WOLKITE UNIVERSITY

COLLAGE OF ENGINEERING AND TECHINOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

DESIGN &COST OPTIMIZATION OF WIND –SOLAR HYBRID POWER SYSTEM

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A final year project submitted to collage of Engineering and Technology on Department of Electrical and computer Engineering-Wolkite University in partial fulfilment of the requirements for the Degree of Bachelor of Science in Electrical and computer engineering.

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DECLARATION

We hereby declare that this project entitled, Design & Optimization of Wind –Solar Hybrid System with HOMER Software submitted in partial fulfillment of the requirement for the award of the BSc degree in Electrical and Computer Engineering (Power Engineering). Wolkite University is a record of our own work carried out by us during the academic year 2019 under the supervision and guidance of Mr. Kibru M, in the College of Engineering and technology, Department of electrical and computer engineering. The extent and source of information are derived from the existing literature and have been indicated through the project at the appropriate places. We strongly declare that all the works included in this thesis document and other related materials are done. The matter embodied in work is original and has not been submitted for the award of any other degree either in or any other university.

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

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ABSTRACT

Hybrid solar PV and wind generation system become very attractive solution in particular for stand-alone applications. Combining the two sources of solar and wind can provide better reliability and their hybrid system becomes more economical to run since the weakness of one system can be complemented by the strength of the other one. The integration of hybrid solar and wind power systems into the grid can further help in improving the overall economy and reliability of renewable power generation to supply its load. Similarly, the integration of hybrid solar and wind power in a stand-alone system can reduce the size of energy storage needed to supply continuous power. Solar electricity generation systems use either photovoltaic or concentrated solar power. The focus in this paper will be on the photovoltaics type. Electricity from solar PV and concentrated solar power plants is significantly expensive and requires significant drop in cost or change in policies by either subsidizing or forcing the use of these technologies to be able to achieve significant market penetration. The output can be extracted from both solar as well as from wind too. To perform this project long mathematical analysis has taken in to consideration and the design and simulation is done on Homer software. Finally, we proposed that standalone system (solar/wind/ battery) is economically feasible and environmentally friendly to replace the existing diesel-only power supply system for Lenda town, Ethiopia.

Key words- Hybrid system, HOMER, Photovoltaic Wind turbine, Diesel Generator

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ACRONYMS

A	Cross sectional area	(m^2)
AC	Alternating current	(A)
COE	Cost of energy	($/kW)
C_p	The power coefficient	
D	the rotor diameter	(m)
DC	Direct current	
f	The PV de-rating factor	(%)
h	tower height	
h_{ref}	The reference height	(m)
I_L	Load current	(A)
I_D	Diode current	(A)
I_{sh}	Shunt resistance current	(A)
KE	The kinetic energy of a stream of air	(J)
KW	kilo watt	
Lf	Load factor	
MW	mega watt	
m	Mass of air parcel	(kg)
NMA	national Metrological Agency	
NPC	Net present cost	($)
n_s	The synchronous speed	
P	Power	(W)
PDF	Probability Density Function	
P_{pv}	The power output of the PV array	(kW)
P	Air pressure	(pa)
P_{mech}	Mechanical power in the wind	(w)
P_{rotor}	power developed by rotor	(w)
PV	photovoltaic	
R_L	Load resistance	(ohm)

R_s	series resistance	(ohm)
R_{sh}	The shunt resistance	(ohm)
R	Specific gas constant	(287 $Jkg^{-1}K^{-1}$)
T	temperature	(K^o)
V	volume of air parcel	(m^3)
v	Wind speed (velocity)	(m/s)
v_{ref}	Reference speed	(m/s)
V_{oc}	The open-circuit voltage	(V)
Z	Height above ground level for the desired speed	(m)
Z_{ref}	Reference height	(m)
z	The number of the blades	

CHAPTER ONE

INTRODUCTION

1.1 Background

Energy is one of the most fundamental elements of our universe. Especially for developing countries like Ethiopia, the significance of energy is vital. Energy in the form of electricity and modern fuels is the lifeblood of modern civilization and is critical factor for economic development and employment. It amplifies human efforts enables humans to produce more, travel farther and faster, communicate more broadly and quickly, and live at a higher standard of living than is possible through human efforts alone. Hence it can be said that like the other basic needs for human beings, energy is the basic inevitability for survival.

Even if Ethiopia has a huge potential of renewable energy (hydro, wind, solar, geothermal), it is suffering from energy crisis throughout characterized by frequent blackouts and interruption. This is because of the unbalance between the increasing energy demands versus energy production in the country. Even due to the limited energy production, there are places; especially remote areas, where energy is not available/ accessed and the people around are living in darkness. In addition to this limited production, the country was concentrating in large energy production systems. But it is difficult to use most of the potentials that the country had and to make all people access to this modern energy without small energy production systems. And it is the aim of this thesis work to assess the potentials and feasibility of renewable energy system of the selected site. [1]

The oil price volatility, growing concerns of global warming, and depleting oil/gas reserves and due to the contradiction between gradual growth of the global energy demand, renewable energy such as solar energy, wind energy, bio-energy, and hydropower might become a new manner in which we produce energy for sustainable development. Photovoltaic (PV) and wind energy systems are the most promising candidates of the future energy technologies, and it has been widely noticed that stand alone and grid connected PV and wind energy markets have grown rapidly. Energy generation system reliability has been considered as one of the most important issues in any system design process. However, natural energy resources are unpredictable, irregular, and seasonally unbalanced. Therefore, a combination of two renewable energy sources may satisfy bigger share of electricity demand and offer reliable and consistent energy supply. The Hybrid PV and Wind Electricity System is well suited to conditions where sun light and wind have seasonal shifts, for example, in summer the sun light is abundant but windless, while in winter wind resource increased that can complement the solar resource. The reliability of the stand-alone hybrid PV-wind system in producing energy has been proven by earlier studies. In the last two decades' solar energy and wind energy has become an alternative to traditional energy sources. These alternative energy sources are non-polluting, free in their availability and renewable. But high capital cost, especially for photovoltaic, made its growth a slow one. The best way to attempt to decrease the cost of these systems is by making use of hybrid designs that uses both wind/photovoltaic. [1]

The purpose of this study is to investigate alternative power supply options for lenda town by replacing the conventional diesel powered electric supply. The town is isolated from main electricity grid system in Ethiopia.

1.2. Power generation in Lenda town

Lenda town is one of the fast growing towns in Hadiya Zone, SNNRP, which is located at a longitude and latitude of 36.5° and 5.9° respectively. Currently the population size of this town is 2700 peoples with 644 households and the way of living is based on agriculture and trade. In this town, there are government institutions (primary and secondary school, health center, and municipality) and religious institutions (Muslim, Protestants, orthodox). The demand of electricity in this town is highly increasing from time to time due to population growth. To come up the shortage of electricity in lenda town the municipality uses diesel generator for limited hour per day that is from 1:00 PM to 4:00 PM. Due to the lack of electricity the people living in this town faces different socio-economic problems like woman‘s waste their time to collect wood, deforestation of trees, environmental pollution due to the use of diesel generator and combustion of wood, peoples pay high bill cost for diesel generator, poor education quality, less health care and other problems are raised in this town.

1.3 Statement of the Problem

Most of the people of Ethiopia (around 85 % of the population) lives in rural areas where energy access is almost negligible, <1% [2, 3]. A possible reason is that either these areas are farther away from the national grid or the people living there are sparsely populated. Extending the national grid to these areas is not up to the economic capacity of the country because of the high cost of transmission and the very low load factor in these areas. However, electrification of the rural communities is very essential specially to ensure the socio economic development of the community and hence of the country. To satisfy their energy needs, these people are using kerosene, which is becoming difficult to afford because of the high and day-by-day increasing price of kerosene; and firewood, cow dung and other traditional biomass resources, which are causing deforestation and soil degradation.

The main problem in lenda town is lack of Electricity, which results in the following problem:

- Short working hour of diesel generator, which is three hours per day.
- The municipality diesel generator does not cover the electricity demand of the peoples live in the town means that not all peoples get electric even for few hours.
- Greenhouse effect from the smoke of the diesel generator of the municipality of the town.
- The people pay high bill cost of electricity compared to grid extension.
- Peoples living around the town pay high cost for mobile charge and travel long distance to charge their battery.
- Lack of pure education quality and good health care in the town due to electricity shortage.

1.4 Objective of the Thesis

1.4.1 General objective

The basic objective of this thesis is feasibility study, design and simulation of solar-wind hybrid power system in the case of lenda town for the electricity use to improve the sustainable power supply by replacing existing conventional diesel powered electric supply.

1.4.2 Specific Objectives

The Specific Objectives are*:*

- Meteorological data collection for the site in consideration (i.e. solar radiation, wind speed at Lenda town)
- Economic evaluation of the systems and compare their feasibilities of solar, wind and diesel generator using HOMER software.
- System design for each energy source at the selected site using analytical methods.
- To create a hybrid energy source from wind and solar for Lend town.
- To decrease the cost of electrical energy of Lenda town by replacing diesel generator energy source with solar-wind hybrid system.

- To supply sufficient electric energy for the peoples living in Lenda town.
- To study the socio-economic impact of the solar-wind power system in the environment.
- To characterize and quantify electrical loads for lenda facilities/homes.
- To assess the feasibility of energy export to local utilities.
- To identify appropriate renewable energy technologies to meet lenda town needs.
- To develop and analyze cost estimates and long term economic benefits for renewable energy technologies (economic analysis).
- To apply power electronic devices and study characteristics of them.

1.5. Scope of the Thesis

The scope of this thesis is to assess the technical and economic feasibility, design and simulation solar-wind-diesel power system to replace the existing diesel generator in lenda town by naturally owned resources of solar and wind. The study will investigate different renewable energy option to incorporate the existing diesel-only system. This project collects and analyze the data and information, examine and select the most suitable Power Generation and Supply Systems, recommend necessary measures that configure a system to accommodate electrical energy demand for the town. The project only focuses on solar energy and wind energy resource assessment in the town. It compares and estimates the cost of electricity generated from hybrid solar-wind-diesel energy system with the grid system and the present cost of fossil fuel (diesel) based electricity generated in lenda town.

1.6. Methodology

The methodologies to accomplish this thesis work is as follows:

1. Wind and solar resource assessment.
2. Determination of system load and energy input required.
3. Design of PV system.
4. Design of WTG system.
5. Determination of the battery storage required.
6. Coupling of the PV and WTG systems.

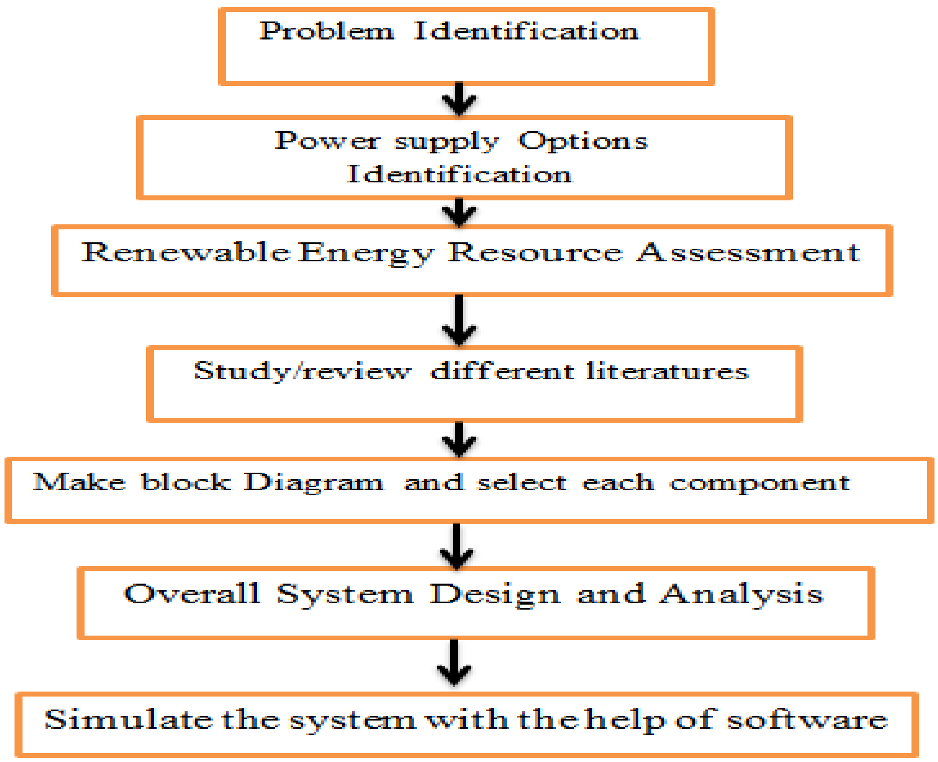


Figure 1. 1.Methodology

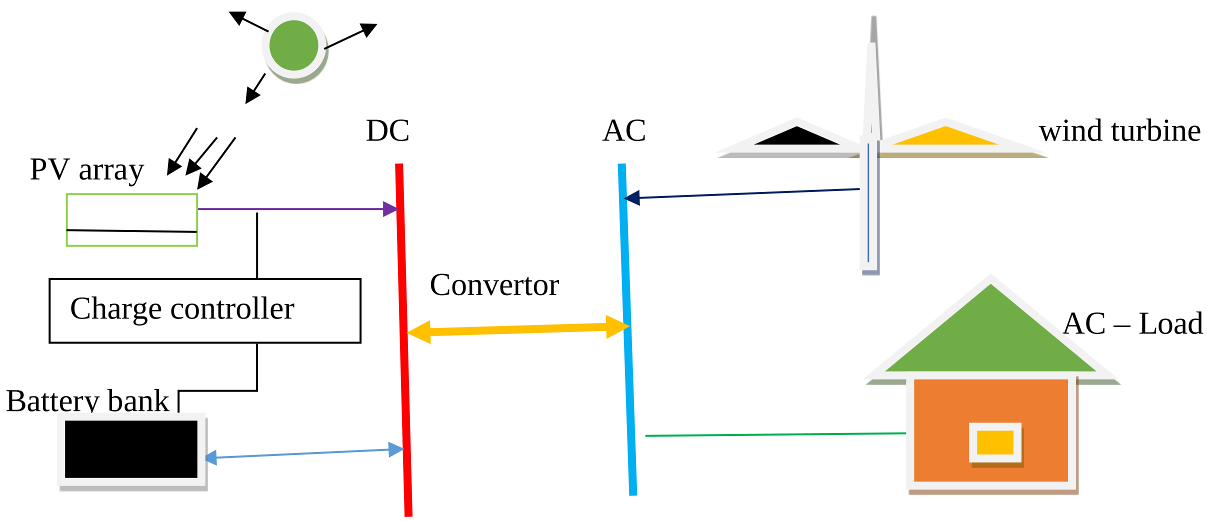


Figure 1. 2 block diagram of the solar-wind hybrid system

CHAPTER TWO

LITERATURE REVIEW

2. Literature review of solar-wind energy system

Energy generated from solar, wind, biomass, hydro power, geothermal and ocean resources are considered as a technological option for generating clean energy. But the energy generated from solar and wind is much less than the production by fossil fuels, however, electricity generation by utilizing PV cells and wind turbine increased rapidly in recent years. This paper presents the Solar-Wind Hybrid Power system that harnesses the renewable energies in Sun and Wind to generate electricity. It ensures the optimum utilization of resources and hence improve the efficiency as compared with their individual mode of generation. Also it increases the reliability and reduces the dependence on one single source. This hybrid solar-wind power generating system is suitable for industries and also domestic areas. [4]

