



ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ELECTRIFICATION OF RURAL VILLAGE USING PV-WIND SYSTEM
(A CASE STUDY ON ABUBEKER AHMED VILLAGE, SOMALIA REGION)

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BY

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Adama Science and Technology University
School of Electrical Engineering and Computing
Department of Electrical and Computer Engineering

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DECLARATION

I the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or other universities, and all sources of materials used for this work have been fully acknowledged.

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

Advisor's Name: _____

Signature: _____

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LIST OF ABBREVIATION

A	Cross sectional area
COE	Cost of Energy
NMSA	National Metrological Service Agency
D	Rotor Diameter
G_{sc}	Solar constant with a value of 1367 W/M ²
NPC	Net Present Cost
UEAP	Universal Electricity Access Program
EEPCo	Ethiopia Electric Power Cooperation
EEP	Ethiopia Electric Power
NASA	National Aeronautics and Space Administration
PV	Photovoltaic
HOMER	Hybrid Optimization and Modeling of Electrical Renewables
HRPGS	Hybrid Renewable Power Generation System
CRGE	Climate-Resilient Green Economy
GHG	Green House Gas
WRC	World Radiation Center
H	Monthly Average daily global solar radiation on horizontal Surface
H_0	Monthly Average daily extraterrestrial solar radiation on horizontal Surface
STC	Standard Test Condition
HAWT	Horizontal Axis Wind Turbine

VAWT	Vertical Axis Wind Turbine
PDF	Probability Density Function
CDF	Cumulative Density Function
WMO	World Meteorological Organization
CFL	Compact Fluorescent Lamp
DC	Direct Current
AC	Alternate Current
AAAC	All Aluminum Alloy Conductor
MV	Medium Voltage
LV	Low Voltage
MOD	Depth of discharge
C	Capacity of battery
C_p	Coefficient of performance
M	Number of data points
K	Kelvin
R	Specific gas constant
PCU	Power conditioning unit

ABSTRACT

The most essential need of human beings is electricity from household to industrial works. In this modern era, it is the need of each family in remote and rural areas. The aim of this study is to investigate alternative power supply options to replace the existing diesel-only power system for remotely located Abubeker Ahmed village isolated from the main national grid in Ethio-Somalia region with a hybrid PV–wind–battery power systems to meet energy consumption of Abubeker Ahmed village.

The work was begun by visiting the site and then investigating wind energy and solar energy potentials of the desired site, collecting data from two different sources and analyzing those data with the help of HOMER software. Solar irradiation data was taken from National Metrological Service Agency of Ethiopia and that of the wind speed data are taken from NASA surface metrology and solar energy for estimation of solar and wind energy potential. The monthly average daily solar global radiation for Abubeker Ahmed village ranges from 5.57 to 7.13 kWh/m²/day and monthly average wind speed varies from 3.8 m/s to 7.47 m/s.

Based on the results obtained through the analysis, the site has plentiful of both solar and wind energy potential which is adequate to be exploited for generating electric energy using standalone PV-wind hybrid system. The design of a standalone PV-wind hybrid power generating system has proceeded based on the promising findings of these two renewable energy resource potentials, wind and solar. The simulations and design has been carried out using the HOMER software.

The hybrid energy system optimized by HOMER software for the village is cost effective as compared to the cost required to electrifying through grid extension for the desire site. And the breakeven grid extension distance is found to be 15.4kms which implies that this hybrid energy system is cost-effective for areas greater than the breakeven distance.

Keywords: HOMER, Hybrid PV-wind, Break even grid extension Distance, Load estimation

CHAPTER ONE

INTRODUCTION

1.1. Background

More than 1.3 billion people worldwide still lack access to electricity, with more than 95% of them located in sub-Saharan Africa and developing Asia, and roughly 2.6 billion people rely on traditional energy, [1] This causes air pollution and has serious potential health implications when used in traditional stoves. According to recent reports indicate that 76.7% of the total population of Ethiopia lives without electricity [1] [2].

Our country is trying to satisfy the current energy demand; in the upcoming years problems associated with it are increasing significantly over coming decades to meet the need of growing populations and economic, changing life styles and evolving consumption, greatly amplifying the existing pressure on limited natural resources. These challenges are most critical especially in countries undergoing accelerated transformation and rapid economic growth or those in countries where no large segment of population has access to modern energy. Global energy demand is expected to grow by more than one-third over the period to 2035 and electricity demand is expected to grow by 70% [1].

Recently, the Ethiopian government plans to export electric power 1000 MW to Kenya, 200MW to Sudan and 200MW Djibouti [3]. Despite the plan currently Ethiopia exports 100MW, 35MW, 60MW to Sudan, Djibouti, and Kenya respectively [4] It also signed deals to send power to Tanzania, Rwanda, South Sudan and Yemen in the near future. In doing this, the government can earn a foreign currency and has its own benefit for both economic and political conditions. However, the domestic consumption of the country especially for rural communities is almost very low, where 85% of the rural households rely on fuel based light sources [5]. UEAP is doing promising work in electrifying rural communities. But, they try to achieve it through grid connected systems.

However, In order to provide modern energy, affordable and environmental sound electric energy to those in needs is to use renewable energy such as solar and wind hybrid power generation.

Using renewable technology like solar photovoltaic-wind hybrid rural area can be electrified. In this work, a hybrid power generation system of solar PV-wind resource has been designed and modeled to replace the existing conventional diesel generator supply of electricity.

