The term resource applies to anything coming from outside the system that is used by the system to generate electric power. That includes the renewable resources (solar, wind, hydro, biogas and etc.). But, in my work, only I considered solar and wind renewable resources. It depends extremely on location. The solar resource depends strongly on latitude and climate, the wind resource on large-scale atmospheric circulation patterns and geographic influences. The nature of the available renewable resources affects the behavior and economics of renewable power systems, since the resource determines the quantity and the timing of renewable power production. The careful modeling of the renewable resources is therefore an essential element of system modeling. [32, 33].

3.4.1. Solar resource

To model a system containing a PV array, the solar resource data for the location of interest is needed. Solar resource data indicate the amount of global solar radiation (beam radiation coming directly from the sun, plus diffuse radiation coming from all parts of the sky) that strikes Earth's surface in a typical year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface (kWh/m^2), monthly average global solar radiation on the horizontal surface (kWh/m^2.day), or monthly average clearness index. Since, typical software I used is provided with monthly average clearness index form and clearness index range from 0.517(a cloudy month) to 0.678 (a very sunny month) is as shown in table 3.8 below. The clearness index is the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere.

Table3. 8 The daily solar radiation and clearance index

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.080	6.570	6.520	6.310	6.360	5.770	5.230	5.360	5.840	6.310	6.270	6.080
0.604	0.633	0.621	0.618	0.659	0.620	0.555	0.541	0.565	0.609	0.621	0.614

3.4.2. Wind energy resource

Likewise solar PV arrays to model a system comprising one or more wind turbines, the wind resource data indicating the wind speeds the turbines would experience in a typical year is needed.

The monthly average wind speed is 4.2m/s. (source NASA) Monthly Averaged Wind Speed at 50 m above the Surface of the Earth for the thesis area is varies from 3.75m/s to 4.73 m/s. The monthly average wind speed is 4.2m/s. This monthly average is taken from NASA surface metrology latitude and longitude of 7°30' 0''N and 40°30'0''E and an elevation of 1606 meters above sea level.

Table3. 9 Monthly averaged wind speed of the village

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.73	4.36	4.03	3.84	4.04	4.51	4.30	4.07	3.79	3.75	4.30	4.67

3.5. Components Assessment

A component is any part of a power system that either generates, delivers, converts, or stores energy. In this HOMER analysis the basic components of the hybrid system are SPV, wind turbines, and diesel generator. Others are additional/auxiliary components which help for full time functioning of the hybrid system such as Batteries and Converters. Batteries and Converters are for storing and converting electricity respectively. The performance and cost of each of the system's components is a major factor for the cost results and design. Thus, the development of these data was carried out with much diligence. A different set of performance and cost parameters is used by HOMER to characterize each of these different components.

Selection of PV Solar panels and Wind Turbines: It is known that as input into HOMER, values are given as primarily load, deferrable loads and component resources. These are the principal guidelines for selecting the size of the power components. Cost minimization is another criterion considered when selecting the components. One of the main criteria for the selection of the wind turbine is the cost. The wind turbines have been selected from different sources; the various wind turbine websites and those suggested by the HOMER program itself. Other selection criteria used are: - the type of current they generate (AC or DC), how low the cut-in wind speed, how expensive the wind turbine and for what application the wind turbine be used for. The cut-in wind speed is one of the main criteria, as the wind resource at the sites is not very high. As the turbine price would also affect the total net present cost, this has been checked with the respective vendors. The type of current they generate, whether AC or DC, is also considered as this would have repercussions on the size of the inverter. A wind turbine that generates AC current has been chosen, as the load assumed for the households is of an AC type. As the aim of the research is to supply electric energy to remotely located communities, the wind turbine selected is which is applicable for home or off-grid use. Based on the selection criteria mentioned above, different wind turbines have been tested by running the simulation several times. From those wind turbines which were candidates for this application, the Fuhrlainder 250 type has been found to be the best in terms of the cut-in wind speed, commonly available on the market and also in respect to other criteria mentioned earlier. This wind turbine was selected from those suggested by HOMER. The power curve is given below.

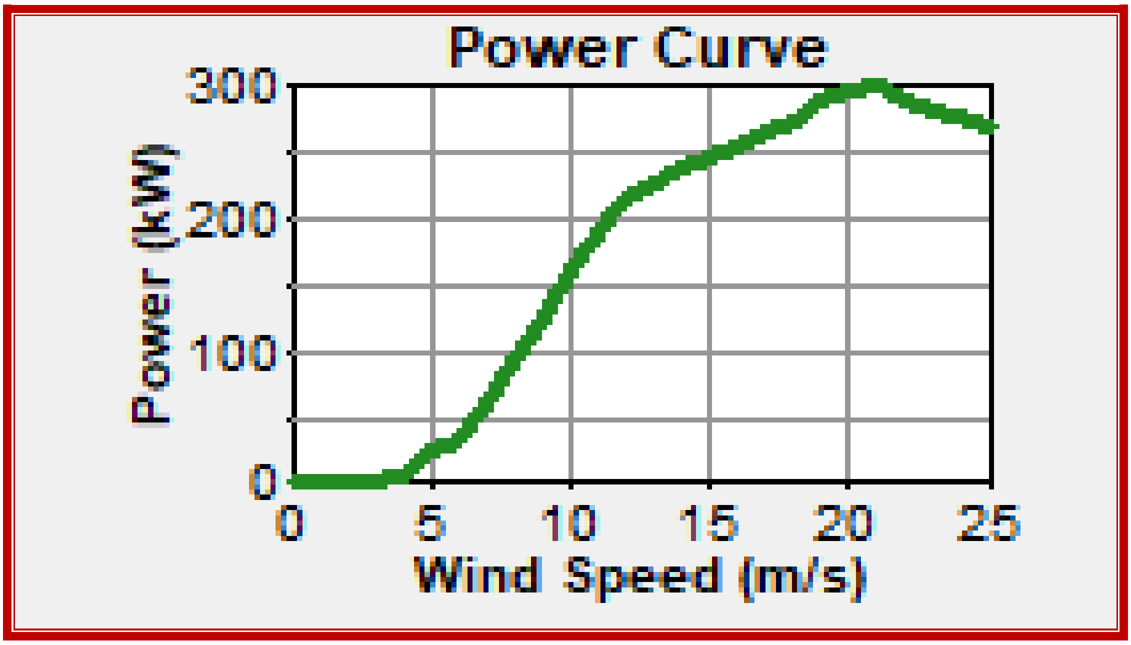

Figure3. 2 Power curve of 250 Kw turbines

Other inputs into the software, such as the range of sizes for the PV and the converter and the number of batteries, are given so as to give flexibility to the software and optimize the output results.

3.6. Cost estimation

3.6.1. Solar array

The PV array is a device that produces dc electricity in direct proportion to the global solar radiation incident upon it. In this paper, the derating factor considered is 80% for each panel to approximate the varying effects of temperature and dust on the panels. The panels have no tracking system and are modeled as fixed latitude of the location with the slope of 0°. To describe the cost of the PV array, its initial capital cost in dollars, replacement cost in dollars, and operating and maintenance (O&M) cost in dollars per year as explained below which is taken from different sources [29].The replacement cost is the cost of replacing the PV array at the end of its useful lifetime, which is specified in years.

In general, the cost of a solar panel bases runs between $0.2 to $1.2/w which will be in average $0.7/W. The cost of solar panel 1 kW rating is given by equation. Assume the labor cost is $100/kW. Capital cost (1kW) = solar panel cost/kW + installation cost/kW

Capital cost (1 kW) = $700 + $100 = $800.

The replacement cost is somewhat less than initial cost which is $700. Operating and maintenance costs are $10per year.

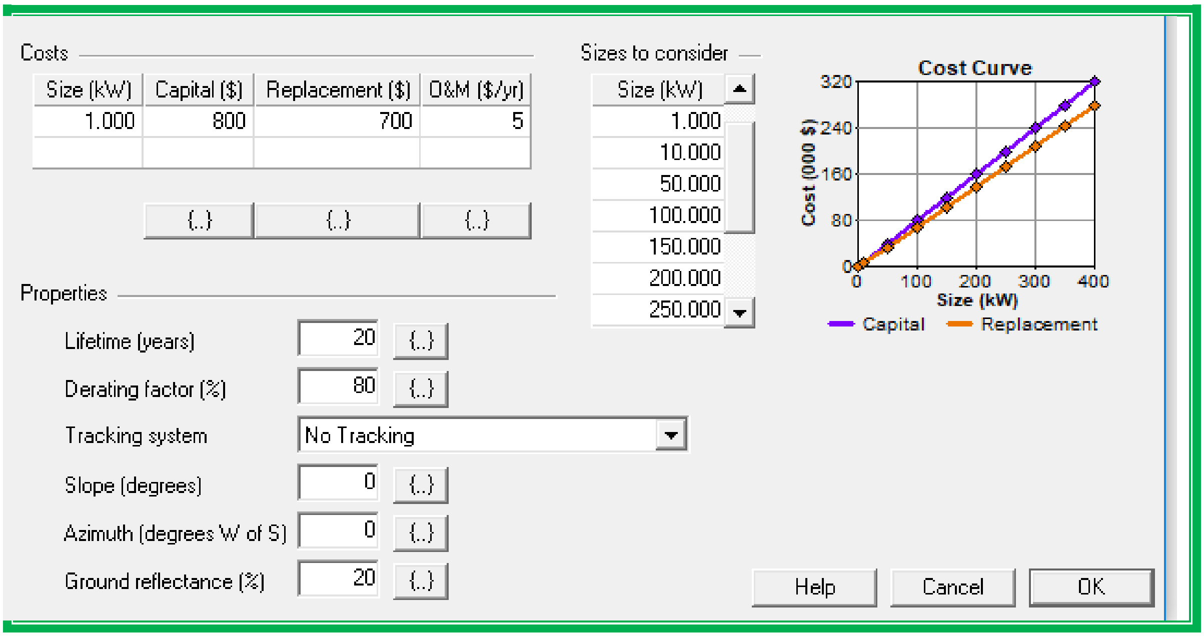

Figure3. 3 The cost of the solar panel

3.6.2. Wind turbine

A wind turbine is a device that converts the kinetic energy of the wind into ac or dc electricity according to a particular power curve, which is a graph of power output versus wind speed at hub height. In addition to the turbine's power curve and hub height, the expected lifetime of the turbine in years, its initial capital cost in dollars, its replacement cost in dollars, and its annual O&M cost in dollars per year has been specified. The primary criterion for the selection of the wind turbine is its cost. The wind turbines have been selected from different sources; the various wind turbine websites and those suggested by the HOMER program itself based on their costs. Other selection criteria used are: the type of current they generate (ac or dc), how low the cut-in wind speed is, and for what application the wind turbine is used for. As the load assumed for the households is of an ac type wind turbine that generates ac current has been chosen. As the aim of the research is to supply electric energy to remotely located communities, the wind turbines selected is applicable for home or off grid applications.

Based on the selection criteria mentioned above, Fuhrlainder 250 type has been found to be the best in terms of the cut-in wind speed and also in respect to other criteria mentioned earlier. [30].

In general, the cost of a wind turbine of per 30kW bases runs between $2000 to $2140.The operating and maintenance cost is $10/year [30].