2.1. Solar energy system

Previous studies on solar energy resource assessment of the country include Neway (1996), Yacob and Frances (1996), Addis Ababa University (AAU) (2001), and Solar and Wind Energy Resource Assessment (SWERA) (2007). The study by Neway (1996) compared the measurement of global solar radiation with corresponding calculated values using Angstrom's relations. The regression coefficients were obtained and the correlation equations were determined to predict the global solar radiation. The results show that Angstrom's relations are valid for the locations under study. Yacob and Frances (1996) used sunshine hour records from 21 meteorological stations in the country to illustrate the general availability of the resource. The report by AAU indicated that the annual average daily solar radiation ranges from4.25 kWh/m2 to 6.25 kWh/m2. Solar radiation maps of the country produced based on satellite data by SWERA (2010) also indicate that the country has significant solar radiation potential. [5]

2.1.1 Solar PV System and Solar Potential in Ethiopia

The sun, the source of solar radiation, is a sphere of intensely hot gaseous matter with a diameter of about 1.39 x 10^9 m, a total mass of 1.99 x 10^30 kg, and on the average 1.50 x 1011 m away from the earth. An atomic reaction taking place in the inner active part of the sun makes the outer surface to have a temperature of 580degree k. Solar radiation in the form of radio magnetic wave emanates from this surface and propagates spherically in space. Some part of the radiation reaches the earth surface after atmospheric effect (reflection, refraction, absorption, scattering etc.). Such radiation is called diffused radiation.

There is also some part of radiation that reaches the earth 's surface without such atmospheric effect which is called direct radiation. The received solar radiation by Earth 's surface can be used directly (in the form of solar PV and solar thermal) or indirectly (in the form of hydro, wind, biomass etc.). [6]

2.1.2. PV Systems

Photovoltaic (PV) systems convert light energy directly into electricity using semiconductor technology in the form of solar/PV cells. The physics of the PV cell is very similar to the classical p-n junction diode (see figure 2.1). When light is absorbed by the junction, the energy of the absorbed photons is transferred to the electron system of the material, resulting in the creation of charge carriers that are separated at the junction. The charge carriers may be electron ion pairs in a liquid electrolyte or electron-hole pairs in a solid semiconducting material. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field and circulate as the current through an external circuit. The current squared times the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the cell [6].

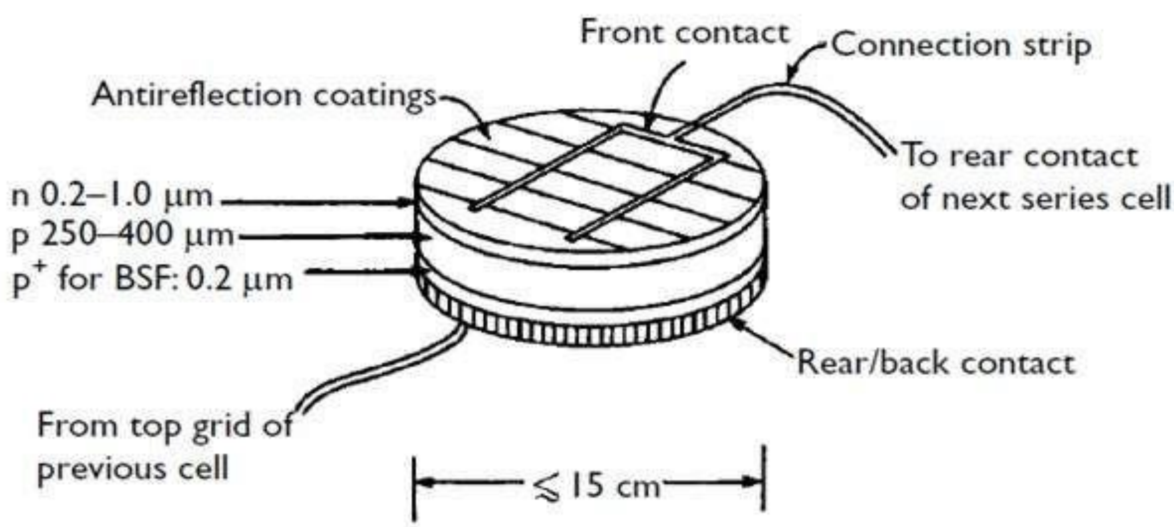


Figure2. 1 Basic structure of p-n junction PV cell [3]

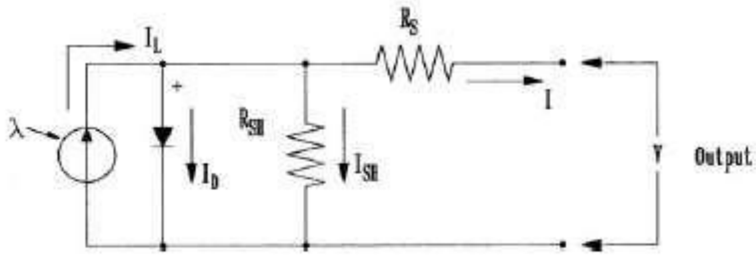


Figure2. 2Equivalent circuit for solar PV cell [3]

The output-terminal current I is equal to the light-generated current I_L, less 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, the impurities and the contact resistance. The shunt resistance R_{SH} is inversely related with leakage current to the ground. In an ideal PV cell, R_S= 0 (no series loss), and R_{SH}=_ (no leakage to ground). In a typical high quality one square inch silicon cell, R_S= 0.05 to 0.10 ohm and R_{SH}= 200 to 300 ohms. The PV conversion efficiency is sensitive to small variations in RS, but is insensitive to variations in R_{SH}. A small increase in R_S can decrease the PV output significantly [7]. The current at the output terminal is given by:

$I = I_L - I_D - I_{SH}$

$I = I_L - I_O\left(\exp\left(\frac{q(V+IRs)}{AKT}\right) - 1\right) - \frac{V+IRs}{Rsh}$

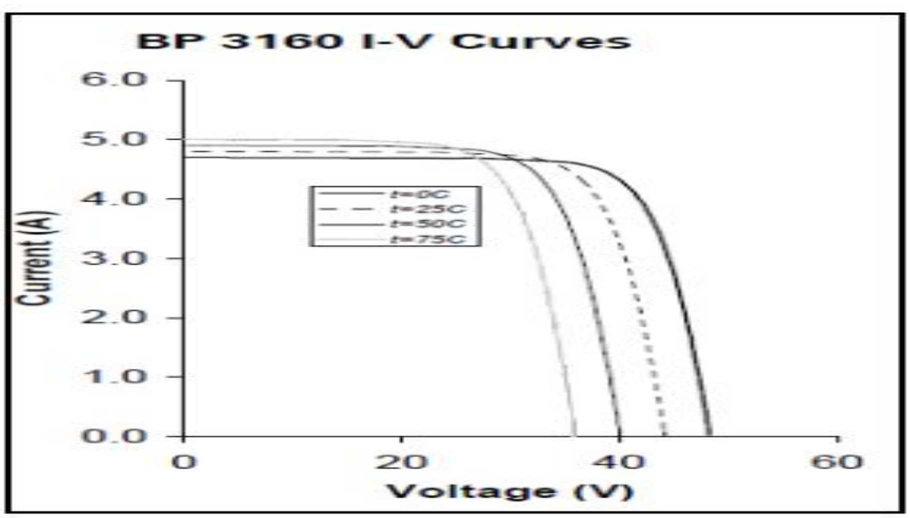


Figure2. 3 V-I characteristics of PV cells against temperature [3]

The current-voltage (I-V) and power-voltage (P-V) characteristics of a typical PV module are shown in Figure 2.3 with the short circuit current at radiation level G, Isc(G), the maximum power current (Imp), maximum power point (Pmp), maximum power voltage (Vmp), and open circuit voltage (Voc) labeled at their respective points. *Pmp* is the maximum power that can be obtained from the module and it corresponds to the maximum rectangular area under the I-V curve. Voc increases logarithmically, whereas Isc increases almost in proportion to the radiation as long as the current axis does not intersect the curved portion of the I-V characteristic. The power output of a PV system is determined by the type and area of the PV material and the incident solar radiation. Mathematically, it can be expressed by equation [7].

$P_{pv}=A_c\eta_{mp}\eta_e G_T$ Where: P_{pv}= power output of PV array

A_c=the array area

η_{mp} =the maximum power point efficiency of the array (≈14%)

η_e =the efficiency of power conditioning equipment (≈90%)

G_T=the incident solar radiation on the array

The solar cell described above is the basic building block of the PV power system. For obtaining high power, numerous such cells are connected in series and parallel circuits on a panel (module). The solar array or panel is then made from a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage.

(i). PV Panel

Photovoltaic (PV) cell, which is made of at least two layers of semi-conductor material such as silicon (one layer has a positive charge, and the other has negative charge), is the basic building block of a PV system. It converts sunlight directly into electricity without creating any air or water pollution. When sunlight is absorbed by these semiconductors, the photons from the light knocks the electrons loose, freeing them to flow through the external circuit and back into the positive layer, producing electricity. This process of converting light to electricity is called the photovoltaic effect. However, an individual PV cell is usually quite small, typically producing about 1 or 2 watts of power. Hence, in order to increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. Modules, in turn, can be connected together to form even larger units called arrays that can be used to produce even more power. Basically, utilization of solar power brings a lot of benefit to the nation.

- It does not produce pollution: By substituting solar power for fossil fuels, greenhouse gases emission can be reduced. The needs of burning fossil fuels can be cut down and reserve for further usage.

- The supply of solar power is infinite: On the contrary, traditional fuels are finite. The world's entire oil supply, for example, is estimated to last about 30-100 more years.
- Solar energy protects people against rising energy costs: Traditional fuel prices will rise as the supplies of these fuels shrink. PV systems, on the other hand, use sunlight, which is infinite and free.
- PV systems are more reliable.

2.1.4 Solar Energy Resource in Ethiopia

Ethiopia receives 4.55 to 6.5 kWh/m2/day annual average of solar insolation throughout the country. This varies significantly during the year, ranging from a minimum of 4.55 kWh/m2 in July to a maximum of 6.55 kWh/m2 in February and March. Other literatures describe the yearly average radiation to be in the range from 4.25 kWh/m2 in the areas of Itang in the Gambella regional state (western Ethiopia), to 6.25 kWh/m2 around Adigrat in the Tigray regional state (northern Ethiopia) [8]. Solar Potential assessment for Lenda town is shown in the table below.

Table 2. 1 Monthly daily radiation (kwh/m2/d) at the site from NASA

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
Radiation	6.12	6.4	6.19	5.71	5.61	5.37	5.23	5.58	5.9	5.6	5.73	5.92	5.776

2.2. Wind Energy System

Wind energy is another potential source of renewable energy. Winds are the motion of air caused by uneven heating of the earth 's surface by the sun and rotation of the earth. It generates due to various global phenomena such as air-temperature difference associated with different rates of solar heating. Since the earth 's surface is made up of land, desert, water, and forest areas, the surface absorbs the sun 's radiation differently. Locally, the strong winds are created by sharp temperature difference between the land and the sea [9].

2.2.1 Wind Power density distributions and mean power density

The distribution of wind is expressed by Weibull distribution which is called a Raleigh distribution for K=2 [9]. It is given by equations below:

$$f(v)= \frac{\pi . v}{2\bar{v}^2} exp\left[-\pi/4\left(\frac{v}{\bar{v}}\right)^2\right]$$

$$\text{prob}(v \leq V)=1- exp\left[-\pi/4\left(\frac{v}{\bar{v}}\right)^2\right]$$

$$\text{prob}(v \geq V) = exp\left[-\pi/4\left(\frac{v}{\bar{v}}\right)^2\right]$$

Where, *f (v)*= Weibull probability density function of wind distribution

v = mean wind speed (m/s)

$\bar{v}$=instantaneous wind speed (m/s)

prob (*v* <*V*) =probability of instantaneous wind speed is less than *V*

prob (*v* >*V*) = probability of instantaneous wind speed is greater than *V*

Wind speeds are always measured at 10 m height anemometer. But, wind turbines are installed at higher elevations at which the wind speed is completely different from the 10 m measurement. This variation of wind speed with height can be expressed with equation below [10].

$$v(z).\ln\left(\frac{Zr}{Zo}\right) = v(Z_f).\ln(z/z_o)$$

Where z_r = reference height (m)

Z = Height where wind speed is to be determined (m)

Z_o = measure of surface roughness (0.1 to 0.25 for cropland)

V(z) =wind speed at height of z m(m/s)

$V(z_f)$ = wind speed at the reference height (m/s)

2.2.2 Wind Turbine Types and Blade Aerodynamics

There are several wind turbine configurations including, drag-type, lift-type, Magnus effect wind plants and Vortex wind plants. Essentially all present day wind turbines are of the lift type and, over 90% of these are of the horizontal axis type. Magnus effect and vortex plants have never played a serious practical role. Lift type wind turbines can be horizontal axis and vertical axis based on the rotation of blades relative to the direction of wind [10].

The most common type of lift-force wind turbines is the horizontal axis wind turbine - HAWT. The rotor axis lies horizontally, parallel to the air flow. The blades sweep a circular or slightly conical) plane normal to the air flow, situated upwind (in front of the tower) or downwind (behind the tower). The main advantage of HAWTs is the good aerodynamic efficiency (if blades are properly designed) and versatility of applications. Their main disadvantage is that the tower must support the rotor and all gearing and electrical generator standing on top of it, plus the necessity of yawing to face the wind.