1.2. Statement of the problem

Abubeker Ahmed Kebele located in Harshin district of Ethio-Somalia region access to electricity is a problem till to day and not connected to the national grid line system. It is known that, the lack of electricity to people who are living in this village has impact on both socio-economic and way of life, this lead to poverty, low grade education quality, poor health care and low living standard. Electrifying this remote community is very challenging over grid system since it has a low load density. To overcome the above problems, the major alternative energy source in Ethiopia is hydro, solar, geothermal and wind. Because of high abundance of solar radiation and wind speed are chosen to replace the existing conventional diesel electric power generation. The purpose of this study is to investigate an alternative power supply option for “Abubeker Ahmed” Kebele in Harshin district of Ethio-Somalia region and replacing the existing conventional diesel electric power supply which are detached from national grid system.

1.3. Scope of the study

The scope of this study is to assess the technical and economic feasibility of the off-grid solar photovoltaic-wind hybrid power system to replace the existing conventional diesel power generation for Abubeker Ahmed Kebele in Ethio-Somali region, It involve collecting, analyzing the data and information to examine the most and select most appropriate power generation and supply system, recommend what necessary measures that configure a system to accommodate the current energy demand of Abubeker Ahmed Kebele in Ethio-Somalia region.

1.4. Objective of the study

1.4.1. General objective

- The main objective of the research which has been described in this Study is to investigate and design an alternative power supply options for rural village to solve the time limited energy coverage by replacing the existing conventional diesel power generation.

1.4.2. Specific objective

- To conduct feasibility study and investigate the potential of both solar and wind resource of the selected site based on the available wind speed and solar radiation data either from national metrological service agency (NMSA) or NASA.
- To determine of both power and energy demand of the selected site.
- To model and design of a PV-wind hybrid renewable energy system to meet the electrical energy demand of the village.
- To perform simulation, optimization and analysis of standalone (off-grid) solar photovoltaic-wind hybrid system.
- To compare the investment cost of hybrid system against cost required to electrify the village by extending the national grid.

1.5. Literature Review

As per in papers [4] [6] presented the feasibility study of the hybridizing of wind turbine to an existing off grid diesel power plant in the northern rural area of the Kingdom of Saudi Arabia. The study has tried to Reduce the running cost of diesel generator by hybridizing with wind turbines generator and accordingly to make almost no environmental pollution. Sensitivity analysis was also made by taking sensitive parameters such as wind speed which can affect the power system during its life time. The simulation result shows that fitting the wind turbine to the existing diesel generator was not feasible for wind speeds less than 6m/s and diesel oil prices of \$0.1/litter.

Studies [5][8][9][10] show that grid extension does not guarantee access to electricity rural customers, in case of the long distance between the load center and the national electrical grid, and other reasons. One solution to the problem of long distances is to use locally available renewable energy sources, such as hydro-plants, solar cells, biomass or wind power generators, and thereby create a local distribution network for the area, which may connect a number of villages.

Other researcher studied [7] the alternative energy source of supplying electricity from solar-wind hybrid power system to a remotely located community of 200 families isolated from the national grid in Ethiopia using HOMER software. The results were compared from the list of feasible renewable power sources sorted based on net present cost and found that hybrid solar and wind system is only the promising technology for power generation to these communities. Hybrid renewable power systems in off-grid applications have been shown to be economically viable, especially in remote locations. During recent years, the combined use of renewable energy sources, especially wind and solar, is becoming increasingly attractive and being widely used as an alternative to fossil-fuel energy [6] [2].

A study conducted in paper [8] [9]. Explain the more about design of alternative energy resource for rural community using solar photovoltaic and wind turbine power generation. A model community consists of a load of 100 households, health clinic and elementary school. This study starts through investigating of the resource potential of solar and wind energy of the site. The HOMER software is used and it's optimal simulation result PV-wind turbine / diesel generator/battery and converter configuration system. The best combination result the total net present cost and cost of energy is \$103,914 and 0.3024\$/KWh respectively the percentile contribution from renewable energy is 84% and the total amount of diesel oil used is 1,955 liters per year and the generator working 633 hours per year.

The system (hybrid system) in addition uses diesel generator and bank of batteries as back up device, Power conditioning units, such as inverters, are also part of the supply system. Hybrid wind turbine and PV 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, and as a result the size of the battery storage can be reduced [10][12]. A hybrid renewable power generation system (HRPGS) is a system aimed at the production and utilization of the electrical energy coming from more than one source, provided that at least one of them is renewable [9]. Hybrid system captures the best features of each energy resource and can provide best quality electricity.

1.6. Significance of the thesis

The significance of this thesis is more power full for those people who are still living without electric power to get a more reliable and clean energy for household needs such as primarily lightning, Radio, mobile charging, TV and other service load in better quality. Simultaneously promote the renewable energy source (Green energy) for rural area which are very far from the national grid line. It also serve as design input or design option for both governmental and non-governmental organization which are working on rural electrification where resource is available.

1.7. Description of the Study Area

Ethio-Somali region is one of the largest regional states in the federal administration system of Ethiopia. It borders Djibouti to the north, Somalia to the east and north-east, and Kenya to the south. To the west it borders Oromiya Region, to the north-west Afar Region. A study was conducted in one of nine administrative zones and the zone is known as Jigjiga zone more specifically study area is well known by its name Abubeker Ahmed village which is found in Harshin district of Jigjiga zone, Harshin district administratively remains in part of Jigjiga zone.

Abubeker Ahmed village is one of the rural villages in Harshin district of Ethio-Somali region of Ethiopia that does not have access to electricity and isolated from national grid system. However, parts of the communities have access to electricity which is generated by the diesel generator and provided by private owner. Study area geographically located in 8.93° latitude and 43.74° longitudes. The field data which includes the population data, number of households and their daily activities related to energy consumption is collected

by visiting the selected village. According to population data collected at “Lanqerta Health Center”, this health center one which is found in the nearby kebele, most of the data taken from it, especially the population number of the village is 7,524 and the community understudy, which equipped with primary school and a health post. And there are 1,074 households with an average 6.8 members per family and out of this much households numbers, 185 household have the access to diesel electricity for limited time of operation. Other than normal household there is one primary school, two Mosques, and one health Post in the village.