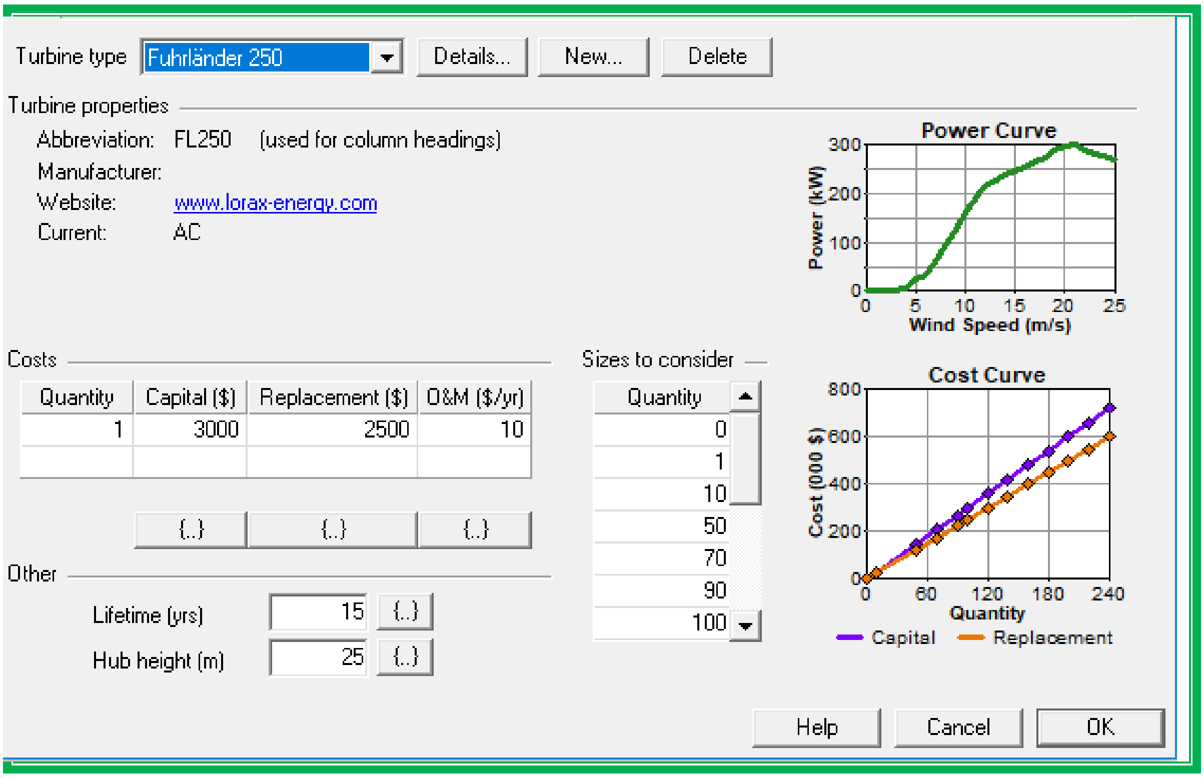

Figure3. 4 The turbine type used by the hybrid system

3.6.3. Battery

A device store a certain amount of DC electricity at fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement. The key physical properties of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. The capacity curve shows the discharge capacity of the battery in ampere-hours versus the discharge current in amperes. Capacity typically decreases with increasing discharge current. The lifetime curve shows the number of discharge–charge cycles the battery can withstand versus the cycle depth. The number of cycles to failure typically decreases with increasing cycle depth. The minimum state of charge is the state of charge below which the battery must not be discharged to avoid permanent damage. The round trip efficiency indicates the percentage of the energy going into the battery that can be drawn back out. The battery bank's capital and replacement costs in dollars, and the O&M cost in dollars per year have been specified as shown below. Any battery is characterized by its nominal voltage and its rated Ah capacity. The cost of 6V, 1156 Ah rating battery bank storage is $600 with 15-year life. So, the total cost of battery is $600+$45 (installation cost) which is $645 and operating and maintenance cost is $10/years [31].

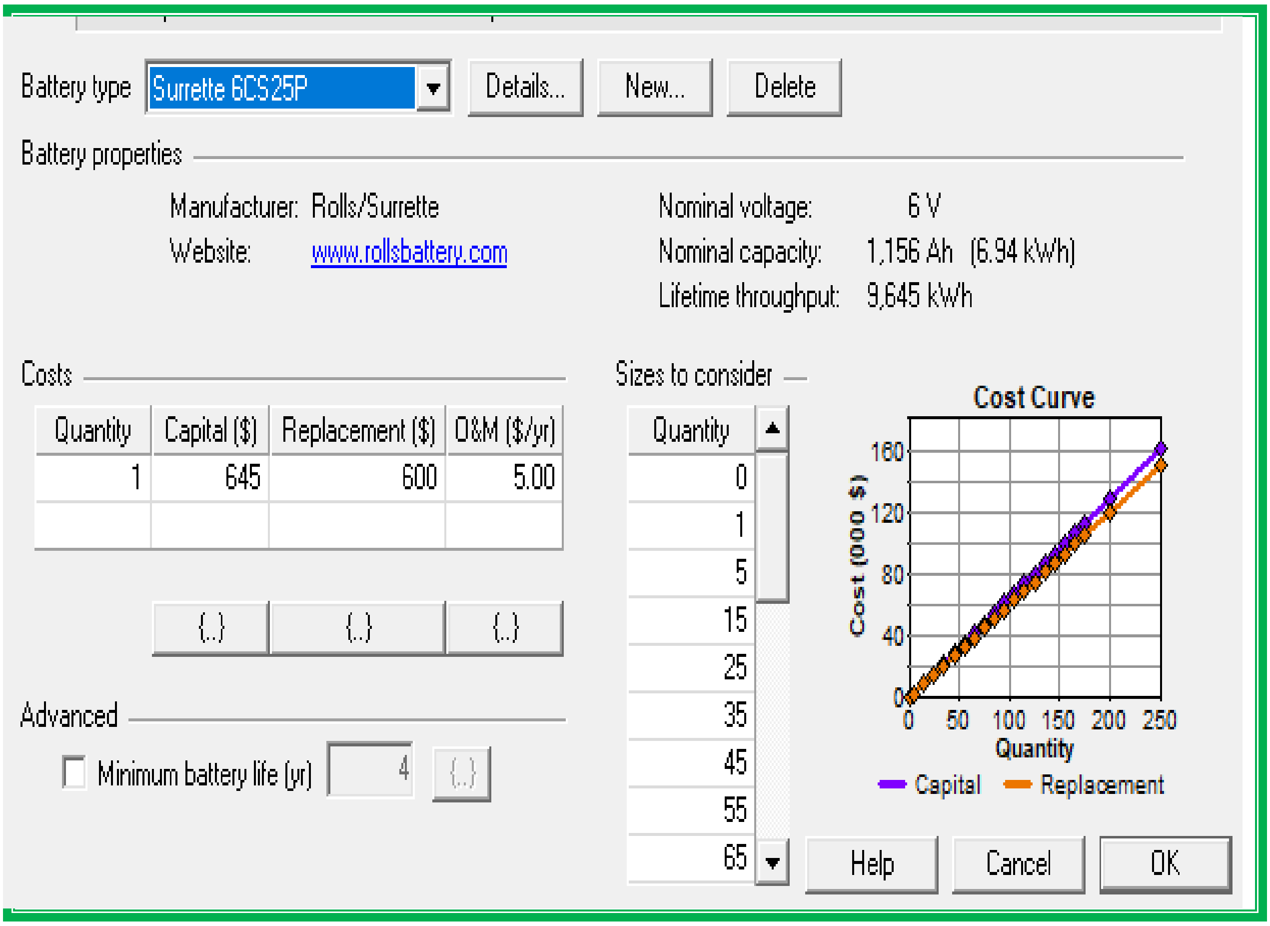

Figure3. 5 The type of battery used for the hybrid system

3.6.4. Converter

A converter is an electronic power device that is required in a hybrid system to maintain the energy flow between AC and DC electrical components. It has an inverter and a rectifier to do the conversions from DC to AC and vice versa. The converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The rectifier capacity, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity has been specified.

The final physical properties of the converter are its inversion and rectification efficiencies, which are assumed to be constant. The economic properties of the converter are its capital and replacement cost in dollars, its annual O&M cost in dollars per year, and its expected lifetime in years. The converter cost with rating 1.5kW has cost of range $100-$200 with best performances [31]. So the cost of converter taken as $200 and maintenance and operating cost $10/year.

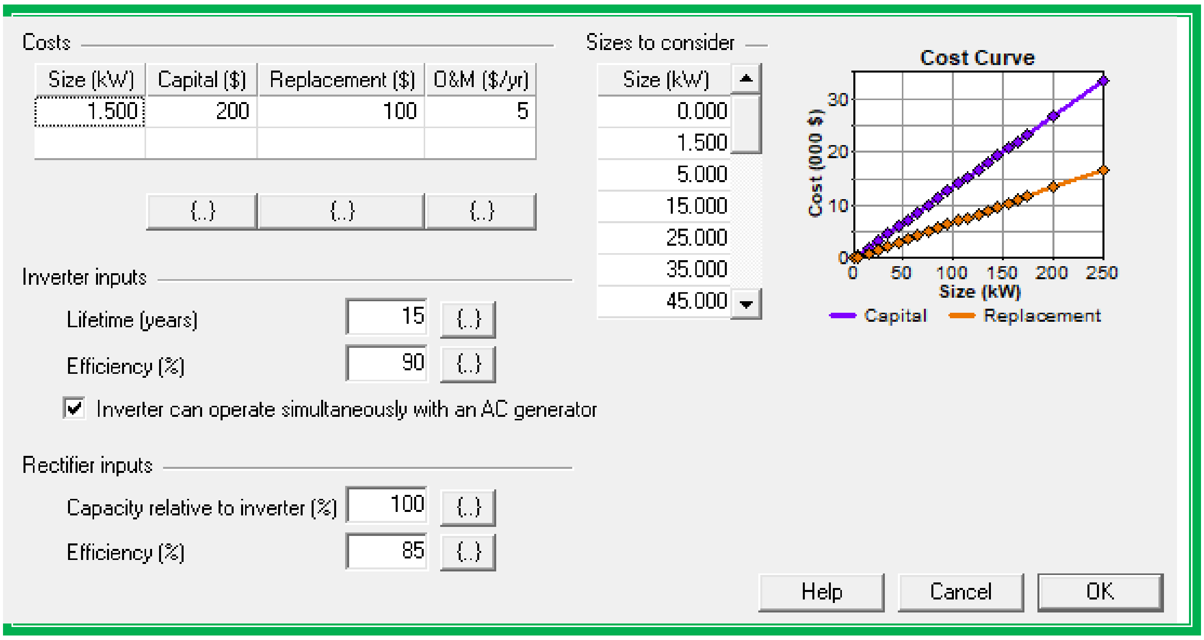

Figure3. 6 The cost of converter used for the hybrid system

3.7. Sensitivity inputs

The key variables for the micro power system are, however, often uncertain. This is a major problem to be overcome in the designing of the system. Here, one of the most important characteristics of HOMER comes into play: This software is able to conduct a sensitivity analysis on hourly data sets with the help of scaling variables. This way, uncertainties in the primary electric load or the renewable energies can be taken into account. Consequently, the sensitivity analysis allows the system designer to create a good and practical design in spite of uncertainties in the key variables [32, 33]. The uncertain variables for which a sensitivity analysis had to be conducted are the wind speed and the PV capital cost multiplier inter linked with the PV replacement cost multiplier. The sensitivities entered for the solar are 6.05kwh/h/d, 5.5kwh/h/d and 7kwh/h/d**.** For wind speed $4.2\frac{m}{s}$, $3.6\frac{m}{s}$and $5.5\ \frac{m}{s}$ and diesel price $0.5\frac{\$}{L}$,$0.74\frac{\$}{L}$ and $1.5\frac{\$}{L}$are the three values entered. For each of these different values the complete system is simulated with the resulting different technical and cost parameters.

3.8. Modeling of hybrid system using HOMER Tool

HOMER designed to overcome the uncertainty and also the complexity of the renewable energies being intermittent, seasonal, non-dispatch able and having uncertain availability.

Modeling of a stand-alone PV-wind-genset hybrid energy system for a community of 300 households, with average four members per family carried out based on the theoretical background discussed so far. As earlier, the main objective of the study is to design and model hybrid pv-wind-genset-battery based standalone power generation systems to meet the load requirements of the community specified earlier with energy management. A schematic representation of the standalone hybrid energy system by HOMER is shown on figure 3.1.

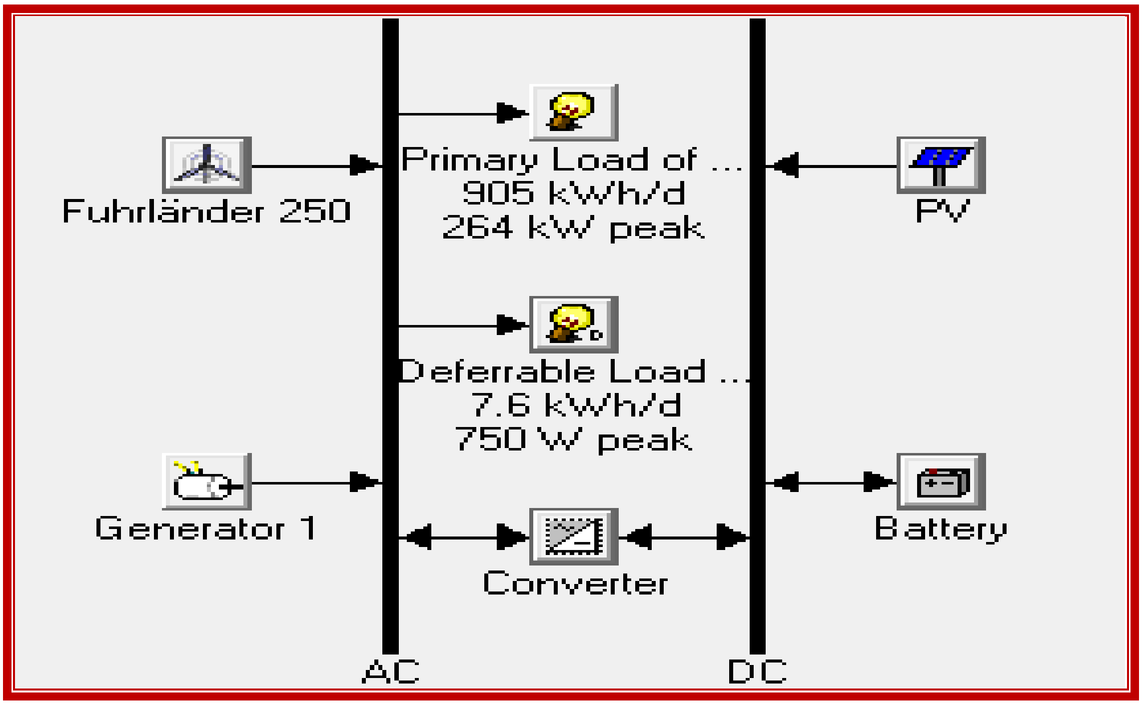

Figure3. 7 A schematic representation of the standalone hybrid energy system

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, the performance of a particular power system configuration for each hour of the year is modeled to determine its technical feasibility and life-cycle cost. In the optimization process, many different system configurations are simulated in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, multiple optimizations are performed under a range of input assumptions to judge the effects of uncertainty or changes in the model inputs. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price. The effects of these can be analyzed with the help of the sensitivity analysis. Figure3.2 shows how simulation, optimization and sensitivity analysis are interrelated. The oval figure enclosed in another oval figure shows that one optimization consists of multiple simulation and one sensitivity analysis consists of multiple optimizations.