Another type of lift-force wind turbines is the vertical axis wind turbine - VAWT. The rotor axis is perpendicular to the air flow (usually vertical). The blades sweep a cylindrical, conical or elliptical plane, perpendicular to the air flow and parallel to the rotor axis. All main power train components (gearbox, generator, brakes and main bearing) are placed on the ground, allowing for easy access for maintenance and lower stress on the tower. Yaw mechanism for facing the wind is not needed as the turbine accepts wind from any direction. All these features result in a simple machine, easily scalable to large dimensions, at lower costs than a horizontal axis one. Their main disadvantage is their requirement of starting torque which may be a critical issue for stand-alone applications.

Wind turbines are used as a means of extracting the wind energy. Their output is greatly affected by their aerodynamics. Their aerodynamics is mainly determined by the geometry of the turbine blade (see Figure 2.4).

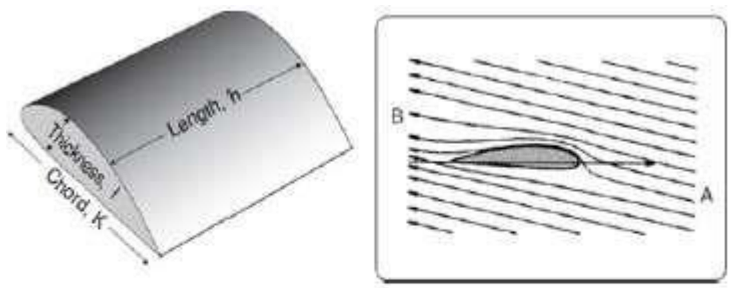


Figure2. 4 cross section of wind turbine blade [5]

If a blade were sawn in half, the cross section has a streamlined asymmetrical shape, with the flattest side facing the oncoming air flow or wind. This shape is called the blade ‘s aerodynamic profile. The shape of the aerodynamic profile is decisive for blade performance. The aerodynamic profile is formed with a rear side that is much more curved than the front side facing the wind. Two portions of air molecules side by side in the air flow moving towards the profile at point A will separate and pass around the profile and will once again be side by side at point B after passing the profile ‘s trailing edge. As the rear side is more curved than the front side on a wind turbine blade, this means that the air flowing over the rear side has to travel a longer distance from point A to B than the air flowing over the front side. Therefore, this air flow over the rear side must have a higher velocity if these two different portions of air shall be reunited at point B. Greater velocity produces a pressure drop on the rear side of the blade, and it is this pressure drop that produces the lift [10]. And this lift force is the source of torque to rotate horizontal axis wind turbines.

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. The energy available in the wind can be expressed using equation below.

$$P_w = \frac{1}{2}\rho A v^3$$

Where: p_w=power in the wind

ρ=density of air

A=the swept area (m^2)

V=instantaneous wind velocity(m^3)

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). This limitation is expressed in terms of Betz limit defined by the power coefficient Cp as given by equation below.

$$Cp = \frac{\text{Rotor Power}}{power\ in\ the\ wind}$$

The power coefficient, CP, is a function of the axial induction factor. The optimum of this function (which is a maximum value for CP) is 0.5926 (=16/27) [10-11]. Thus the electrical power output from the wind turbine can be expressed by equation below.

$$P_{wout}= \eta t c p \frac{1}{2}\rho A v^3$$

Where: *Pwout*= output power of wind turbine ηt =Overall efficiency

of the transmission system/power train

Cp=the power coefficient

The power coefficient and efficiency of wind turbines vary greatly from manufactures to manufacturers. As a result, the power output of wind turbines varies from turbine to turbine and is given by power curve which plots the output power of a turbine against wind speed (see Figure 2.5)

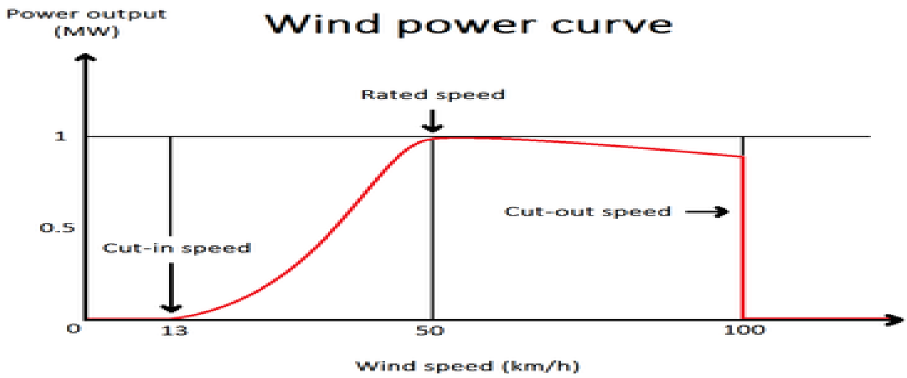


Figure2. 5Power output of EOLTEC CHINOOK 17-65 Wind Turbines with steady wind speed characteristics.

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-out speed is the wind at which the turbine be shut down to protect the rotor and drive train machinery from damage, or high wind stalling characteristics.

Power Control Mechanism

Power output from the rotor can be decreased at high winds by decreasing the power coefficient through aggravated aerodynamic conditions, implying decreased lift forces. Such regulation helps the turbine operating nearly at its rated capacity during high wind speeds. There are three commonly used types of power control in the industry [10].

- Stall Control
- Pitch Control
- Active stall regulation

In stall controlling method, the wind is allowed to meet the blade at very big angle of attack. This makes the wind flow to separate and swirl on the suction side which increases the drag force and decrease the lift force. Firmly fixed blades to the hub have made such stall control mechanisms simple and less costly. But, it is not possible to maintain stable output and turbines with such control mechanism should be able to sustain large thrust forces at high winds.

In the Pitch control mechanism, the blade turns around its longitudinal axis, thus being able to maintain a given angle of attack (i.e. a given maximum lift force and power output) at changing wind speed without increasing much the trust on the rotor. Such control mechanism results in a smooth power output. Their demerit is their complicated arrangement (pitch motor and blade bearings) which adds cost and decreases reliability of the machine.

With an active stall regulation mechanism, the machine is usually programmed to pitch the blades much like a pitch-controlled machine at low wind speeds, so as to get a reasonably large torque at low wind speeds. If the generator is about to be over loaded, then the machine also pitches its blades to increase the angle of attack of the rotor blades forcing the blades to go into a deeper stall thus wasting the excess energy in the wind [11]. In this control mechanism the machine can be run almost exactly at rated power at all high wind speeds.

Wind Turbine

Wind turbines offer a partial solution to the world ‘s renewable energy sources. Instead of operating like a fan which uses electricity to create wind, wind turbine uses wind to create electricity. It operates on a simple principle with its three crucial parts (*How Wind Power Works* 2008) are:

- Rotor blades

The blades are basically the sails of the systems. In their simplest form, they acted as barriers to the wind. When the wind forces the blades to move, it transferred the kinetic energy from the wind to the rotor.

- Shaft

The wind turbine shaft is connected to the center of the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end.

- Generator

A simple generator which consists of magnets and a conductor uses the properties of electromagnetic induction to produce electricity. The conductor is typically a coiled wire. Inside the generator, the shaft connects to an assembly of permanent magnets that surrounds the coil of wire. In electromagnetic induction, if a conductor is surrounded by magnets, and one of those parts is rotating relative to the other, it induces voltage in the conductor. When the rotor spins, the shaft spins the assembly of magnets, generating voltage in the coil of wire. That voltage drives electrical current (typically alternating current, or AC power) out through power lines for distribution.

In the past, when wind turbines are first being used to produce electricity, complaints are all over the place concerning about their ugliness towards the natural landscape and noise that they cause.

However, recently, technology has been improved to minimize the mechanical noise that wind turbines produce. If one or two wind turbines are used to generate electricity for a single house, noise is no more a problem to the resident.

Wind Resource in Ethiopia

Ethiopia has exploitable reserve of 10,000 MW 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 [9,12, 11,13, 24]. Currently two projects are constructed, one Asheoda wind park (near Mekelle) of 120MW and the other Adama Wind Park of nearly 40MW. Wind Potential Assessment in lenda town is shown in the following table.

Table 2. 2 Monthly average wind speed (m/s) at the site from NASA

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
Ave. speed	4.15	4.08	3.84	3.63	3.28	3.08	2.88	2.82	2.93	3.35	3.79	3.97	3.48

2.3 Hybrid Energy Systems

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, battery and wind energy. A hybrid system uses a combination of energy producing components that provide a constant flow of uninterrupted power. Hybrid, wind turbine and photovoltaic modules, offer greater reliability than any one of them alone because the energy supply does not depend entirely on any one source. For example, on a cloudy stormy day when PV generation is low there's likely enough wind energy available to make up for the loss in solar electricity (Science Direct, 2005).

Wind and solar hybrids also permit use of smaller, less costly components than would otherwise be needed if the system depended on only one power source. This can substantially lower the cost of a remote power system. The use of renewable energy sources presents a tremendous potential for many applications and especially off-grid standalone systems. In this context, one of the most promising applications of renewable energy technology is the installation of hybrid energy systems (HES) in remote areas, where the grid extension is costly and the cost of fuel increases drastically with the remoteness of the location (green, 2010).

Despite advances by hybrid power systems in improving reliability and reducing the overall size of the power system, initial costs remain relatively high. It heaves the potential user to reduce demand as much as possible to keep costs down. Advances in energy efficiency permits users to meet their energy needs from smaller, less expensive power systems than once were possible.

2.3.1 Stand Alone Hybrid System

The stand-alone hybrid power system is used primarily in remote areas where utility lines are uneconomical to install due to the terrains right-of-way difficulties, or environmental concerns. Building new transmission lines is expensive even without these constraints. A 130-kV line costs in Ethiopia more than $125,000 per kilometer. A stand-alone system would be more economical for remote villages/towns than the rural towns are found many kilometers far from the nearest transmission line.

Solar and wind power outputs can fluctuate on an hourly or daily basis. The standalone system, therefore, must have some means of storing excess energy on a sunny day or a windy day for use on a rainy day or without wind. Alternatively, wind turbines and PV modules can be used in a hybrid configuration with a Diesel engine generator in remote areas or with a fuel cell in urban areas. For this thesis it only focuses on PV modules and wind turbine configurations with storage battery system.

CHAPTER THREE

MATHEMATICAL ANALYSIS

3. Electrical Energy Demand and Present Electric Status of Lenda Town

Energy consumption is the electrical power your loads consume in a period of time. It is measured in kWh. Loads are usually the largest single influence on the size and cost of a PV and wind turbine system. In order to reduce the cost of the PV and wind turbine system it is necessary to use more efficient, lower demand appliance and to eliminate, partially or completely, the use of other loads.

3.1 Present Electric Status of Lenda Town

The present electrification status of Lenda town indicated that the grid electricity from Hosanna substation is 59Km distance far away from Lenda town, which is under construction. The town uses a municipality diesel generator which works three hours per day for some households of the town and some peoples and institutions use their own generator. The current electric power data of the town is listed as below:

Table3. 1 present electric status of lenda town

Name of power station	Generator capacity	Energy generated (KWH)	Fuel consumption	Service hour of generators (3 hour per day)	Population size	Energy consumption per person
Lenda	40KW	43,800	10,950(Liter)	1095(per year)	2,700	16.22KWH/pers on

3.2. Estimation of Residential Load Consumption

To calculate the estimated connected load on each house of the town, the first thing to be done is to know the number of people in that area (Lenda town) and the number of house hold. The near statically data indicates that in 2018 GC the number of people living in lenda town is around 2,700 people and its household is 644. The electric loads are estimated as below:

1. Electric lighting load

From the data taken all of the people living in this town need lighting as their primary choice. The average number of lamp used per household is 2. The rating of power saver fluorescent lamp selected for this thesis 11w.

Total lighting load=power saver fluorescent lamp*No. of households*No. of lamps in use Total lighting load=11w*644*2=14168w=14.168kw

2. Television load

The power saver 21-inch television is selected for this thesis is 60 w. The percentage of people interested to use television is around 232 from the total 644 households.

Total television load=60w*232=13920w=13.92kw

3. Radio rating

From the interview that taken in Lenda town in all of peoples are interested to use radio as their home appliance. The power saver radio rating we select is about 5w.

Total electric radio load=power saver radio rating*No. users

Total electric radio load =5w*644=3.22kw

4. Cellphone recharge

From the questionnaire that taken in Lenda town around half of the people are users of mobile technology. The rough estimation is done about 500 households are need to use cellphone recharge for their home. The rating of cellphone is 3w.

Total cellphone recharge load=cellphone rating*No. of users

Total cellphone recharge load=3w*500=1500w=1.5Kw

5. Computer rating- (desktop)

From the questionnaire that taken in lenda town most of people are not interested to use computer as their home appliance. But there is a primary and secondary school need to use total of 24 total computers, three printers, and two copy machine. The rating of computer is 120w.

Total computer load=computer rating*No. of computers
Total computer load=120w*24=2880w=2.88Kw

Total printer load= 100w*3=100w=0.3kw

Total copy machine =120w*2=0.24kw

6. Refrigerator Rating

From the questionnaire that taken in lenda town most of people are not interested to use refrigerator as their home appliance. But around 15 house hold are interested to use refrigerator for their home appliance and for business service. The rating of refrigerator in power saver mode is 120w.

Refrigerator load=power saver refrigerator rating*No. of refrigerators

Frig/Freezer 16cf / 453.ltr (13 hours) =475w for cafes = 6* 475=2.85kw

Frig Sun Frost 12cf DC for Home= 15*70w=1.05kw

Total refrigerator load=2.85kw+1.05kw=3.9kw

7. Electric Stove

From the questionnaires that taken in Lenda town one fourth of the households are interested to use electric stove for their home appliance. That means 150 people need to use electric stove for their home. The rating of electric stove is 250w.

Total electric stove load=electric stove rating*No. of users/households

Total electric stove load=150w*250=37500w=37.5kw

8. Tea machine - 6*200w=1.2kw
9. Flour –making mill -Total Load=5.7kw*1=5.7kw
10. —Buna Mefelfeya-Total load=11.5kw
11. Health clinic station: The lenda town health center is already electrified by giz.
12. Municipality of lenda.

Lenda town is located in southern nations and nationalities and it has its own growing municipality with some offices and accessories. The municipality has the following loads:

Table3. 2Total load of the municipality

Type of load	Rating (w)	Item	Total load (w)
Power saver light	11	15	165
Straight light(MASTER LED spot 230V)	16	25	400
Computer	120	1	120
Printer	60	1	60
TV color for staff	60	1	60
Radio	5	1	5
Total			810w

As we saw from the above specification and calculation the load requirement for the municipality is 810w.