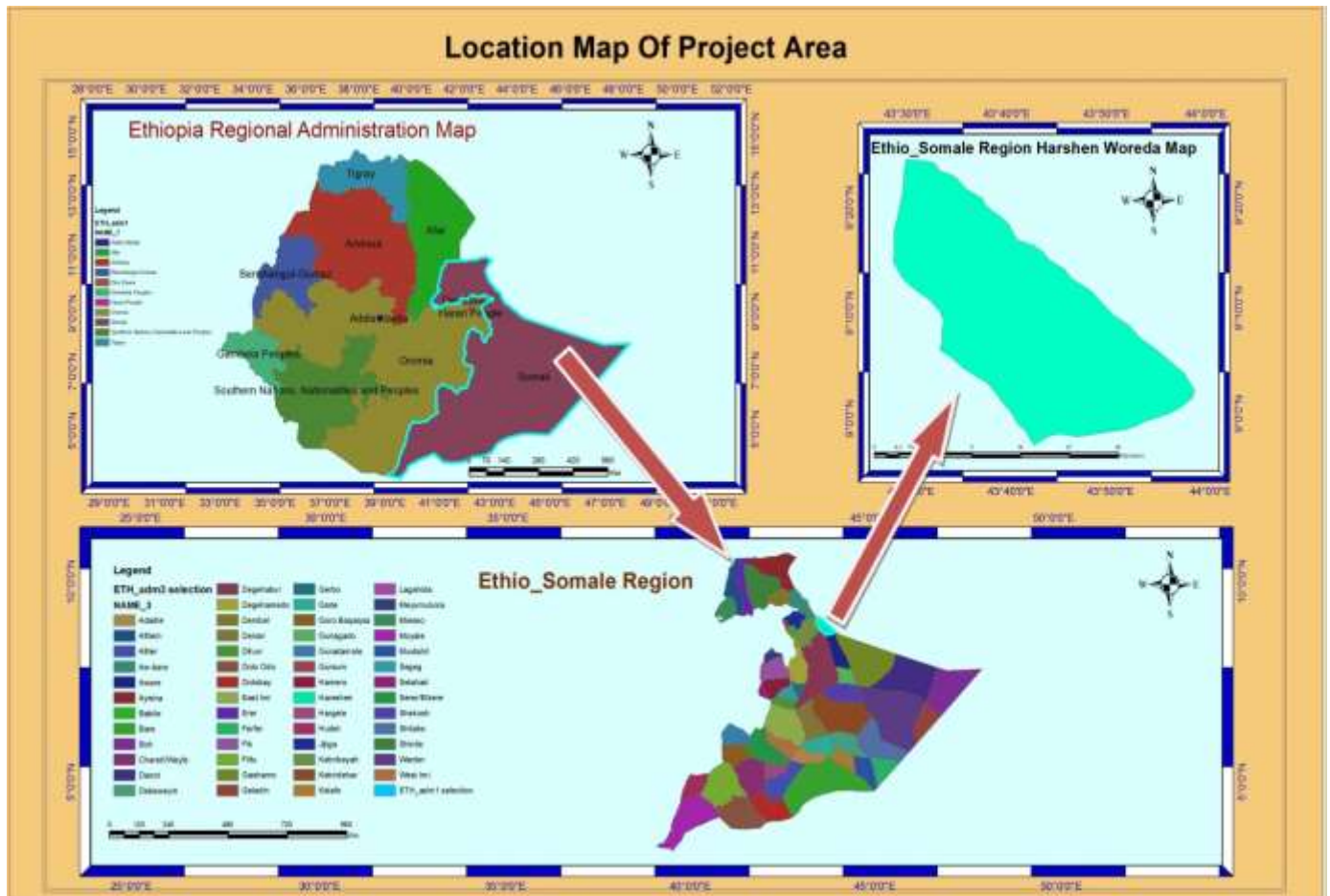


Figure 1.1: Location map of project area.

1.8. From Country Policy and Strategy view

The Government of the Federal Democratic Republic of Ethiopia has set a strategy that initiated the Climate-Resilient Green Economy (CRGE) initiative to protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle-income status before 2025.

Ethiopia aims to achieve middle-income status by 2025 while developing a green economy. Following the conventional development path would, among other adverse effects, result in a sharp increase in GHG emissions and unsustainable use of natural resources. To avoid such negative effects, the government has developed a strategy to build a green economy. The electric power sector expected to play a vital role in speeding up the green economy.

According to EEPCo (EPA) master plan, the current diesel power plants and off-grid diesel generators will be switched off between 2012 and 2014. From 2015 onwards, EEPCo (EPA) plans to generate power exclusively from clean or renewable sources (on average around 90% from hydro, 6% geothermal and 4% wind) – while retaining some diesel generators as standby solutions. However, since the plan is to establish a more reliable and stable power supply throughout the country, the use of such standby facilities is expected to decrease dramatically to reach virtually 0% by 2030 [11][13].

This study directly or indirectly play a vital role in green economy by combatting deforestation and promoting renewable energy. Thus it can be taken as one of those important strategies to achieve the green economy.