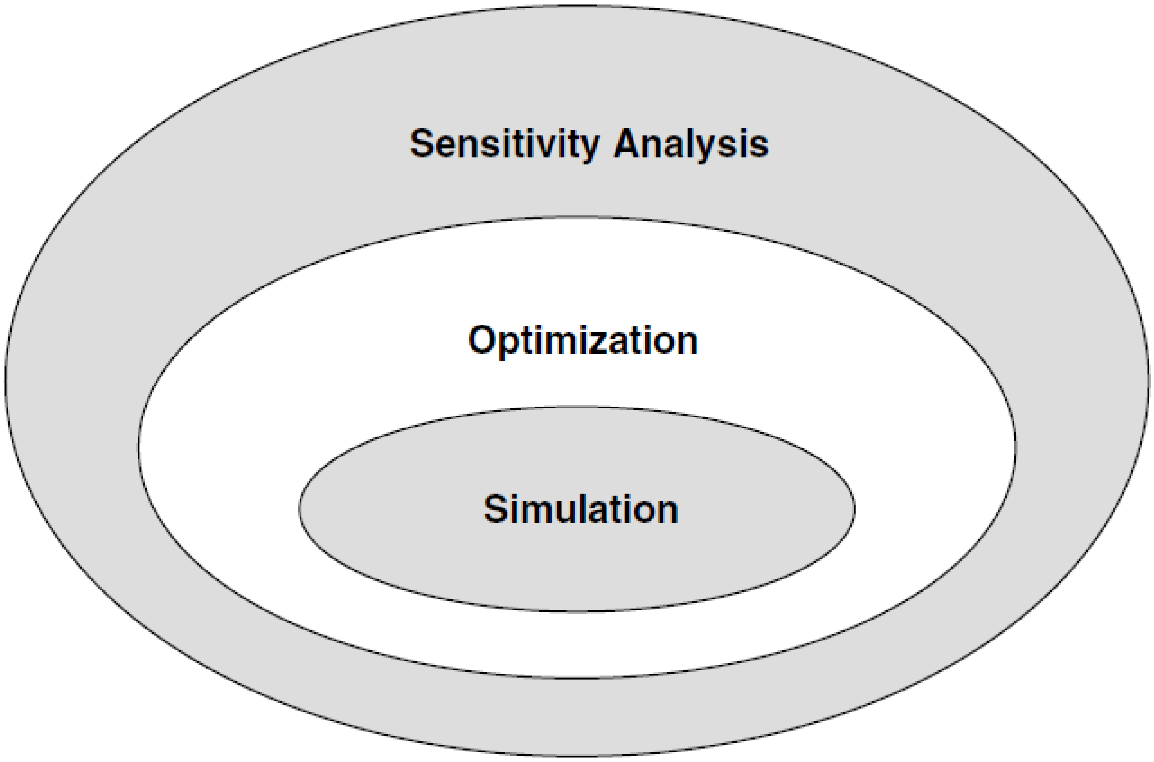

Figure3. 8 Conceptual relationship between simulation, optimization, and sensitivity analysis

In the next section how HOMER models the physical operation of a system is provided in greater detail. A power system must comprise at least one source of electrical energy (such as SPV system, a diesel generator, a wind turbine, or the grid), and at least one destination for that energy (electrical load). It may also comprise conversion devices such as a dc-ac converter or and energy storage devices such as a battery bank.

3.9. Hybrid energy system management and controlling using PLC

PLC used in thesis has four inputs (PV array, diesel generator, storage battery and wind turbine) and five out puts or loads (domestic loads, churches loads, healthy center loads, school loads and deferrable loads). When a system has more than two sources it is necessary to have an energy management system which is expected to optimize the power sharing among resources, the cost production and emission.

The main purpose of EMS based on PLC in this work:-

- ✓ Load control (switching)-on/off loads to achieve economic and effective energy use.
- ✓ Source control (switching) - which type source at what time (solar, wind, diesel generator and battery) continuous and reliable operation at economic level. The PLC controller makes decision on the output based on the operating state of the input.

Table3. 10 States of power supply units with respect to load demand and operating time in EMS based on plc control

Operating time	Demands (kw)	Wind Energy	Solar Energy	Diesel Generator	Battery
00:00-01:00	5.175	On	Off	Off	On
01:00-02:00	5.010	On	Off	Off	On
02:00-03:00	5.010	On	Off	Off	On
03:00-04:00	5.010	On	Off	Off	On
04:00-05:00	5.160	On	Off	Off	On
05:00-06:00	5.160	On	Off	Off	On
06:00-07:00	101.410	On	Off	On	On
07:00-08:00	38.952	On	On	Off	On
08:00-09:00	31.610	On	On	Off	On
09:00-10:00	39.680	On	On	Off	On
10:00-11:00	38.540	On	On	Off	Off
11:00-12:00	40.760	On	On	Off	Off
12:00-13:00	101.362	On	On	On	On
13:00-14:00	41.250	On	On	Off	On
14:00-15:00	40.310	On	On	Off	Off
15:00-16:00	40.280	On	On	Off	Off
16:00-17:00	40.050	On	On	Off	Off
17:00-18:00	40.225	On	On	Off	Off
18:00-19:00	45.560	On	Off	Off	On
19:00-20:00	150.450	On	Off	On	On
20:00-21:00	49.380	On	Off	On	On
21:00-22:00	19.155	On	Off	Off	On
22:00-23:00	18.675	On	Off	Off	On
23:00-00:00	5.175	On	Off	Off	On

Table3. 11 Generalized states of power supply units with respect to load demand and operating time in EMS based on PLC control

Operating time	Demands (kw)	Wind Energy	Solar Energy	Diesel Generator	Battery

00:00-06:00 **A**		30.525	On	Off	Off	On
06:00-07:00 **B**		101.41	On	Off	On	On
07:00-10:00 **C**		110.242	On	On	Off	On
10:00-12:00 **D**		79.3	On	On	Off	Off
12:00-13:00 **E**		101.362	On	On	On	On
13:00-14:00 **F**		41.250	On	On	Off	On
14:00-18:00 **G**		160.865	On	On	Off	Off
18:00-19:00 **H**		45.56	On	Off	Off	On
19:00-21:00 **I**		199.83	On	Off	On	On
21:00-00:00 **J**		43.005	On	Off	Off	On

When all resources (wind, solar, diesel generator and battery) are operating to supply demands i.e. between 12:00-13:00 (E-green color) time intervals**.**

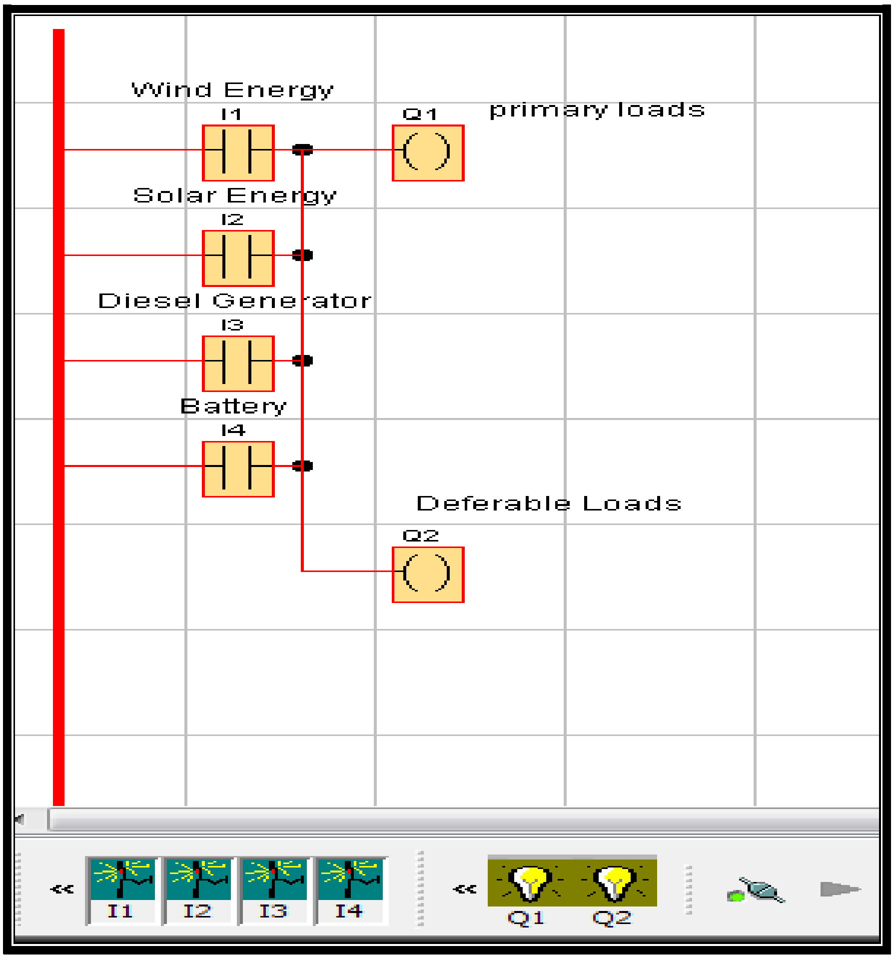

Figure3. 9 All energy sources are on

When all resources except solar energy are operating to supply demands i.e. between 06:00-07:00(B) and 19:00-21:00(I) time intervals which is blue color.

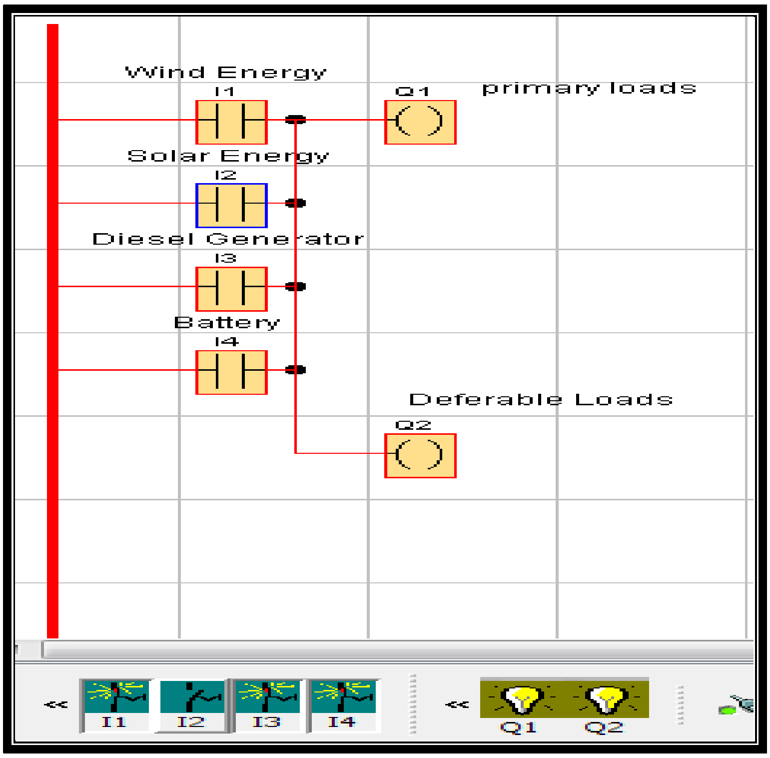

Figure3. 10 Solar energy source is off

When wind and solar energy are operating to supply demands i.e. between 10:00-12:00 (D) and 14:00-18:00 (G) time intervals which is red color.