Total load of municipality =810w=0.81kw

13. Schools

We made an interview to know the education facility per households; the collected data indicate Most of people are illiterate because of there is no education facility in the town. The thesis is to come up with electric facility for the people in lenda town. The thesis mainly aims to fulfill the energy demand of one elementary (1-8) and one high school (9-10) of the town.

i. Elementary school (1-8)

The thesis considers different electric requirement for the primary school.

Table3. 3 Total load of elementary school

Electric load	Rating (w)	Item	Total load(w)
Electric Lighting	15	38	570
Computer	120	1	120
Printer	100	1	100

Copy machine	120	1	120
Teaching aids			
Radio	5	5	25
TV (19 inch color)	70	2	140
Total			=1075

As we saw from the above specification and calculation, the demand for elementary school is 1075w.The total load requirement is1075w.

ii. High school (9-10)

The project considers different electric requirement for secondary school.

Table3. 4 Total load of high school

Electric load	Rating(w)	Item	Total load (w)
Electric lighting	15	28	420
Teaching aids			
Computer	120	22	2640
Radio	5	4	20
TV (plasma)	100	20	2000
VCR(satellite receiver)	30	1	30
Power tool for workshop	220	1	220
Total			=5330

Total electric load for secondary school is 5330w

Total electric load of school=total electric load of elementary school +total electric load of high school=5.33kw+1.075kw=6.405kw

14. Religious institutions

The rough sampling shows that there are five religious institutions in lenda town the electric load demand listed as follows:

i. The electric demand of Orthodox Church

The assumption of electric load requirement is lighting and loud speaker.

Table3. 5Total load of orthodox church

Electric load	Rating (w)	Item	Total electric load (w)
Lighting	15	20	300
Loudspeaker	400	1	400
Total			700

ii. The electric demand of Muslim mosque

The assumption of electric load requirement is lighting and loudspeaker.

Table3. 6 Total load of mosque

Electric load	Rating (w)	Item	Total electric load (w)
Lighting	15	15	225
Loudspeaker	400	1	400
Total			625

iii. The electric demand of protestant church

The assumption of electrical load requirement is lighting, loudspeaker and musical instrument.

Table3. 7Total load of protestant church

Electric load	Rating (w)	Item	Total electric load (w)
Lighting	15	10	150
Loudspeaker	400	1	400
Musical instrument	100	1	100
Total			650

Since there are three protestant churches, therefore the total electric load is =3*650w=1950w
Total electric demand of religious institution =700w+625w+1950w=3275w=3.275Kw

The electrical energy demand of lenda town

The case study area contains around 2,700 people in which there are 644 households.

Table3. 8The total electric demand of the town

Load		Quantity			Rating (in watt)		Usage (hr/day)	Usage (day/wee)	Energy (kwh/day)
		No of item	No of people used	total		Total power in kw			
Lighting		2	644	1288	11	14.168	12	7	170.016
Television		1	232	232	60	13.92	4	7	55.68
Radio rating		1	644	644	5	3.22	8	7	61.824
Cell-phone recharge		1	500	500	3	1.5	2	7	3.864
Refrigerator	cafe	1	6	6	475	2.85	24	7	68.4
	home	1	15	15	70	1.05	24	7	25.2
Electric stove		1	150	150	250	37.5	2	7	75
School		1	1 for 644 house hold			6.405	8	7	51.24
Municipality		1	1 for 644 house hold	1	810	0.81	8	7	6.48
Religious institution		1			3275	3.275	6	7	19.65
Flour-making mill		1	1 for 644 house hold	1	5700	5.7	11	7	62.7
Tea machine		6	6 for 644 house hold	6	200	1.2	12	7	14.4
Coffee hatchery (Buna Mefelfeya)		1	1 for 644 house hold	1	11500	11.5	11	7	126.5
Total						103.1			**740.954**

The optimal design is of this thesis is to design the load demand of Lenda town by hybrid solar-wind energy system. As we saw from the above table the load demand for present status is 103.098kw, this does not consider 20% system loss.

Optimal system output=103.098kw + (0.2*103.098kw) =123.7176kw

Optimal energy consume per year=(123.7176kw *8760h)= 1,083,766.176kw, where all loads consuming energy from the system for 24 hours but to design optimal system we have to consider operating hours of loads.

The optimal design of system energy=740.954kwh/day*365day=270,448.21kwh+loss of system energy*8*365=270,448.21kwh+(20.6196*365*8) =1,511,938.49 kwh per year.

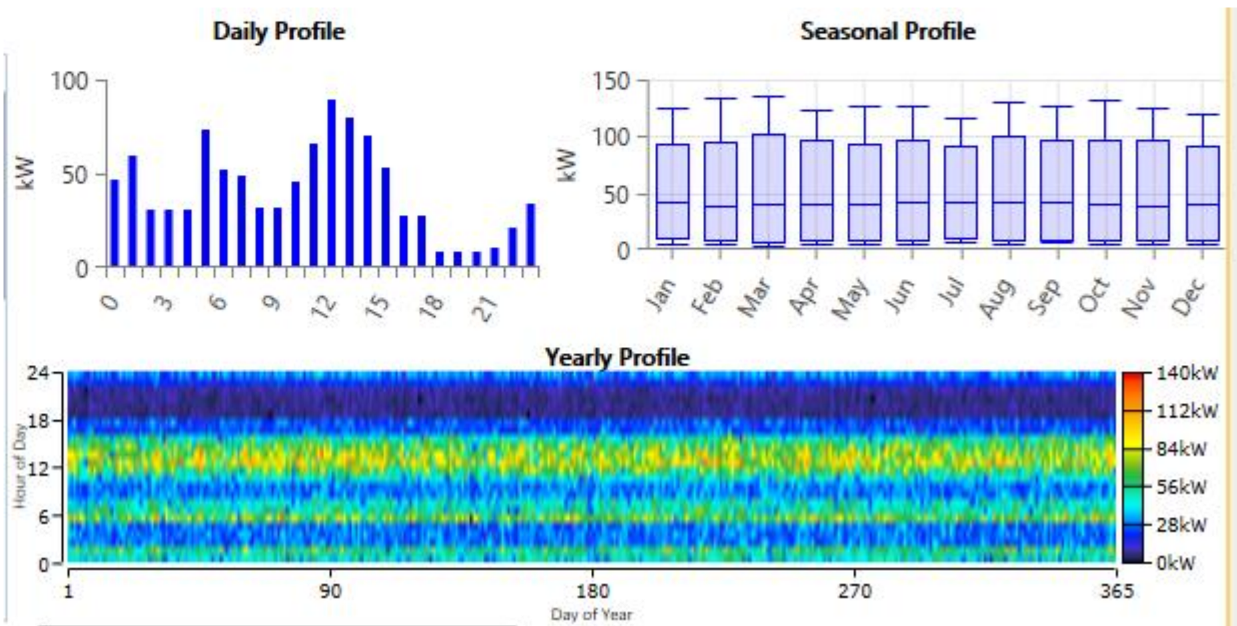
The energy consumption in optimal design is calculated in the above case the next thing that can be done is calculating the optimal system design for the two renewable energy system.

Table3. 9Total Daily load profile of Lenda town

Hours	**Load (kw)**
00:00-01:00	46.92
01:00-02:00	59.62
02:00-03:00	30.92
03:00-04:00	30.92
04:00-05:00	30.92
05:00-06:00	73.164
06:00-07:00	52.49
07:00-08:00	49.06
08:00-09:00	31.56
09:00-10:00	31.56
10:00-11:00	45.82
11:00-12:00	66.22
12:00-13:00	89.298
13:00-14:00	79.298

14:00-15:00	69.93
15:00-16:00	53.56
16:00-17:00	27.377
17:00-18:00	27.377
18:00-19:00	9.005
19:00-20:00	9.005
20:00-21:00	8.89
21:00-22:00	10.52
22:00-23:00	21.36
23:00-24:00	33.54

The daily load profile of lenda town is shown in figure below. Note that the load profile used is calculated based on the total hourly load consumed by 644 households and institutions in the town.



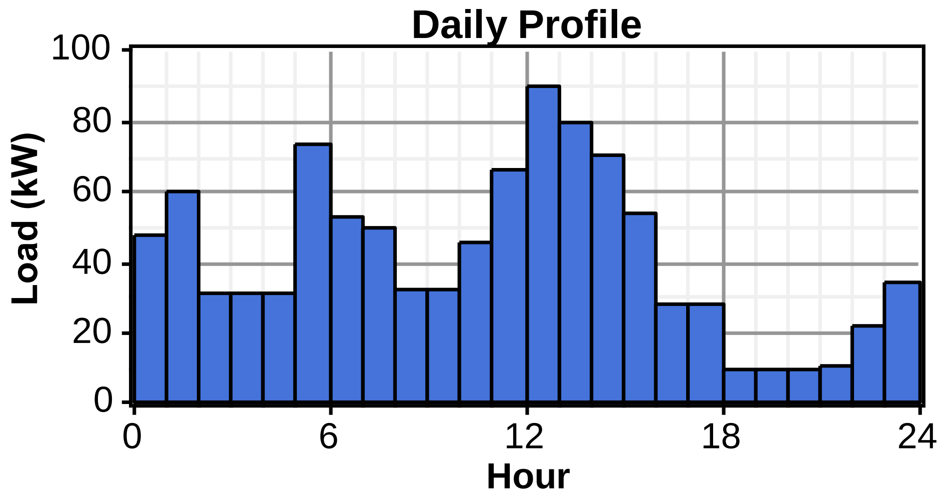


Figure3. 1Graph of Load Profile

Based on the observation above, when it reaches from 12:00 a.m. to 2:00 a.m. in the morning, where housewives started to wake up to make breakfast for their children and husbands to eat before going to school or work, more electricity will be used, for example, switching on the lamp for preparing food because the sun has not risen yet or just rising. A constant load of 30.92kw will be used at 2:00 a.m to 5:00 a.m in the morning, some may switch on the radio to listen for news or songs for a few hours which add in the electricity load but total load consumed is less load than between 12:00-2:00 a.m because the electric stove is switch off and lightening load decrease because of the sun rise. Then from 5:00a.m to 6:00 a.m the homemakers start to prepare food for lunch time this increase the load. Then during afternoon at around 2:00p.m, housewives may switch on television for entertainment. The electricity load usually reaches its _maximum (89.298kw) at 12:00pm, Husbands and children coming back from work or school will gather for dinner, and later after dinner, all the family member will do their own activities like watching television or listen to the radio, so more lamps will be switched on by that time. Then after 4:00pm, some of the family member will sleep which lead to the decrease in load consumed. During night time, a constant load of will be used from 6:00 p.m. to 11: 00p.m in the morning, where all the villages are still asleep. This is the less load consumed everyday with onlyrefrigeratorsoperating24hoursineachhouse only refrigerators operating 24hoursineachhouse.

3.3 Wind energy system design

3.3.1 Wind system parameter design for the purposed project

I. Speed parameter mathematical calculation

The first thing is to find the scale factor for each month from the above equation for k=2, the following is obtained: C= 2/√∏*V_{ave} equation1

Fore January C= 2/√∏*V_{ave}= 2/√∏*4.15=4.68m/sec ………..similarly

For February C= 2/√∏*V_{ave}= 2/√∏*4.08= 4.064 m/sec

For March C= 2/√∏*V_{ave}= 2/√∏*3.84= 4.333 m/sec

For April C= 2/√∏*V_{ave}= 2/√∏*3.63=4.096m/sec

For May C= 2/√∏*V_{ave}= 2/√∏*3.28=3.701m/sec

For June C= 2/√∏*V_{ave} = 2/√∏*3.08=3.4754m/sec

For July C= 2/√∏*V_{ave} = 2/√∏*2.88=3.25 m/sec

For August C= 2/√∏*V_{ave}= 2/√∏*2.82=3.182m/sec

For September C= 2/√∏*V_{ave}= 2/√∏*2.93=3.306m/sec

For October C= 2/√∏*V_{ave} = 2/√∏*3.35=3.78m/sec

For November C= 2/√∏*V_{ave}= 2/√∏*3.79=4.276m/sec

For December C= 2/ √ ∏*V_{ave}= 2/ √

∏*3.97=4.48m/sec

Speed at 40 meter or Hub height

$$\frac{v(Z2)}{V(Z1)} = \frac{(Z2)}{(Z1)}\alpha$$ ....equation 2

V=the wind speed at desired height,

Z_{ref}= wind speed at reference height,∝=Roughness constant

V (Z2) the wind speed at desired height Z2, V (Z1) the wind speed at measured height Z1 and $\propto$ roughness constant.

The surface roughness length is a parameter that characterizes the roughness of the surrounding terrain. The table below contains representative surface roughness lengths taken from Maxwell, McGowan, and Rogers (NREL, 2008):

Table3. 10 Representative surface roughness lengths different terrain (source: HOMER)

Terrain Description	z_0
Very smooth, ice or mud	0.00001 m
Calm open sea	0.0002 m
Blown sea	0.0005 m
Snow surface	0.003 m
Lawn grass	0.008 m
Rough pasture	0.010 m
Crops	0.05 m
Many trees, few buildings	0.25 m
Suburbs	1.5 m
City center, tall buildings	3 m
Few trees	0.14m

For this project the place is considered inland place with few trees the roughness constant is 1/7=0.14.