CHAPTER TWO

2.1. Solar Energy Resource and Solar Energy System

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet earth because factor such as geographical location, seasonal variation, cloud cover, and the land available to humans limit the amount of solar energy that we can obtain. Geography affects solar energy potential because areas that are closer to the equator have a greater amount of solar radiation. However the use of photovoltaic that can follow the position of the sun analogues to sun flower can significantly increase the solar energy potential in areas that are farther from the equator [14]. Time variation affects the solar energy because during the night time almost there is no solar radiation on the surface of the earth for solar panels to absorb. This limits the amount energy that the solar panels can absorb in one day. Cloud Cover can affect the potential of Solar panels because cloud block incoming light from the sun and reduce the light available for solar cells.

2.2. The Sun

The sun is a sphere of intensely hot gaseous matter with a diameter of $1.39 \times 10^9 m$ and is, on the average, $1.5 \times 10^{11} m$ from the earth. As seen from the earth, the sun rotates on its axis about once every 4 weeks. However, it does not rotate as a solid body; the equator takes about 27 days and the Polar Regions take about 30 days for each rotation. The sun has an effective blackbody temperature of 5777 K. a blackbody radiating the same amount of energy as does the sun. The temperature in the central interior regions is variously estimated $8 \times 10^6 K$ to $40 \times 10^6 K$ and the density is estimated to be about 100 times that of water.

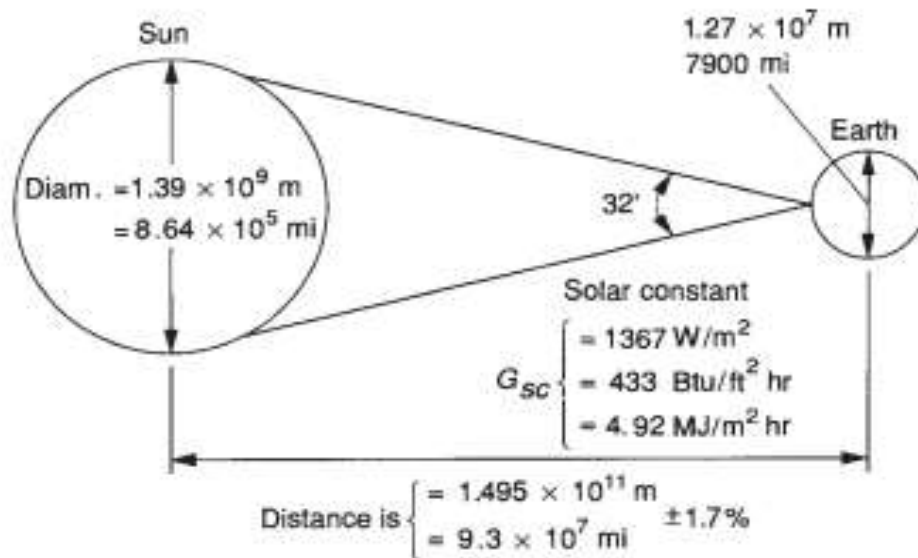


Figure 2.1: The sun-earth relationships [15]

2.3. Solar Energy

Solar constant is the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of radiation at mean earth-sun distance outside the atmosphere. According to world radiation center (WRC) has adopted a value of 1367 w/m^2 with uncertainty of order of 1%. Thus a value of G_{SC} of 1367 w/m^2 is used in these work.

The sun is a large sphere of very hot gases, the heat being generated by various kind of fusion reaction. Its diameter is $1.39 \times 10^6 \text{ km}$ while that of the earth is $1.27 \times 10^4 \text{ km}$. the mean distance between the sun and earth is $1.5 \times 10^8 \text{ km}$ the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its center to its edge. However for engineering calculation, it is customary to assume that the brightness all over the solar disc is uniform.

The rate at which solar energy arrives at the top of the atmosphere is called the solar constant G_{sc} . This is the amount of energy received in unit time on a unit area perpendicular to the sun direction at the mean distance of the earth from the sun, Because of the sun's distance and activity very throughout the year. The rate of arrival of solar radiation varies accordingly. The distance between the earth and the sun varies a little through the year because of this extraterrestrial radiation also vary. The earth is the closest to the sun in summer and farthest away in the winter. This variation in distance produces a nearly sinusoidal variation in the intensity of solar radiation that reaches the earth.

$$G_{on} = G_{SC} \left(1 + 0.033 \frac{360n}{365} \right) \quad (2.1)$$

Where: $G_{on} = \text{the extratersiterral radiation } [W/m^2]$

$G_{SC} = \text{Solar radiation constant, } 1367 [W/m^2]$

2.4. Solar Radiation

A major source of renewable energy is solar radiation being regularly received by most land area of the globe. Solar energy is a free source which is not only naturally renewable but is also environmentally sociable and aids in shrinking the greenhouse effect.

Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called direct radiation or beam radiation. It is the radiation which produces a shadow when interrupted by an opaque object. Diffuse radiation is that solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere. Because of the solar radiation is scattered in all direction in the atmosphere, diffuse radiation comes to the earth flow all parts of the sky. The total solar radiation received at any point on the earth surface is the sum of the direct and diffuse radiation. This referred to general sense as the insolation. The insolation is defined as the total solar radiation energy received on a horizontal surface of unit area.

The designer more interested in the energy received at the earth surface than in the surface of the earth is entirely different due to the earth than received at outside of the atmosphere is due to two major absorption and scattering. Absorption as solar radiation passes through the earth atmosphere the short wave ultra-violet rays absorbed by the ozone in the atmosphere and the long wave infrared waves are absorbed by the carbon dioxide and moisture in the atmosphere. Whereas scattering as solar radiation passes through the earth atmosphere the components of the atmosphere, such as water vapor and dust, scatter radiation always reaches the earth surface as diffuse radiation. Thus the radiation finally received at the earth surface consists partly of beam radiation and partly of diffuse radiation.