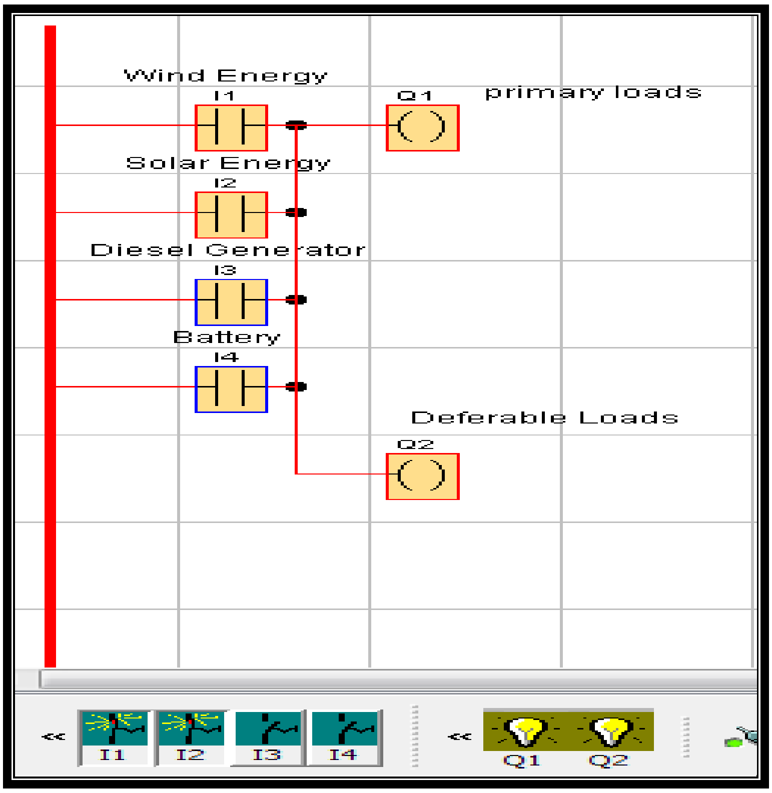

Figure3. 11 Energy source from battery and diesel generator are off

When wind energy and battery are operating to supply demands i.e. between 00:00-06:00(A), 18:00-19:00(H) and 21:00-00:00(J) time intervals which is yellow color.

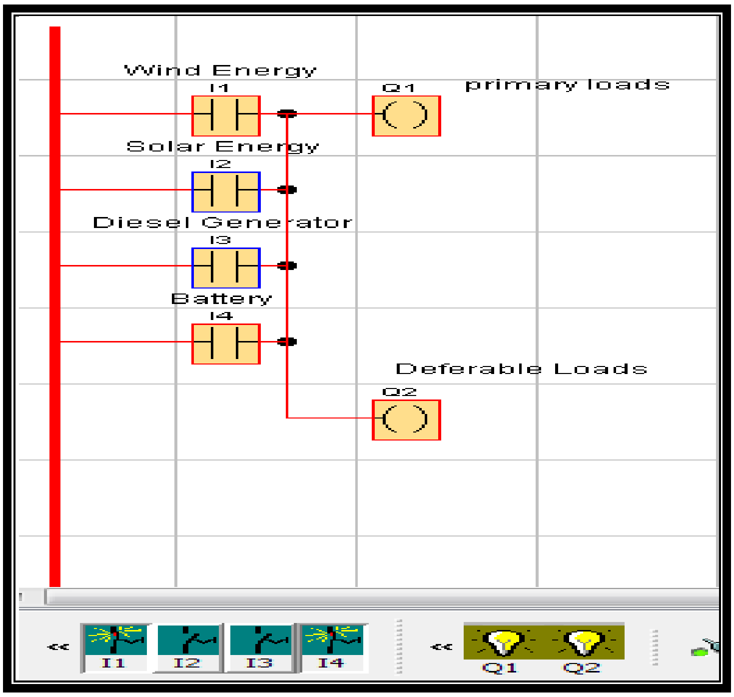

Figure3. 12 Energy source from solar and diesel generator are off

When all resources except diesel generator are operating to supply demands i.e. between 07:00-10:00(C) and 13:00-14:00(F) time intervals which is white color.

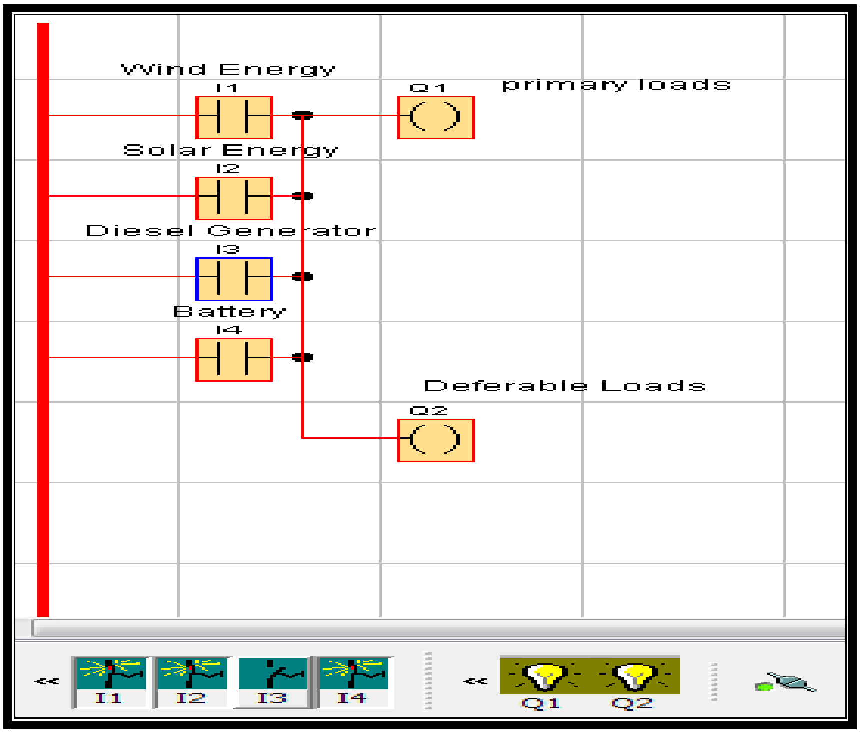

Figure3. 13 Energy source from battery is off

3.10. System dispatch

Apart from choosing the different components, HOMER has to make various decisions regarding the working together of these components, such as whether power should be sold to or bought from the grid, whether batteries should be charged or discharged, which generators should operate and at what power level etc. Furthermore, all of these decisions have to be taken for every hour of the day. The concepts of operating reserve and load priority affect HOMER's dispatch decisions. [32].

Operating reserve: Problems arising with micro power systems are the variability of the RES‟ power output and the possibility that the electric load demand might suddenly increase to exceed the operating capacity (which will lead to an outage). Therefore, every system needs an operating reserve, which is surplus generating capacity to provide a safety gap and be able to respond to these problems. The amount of a system's operating reserve always equals its operating capacity minus the electrical load.

Load priority: HOMER follows a load priority system, where it takes a separate set of decisions on the allocation of electricity produced by the system. HOMER serves the electricity produced from an AC source to an AC load first, the same goes for DC. In this study, as all loads are of AC connections, HOMER serves primary load followed by the deferred load.

Economic modeling: As aim of this thesis is finding the optimal system configuration; economics play a crucial role in the simulation. The indicator chosen to compare the different configurations' economic is the total NPC is taken as the economic figure of merit. The advantages of these indicators are as below.

The main difference between renewable and non-renewable resources regarding costs is that non-renewable resources usually have low capital and high operating costs, whereas for RES the costs are generally distributed in the opposite way: After a considerable investment in the beginning, the system can be operated at a comparatively low cost. To be able to compare the economics of numerous different system configurations with a varying share of renewable and non-renewable energy sources, HOMER has to take into account both the operating and capital costs. Since the NPC comprises of all costs incurred during the system's life span, it considers these factors and therefore is the appropriate parameter to compare the different configurations [33].The different items making up the NPC are the costs for construction, maintenance including component replacements and miscellaneous other costs. Furthermore, the NPC also considers salvage costs, which is the residual value of system components after the thesis's end [34].

An alternative to the NPC to compare the economics of various system configurations is the leveled COE, which is defined as the average cost for every kWh of electricity produced by the system. Yet, HOMER has chosen the NPC as primary economic figure of merit [34].

Economic inputs: The thesis's lifetime is considered to be 15 years with an annual interest rate of 10%. The nominal interest rate minus the inflation rate gives the real interest rate. The system fixed capital cost is considered to be $2,500 for the whole project and the system fixed O&M cost is estimated to be $2000/year for the project lifetime [35]. The system fixed capital costs includes various civil constructions, logistics, labor wages, required licenses, administration and government approvals and other miscellaneous costs. The penalty for capacity shortage is not considered in this case.

3.11. The grid system

The grid is modeled as a component from which the micro power system either buys AC electricity or sells AC electricity by feeding it back into the grid. In this study the grid is used by HOMER, to be compared with cost of the hybrid energy system. Therefore the cost of a grid extension is taken into the analysis to see whether a grid extension is viable or it is more economical for an off-grid system to operate. This way, the breakeven grid extension distance is determined. The breakeven grid extension distance is the distance from the grid which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Farther away from the grid, the stand-alone system is optimal. Nearer to the grid, grid extension is optimal. The capital cost of grid extension per kilometer of the Nura Hase village is considered to be $13,216.762/km. The detail analysis for the cost of grid extension is briefly expressed in table 3.12.

3.12. System constraints

If a small amount of load is allowed to go unserved, this can significantly affects the economic performance of the hybrid energy system. If the system can be designed to be down for a short period of time in a year or if some load can be shed, this can help in reducing the battery bank and hence significantly reduce the capital cost of the hybrid system [36]. The maximum annual capacity shortage is set at 1% and the minimum renewable fraction is taken as 50%. It also includes the Operating reserve, which was discussed above. An operating reserve of 15% of hourly load, 50% of solar output power and 40 % wind power output respectively is suggested.

3.13. Cost estimation of grid extension

Power is transmitted to the end users through distribution lines. This is mainly done by extending the national grid from a near-by substation or from an overhead medium voltage (MV) distribution line. The medium voltage levels that are most commonly used in MV system by the UEAP under the EEU are 33KV and 15KV. But now, the UEAP is using the 33KV voltage level for electrifying the remote rural areas due to its advantage over the other options.

However, voltage level which is extended for electrifying the remote rural areas which are nearby my study case is 15KV.The main components of an overhead distribution line that can affect the cost of grid extension are: the transformer, line supports and their foundation, insulators, line accessories, conductors and overhead earth wires. The line supports can be made from wood (like local wood pole and South Africa pole), reinforced concrete pole and steel, but due to its strength and availability UEAP is using concrete poles for MV distribution line to give electric access for selected rural areas.

The main tasks done during extension are surveying, excavation, pole erection, pole top configuration and stringing of conductors. For the MV distribution line construction Aluminum Alloy Conductor with a size of $95mm^2$ is used for the 15KV line. However, the number of poles to be erected and the requirement of guy wire depends on the distance of the site from a nearby substation or MV distribution line, and geographical location of the selected sites. Moreover, different accessories are used depending on type of assemblies; and these can be classified as suspension, light angle 1, light angle 2, heavy angle, T-off, tension tower, and dead-end assemblies based on the angle deviation from a straight line.

Based on the data mentioned above, the cost estimation for delivering electric access to Nura Hase village, which is found in Bosat district, is done. The distance of it from an existing grid is 40km, and a rough survey is conducted to select the type of assemblies to be used for MV distribution line construction. This village needs 2x200KVA and 5x630KVA rating transformers for supplying power to the people. To give electric access to the 300 household from the national grid found nearby, it needs extension of 40 km MV, 1.5 km LV distribution line and erection of two transformers with a rating of2x200KVA and 5x630KVA. Hence, the cost is analyzed using an interlinked spread Microsoft excel sheet used by the UEAP; and the result obtained is as indicated in table 3.12.The total cost as indicated on the table 3.12 includes material, transportation and labor cost, and the investment cost is therefore 14,546,420.89 Ethiopian birr which is equivalent to 528,670.47 US dollar currently.

Table3. 12 Total cost summary needed for extending a grid to the selected site Nura Hase

SUMMARY OF COST ESTIMATION	
List of Payment	Cost
1) Trafo. (Netstation) erection	4,501,877.49
2) L.T Line Extension	2,962,479.71
3) H.T.Line Extension	6,256,389.24
4) New Connection/Pillar	311,674.45
6)Trafo Partial	0.00
5) Substation. Partial	0.00
6) H.T. Partial	189,000.00
7) L.T Line Partial	0.00
8) Estimation Fee	600.00
9) Deposite	18,900.00
10) Unsold electric	1,500.00
11) El. Installation plan approval fe	304,000.00
12) Trans.Improvement	0.00
13)Allowance	0.00
Sub total	14,546,420.89
Trafo Deduct	0.00
Total	14,546,420.89

CHAPTER – 4: RESULTS AND DISCUSSIONS

In this chapter the results of the feasibility of a PV-wind-genset hybrid power system are presented. The conclusions and recommendations from the findings are drawn and made at the end. The feasibility of hybrid system, which supplies electricity to 300 model communities, was introduced previously. As it is shown on the figure 3.1 the inputted data fed for the HOMER simulation software described the primary load, deferrable load and system components (PV, 30 wind turbine type, Battery bank Surrette 6CS 25P type, and converter) with their costs. The system's simulations are performed by HOMER software.