$V=3.48(\frac{40m}{10m})^{0.14}=4.225$ m/sec

Cut in speed: V_c = ½*V_m $=1/2*4.225$m/sec=2.1126m/sec

Rated speed: $V_r=1.8*V_m=1.8*4.225$m/sec=7.6056m/sec

Furling speed: $V_F=2*V_{rate}=2*7.6056=15.21125$m/sec

II. Power density mathematical analysis for Lenda town

$P_{wm}=1/2*\rho*c^3*3*\sqrt{\prod}/4$ ---equation 3

For January $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(4.68)^3*3/4\sqrt{\prod}=83.4376w/m^2$

For February $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(4.604)^3*3/4\sqrt{\prod}=79.4383w/m^2$

For March $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod} =1/2*1.225*(4.333)^3*3/4\sqrt{\prod}=66.221w/m^2$

For April $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod} =1/2*1.225*(4.096)^3*3/4\sqrt{\prod} =55.937w/m^2$

For May $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod} =1/2*1.225*(3.701)^3*3/4\sqrt{\prod} =41.265w/m^2$

For June $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod} =1/2*1.225*(3.4754)^3*3/4\sqrt{\prod} =34.17w/m^2$

For July $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(3.25)^3*3/4\sqrt{\prod} =27.94309375w/m^2$

For August $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod} =1/2*1.225*(3.182)^3*3/4\sqrt{\prod}=26.225 w/m^2$

For September $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(3.306)^3*3/4\sqrt{\prod}=23.323 w/m^2$

For October $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(3.78)^3*3/4\sqrt{\prod}=43.964 w/m^2$

For November $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(4.276)^3*3/4\sqrt{\prod}=63.641 w/m^2$

For December $P_{wm}=1/2_{\varrho*}c^3*3/4\sqrt{\prod}=1/2*1.225*(4.48)^3*3/4\sqrt{\prod}=73.191 w/m^2$

Table3. 11 Wind parameters speed, scaled speed and power density

MONTH	**Monthly average wind speed**	**Scale factors(C)**	**Power density(w/m^2)**
JANUARY	4.15 m/sec	4.68m/sec	83.4376 (w/m^2)
FEBRUARY	4.08 m/sec	4.604 m/sec	79.4384 (w/m^2)
MARCH	3.84 m/sec	4.333 m/sec	66.2202 (w/m^2)
APRIL	3.63 m/sec	4.096 m/sec	55.937 (w/m^2)
MAY	3.28 m/sec	3.701 m/sec	41.265 (w/m^2)
JUNE	3.08 m/sec	3.4754 m/sec	34.169 (w/m^2)
JULY	2.88 m/sec	3.25 m/sec	27.943 (w/m^2)
AUGEST	2.82 m/sec	3.182 m/sec	26.225 (w/m^2)
SEPTEMBER	2.93 m/sec	3.06 m/sec	23.323 (w/m^2)
OCTOBER	3.35 m/sec	3.78 m/sec	43.964 (w/m^2)
NOVEMBER	3.79 m/sec	4.276 m/sec	63.641 (w/m^2)
DECEMBER	3.97 m/sec	4.48 m/sec	73.191 (w/m^2)
MONTHLY ANNUAL AVERAGE	3.48 m/sec	3.9303 m/sec	48.644(w/m^2)

III. Mathematical calculation for rating of turbine and energy generated from wind

Energy generated from wind is calculated as follow:

The total energy consumption of lenda town is 740.954kwh/day. Energy generated from wind turbine is 17% as we get from HOMER Optimization. To design the wind turbine, we consider 25% loss of system component.

Ed total=1.25*740.954kwh/day =926.1925kwh/day

Therefore, the energy generated from wind energy is given by:

Ed wind=926.1925kwh/day *0.17=157.453kwh/day

The total load of Lenda town is 103.1kw and from this 17% is generated from wind energy as we get from the HOMER Optimization result. Therefore, the power generated from wind turbine by considering system loss 25% is

=103.1kw*0.17*1.25=21.90875kw

As a designer we select the Generator efficiency η_G=94%=0.94

$P_{Electrical}$=21.90875kw

$\eta_G = \frac{p\ electrical}{p\ mechanical}$-- equation 4

$P_t^{(m)} = \frac{Pe}{0.94} = \frac{21.90875kw}{0.94} = 23.307kw = 24kw$ (Turbine capacity)

Cp is the rotor coefficient (ratio of shaft power of the windmill to the power in the wind in the
cross sectional area of the rotor)

$C_p = 4\propto(1-\propto)^2$--equation 5

$C_p = 4(0.14)\ (1-0.14)^2 = 4(0.14)\ (0.83)^2 = 0.56(0.83)^2 = 0.41$

$C_p = \frac{Pt}{Pw}$ $P_W = \frac{24kw}{0.41} = 58.5366$kw

$E_{Generated}$ =C. F*Generator capacity*8760---------------------------------------equation 6

Capacity factor = $\frac{energy\ generated\ from\ generator}{power\ capacity\ of\ wind}$----------------------------equation 7

Capacity factor $= \frac{21.90875kw}{58.5366kw} = 0.374$

E $_{\textbf{Generated}}$ = 0.374*21.90875kw *8760=71,778.323kwh

The shaft power of a wind rotor is given by equation 8

$P_w = \frac{1}{2}\rho C_p A V_m^3$ --equation 8

$P_w = \frac{1}{2}(1.225kg/m^3)*0.41*\frac{\pi * D2}{4}*(4.225 m/sec) = D^2*(14.875) = 58.5366kw$; $D^2 = 3.9352m^2$

Where, $\rho = 1.225kg/m3$ is wind density of the air which varies slightly with altitude and temperature.

Diameter of the turbine

D=1.9837m; $R = \frac{1.9837}{2} = 0.992$m (radius of the turbine or blade length)

Swept Area

The output power is also related to the area intercepting the wind, that is, the area swept by the wind turbines rotor. Double this area and you double the power available. The relationship between the rotor 's diameter and the energy capture is fundamental to understanding wind turbine design. Relatively small increases in blade length or in rotor diameter produce a correspondingly bigger increase in the swept area, and therefore, in power. For the horizontal axis turbine, the rotor swept area is the area of a circle: Where D is the rotor diameter in meters.

$A = \frac{\pi}{4} D^2 = 3.14(1.9837m)^2/4 = 3.09m^2$

Tip speed Ratio-

is an extremely important factor in wind turbine design. TSR refers to the ratio between the wind

speed and the speed of the tips of the wind turbine blades.

$$\lambda = \frac{4\pi}{n} + 1 = \frac{4(3.14)}{3} + 1 = 5$$

Number of blades

$B = 80/\lambda^2 = 80/5^2 = 3.2 = 3$

Width of blade

The outer portion of the width of the blade

$C = 40/(\lambda^2 * B) = 40/(5^2*3) = 0.5333m = 53.3cm$

Starting Torque

$Torque = V(Z)*R^3/\lambda^2 = 4.225m/sec*(0.992m)^3/5^2 = 0.165Nm$

Shaft speed

Shaft rpm = $\frac{60*\lambda*V(Z)}{D\pi}$ = $\frac{60*5*(4.225)}{1.67m*3.14}$ =241.71rpm = $\frac{241.71*2\pi}{60}$=25.31rad/sec

The maximum torque

$T^{max}=\frac{Pr}{W}=\frac{24,000w}{25.31rad/sec}$=948.241kNm

Mass of blade

Mass of blade=0.1452*$R^{2.9158}$=0.1452*$(0.992)^{2.9158}$ =0.141kg

For three blade =3*0.141kg = 0.423kg

3.4 Solar system design for the proposed project

3.4.1. The Area under Investigation

Lenda town is located in Ethiopia, around southern nation and nationalities region at 5.9 ° latitude and 36.5° longitude. The prevailing wind is the wind that blows most frequently across a particular region. Different regions on Earth have different prevailing wind directions which are dependent upon the nature of the general circulation of the atmosphere and the latitude of the place.

Table3. 12 lenda Town daily solar radiation and clearance index

Month	Clearance index	Daily solar radiation
January	0.651	6.12
February	0.644	6.4
March	0.596	6.19
April	0.548	5.71
May	0.553	5.61
June	0.542	5.37
July	0.524	5.23
August	0.545	5.58
September	0.571	5.9
October	0.559	5.6
November	0.604	5.73
December	0.645	5.92

The design of the system must include loss by panel component to consider this, from the load calculation. The total energy consumption of Lenda town is 740.954kwh/day. Energy generated from solar panel is 83% as from HOMER Optimization. To design the PV panel, we consider 20% loss of system component.

Ed total=1.2*740.954kwh/day =889.1448kwh/day

Therefore, the energy generated from solar energy is given by:

Ed pv=889.1448kwh/day*0.83=737.99kwh/day

1. Note that, the calculation above showed the maximum load that a will use in the town. Total

AC load used = 740.954kwh /*day*

2. Multiply line 1 by 1.25 to correct for inverter loss and battery efficiency.

   740.954kwh /day **1.25=926.1925* kwh /day

3. Choose inverter DC input voltage; usually 12V or 24V. This is the DC system voltage.

   ∴Chosen DC system voltage = 24V

4. Divide line 2 by line 3. This is the total amp hours per week used by AC loads.

   ∴Total amp hours per week used= $\frac{926.1925 \text{ kwh /day}}{24v}$ =38591.35Ah/day

Steps for PV Calculation

1. Total average amp hours per day from the system loads.

   =38591.35Ah/day

   Since energy generated from PV system is 83%
   38591.35Ah/day*0.83=32,030.8205Ah/day

2. Multiply line 1 by 1.2-1.4 to compensate for loss from battery charge/discharge.

   32,030.8205Ah/day*1.2=38,436.9846Ah/day

3. Find Average sun hours per day.

   ∴8 hours

3. Divide line 2 by line 3. This is the total solar array amps required.

   = $\frac{38{,}436.9846\text{Ah/day}}{8h/day}$ =4,804.623A

5. Optimum or peak amps of solar module used. See module specifications.

   ∴Chosen PV module = Kyocera KC130GT.

   Its maximum power current *p I)* = 7.39A

6. Total number of solar modules in parallel required. Divide line 4 by line 5.

   = $\frac{4{,}804.623\text{A}}{7.39\text{A}}$ = 650.152 panels

7. Round of the value of line 6.

=650.152 ≈ 651panels

8. Number of modules in each series string to provide DC battery voltage (using PWM Charge Controller).

=2

9. Total number of solar modules required. Multiply line 7 by line 8. ∴Total number Of solar modules required = 651× 2 = 1302panels

Steps for Sizing Converter

1. For Lenda town, the inverter rating needed is calculated as:

Total power needed for this town is 103.1kw

2. The inverter chosen in this design is PM-1200L (12V) which has a power of 1200W each. Thus, a total of $\frac{103.1kw}{1.2kw}$=85.92≈ 86 inverters are needed.

Steps for Sizing Battery

1. Total average amp hours per day from the system loads.

   =38591.35Ah/day
2. Maximum number of continuous cloudy days expected.

   =1.5 days
3. Multiply line 1 by line 2.

   38591.35Ah/day×1.5*days=57887.025Ah*
4. Divide line 3 by (maximum) 0.8 to maintain a 20% reserve after deep discharge period.

   $=\frac{57887.025Ah}{0.8}$=72358.78Ah
5. Amp-hours of battery chosen.

∴Surrette 4KS25P with 1900Ah.

5. Divide line 4 by line 5. This is the total number of batteries in parallel required.

$=\frac{72358.78Ah}{1900Ah}=38.08$

≈39 batteries

7. To determine the number of batteries required in series, divide the system voltage (12V, 24V
or 48V) by the voltage of the chosen battery (2V, 6V or 12V).

$\frac{24V}{12V}$=2

8. Multiply line 6 by line 7. This is the total number of the chosen battery needed for the system. 39× 2 = 78 batteries are needed.

3.4.2. Sizing of PV modules

Different size of PV-modules will produce different amount of power. To find out the sizing of PV modules will produce different amount of power. To find out the sizing of PV modules, the total peak watt produces needs. The peak watt (WP) produces depends on the size of the PV module and climate of site location we have to consider panel generation factor.

- Aging (5%)
- Dust particle (10%)
- Glass reflection factor (5%)

Calculating panel Generation factor

Panel generation factor is found through multiplying collection efficiency with average solar radiation in least sunny month (kw/m2/day).

For this project the data from NASA indicated that the average solar radiation in least sunny month is July 5.23 kwh/m2/day.

- To find out the efficiency of panel.
- Due to sun light striking panel straight (caused by glass increasing reflectance at lower angular of incidence = 5%)
- For dirt =5%
- Allowance for panel being bellow specification and for aging = 10%

Ƞpg= (100-5) % * (100-5) % * (100-10) =95% * 95% * 90% =0.95*0.95*0.9 =0.81

The panel Generation factor is calculated as follows

PGF= Ƞpg*Lsl =0.812225*5.23kwh/m2/day =4.248 =4

Determining the need area to install PV Panels

Total panel size = $\frac{energy\ generated\ from\ pv}{panel\ generation\ factor} = \frac{1397.435kwh/day}{4}$ =349.3587kwp

Area for PV panel

In East Africa from most literature 1kwp=10m^2

1kwp=10m^2

349.3587kwp=x

$$\frac{X*1kwp}{1kwp}=\frac{349.3587\ kwp*10\ m2}{1kp}$$

$X=3493.587m^2$

Therefore; the area taken by panels is = $3493.587m^2$

3.4.3. Charge controller (MPPT)

The power output required per house hold and institutions if all appliances are functional at the same time is 103.098kw and the voltage required for the solar home system is usually 24V. So the charge controller must work at a maximum current of

$$I_T=\frac{103,098w}{24v}=4.29575kA$$

Number of modules connected in series is given by:

$$N_s=\frac{Vsystem}{Vmod}=\frac{24v}{12}=2$$

$N_p=\frac{Eb}{Vsys}(*D_{sh}*I_{sc}*PV_{mod})$, where $Eb=Eu/\eta b$=1,863.99 Kwh/day

$$N_p=\frac{1863.99*10\ wh/day}{24v*6hr*i}*\frac{1}{8.094}$$

$N_p=428$

$N_{mod}=428*2=856$ modules

Inverter sizing

The sizing of inverter is basically dependent up on the total demand of the system. The inverter capacity (I_c)

$$I_c=\frac{Pest}{(ni*\cos\emptyset*K\ loss)}$$

K_{loss} = (100-15)*(100-25)*(100-20)

= 85% * 75% *

80%=0.51 Cos∅ = 0.95

$$I_c=\frac{103.098k\ w}{0.9*0.51*0.95}=236436kw$$

$V_{batt}=N_{cells}*V_{cell}$

$N_{cells}=4*36=144$

$$V_{cell}=\frac{Vmode}{Ncells}=\frac{12}{144}=0.083$$

$V_{batte}=N_{cell}*V_{cell}=0.0834*144=12$

Number of Batteries: To determine the number of batteries required in series, divide the system voltage (12V, 24V or 48V) by the voltage of the chosen battery (2V, 6V or 12V).

$$\text{Nseries}=\frac{\text{Vsystem}}{\text{Vbatt}}=24v/12v=2$$

Battery sizing

Battery sizing consists in calculating the number of batteries needed for a hybrid renewable energy system. This mainly depends on the days of autonomy desired. Days of autonomy are the number of days a battery system will supply a given load without being recharged by a PV array, wind turbine or another source. If the load being supplied is not critical then 2 to 3 autonomy day are commonly used. For critical loads 5 days of autonomy are recommended. A critical load is a load that must be used all the time.