Altitude angle α (Solar Altitude) it is a vertical angle between the projection of the sun's rays on the horizontal plane and direction of suns.

Zenith Angle (θ_z) it is complimentary angle of sun's altitude angle. It is a vertical angle between the sun's rays and a line perpendicular to horizontal plane through the point i.e. the angle between the sun and the vertical.

$$\theta_z = \frac{\pi}{2} - \alpha \quad (2.2)$$

The Declination (δ) is the angular distance of the sun's ray north (or south) of the equator. It is the angle between a line extending from the center of the sun to the center of the earth and the projection of this line upon the earth's equatorial plane. The declination in degree for any given day may be calculated from the approximate equation (2.3) of cooper (1969) [15].

$$\delta(\text{in degrees}) = 23.45 \sin\left(\frac{360}{365} (284 + n_d)\right) \quad (2.3)$$

Where: n_d Is the day in the year, 1st January as 1 through 365 ($n_d=1$ on 1 January)

Table 2.1: Recommended Average Days for Months and Values of n by Months [15].

For average day of the month				
Month	n_d for i^{th} Day of Month	Date	n_d	δ
January	i	15	17	20.9
February	$31 + i$	16	47	13.0
March	$59 + i$	16	75	-2.4
April	$90 + i$	15	105	9.4
May	$120 + i$	15	135	18.8
June	$151 + i$	11	162	23.1
July	$181 + i$	17	198	21.2
August	$212 + i$	16	228	13.5
September	$243 + i$	15	258	2.2
October	$273 + i$	15	288	-9.6
November	$304 + i$	14	318	18.9
December	$334 + i$	10	344	23.0

Ethiopia is one of the developing countries without properly recorded solar radiation data and, like many other countries, the available is sunshine duration data. However, given a knowledge

of the number of sunshine hours and local atmospheric conditions, sunshine duration data can be used to estimate monthly average solar radiation, In this paper, a generally accepted modified form of the formula first introduced by Angstrom is used to relate average daily global radiation with average daily sunshine hours, with the help of empirical equation 2.4 [15].

$$H = H_o \left(a + b \left(\frac{n}{N} \right) \right) \quad (2.4)$$

Where: H → The monthly average daily global radiation on horizontal surface [MJ/m^2]

H_o → The monthly average daily extraterrestrial radiation on horizontal surface [MJ/m^2]

n → The monthly average daily number of hours of bright sunshine

N → The monthly average daily maximum number of hours of possible sunshine (or day length)

a and b → are the regression coefficients which are dependent on the location and having an average value of 0.33 and 0.43 respectively [16] [17]. The regression coefficient a and b vary from country to Country. For any specific location which can be obtained by using the following equation 2.5 used to find it.

$$a = \frac{\sum \frac{H}{H_o} \sum \left(\frac{n}{N} \right)^2 - \sum \left(\frac{n}{N} \right) \sum \frac{H}{H_o} \frac{n}{N}}{M * \sum \left(\frac{n}{N} \right)^2 - \left(\sum \frac{n}{N} \right)^2} \quad (2.5)$$

$$b = \frac{M * \sum \frac{H}{H_o} \frac{n}{N} - \sum \left(\frac{n}{N} \right) \sum \frac{H}{H_o}}{M * \sum \left(\frac{n}{N} \right)^2 - \left(\sum \frac{n}{N} \right)^2} \quad (2.6)$$

Where: M is the number of data points

Solar radiation also known as extraterrestrial radiation

$$H_o = \frac{24 * 3600 * G_{SC}}{\pi} \left(1 + 0.033 * \cos \frac{360n_d}{365} \right) * \left(\cos \phi \cos \delta \sin \phi + \frac{\pi \omega_s}{180} \sin \phi \sin \delta \right) \quad (2.7)$$

Where: $n_d =$ The day number

$G_{SC} =$ solar constant with a value $1367w/m^2$

$\phi =$ The latitude of location(8.93°)

The day length, N is the maximum possible daily sunshine hours are given by the equation 2.8 which is shown below.

$$N = \frac{2}{15} \cos^{-1}(-\tan \phi \tan \delta) \quad (2.8)$$

$$N = \frac{2}{15} \omega_s \quad (2.9)$$

Where: $\omega_s =$ the sunset or sunrise hour angle

The solar hour angle (ω_s) is the angular displacement of the sun east or west of the local meridian; morning negative, afternoon positive. The solar hour angle is equal to zero at solar noon and varies by 15 degrees per hour from solar noon. The sunset hour angles (ω_s) is the solar hour angle corresponding to the time when the sun sets and it is given in equation 2.9.

2.5. Solar Energy Resource in Ethiopia

Our country Ethiopia is located near the equator. As result of this, there is enough amount of solar energy is found. Moreover it is proven by many researchers. Investigation indicates that, the yearly average daily solar radiation reaching the earth surface is ranging in between 4.55 to 6.55 kwh/m^2 [18] [19]. Ethiopia have over 3000h of sunshine per year and receive solar radiation in excess of 5 kwh/m^2 . The abundance of solar energy very noticeable in the northern region where estimated annual solar energy is generally of the order of over 6 kwh/m^2 per

day [17]. This varies significantly during the year, ranging from a minimum of 4.55 kwh/m^2 in July to a maximum of 5.55 kwh/m^2 in February and March. On regional basis, the yearly average radiation ranges from values as low as 4.25 kwh/m^2 in the areas of Itang in the Gambella regional state (western Ethiopia), to values as high as 6.25 kwh/m^2 around Adigrat in the Tigray regional state (northern Ethiopia) and in Afar and Somali Region of Eastern Ethiopia [18].