The simulation result consists of several combinations of each source, with initial capital and net present cost of each of them. The monthly average solar radiation for Nura Hase village with latitude and longitude of 7°30' 0''N and 40°30'0''E and an elevation of 1606 meters above sea level fed into HOMER. Figure 4.1 and Figure 4.2 below show the solar radiation resource data with their clearance index and wind resource data of the village obtained from NASA surface metrology.

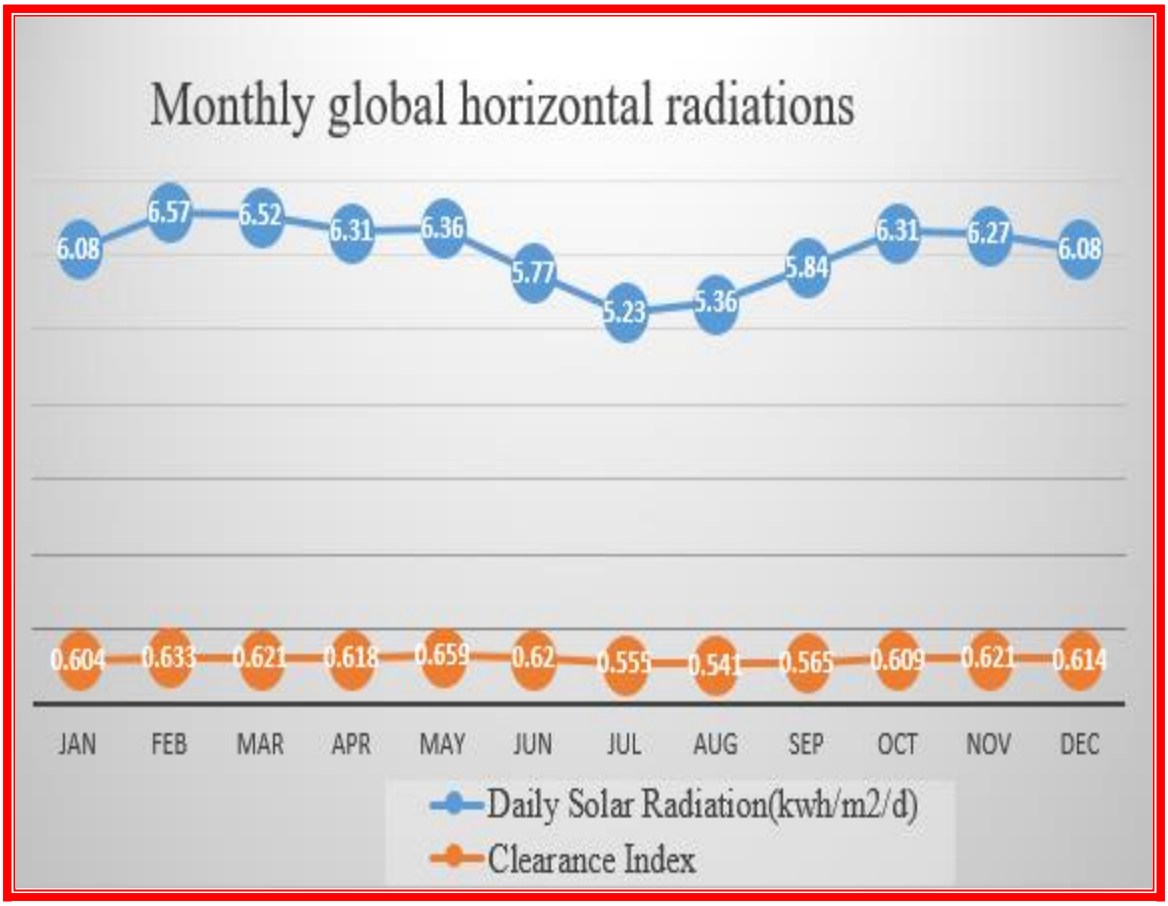

Figure4. 1 Monthly global horizontal radiations

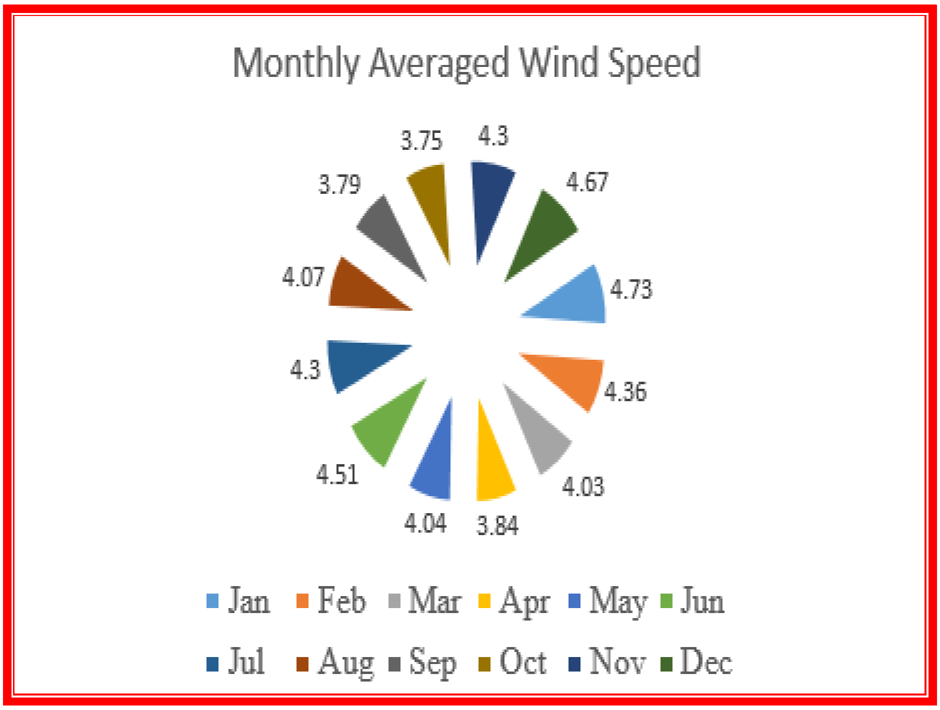

Figure4. 2 The wind resource of Nura Hase village

After feeding the available data to the software, to determine the optimum solutions from different system configurations, HOMER is simulated several times by varying decision variables that have effect on the output. The decision variables that affect the output are the size of PV panel, size of wind turbine, the number of battery bank, size of diesel generator and the size of converter. The outputs of the simulation result list the feasible combinations of solar panel, wind turbine, diesel generator, converter and battery of the hybrid system and discarding the infeasible combination of hybrid system. The optimization results are generated in two forms. The first result is the overall optimization results of hybrid system configurations are listed according to their best economical Net Present Cost (NPC) or the Initial Capital. The second result is the categorized optimum result of the system with only the least cost system configuration of the hybrid system configuration is selected for each system components.

The economic dispatch of the hybrid solar-wind-genset power system shows that most of the energy produced by the system is from the wind turbine system. So the cost of the wind turbine system is higher than of the solar system. The environmental impact of the hybrid system is zero which shows that it is a clean energy, free from environmental pollutant gases such as carbon dioxide and the other green gases. The overall optimization results of hybrid solar-wind-genset system simulated using HOMER Software is shown in figure 4.3.

Double click on a system below for simulation results.

PV (kW)	FL250	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
50	10	55	175	20...	$ 215,210	$ 336,530	0.111	1.00	0.01	5,730	509
50	10	65	165	17...	$ 206,002	$ 338,790	0.112	0.99	0.01	7,863	617
50	10	65	165	16...	$ 204,669	$ 338,968	0.112	0.99	0.01	8,135	643
50	10	65	155	20...	$ 202,886	$ 339,156	0.112	0.99	0.01	8,550	665
50	10	65	165	20...	$ 209,336	$ 340,961	0.113	0.99	0.01	7,550	580
50	10	45	200	20...	$ 230,759	$ 341,076	0.113	1.00	0.01	3,272	365
50	10	65	175	16...	$ 211,119	$ 341,221	0.113	0.99	0.01	7,192	569
10	10	65	200	17...	$ 196,577	$ 341,364	0.113	0.99	0.01	8,932	663
50	10	65	175	17...	$ 212,452	$ 341,709	0.113	0.99	0.01	7,012	549
10	10	65	200	20...	$ 199,911	$ 342,675	0.114	0.99	0.01	8,504	612
50	10	65	175	20...	$ 215,786	$ 342,784	0.113	0.99	0.01	6,544	494
50	10	55	175	25...	$ 221,876	$ 342,851	0.114	1.00	0.01	5,375	459
50	10	75	165	15...	$ 203,912	$ 343,378	0.114	0.99	0.01	8,930	627
50	10	75	175	15...	$ 210,362	$ 344,151	0.114	0.99	0.01	7,777	546
50	10	55	200	17...	$ 228,001	$ 344,324	0.114	1.00	0.01	4,281	411
50	10	75	165	16...	$ 205,245	$ 344,689	0.114	0.99	0.01	8,866	621
50	10	55	200	20...	$ 231,335	$ 344,784	0.114	1.00	0.01	3,723	342
10	10	75	175	20...	$ 184,362	$ 345,108	0.114	0.99	0.01	11,929	756
10	10	75	175	17...	$ 181,028	$ 345,283	0.114	0.99	0.01	12,571	810
50	10	75	165	17...	$ 206,578	$ 345,550	0.114	0.99	0.01	8,747	601
50	10	75	175	16...	$ 211,695	$ 345,624	0.114	0.99	0.01	7,735	541
50	10	75	145	15...	$ 191,012	$ 345,711	0.114	0.99	0.01	11,769	824
50	10	75	175	17...	$ 213,028	$ 345,848	0.114	0.99	0.01	7,524	511
10	10	75	175	16...	$ 179,695	$ 345,981	0.115	0.99	0.01	12,914	841
50	10	65	155	25...	$ 209,552	$ 346,094	0.115	0.99	0.01	8,287	630
50	10	75	155	15...	$ 197,462	$ 346,159	0.115	0.99	0.01	10,578	740
50	10	65	165	25...	$ 216,002	$ 346,176	0.115	0.99	0.01	7,034	530

Figure4. 3 The overall optimization result of hybrid system

The categorized optimization result of the hybrid solar-wind-genset system which selects the optimal combination of each system of the hybrid system with the least capital cost is shown in figure 4.4.

Double click on a system below for simulation results.

PV (kW)	FL250	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
50	10	55	175	20...	$ 215,210	$ 336,530	0.111	1.00	0.01	5,730	509
	10	45	250	25...	$ 229,675	$ 346,616	0.115	1.00	0.01	2,875	291
100	10		250	25...	$ 307,083	$ 414,179	0.137	1.00	0.01		
	50		250	25...	$ 347,083	$ 468,575	0.155	1.00	0.01		
300		75	250	25...	$ 441,403	$ 685,063	0.227	0.92	0.01	17,566	968
	50	200			$ 164,020	$ 903,066	0.299	0.99	0.01	96,323	3,007
1	50	200		1.5	$ 165,020	$ 903,955	0.299	0.99	0.01	96,284	3,006

Figure4. 4 The optimal results with the least cost of the system

Simulation approach: Figure 4.5 shows the optimal result with least cost of the system which has some alternative solutions ranked from 1 up to 7 are possible configurations able to feed the system loads. Despite the numerous alternatives with equal renewable fraction, the choice of optimal system type is restricted by the varying nature of initial capital, net present cost, excess electricity and COE of each set-up. Accordingly, the one which is marked in blue color (the first rank) in which total NPC is $ 336,530 is the best optimum solar-wind-genset hybrid system configuration.

System components and cost summary: Best optimum hybrid power system containing solar, wind and genset power sources marked in blue color in figure 4.4 is summarized in table 4.1.

Table4. 1 System components

Configured hybrid system components	Amount(Kw)
Solar PV array	50
FL250 wind generator turbine	10*250
G (Diesel generator)	55
Surrette 6CS25P	175 units
Converter	20

Table4. 2 Cost summary

Cost type	Cost in $	Cost in ETB
Initial Capital($)	215,210 $	5,921,524.671 ETB
Total NPC($)	336,530 $	9,137,294.295 ETB
COE($/Kwh)	0.111 $/Kwh	3.0541761 ETB/Kwh

Source: -commercial bank of Ethiopia (CBE) on 05/May/2018, (1$=27.5151 ETB).

Furthermore, capacity shortage is 0.01 which is nearly zero.