The minimum energy that can be stored in the battery is given by: The battery selected is lead

acid and its efficiency is; η_b=90%=0.9

$E_b=\frac{Eu}{\eta b}=\frac{1,397.435\ kwh/day}{0.9*0.85*0.98}=1,863.99$ Kwh/day

1. Assuming the working voltage for direct current; V_{dc}=24v then, the net capacity that the battery
2. can store in Ah/day will be $C_{bn}=\frac{Eb}{Vcc}=\frac{1863.99\frac{Kwh}{day}}{24v}=77.666$ Ah/day
3. The net capacity of the battery depends on the depth of the battery (DDP), the battery discharge determines the life cycle of battery. Deep cycle lead acid battery can store 50% to 80%,
4. DDP=60% the total commercial capacity of the battery calculates
5. $C_b=C_{bn}$/DDP=77.666/0.6=129.444Ah
6. This value is compatible and correct if and only if there are not cloudy days. Considering cloudy days, let assume the battery have energy demand of two days.

C_b=129.444Ah*2=258.888Ah

Table3. 13 Solar irradiance parameters for lenda town

$\boldsymbol{\delta}$	Declination	N	Bright sunshine hour
$\emptyset$	Inclination	N	Day length
$\boldsymbol{\theta}$	Angel of incidence	H_o	Daily extraterrestrial radiation
$\boldsymbol{\omega}_s$	Sun set hour angle	H	Daily solar irradiation
$\boldsymbol{\beta}$	Tilt angel	H_b	Beam radiation
G_{sc}	Solar constant	H_d	Diffuse solar radiation
$\boldsymbol{\theta}_z$	zenith angel		

Latitude → $5.9^0 = 6^0$

Longitude → $36.5^0 = 37$

Above sea level = 1032m

Tilt angel ($\boldsymbol{\beta}$)

$\boldsymbol{\beta}_{\textbf{Summer}} = 5.9^0 - 15^0 = -9.1^0 + 180^0 = 170.9^0$ (5% reduction in Annual energy production)

$\boldsymbol{\beta}_{\textbf{Spring}} =$ latitude $= 5.9^0$

$\boldsymbol{\beta}_{\textbf{Autumn}} =$ latitude $= 5.9^0$

} Maximum radiation

$\boldsymbol{\beta}_{\textbf{Winter}} =$ latitude $+ 15^0 = 5.9^0 + 15^0 = 20.9^0$ (15% reduction in annual energy production)

Declination angle

The declination is the angular position of sun at solar noon, with respect to the plane of equator.

it is value in degree given by cooper 's equation (NREL, 2008):

$$\delta = 23.4 \sin\left(360^0 \frac{284+n}{365}\right)$$

Table3. 14 declination angle

Month	**Number of days**	**Declination angle($\boldsymbol{\delta}$)**
January	N=1	-23.01^0
February	N=32	-17.52^0
March	N=61	-7.91^0
April	N=93	4.81^0
May	N=125	16.11^0
June	N=156	22.53^0
July	N=188	22.59^0
August	N=220	15.96^0
September	N=252	4.61^0
October	N=284	-8.1^0
November	N=315	-18.17^0
December	N=347	-23.74^0

CHAPTER FOUR

HOMER ANALYSIS

4.1 Selection of Loca0tion for Hybrid Energy Implementation

In order to improve the living standard of a rural area in the Town of Lenda, hybrid system is proposed. However, the type of hybrid energy system implemented, is still depends on the result of the analysis done in this thesis. Systems which generate the cheapest cost of energy (COE) will be favorable for implementation. Furthermore, take note that this thesis is designed to provide for a total of 644 families with the assumption that each family will have the basic household appliances of television, power saving lamps, radio, electric stove and refrigerator.

4.2 HOMER Input Data

4.2.1 Components needed in the system (Prices of each component)

(i) PV Panel

Table4. 1Cost of PV

Size(kw)	**Capital($)**	**Replacement ($)**	**O&M ($/yr)**
1	2000	2000	0

As can be observed from Table 4.1 above, both the capital and replacement costs of these PV panels are specified at $2000/kW. These capital and replacement cost include the price of PV panels, mounting hardware, tracking system, control system (maximum power point tracker), wiring and installation. Whereas the operating and maintenance cost is specified at zero because it is a maintenance free system. In addition, Figure 4 illustrates the properties that will be applied to the PV panels used in this analysis.

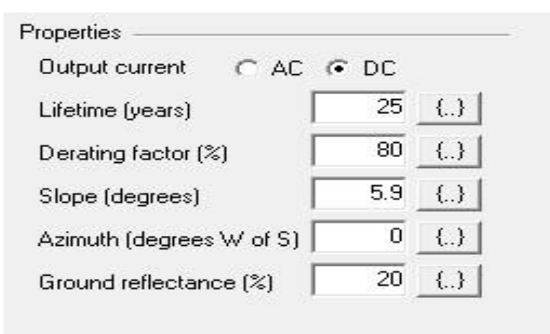


Figure4. 1Properties of pv

Table4. 2Variable Description

Variable	**Description**
Output current	Whether the PV array used produce AC or DC power.
Lifetime	The number of years the PV panels will last.
De-rating factor	A scaling factor applied to the PV array power output to account for reduced output in real-world operating conditions compared to the operating conditions at which the array was rated. For example, the de-rating factor is used to account for such factors as soiling of the panels, wiring losses, shading, dust cover, aging, and so on.
Slope	The angle at which the panels are mounted relative to the horizontal. Usually equal to the latitude, in order to maximize the annual PV energy production.
Azimuth	The direction towards which the panels face
Ground reflectance	The fraction of solar radiation incident on the ground that is reflected. A typical value for grass-covered areas is 20%.

Note also that, in this optimization analysis for PV panels, no tracking system is applied.

(ii) Wind Turbine

Figure4. 2Power Curve of Integrity eW15 Wind Turbine

The Integrity eW15 wind turbine with the power curve shown in Figure will be used in this hybrid energy system design. It is a simple and rugged wind turbine designed for high reliability, low maintenance, and automatic operation in adverse weather conditions. It will offset approximately 1.2 tons of air pollutants and 250 tons of greenhouse gases over its 30 years of operating life. The initial capital costs for installing each of these 40-meter-high wind turbines would be approximately $ 48740 including cost of the tower, controller, wiring, installation, and labor. The replacement cost however, may be different from the initial capital cost due to several reasons:

Not all of the component may require replacement at the end of its life. For example, the wind turbine nacelle may need replacement but the tower may not.

- The initial capital cost may be reduced or eliminated by a donor organization, but the replacement cost may not.
- One may want to account for the fixed costs (e.g. travel cost) of a visit to the site.

At initial construction, these costs are shared by all components, but at replacement time they may not.

- One may want to account for a reduction over time in the purchase cost of a particular technology.

In this case of the analysis, the replacement cost is specified at $3000, which is cheaper than the initial capital cost while the operation and maintenance is specified at $900/year, as shown in table 4.3.

Table4. 3Cost of Wind Turbine

Size(kw)	Capital(**$**)	**Replacement ($)**	**O&M ($/yr)**
1	48740	30000	900

iii) Diesel Generator

Diesel generators used in hybrid energy systems are synchronous alternators, which are directly coupled to a diesel engine. By adjusting the flow of fuel to the engine, their operating speed can be controlled and this determines the frequency of the AC output voltage. It has a total of 40000 operating hours and a minimum load ratio of 20% each. The operating cost of this diesel generator will be governed by its fuel consumption, while the maintenance cost depends strongly on the number of operating hours and the loading of the engine. Table 5 determines the cost of a 40kw diesel generator. Its replacement costs is $25000, while its operation and maintenance cost is $1/kW per hour. In this thesis the capital cost is zero because the diesel is already installed by the town municipality.

Table4. 4Cost of Diesel Generator

Size(kw)	Capital(**$**)	Replacement ($)	O&M ($/hr)
40	0	25000	1.000

(iv) Battery Bank

There are many types of batteries potentially available for use in the hybrid energy systems, including the lead-acid, nickel-cadmium, nickel-metal-hydride, rechargeable alkaline manganese (RAM), lithium-ion, lithium-polymer and redox (reducing oxidizing) batteries. However, at present, the most commonly used battery is still the lead-acid batteries due to the following reasons:

- Easy to obtain
- Reasonable price- low cost
- Longer life in high temperature applications
- Provides up to twice the life of flooded lead acid batteries
- Lower life-cycle costs
- Reduces corrosion which improve life
- Reliable
- Have good charge and discharge curves: produce stable power
- Have very high conversion efficiency at 85%-95%. (Higher than Nickel- Cadmium at 65% Alkaline (NiFe) at 60%, or other inexpensive battery technologies)
- Spill resistant
- Environmentally friendly

Table4. 5 Cost of Battery

Quantity	**Capital($)**	**Replacement ($)**	**O&M ($/yr)**
1	833	555	15

From Table 4.5, it is clear that the capital and replacement cost for installing a battery is $400, while the operation and maintenance cost is zero.

(v) Converter

In this optimization analysis, a converter that can be both inverter and rectifier is needed. When electricity from PV and battery are needed for the AC load, the converter will automatically have acted like an inverter to convert DC electricity to AC electricity. On the other hand, when AC electricity generated from both diesel generator and wind turbines exceeded the load demand, the excess electricity will be stored in the battery for future usage. Under this condition, the converter will act as a rectifier that converts AC electricity back to DC electricity for battery storage. Thus, a converter with the following properties is chosen to be use.

As indicated in Figure 4.3, the converter used in this analysis will last for 15 years before replacement. When it is in the form of an inverter, it has 90% efficiency of converting DC electricity to AC electricity. However, when it acts as a rectifier, a 5% reduction in the conversion efficiency (85%) will be applied if compare to its efficiency in the form of an inverter. Moreover, the capacity relative to inverter is set to 100%, which means that the rated capacity of the rectifier relative to that inverter is 100%.

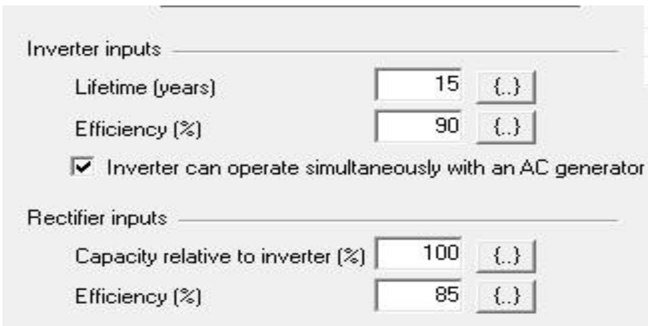


Figure4. 3 Properties of the Converter

Table4. 6 Cost of Converter

Size(kw)	Capital($)	Replacement ($)	O&M ($/yr)
1	700	700	0

Table 4.6 shows the cost of a 1kw converter. The capital and replacement cost for each of these converters are $700, while the operation and maintenance cost is zero.

(vi). Charge Controller

A charge controller or charge regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against over voltage, which can reduce the battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining (―deep discharging‖) a battery, or perform controlled discharge, depending on the battery technology, to protect battery life. Basically, there are various types of charge controllers which include the simple switch on/off controllers, PWM (pulse-width modulated) charge controllers and the MPPT (maximum power point tracking) controllers. A simple charge controller contains a shunt transistor to PV charging circuit, terminating the charge at a pre-set high voltage and, once a pre-set reconnect is reached, opens the shunt, allowing charging to resume. PWM charge controller however will charge the battery with constant voltage or constant current (the most commonly used controllers in PV systems). The MPPT types are more costly and better suited to large systems where the investment in an expensive MPPT regulator gives quick returns.

4.3 Breakeven Grid Extension Distance

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.

HOMER calculates the breakeven grid extension distance using the following equation:

$$D_{grid}=\frac{CNPC-CRF(i.Rpro)-CpowerLtot}{Ccap-CRF(i,Rpro)+Com}$$

Table 4.6 presented below the total distance of Lenda town far from the nearest gird and cost associated with gird extension.

Table4. 7Grid extension cost for lenda town

Name	Nearest substation	Voltage level	Unit cost per km($)	Total Transmission line cost($)	O& M cost	Total cost ($)
LENDA	Hosanna	132kv	125,000	11,125,000	2500*59	11,272,500

The total capital costs of grid extension are 11.35 Million US dollar. Moreover, the breakeven distances from the grid extension is 16.5Km for PV-wind, 18.1Km for PV-wind-diesel, and 17.7Km for PV-diesel meaning which is the net present cost of grid extension equals the net present cost of the stand-alone system. But the town is located far from breakeven grid extension and the detail for this we will discuss next chapter. If you go farther from this point (breakeven grid extension distance) the stand alone is the optimal solution power supply of the selected town.

4.4. System Architectures

Hybrid systems are fundamentally of two types: direct current (DC) bus and alternating current (AC) bus. The key difference between the systems is that in a DC bus system, all electricity from renewable energy sources must be produced nearby the battery bank (located in the power house). In an AC bus system, electricity generation can occur anywhere along the AC transmission system. Thus, solar panels can be distributed in several different locations in the town. From this reason, AC bus systems are considered to be more flexible and expandable. The figure below indicates that the system architectures of lenda town. The total components needed to the power supplied of the will discussed next portion. The equipment to be considering which indicated in the figure below could be the optimal solution of the existing conventional diesel generator and the existing diesel generator served as stand by.