2.6. Solar Energy Assessment of Harshin District, Jigjiga zone

The assessment of the potential for solar radiation of the selected area is done by taking data from two sources. These are NASA and Jigjiga branch of National metrological service agency of Ethiopia. Jigjiga branch station is chosen because of two reasons; one there is no metrological station at site and the other is its nearby station. In most developing countries there only sunshine hour, there is only sunshine duration data recorded at the nearby stations. The sunshine duration data taken from the National Metrological Agency of Ethiopia, Jigjiga branch, is changed into solar radiation using Angstrom Radiation-Sunshine Relation [15]. Therefore, for calculating the radiation in kwh/m^2 from the sunshine duration, the values for the regression coefficients a and b are taken to be 0.33 and 0.43 respectively [16][17]. Finally, this result is compared with the data taken from NASA and it is found that the annual average solar radiation obtained from NMSA is 6.46 kwh/m^2 and from NASA is 6.20 kwh/m^2 .

Table 2.2: Analysis of the monthly average solar radiation in MJ/m² for year 2015

Mid of month	n_d	δ (°)	ϕ (°)	ω_s (°)	N (hour)	n	n/N	H_0 (MJ/ m ² /day)	H(MJ/ m ² /day)	H(kwh/ m ² /day)	NASA (kwh/m ² /day)
Jan 15	15	-21.3	8.9	86.48	11.53	8.32	0.71	38.94	24.73	6.86	6.31
Fe 14	45	-13.6	8.9	87.82	11.71	7.5	0.64	35.23	21.32	5.92	6.87
Mar 15	74	-2.86	8.9	89.55	11.94	9.36	0.78	37.7	25.08	6.96	6.78
Apr 15	105	9.37	8.9	91.48	12.2	7.7	0.63	39.37	23.60	6.55	6.20
May 15	135	18.76	8.9	93.05	12.4	6.59	0.52	39.3	21.75	6.03	6.29
Jun 15	166	23.31	8.9	93.88	12.52	6.7	0.53	39.02	21.76	6.04	5.87
July 15	196	21.54	8.9	93.55	12.47	9.26	0.74	39.19	25.40	7.05	5.36
Aug 15	227	13.83	8.9	92.21	12.29	7.68	0.62	39.5	23.56	6.54	5.84
Sep 15	258	2.28	8.9	90.36	12.05	9.33	0.77	38.68	25.57	7.13	6.38
Oct 15	288	-9.53	8.9	88.48	11.79	10.4	0.88	36.26	25.68	7.13	6.00
Nov 15	319	-19.1	8.9	86.88	11.58	8.29	0.71	33.19	21.08	5.85	6.33
Dec 15	349	-23.3	8.9	86.12	11.48	8.29	0.71	31.59	20.06	5.57	6.18
Average									23.29	6.46	6.20

The value of a and b are approximated to 0.33 and 0.43 respectively.

Table 2.3: solar radiation data that are calculated and solar radiation data taken from NASA surface metrology and solar energy.

Data Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
NMSA	6.86	5.92	6.96	6.55	6.03	6.04	7.05	6.54	7.13	7.13	5.85	5.57	6.46
NASA	6.31	6.87	6.78	6.20	6.29	5.87	5.36	5.84	6.38	6.00	6.33	6.18	6.20

From the above table 2-2 result what we could understand is that, Very interestingly, there is enough solar radiation for electric generation using solar photovoltaic in the project site.

Now we have two results one is calculated one by using equation and the other data we got from NASA solar energy and surface metrological online data base. As per the calculated the area has solar radiation potential of $6.46 \text{ kwh/m}^2/\text{day}$ and for this study the calculated monthly average daily radiation summarized in the above table 2-2 in the 11th column is used.

2.7. Photovoltaic Technology

2.7.1. Photovoltaic Module

Solar cells are the building block of the PV power System. To obtain high power output many PV cells are connected either in series or parallel this depended on the Voltage or current demand. PV cell are connected in series to increase the voltage output while cells are connected in parallel to increase the current output. Usually there are 36 or 72 cell modules are the industry standard for large power production. Similar to one describe in above sentence a number of PV modules are combined as an array to meet the different energy demand.

2.7.2. Photovoltaic Array

A single Photovoltaic array is a combination of PV cells. In other words, it is an interconnection of modules which in turn is made up of many PV cells in series or parallel.

The power produced by single module is not enough to meet the requirements of commercial

applications, so modules are connected to form array to supply the load. In an array the connection of the modules is same as that of cells in a module. The modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current.

2.7.3. Types of PV Cell

The basic ingredients of PV cells are semiconductor materials, such as silicon. Based on the structure of the basic material from which they are made and the particular way of their preparation the photovoltaic cells of silicon are categorized into three.

- I. **Single-Crystalline Silicon:** The basic material is mono-crystalline silicon. In order to make them, silicon is purified, melted, and crystallized into ingots. It is the oldest and more expensive production technique, but it's also the most efficient and widely used sunlight conversion technology available. Cells efficiency oscillates between 14% and 18% [20].
- II. **Polycrystalline or Multi-crystalline Silicon:** The particular cell is relatively large in size and it can be easily formed into square shape which virtually eliminates any inactive area between cells. It has a slightly lower conversion efficiency compared to single crystalline and manufacturing costs are also lower. Cells efficiency oscillates between 10% and 13% [21].
- III. **Thin Film or Amorphous Silicon:** is the cheapest and least efficient type of solar PV. Amorphous or thin film silicon cells are solids in which the silicon atoms are much less ordered than in a crystalline form. The efficiency of this cell oscillates between 6% and 10% [20].