4.1. Sensitivity analysis results

This section describes and interprets sensitivity results in graphs and tables and determines under what conditions a wind-solar-genset system is more cost-effective and feasible. The HOMER software simulates all the systems in their respective search space for each of the sensitivity values. A feasible system is defined as the hybrid system which meets the required loads. The software eliminates all infeasible systems and presents the results in ascending order of NPC.

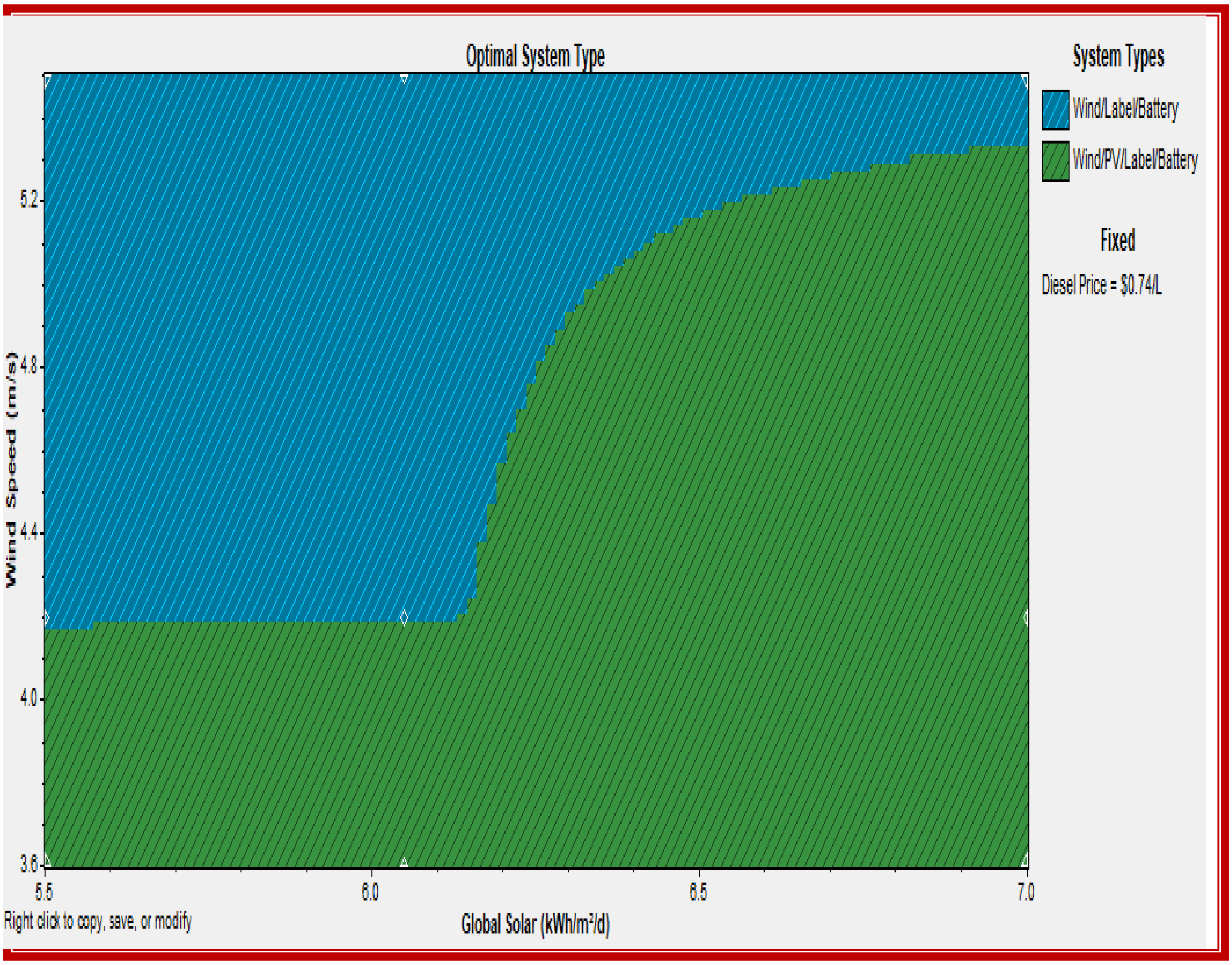

Figure4. 5 Optimal system type (OST) graph

On the Optimal System Type (OST) graph, we simultaneously see that the results for all the wind speeds, diesel cost and solar radiation we entered. The graph shows that the optimal system design depends both on the annual average solar radiation, diesel price and on the wind speed.

4.2. Cost comparison result

Figure 4.6. displays simulation result of cost comparison of the standalone system against grid extension. As it is seen from simulation result the breakeven extension distance is 9.94Km where the net present cost of extending the grid equal to the net present cost of the stand-alone system which is 336,530 US dollars. If you go farther away from this point (breakeven extension distance) the stand-alone system is the optimal solution power supply since, net present cost of extending the grid becomes much higher. Meaning that, the selected

area (Nura Hase Village) is located 40km from nearest national grid system and very far from the points that the stand-alone system is the optimal solution for it.

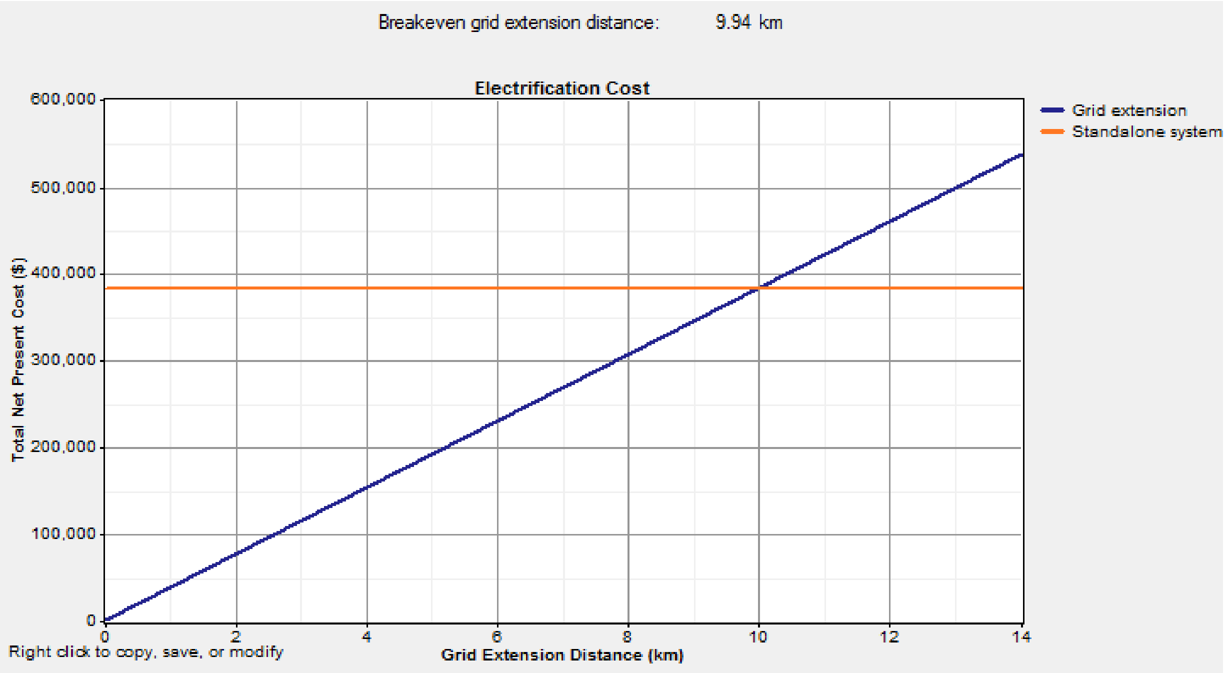

Figure4. 6 Breakeven grid extension distance obtained using HOMER

CHAPTER – 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this thesis, works that have been done are first, wind and solar resource analyses, data collection, community load estimation and feasibility Study of a Standalone Solar-Wind-Genset with Energy Management System for electrification of 300 households in Bosat district .Finally, HOMER is used for optimization, sensitivity analysis of the proposed hybrid system. Then compared cost of hybrid system with the cost required to electrify the village by extending the grid and PLC has been incorporated for energy management to automate the off-grid system.

The Result of feasibility Study of a Standalone Solar-Wind-Genset with Energy Management System shows that there are numerous alternative feasible hybrid set-ups with 100% contribution by the renewable resources and narrow ranges of COE. According, the community electric demands can be satisfied by a hybrid power source containing 50Kw PV, 10*250Kw (Fuilendre250 type) wind turbine, 55Kw diesel generator, 20Kw converters and 175 units of surrete 6CS25P batteries. This hybrid system needs $215,210 initial capital ,$336,530 total NPC with COE selected hybrid system found to be 0.111$/kwh.

The grid extension designed from the closest substation shows that the study area can be electrified by the investment cost 14,546,420.89 Ethiopian birr.

Hence, the attempt of electrifying Nura Hase is determined by comparing by the standalone hybrid system with grid extension. Accordingly, the comparison result shows that the breakeven extension distance was found to be 9.94Km.Therefore, up to 9.94Km extending the grid becomes cost effective and beyond 9.94Kms the standalone system is better.

5.2. Recommendations

Further investigations needed to be carried out to modify this thesis are the following points.

- Since the study focused only on one selected villages in Oromia, East Shoa, and Bosat district and doesn't covers all villages. So, the future researcher should expand this research work in others sites of regions, zones and districts.
- A major hindrance to the use of hybrid energy systems is the high initial capital cost. So the governmental and non-governmental organization should subside to motivate and increase the interest of the rural community to use electricity.
- Use of MMPT solar tracking will increase generation efficiency of the solar panel.

- Addressing the possibility of replacing the diesel generator in the hybrid system by locally generated biofuels.
- Integrating the standalone hybrid power system with the national grid
- Computerizing Energy management using ASCADA system

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APPENDIX A: DETAILED OVERALL OPTIMIZATION RESULT

PV (kW)	FL250	Gen1 (kW)	Battery	Converter (kW)	Initial capital	Total NPC	COE ($/kWh)	Renewable fraction
50	10	55	175	200.0	$ 215,210	$ 336,530	0.111	1.00
50	10	65	165	175.0	$ 206,002	$ 338,790	0.112	0.99
50	10	65	165	165.0	$ 204,669	$ 338,968	0.112	0.99
50	10	65	155	200.0	$ 202,886	$ 339,156	0.112	0.99
50	10	65	165	200.0	$ 209,336	$ 340,961	0.113	0.99
50	10	45	200	200.0	$ 230,759	$ 341,076	0.113	1.00
50	10	65	175	165.0	$ 211,119	$ 341,221	0.113	0.99
10	10	65	200	175.0	$ 196,577	$ 341,364	0.113	0.99
50	10	65	175	175.0	$ 212,452	$ 341,709	0.113	0.99
10	10	65	200	200.0	$ 199,911	$ 342,675	0.114	0.99
50	10	65	175	200.0	$ 215,786	$ 342,784	0.113	0.99
50	10	55	175	250.0	$ 221,876	$ 342,851	0.114	1.00
50	10	75	165	155.0	$ 203,912	$ 343,378	0.114	0.99
50	10	75	175	155.0	$ 210,362	$ 344,151	0.114	0.99
50	10	55	200	175.0	$ 228,001	$ 344,324	0.114	1.00
50	10	75	165	165.0	$ 205,245	$ 344,689	0.114	0.99
50	10	55	200	200.0	$ 231,335	$ 344,784	0.114	1.00

10	10	75	175	200.0	$ 184,362	$ 345,108	0.114	0.99
10	10	75	175	175.0	$ 181,028	$ 345,283	0.114	0.99
50	10	75	165	175.0	$ 206,578	$ 345,550	0.114	0.99
50	10	75	175	165.0	$ 211,695	$ 345,624	0.114	0.99
50	10	75	145	155.0	$ 191,012	$ 345,711	0.114	0.99
50	10	75	175	175.0	$ 213,028	$ 345,848	0.114	0.99
10	10	75	175	165.0	$ 179,695	$ 345,981	0.115	0.99
50	10	65	155	250.0	$ 209,552	$ 346,094	0.115	0.99
50	10	75	155	155.0	$ 197,462	$ 346,159	0.115	0.99
50	10	65	165	250.0	$ 216,002	$ 346,176	0.115	0.99
50	10	75	145	175.0	$ 193,678	$ 346,204	0.115	0.99
50	10	75	155	165.0	$ 198,795	$ 346,214	0.115	0.99
50	10	75	135	175.0	$ 187,228	$ 346,334	0.115	0.99
50	10	75	175	200.0	$ 216,362	$ 346,388	0.115	0.99
50	10	75	155	175.0	$ 200,128	$ 346,408	0.115	0.99
50	10	75	145	165.0	$ 192,345	$ 346,432	0.115	0.99
10	10	65	200	250.0	$ 206,577	$ 346,445	0.115	0.99
	10	45	250	250.0	$ 229,675	$ 346,616	0.115	1.00