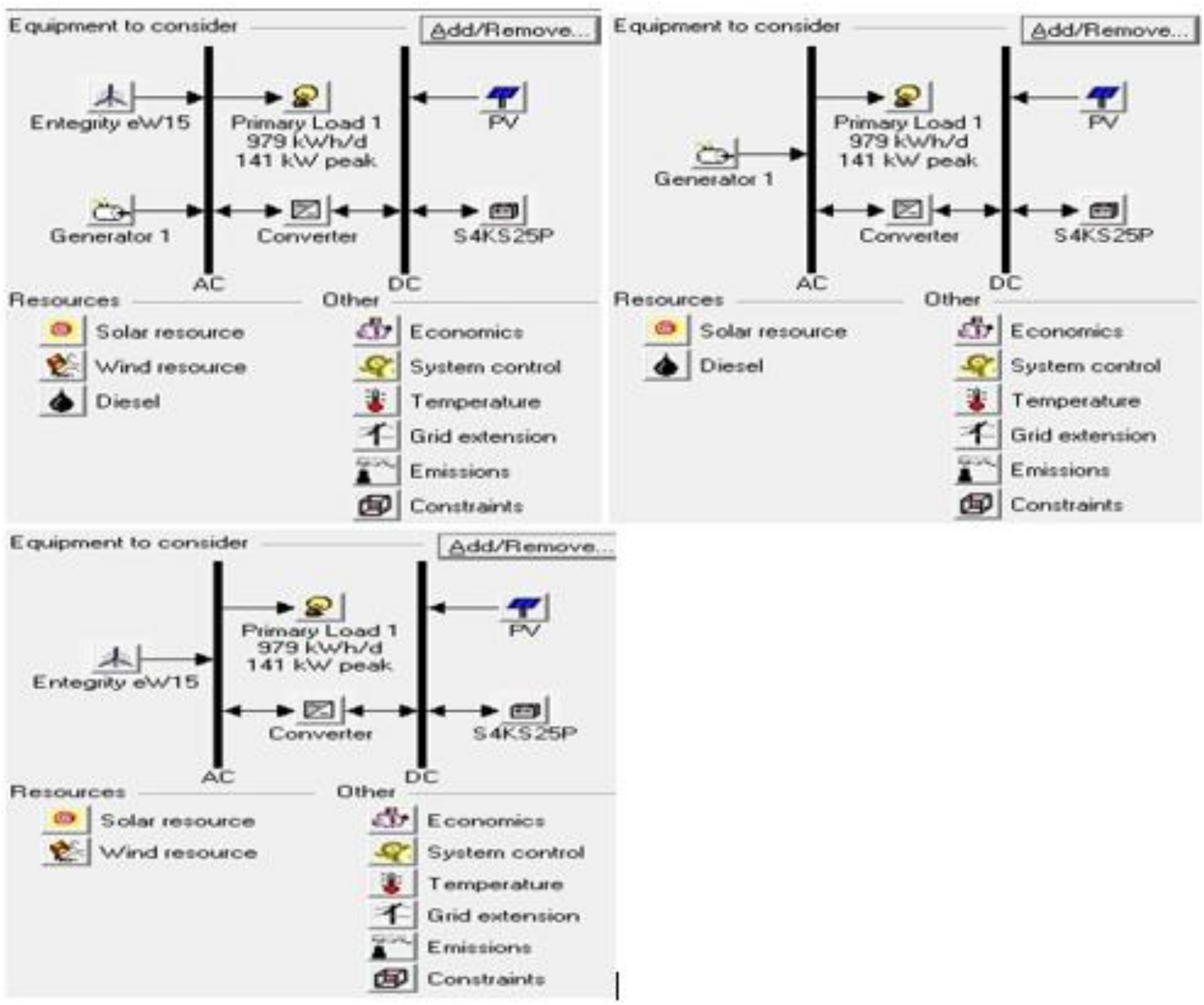


Figure4. 4a) Equipment to consider and PV-Wind Diesel hybrid system configuration

Figure4. 4b) Equipment to consider and PV-Wind Diesel hybrid system configuration

Figure4.4c) Equipment to consider and PV-Wind Diesel hybrid system configuration

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 General

In this chapter we use all concept, formulas and tables presented in previous chapters to evaluate of hybrid renewable energy system, wind turbine and photovoltaic modules, for lenda town. The energy demand of the town assumes to be serving a residential load and nonresidential load of a total 740.954Kwh/day for lenda town per day. These load covered street light, commercial and residential energy consumption in lenda town. In the economic analysis use a life time period of 25 years with an inflation rate of 6% and nominal interest rate on the loan to finance the hybrid system of 10%. For this location we use solar and wind data, and our optimization procedure to design hybrid renewable power system. We consider a standalone system and grid connected system. For the stand alone system we determine the most economic combination of PV modules and wind turbines to serve the residential and nonresidential load. We assume batteries have a life time of 12 years, thus a replacement of batteries is considered at the end of year 12 and each component are to replace at the end of life time.

5.2. Simulation Results

The simulation software provides the results in terms of optimal systems and the sensitivity analysis. In this software the optimized results are presented categorically for a particular set of sensitivity parameters like wind speed, maximum annual capacity shortage (MACS), net present cost and fuel price in the present case.

The optimization and sensitivity results are presented in the forthcoming paragraphs.

5.2.1 Optimization Results

The optimization result for Lenda town is summarized in figure 5.1, Figure 5.2 and Figure5.3 below shows the results from HOMER modeling for lenda town. The modeling simulates 8,760 hours (one year) of operation and thousands of different system configurations. The system with the overall least cost of energy is the one highest on the list. The first columns of the HOMER results table show graphic icons representing which components are present in the optimized system. The remaining columns show the optimized capacity of each component, the initial capital cost, the total net present cost, the cost of energy (in $ per kWh), renewable energy fraction, total liters of diesel consumed per year, and the number of hours' diesel generator operates and life time of the battery.

PV (kW)	eW15	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
300	2	40	500	150	$ 1,218,980	25,337	$ 1,614,799	0.289	0.99	0.00	1,332	119
250	2	40	500	150	$ 1,118,980	32,333	$ 1,624,084	0.291	0.96	0.00	6,459	546

PV (kW)	eW15	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
300	2		500	150	$ 1,170,240	22,611	$ 1,459,290	0.321	1.00	0.01		
300	2	40	500	150	$ 1,170,240	23,555	$ 1,471,355	0.322	0.99	0.00	1,108	96

a)

PV (kW)	eW15	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
250	2	500	120	$ 1,097,980	23,530	$ 1,465,568	0.272	1.00	0.04
300	1	500	100	$ 1,135,240	22,245	$ 1,482,745	0.269	1.00	0.02

b)

PV (kW)	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
300	40	500	150	$ 1,121,500	29,297	$ 1,579,179	0.283	0.97	0.00	5,517	504
300	40	500	120	$ 1,100,500	30,952	$ 1,584,031	0.284	0.96	0.00	7,147	646

c)

Figure 5. 1a) Overall optimization results for PV-wind-diesel,
b)PV-wind,
c) PV-diesel sorted by *total net present cost for lenda town respectively.*

The above optimization results for wind speed of 3.47 m/s daily radiation of 5.78 Kwh/m2 /day, diesel price of 1.25 $/L, wind operating reserve of 5% and maximum annual capacity shortage of 5% for lenda town.

Based on the HOMER modeling, the optimal system for lenda town in figure 5.1 a first row, a hybrid solar/wind/diesel /battery/converter, with 300 kW of solar, a 2*50 kW wind turbines ,500 S4KS25P batteries (each 1900AH capacity) and 150 kW bi-directional inverter are required power supplied for lenda town. This ―optimal‖ system uses 96% renewable energy, and the cost of electricity is $0.289/kWh including depreciation on capital and leveled O&M with net present cost of $1,614,799.

Based on the HOMER modeling, the optimal system for lenda town in figure 5.1 a first row, a hybrid solar-wind/battery/converter, with 250 kW of solar, a 2*50 kW wind turbines ,500 S4KS25P batteries (each 1900AH capacity) and 120 kW bi-directional inverter are required power supplied for lenda town. This ―optimal‖ system uses 100% renewable energy, and the cost of electricity is $0.272/kWh including depreciation on capital and leveled O&M with net present cost of $1,465,568. Based on the HOMER modeling, the optimal system for lenda town in figure 5.1 a first row, a hybrid solar-diesel /battery/converter, with 300 kW of solar, 500 S4KS25P batteries (each 1900AH capacity) and 150 kW bi-directional inverter are required power supplied for lenda town. This optimal‖ system uses 97% renewable energy, and the cost of electricity is $0.283/kWh including depreciation on capital and leveled O&M with net present cost of $1,579,179.

The energy yield from different components of the PV-wind-diesel is shown in Fig. 5.2 of the total primary energy requirement (554,450 kwh/yr) for this town, the wind machines produced 82,262 kWh (15% of the total energy served), solar PV produced almost 84% of the energy i.e. 468,381 kWh while the diesel generator produced (3,806) i. e1%. Although an excess energy of 124,346 kWh (22.4%) was produced but a capacity shortage of only 210kwh was experienced during the year. This capacity shortage cannot affect the system since some amount load shedding could be applicable power utility company per year.

The energy yield from different components of PV-wind system is shown in Fig. 5.2 of the total primary energy requirement (472,579kwh/yr) for this town, the wind machines produced 82,262 kWh (17% of the total energy served), solar PV produced almost 83% of the energy i.e. 390,317 kWh. Although an excess energy of 57,150 kWh (12.1%) was produced but a capacity shortage of only 15,881kwh was experienced during the year. This capacity shortage cannot affect the system since some amount load shedding could be applicable power utility company per year.

The energy yield from different components of the PV-diesel is shown in Fig. 5.2 of the total primary energy requirement (483,996kwh/yr) for this town, solar PV produced almost 97% of the energy i.e. 468,381 kWh while the diesel generator produced (15,615) i. e3%. Although an excess energy of 45,582 kWh (9.42%) was produced but some capacity shortages of only 550kwh was experienced during the year. This capacity shortage cannot affect the system since some amount load shedding could be applicable power utility company per year.

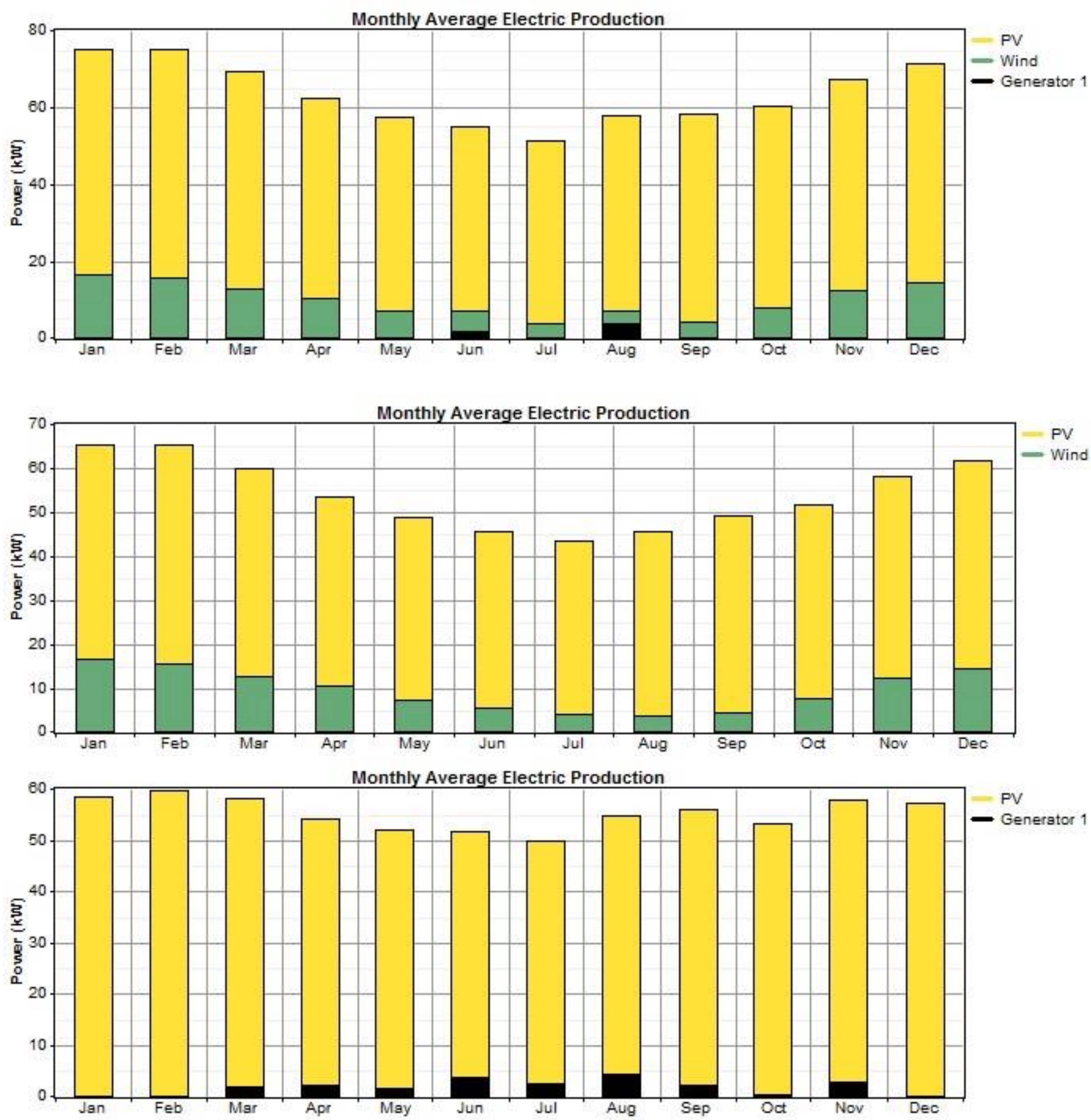


Figure 5. 2Monthly average Electric production of Lenda town for three hybrid system .

5.3 Economic Analysis

The project life time was taken as 25 years and the annual real interest rate and the nominal rate as 4% and 10%, respectively and each component are its own life time and it expecting to replace at the end of life time.

The initial capital cost of a component is the total installed cost of that component at the beginning of the project. The leveled cost of energy (COE), net present cost and initial cost of this town is presented in the forthcoming paragraphs.