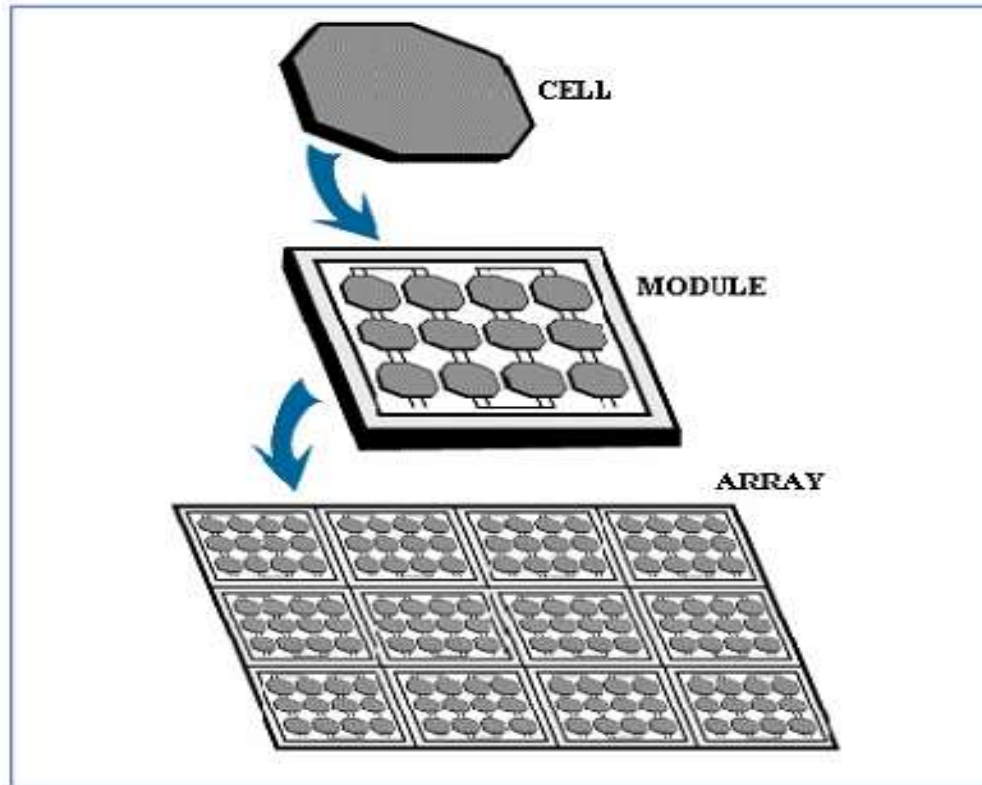


Figure 2.2: the construction of photovoltaic cell in to photovoltaic array [20]

2.7.4. Working Principle of Photovoltaic System

A photovoltaic system makes use of one or more solar panel to convert solar energy into electricity. The basic principle behind the operation of a PV cell is photoelectric effect. The photons from the sunlight will interact with the outermost part of the electrons of an atom. The photon free the electron in the n dope region which crossover to the hole in the p dope region. This creates an electrical current when the PV cell is connected to a load. The photon from the sunlight that frees the electron is called the photovoltaic effect.

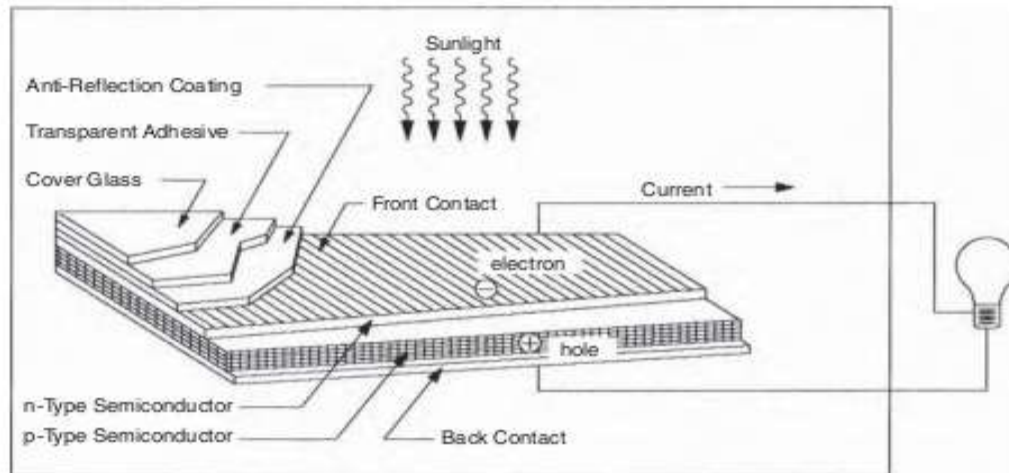


Figure 2.3: Basic construction of photovoltaic cell [20]

The basic constituents of solar PV cells are semiconductor materials, most commonly such as silicon. For solar cells, a thin semiconductor double-decker creates an electric field, on one side positive and negative on the other. When light energy strikes the solar cell, electrons are knocked a loose from the atoms in the semiconductor material. When electrical conductors are connected to the positive and negative sides an electrical circuit is formed and electrons are captured in the form of an electric current that is, electricity. This electricity is used to power a load. A solar PV cell can either be circular or square in construction.

2.7.5. Equivalent Electrical Circuit of PV Cell

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 2-4 below. The following parameters call for consideration. The current I at the output terminal 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, impurity, and contact resistance. The shunt resistance R_{SH} is inversely related to the leakage current to the ground. In an ideal PV cell $R_S = 0$ and $R_{SH} = \infty$. The PV conversion efficiency is sensitive to small variations in R_S , but insensitivity to variations in R_{SH} . A small increase in R_S can decrease the PV output significantly.