50	10	75	175	145.0	$ 209,028	$ 346,760	0.115	0.99
50	10	75	135	165.0	$ 185,895	$ 346,836	0.115	0.99
	10	85	165	175.0	$ 167,154	$ 346,856	0.115	0.99
10	10	85	155	175.0	$ 168,704	$ 346,879	0.115	0.99
10	10	75	200	145.0	$ 193,153	$ 347,067	0.115	0.99
	10	85	165	165.0	$ 165,821	$ 347,089	0.115	0.99
50	10	45	200	250.0	$ 237,425	$ 347,156	0.115	1.00
1	10	45	250	250.0	$ 230,475	$ 347,222	0.115	1.00
	10	85	165	155.0	$ 164,488	$ 347,351	0.115	0.99
1	10	85	165	155.0	$ 165,288	$ 347,417	0.115	0.99
10	10	85	155	165.0	$ 167,371	$ 347,516	0.115	0.99
50	10	75	145	200.0	$ 197,012	$ 347,550	0.115	0.99
	10	85	165	200.0	$ 170,488	$ 347,551	0.115	0.99
50	10	75	165	200.0	$ 209,912	$ 347,630	0.115	0.99
50	10	75	155	200.0	$ 203,462	$ 347,686	0.115	0.99
10	10	45	250	200.0	$ 231,009	$ 347,878	0.115	1.00
	10	85	175	175.0	$ 173,604	$ 347,913	0.115	0.99
10	10	85	155	155.0	$ 166,038	$ 348,171	0.115	0.99
50	10	75	135	200.0	$ 190,562	$ 348,204	0.115	0.99

1	10	75	200	175.0	$ 189,953	$ 348,208	0.115	0.99
50	10	65	175	250.0	$ 222,452	$ 348,217	0.115	0.99
50	10	85	175	165.0	$ 212,271	$ 348,254	0.115	0.99
10	10	85	165	175.0	$ 175,154	$ 348,259	0.115	0.99
10	10	85	155	200.0	$ 172,038	$ 348,377	0.115	0.99
	10	75	200	165.0	$ 187,820	$ 348,515	0.115	0.99
	10	75	200	175.0	$ 189,153	$ 348,604	0.115	0.99
50	10	85	165	175.0	$ 207,154	$ 348,615	0.115	0.99
50	10	85	165	155.0	$ 204,488	$ 348,660	0.115	0.99
1	10	75	200	165.0	$ 188,620	$ 348,688	0.116	0.99
50	10	85	175	175.0	$ 213,604	$ 348,688	0.115	0.99
1	10	55	250	200.0	$ 224,385	$ 348,708	0.115	1.00
	10	85	175	165.0	$ 172,271	$ 348,814	0.115	0.99
50	10	75	155	145.0	$ 196,128	$ 348,837	0.115	0.99
10	10	75	200	155.0	$ 194,487	$ 348,843	0.115	0.99
	10	55	250	200.0	$ 223,585	$ 348,864	0.116	1.00
10	10	85	165	165.0	$ 173,821	$ 348,881	0.115	0.99
1	10	85	175	175.0	$ 174,404	$ 348,884	0.116	0.99
10	10	85	165	200.0	$ 178,488	$ 349,023	0.116	0.99

1	10	75	200	200.0	$ 193,287	$ 349,220	0.116	0.99
50	10	85	165	200.0	$ 210,488	$ 349,301	0.116	0.99
1	10	85	165	175.0	$ 167,954	$ 349,335	0.116	0.99
50	10	85	145	165.0	$ 192,921	$ 349,348	0.116	0.99
50	10	85	165	165.0	$ 205,821	$ 349,355	0.116	0.99
1	10	85	175	165.0	$ 173,071	$ 349,467	0.116	0.99
50	10	85	145	175.0	$ 194,254	$ 349,480	0.116	0.99
50	10	65	200	200.0	$ 231,911	$ 349,521	0.116	1.00
50	10	85	175	155.0	$ 210,938	$ 349,611	0.116	0.99
1	10	85	165	200.0	$ 171,288	$ 349,683	0.116	0.99
10	10	85	165	155.0	$ 172,488	$ 349,710	0.116	0.99
	10	75	200	200.0	$ 192,487	$ 349,746	0.116	0.99
1	10	85	165	165.0	$ 166,621	$ 349,788	0.116	0.99
10	10	85	145	200.0	$ 165,588	$ 349,810	0.116	0.99
50	10	85	145	155.0	$ 191,588	$ 349,841	0.116	0.99
10	10	75	175	250.0	$ 191,028	$ 349,844	0.116	0.99
50	10	65	200	175.0	$ 228,577	$ 350,009	0.116	1.00
	10	85	175	200.0	$ 176,938	$ 350,012	0.116	0.99
50	10	85	175	200.0	$ 216,938	$ 350,021	0.116	0.99

	10	85	175	155.0	$ 170,938	$ 350,092	0.116	0.99
50	10	75	175	250.0	$ 223,028	$ 350,210	0.116	0.99
50	10	55	200	250.0	$ 238,001	$ 350,347	0.116	1.00
1	10	85	175	155.0	$ 171,738	$ 350,400	0.116	0.99
10	10	85	200	155.0	$ 195,063	$ 350,488	0.116	0.99
10	10	85	175	200.0	$ 184,938	$ 350,544	0.116	0.99
50	10	85	155	165.0	$ 199,371	$ 350,643	0.116	0.99
10	10	85	155	145.0	$ 164,704	$ 350,707	0.116	0.99
50	10	85	165	145.0	$ 203,154	$ 350,839	0.116	0.99
50	10	65	200	165.0	$ 227,244	$ 350,869	0.116	1.00
10	10	85	175	175.0	$ 181,604	$ 350,912	0.116	0.99
1	10	85	175	200.0	$ 177,738	$ 350,921	0.116	0.99
50	10	85	155	155.0	$ 198,038	$ 350,935	0.116	0.99
50	10	85	145	200.0	$ 197,588	$ 351,255	0.116	0.99
10	10	85	200	145.0	$ 193,729	$ 351,355	0.116	0.99
10	10	85	165	145.0	$ 171,154	$ 351,372	0.116	0.99
50	10	65	200	155.0	$ 225,911	$ 351,546	0.116	1.00
10	10	75	200	165.0	$ 195,820	$ 351,612	0.116	0.99
10	10	45	250	250.0	$ 237,675	$ 351,627	0.116	1.00

10	10	95	155	175.0	$ 169,280	$ 351,675	0.116	0.99
50	10	85	155	175.0	$ 200,704	$ 351,767	0.116	0.99
10	10	75	200	200.0	$ 200,487	$ 351,799	0.116	0.99
10	10	85	175	165.0	$ 180,271	$ 352,128	0.117	0.99
	10	55	250	250.0	$ 230,251	$ 352,252	0.117	1.00
	10	85	175	145.0	$ 169,604	$ 352,437	0.117	0.99
10	10	85	175	155.0	$ 178,938	$ 352,494	0.117	0.99
50	10	95	165	175.0	$ 207,730	$ 352,499	0.117	0.99
	10	85	165	250.0	$ 177,154	$ 352,511	0.117	0.99
1	10	55	250	250.0	$ 231,051	$ 352,530	0.117	1.00
50	10	75	165	250.0	$ 216,578	$ 352,570	0.117	0.99
10	10	85	200	135.0	$ 192,396	$ 352,613	0.117	0.99
50	10	85	175	135.0	$ 208,271	$ 352,738	0.117	0.99
50	10	85	145	145.0	$ 190,254	$ 352,772	0.117	0.99
50	10	85	165	135.0	$ 201,821	$ 352,805	0.117	0.99
10	10	75	200	175.0	$ 197,153	$ 352,821	0.117	0.99
50	10	85	155	200.0	$ 204,038	$ 352,985	0.117	0.99
1	10	85	175	145.0	$ 170,404	$ 353,082	0.117	0.99
10	10	55	250	175.0	$ 228,251	$ 353,152	0.117	1.00
50	10	85	155	145.0	$ 196,704	$ 353,157	0.117	0.99

50	10	85	135	175.0	$ 187,804	$ 353,168	0.117	0.99
50	10	95	165	200.0	$ 211,064	$ 353,172	0.117	0.99
50	10	85	175	145.0	$ 209,604	$ 353,246	0.117	0.99
10	10	85	165	135.0	$ 169,821	$ 353,253	0.117	0.99
10	10	95	155	200.0	$ 172,614	$ 353,262	0.117	0.99
50	10	85	135	155.0	$ 185,138	$ 353,308	0.117	0.99
	10	85	200	175.0	$ 189,729	$ 353,518	0.117	0.99
1	10	85	200	155.0	$ 187,863	$ 353,534	0.117	0.99
10	10	85	175	145.0	$ 177,604	$ 353,563	0.117	0.99
10	10	85	200	165.0	$ 196,396	$ 353,622	0.117	0.99
10	10	95	155	165.0	$ 167,947	$ 353,673	0.117	0.99
1	10	85	165	250.0	$ 177,954	$ 353,778	0.117	0.99
10	10	95	155	155.0	$ 166,614	$ 353,894	0.117	0.99
50	10	85	135	165.0	$ 186,471	$ 353,905	0.117	0.99
50	10	95	175	175.0	$ 214,180	$ 354,001	0.117	0.99
50	10	95	165	165.0	$ 206,397	$ 354,031	0.117	0.99
	10	65	250	200.0	$ 224,161	$ 354,126	0.117	1.00
50	10	95	165	155.0	$ 205,064	$ 354,211	0.117	0.99

50	10	85	175	250.0	$ 223,604	$ 354,264	0.117	0.99
10	10	95	165	155.0	$ 173,064	$ 354,276	0.117	0.99
50	10	75	155	250.0	$ 210,128	$ 354,295	0.117	0.99

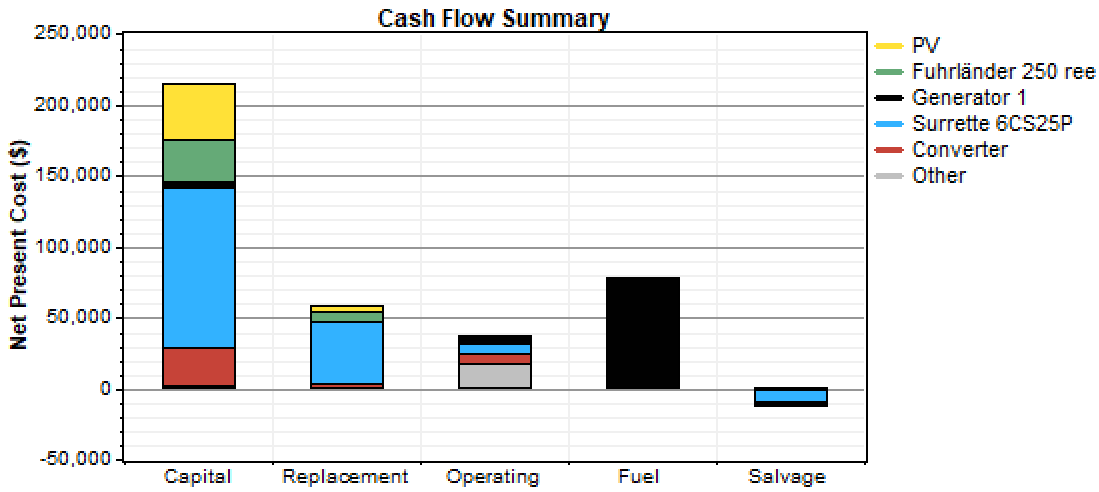
APPENDIX B: SYSTEM REPORT OF THE FIRST COST EFFECTIVE IN FIRST ROW IN FIGURE 4.4

System architecture

PV Array	50 kW
Wind turbine	10 Fuhrländer 250
Generator 1	55 kW
Battery	175 Surrette 6CS25P
Inverter	200 kW
Rectifier	200 kW
Dispatch strategy	Cycle Charging

Cost summary

Total net present cost	$ 378,115
Levelized cost of energy	$ 0.125/kWh
Operating cost	$ 17,947/yr