Table 5.1 and Figure 5.3 summaries the economic performance of the winning system for lenda town. The capital cost constituted the largest portion of the total NPC, followed by replacement cost and O&M costs. The component incurring the largest cost is the battery bank, followed by the PV modules, converter wind turbines generator and generator. Graphically can be expressed as below:

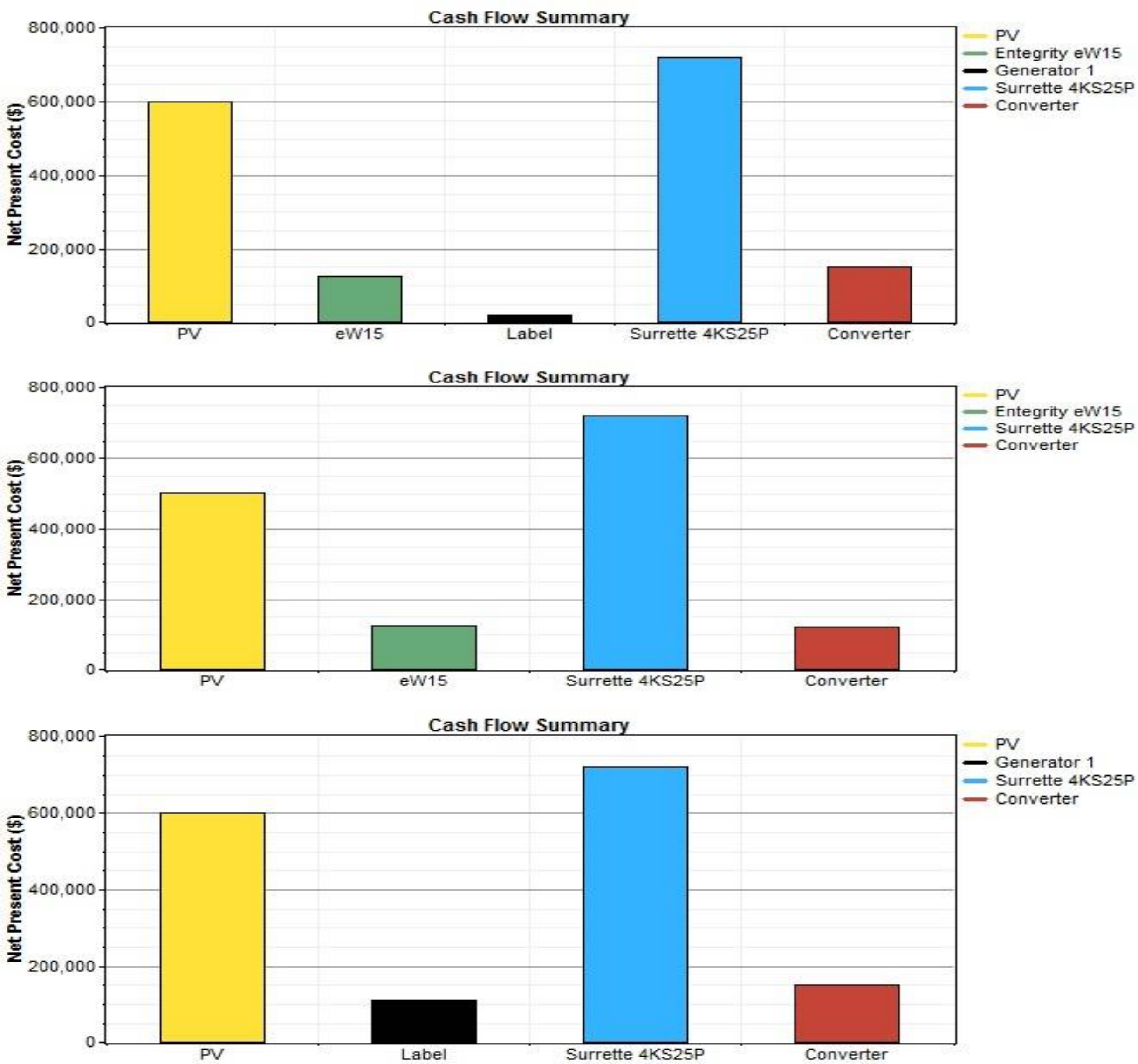


Figure 5. 3 cash flow summery for the three systems

Table 5. 1 Economic performance of the hybrid stand-alone system for lenda town

Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	600,000	0	0	0	0	600,000
Entegrity eW15	97,480	0	28,120	0	0	125,600
Generator 1	0	0	1,859	26,018	-8,680	19,196
Surrette 4KS25P	416,500	281,585	117,166	0	-95,420	719,830
Converter	105,000	58,303	0	0	-13,129	150,174
System	1,218,980	339,887	147,144	26,018	-117,230	1,614,800

Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	500,000	0	0	0	0	500,000
Entegrity eW15	97,480	0	28,120	0	0	125,600
Surrette 4KS25P	416,500	281,585	117,166	0	-95,420	719,830
Converter	84,000	46,642	0	0	-10,503	120,139
System	1,097,980	328,227	145,285	0	-105,924	1,465,568

Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	600,000	0	0	0	0	600,000
Generator 1	0	0	7,874	107,726	-6,424	109,176
Surrette 4KS25P	416,500	281,585	117,166	0	-95,420	719,830
Converter	105,000	58,303	0	0	-13,129	150,174
System	1,121,500	339,887	125,039	107,726	-114,973	1,579,179

The COE for the optimum system is found to be US$0.0.289/kWh for PV-wind-diesel, $0.0.272/kWh for PV-wind, and $0.0.283/kWh for PV-wind.

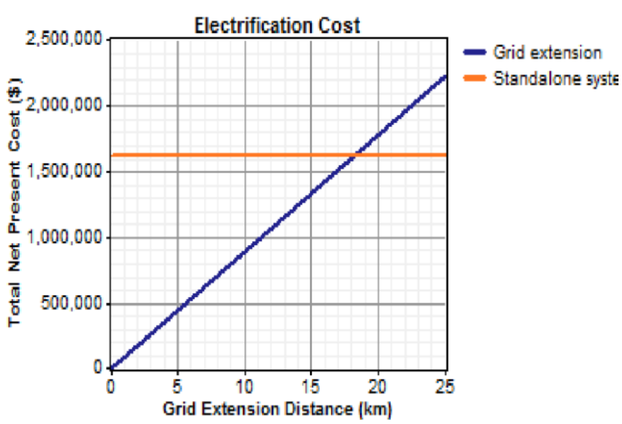
5.4 Sensitivity Results

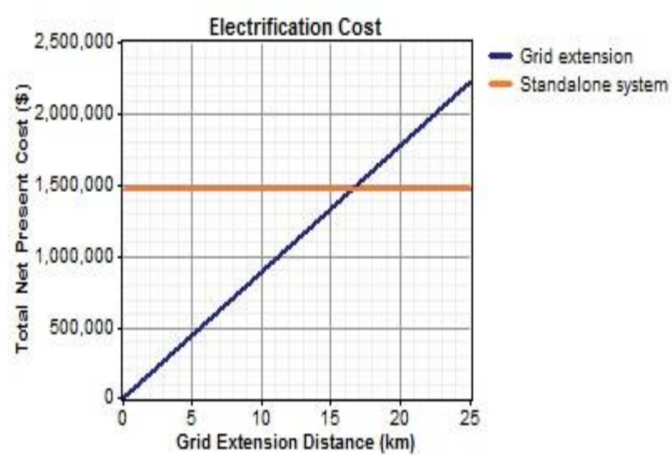
The HOMER software simulates all the systems in their respective search space for each of the sensitivity values. An hourly time series simulation is performed for one complete year. A feasible system is defined as the hybrid system which meets the required load. The software eliminates all infeasible systems and presents the results in ascending order of NPC.

5.6 Comparison of the Grid extension with standalone (Off Grid) System

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 unit cost of 132 kV single circuit transmission line (steel lattices supported) with Optical Fiber Ground Wire (OPGW) is 125,000USD per km. The operating and maintenance cost of the transmission is 2% of capital cost is around $2500/Km per year. Lenda town is located 59 Km from nearest national grid system.

The total capital costs of grid extension are11.3475 Million US dollar, from hosanna substation to lenda. Moreover, the breakeven distances from the grid extension are 18.1 Kilometers for PV-wind -diesel, 16.5Km for PV-wind and 17.7 Km for PV-diesel system meaning which is the net present cost of grid extension equals the net present cost of the stand-alone system. The town is located very far from breakeven grid extension. If you go farther from this point (breakeven grid extension distance) the stand alone is the optimal solution power supply of the selected town. Figure5.4 shows the net present cost comparison of standalone system with grid extension of lenda town. Therefore, the standalone system is the optimal solution of power supply since the net present cost of grid extension much higher than standalone.





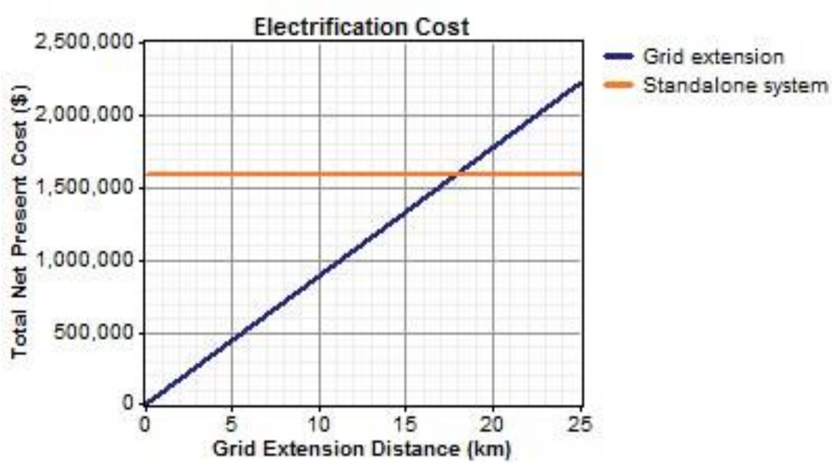


Figure 5. 4 comparison of grid extension with standalone system of lenda town for the three hybrid system

Solar-wind hybrid options performed better than grid extension for distances greater than 16.5 kilometers and the energy cost was computed as 0.272$/kWh. From this we can observe that grid extension energy cost is higher than a hybrid option.

In conclusion, after investigating all the possible designs done in this Chapter, the PV-Wind hybrid energy system was found to be the most cost effective compared to the others, with its lowest total net present cost of $1,465,568 and its ‘cheapest leveled cost of energy of $0.272/kwh. Therefore, we are going to design PV-Wind hybrid system for lenda town in the next chapter.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusions

This study aimed to identify options (feasibility study) and to design the feasible system to provide electricity for lenda town in SNNPR region, Ethiopia, by harnessing power from renewable energy resources. Two power supply options have been identified. The first option was a hybrid (standalone Solar/wind/battery) system and the second option was to construct new transmission line from nearest substation to selected towns. The HOMER simulation program developed by the NREL has been used as the design tool for both options.

HOMER modeling results indicate that lenda town electricity needs could be met at considerable overall cost savings with a hybrid (wind/solar/Battery) system compared with existing separate diesel generator systems. At existing diesel prices and in a ―base case‖ load scenario, the optimum system comprises a hybrid solar/wind/battery system., based on the simulation result, the optimal system for Lenda town, a hybrid solar/wind/battery, with 250 kW of solar, a 2*50 kW wind turbine 500 S4KS25P batteries (each 1900AH capacity) and 120 kW bi-directional inverter. This optimal‖ system uses 100% renewable energy, and the cost of electricity is US$0.272/kWh including depreciation on capital and leveled O&M with net present cost of $ 1,465,568.

The second option looked at power supplied from the nearest substation. This option also performed better for grid extension for distance less than 16.5km (but this town is located very far from this point). The total capital costs of grid extension are 11.275Million US dollar, from near substation to Lenda town. Furthermore, the breakeven distances from the grid extension is 16.5 Kilometers, meaning which is the net present cost of grid extension equals the net present cost of the stand-alone system. If you go further from this point (breakeven grid extension distance), a hybrid (stand-alone) system is optimal solution the power supplies the selected town. But lenda town is located 59 km from the nearest national grid, lenda town is located 59km from existing substation and a 132 kV voltage level is selected. The voltage selection criteria of transmission lines are mainly based on the power to be transmitted and on the distance between delivery and receiving ends. Total net present cost of transmission line is $11.347Million, whereas for hybrid (solar/wind/battery) system total net present cost is $ 1.465 Million systems.

A grid extension power supply option almost $8 million higher than standalone system throughout project life time. Solar-wind hybrid options performed better than grid extension for distances greater than 16.5 kilometers and the energy cost was computed as 0.272$/kWh. From this we can observe that grid extension energy cost is higher than a hybrid option. Finally, the Author proposed that standalone system (solar/wind/ battery) is economically feasible and environmentally friendly to replace the existing diesel-only power supply system for Lenda town, Ethiopia.

7.2 Recommendation and Further Work

- This study shows only focus on selected town of SNNPR region in Ethiopia and it does' t cover all towns and villages around that region. So, the future researchers should expand this research work in other sites and make the rural people beneficial with renewable energy resource.
- In spite of the huge hydroelectric potential of Ethiopia, severe power cuts in recent years have a heavy impact on the country 's economy. Solar thermal technology recommended to be incorporated for the future grid connected application to create a strength, reliability and maintaining sustainable energy supply of the country. Lenda town has a great solar resource potential and has not yet properly exploited this resource.
- Solar-Wind energy generation should be used for electrifying the rural areas.
- The selected area (lenda town) has good renewable energy potential, so the project should be implemented to electrify the area.
- We recommend better feasibility study must be taken before implementing grid extension across rural areas.
- From this project work, it has seen that Ethiopia has a good potential places for rural electrification through the off grid system. There are, however, Challenges like low purchasing power of the rural people, public attitude towards the private sector and unfair regulations that work against development and distribution of renewable energy technologies. It is thus recommended that the government, non-governmental organizations and the Public make combined efforts to overcome these challenges by using more flexible approaches to improve the current terrible state of rural electrification in Ethiopia.

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APPENDIX: A

HOMER Input Summary for lenda town.

Declination angle ($\boldsymbol{\delta}$)

January $\delta = 23.4\sin(360^0 \frac{284+1}{365}) = -23.01^0$, where n = 1

February $\delta = 23.4\sin(360^0 \frac{284+31}{365}) = -17.52^0$, where n = 31 + 1 = 32

March $\delta = 23.4\sin(360^0 \frac{284+61}{365}) = -7.91^0$, where n = 32+28 = 61

April $\delta = 23.4\sin(360^0 \frac{284+93}{365}) = 4.81^0$, where n = 61+31+1=93

May $\delta = 23.4\sin(360^0 \frac{284+125}{365}) = 16.11^0$, where n=93+31+1=125

June $\delta = 23.4\sin(360^0 \frac{284+156}{365}) = 22.53^0$,where n=125+30+1=156

July $\delta = 23.4\sin(360^0 \frac{284+188}{365} = 22.59^0$, where n=156+31+1=188

August $\delta = 23.4\sin(360^0 \frac{284+220}{365}) = 15.96^0$,where n=188+31+1=220

September $\delta = 23.4\sin(360^0 \frac{284+252}{365}) = 4.61^0$, where n=220+31+1=252

October $\delta = 23.4\sin(360^0 \frac{284+284}{365}) = -8.1^0$,where n=252+31+1=284

November $\delta = 23.4\sin(360^0 \frac{284+315}{365}) = -18.17^0$, where n=284+31+1=315

December $\delta = 23.4\sin(360^0 \frac{284+347}{365}) = -23.24^0$, where n=315+31+1=347