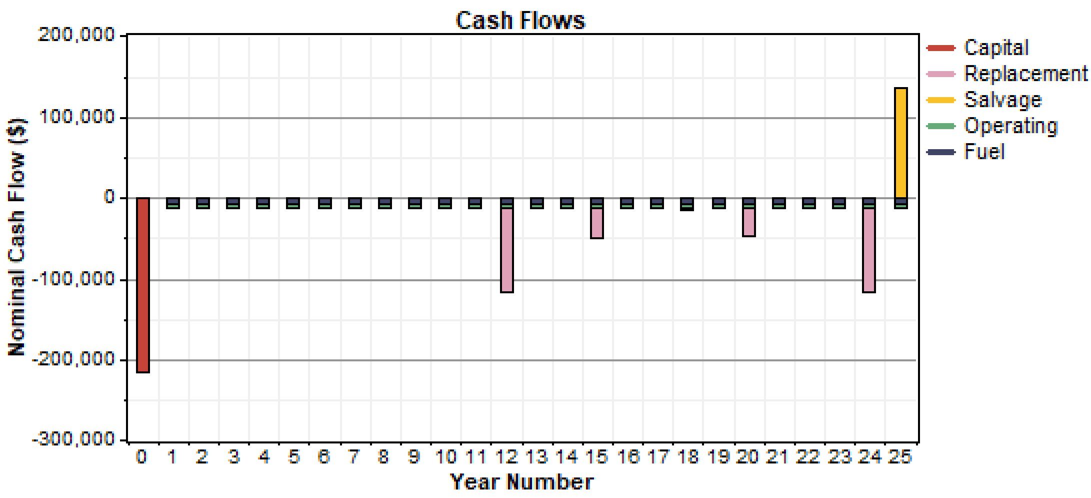
Net Present Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	40,000	5,203	2,269	0	-2,423	45,049
Fuhrländer 250 r	30,000	5,985	908	0	-769	36,123
Generator 1	3,168	384	2,543	78,755	-112	84,738
Surrette 6CS25P	112,875	44,116	7,942	0	-8,883	156,050
Converter	26,667	3,192	6,051	0	-410	35,500
Other	2,500	0	18,154	0	0	20,654
System	215,210	58,880	37,868	78,755	-12,597	378,115

Annualized Costs

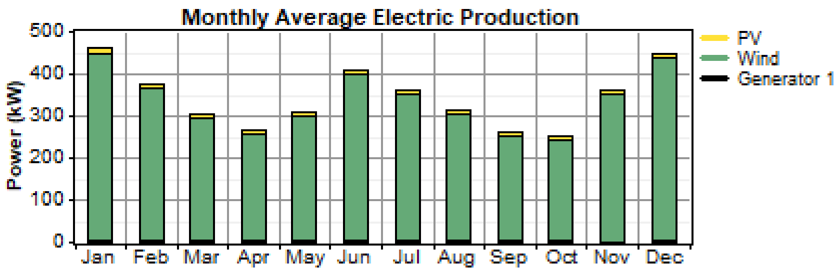
Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
PV	4,407	573	250	0	-267	4,963

Fuhrländer 250 ree	3,305	659	100	0	-85	3,980
Generator 1	349	42	280	8,676	-12	9,335
Surrette 6CS25P	12,435	4,860	875	0	-979	17,192
Converter	2,938	352	667	0	-45	3,911
Other	275	0	2,000	0	0	2,275
System	23,709	6,487	4,172	8,676	-1,388	41,656



Electrical

Component	Production (kWh/yr)	Fraction
PV array	88,305	3%
Wind turbines	2,891,370	96%
Generator 1	31,956	1%
Total	3,011,631	100%



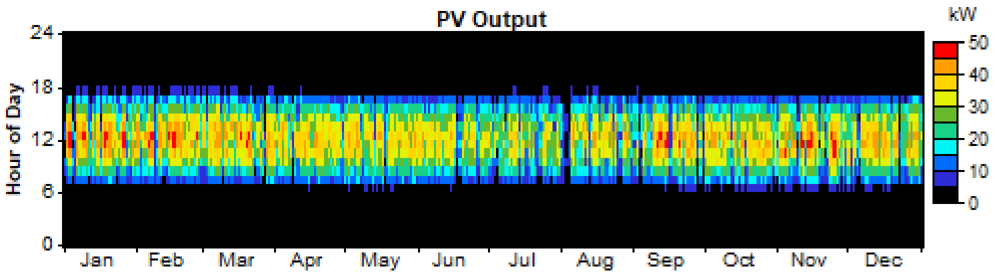
Load	Consumption (kWh/yr)	Fraction
AC primary load	330,061	99%
Deferrable load	2,783	1%
Total	332,844	100%

Quantity	Value	Units
Excess electricity	2,644,679	kWh/yr
Unmet load	264	kWh/yr
Capacity shortage	3,057	kWh/yr
Renewable fraction	0.904	

PV

Quantity	Value	Units
Rated capacity	50.0	kW
Mean output	10.1	kW
Mean output	242	kWh/d
Capacity factor	20.2	%

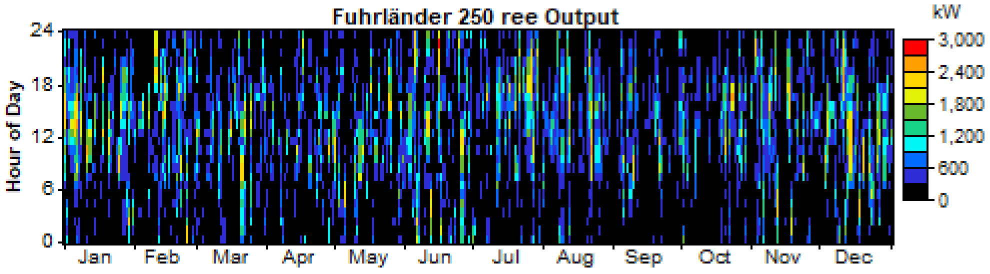
Total production	88,305	kWh/yr
Minimum output	0.00	kW
Maximum output	48.1	kW
PV penetration	26.7	%
Hours of operation	4,380	hr/yr
Levelized cost	0.0562	$/kWh



AC Wind Turbine: Fuhrländer 250

Variable	Value	Units
Total rated capacity	3,000	kW
Mean output	330	kW
Capacity factor	11.0	%
Total production	2,891,370	kWh/yr
Minimum output	0.00	kW
Maximum output	2,713	kW
Wind penetration	875	%
Hours of operation	7,608	hr/yr

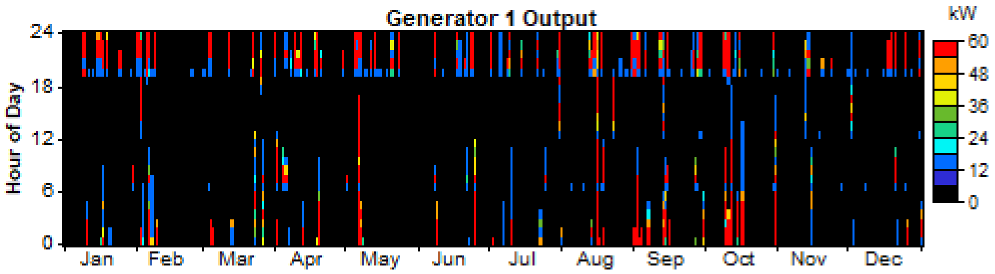
Levelized cost	0.00138	$/kWh



Generator 1

Quantity	Value	Units
Hours of operation	849	hr/yr
Number of starts	137	starts/yr
Operational life	17.7	yr
Capacity factor	6.63	%
Fixed generation cost	3.72	$/hr
Marginal generation cost	0.185	$/kWhyr
Electrical production	31,956	kWh/yr
Mean electrical output	37.6	kW
Min. electrical output	16.5	kW
Max. electrical output	55.0	kW
Fuel consumption	11,725	L/yr
Specific fuel consumption	0.367	L/kWh
Fuel energy input	115,371	kWh/yr

Mean electrical efficiency	27.7	%

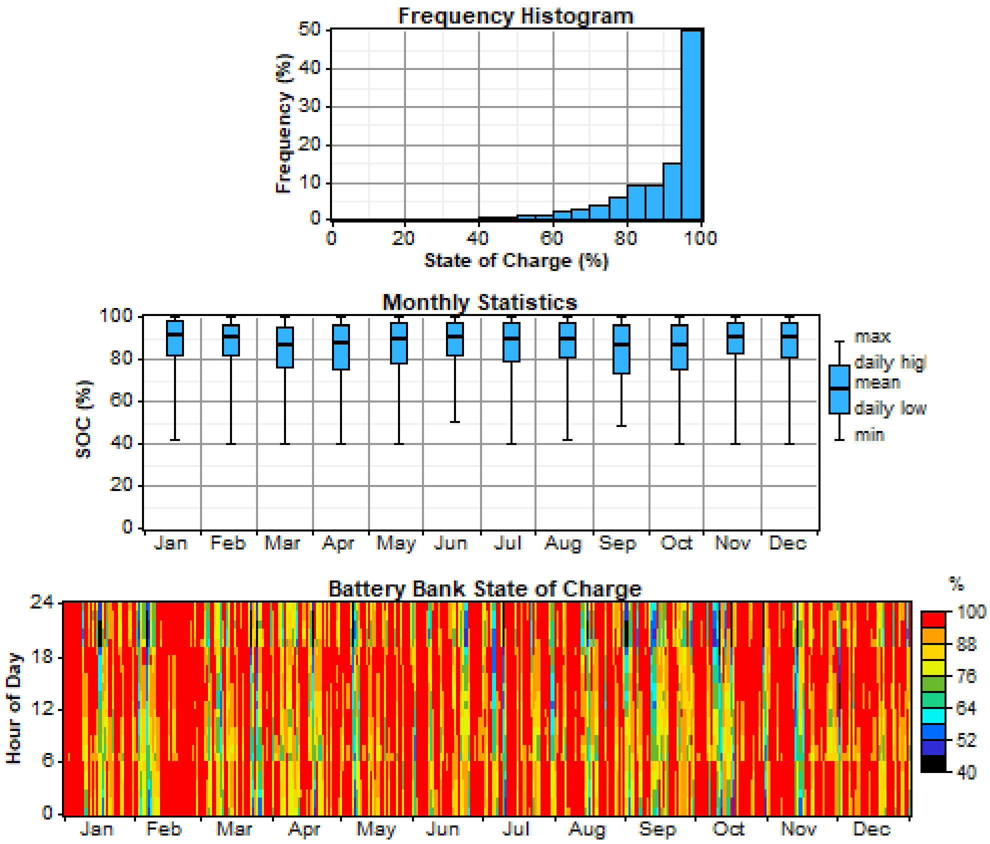


Battery

Quantity	Value
String size	1
Strings in parallel	175
Batteries	175
Bus voltage (V)	6

Quantity	Value	Units
Nominal capacity	1,214	kWh
Usable nominal capacity	728	kWh
Autonomy	19.2	hr
Lifetime throughput	1,687,910	kWh
Battery wear cost	0.070	$/kWh
Average energy cost	0.042	$/kWh
Energy in	81,746	kWh/yr
Energy out	65,434	kWh/yr

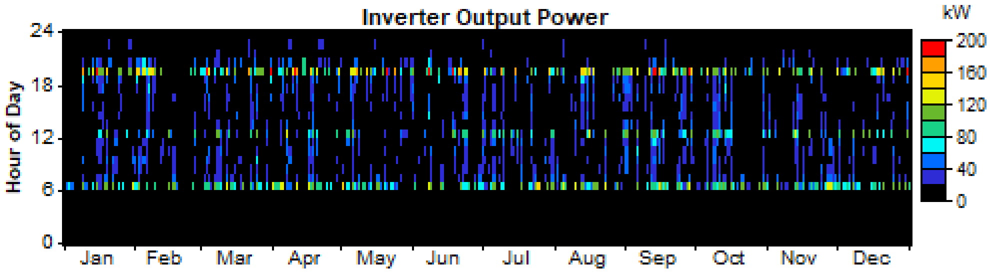
Storage depletion	48.6	kWh/yr
Losses	16,263	kWh/yr
Annual throughput	73,158	kWh/yr
Expected life	12.0	yr

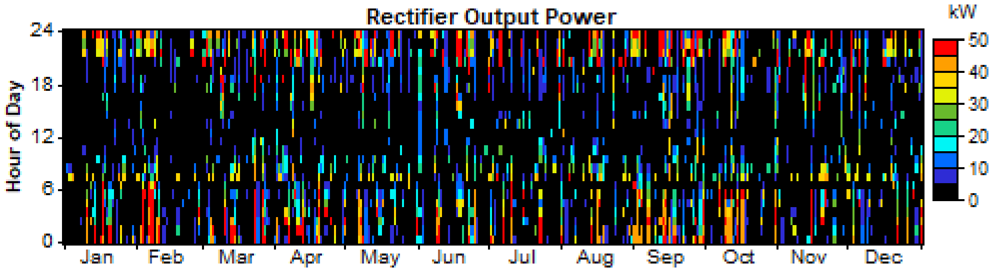


Converter

Quantity	Inverter	Rectifier	Units
Capacity	200	200	kW
Mean output	9	6	kW
Minimum output	0	0	kW
Maximum output	200	48	kW
Capacity factor	4.3	3.1	%

Hours of operation	2,273	4,110	hrs/yr
Energy in	82,930	63,403	kWh/yr
Energy out	74,637	53,893	kWh/yr
Losses	8,293	9,510	kWh/yr





Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	30,875
Carbon monoxide	76.2
Unburned hydrocarbons	8.44
Particulate matter	5.75
Sulfur dioxide	62
Nitrogen oxides	680