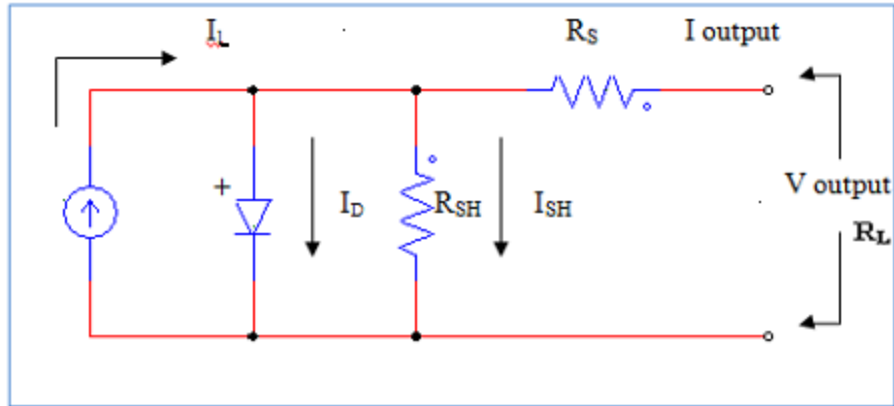


Figure 2.4: A PV cell equivalent electrical circuit.

The open-circuit voltage V_{oc} of the cell is obtained when the load current is zero and is given by the following:

The open-circuit voltage V_{oc} of the cell is obtained when the load current is zero and is given by the following equation.

$$V_{oc} = (I_L - I_{SH}) * R_{SH} \quad (2.10)$$

The diode current is given by the classical diode current expression:

$$I_D = I_o \left[\exp\left(\frac{qV_{oc}}{AKT}\right) - 1 \right] \quad (2.11)$$

Where I_o is the saturation current of the diode (A), q is electron charge (1.6×10^{-19} C), A is curve-fitting constant, K is Boltzmann constant (1.38×10^{-23} J/°K), T is temperature on absolute scale °K.

Thus, the load current is given by the expression:

$$I = I_L - I_D - I_{SH} \quad (2.12)$$

$$I = I_L - I_o \left[\exp\left(\frac{QV_{oc}}{AKT}\right) - 1 \right] - \frac{V_{oc}}{R_{SH}} \quad (2.13)$$

The last term is the leakage current to the ground. In practical cells, it is negligible compared to I_L and I_o and is generally ignored.

The two most important figure of merits widely used for describing PV cell electrical performance are the open-circuit voltage V_{oc} and the short-circuit current I_{SH} under full illumination. The short-circuit current is measured by shorting the output terminals and measuring the terminal current. Ignoring the small diode and ground leakage currents under zero voltage, the short-circuit current under this condition is the photo current I_L .

The maximum photo voltage is produced under the open-circuit voltage. Again by ignoring the ground leakage current, equation 2.13 with I give the open-circuit voltage as follows:

$$V_{oc} = \frac{AKT}{Q} \ln \left[\frac{I_L}{I_o} + 1 \right] \quad (2.14)$$

2.8. I-V and P-V Curve

The electrical characteristic of the PV cell is generally represented by the current verses voltage (I-V) curve. The figure 2-5 depicts the I-V curve of typical PV cell. This curve shows the variation of current and voltage when cell resistance varies from zero to infinity. In this curve the point at which the voltage is zero is called the short-circuit current. This is the current we would measure with output terminal shorted. On the other hand the point at which current is zero is known as open-circuit voltage. This is the voltage we would measure with output terminal open. Somewhere in the middle of the two regions, the curve has a knee point.

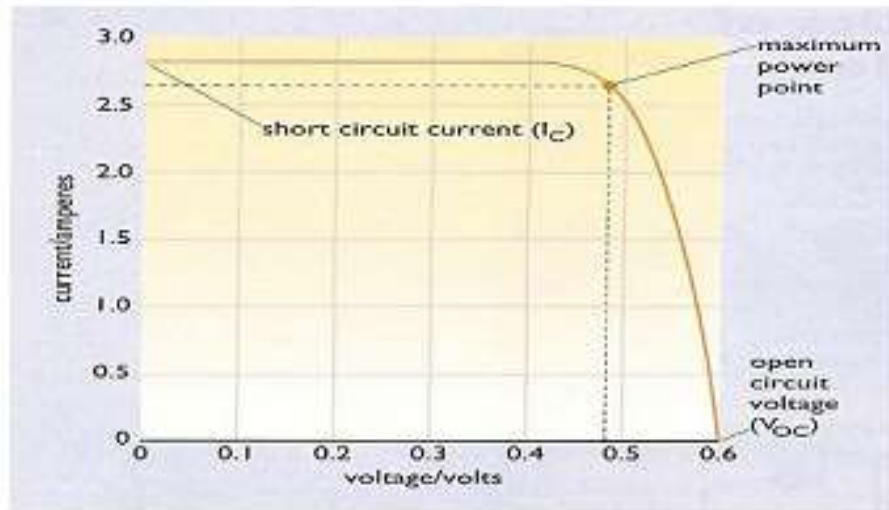


Figure 2.5: I-V curve of a typical silicon PV [22]

The power output of the panel is the product of the voltage and current outputs. In Figure 2-6 the power is plotted against the voltage which is P-V curve of the PV cell. The cell produces the maximum power at the voltage corresponding to the knee point of the I-V curve. Lastly in order to measure the photovoltaic cells output power the following Test Conditions are established internationally. Standard Test Conditions (STC) are defined by a module (cell) operating temperature of 25°C (298K), an incident solar irradiant level of 1000 w/m² and under Air Mass 1.5 spectral distribution.

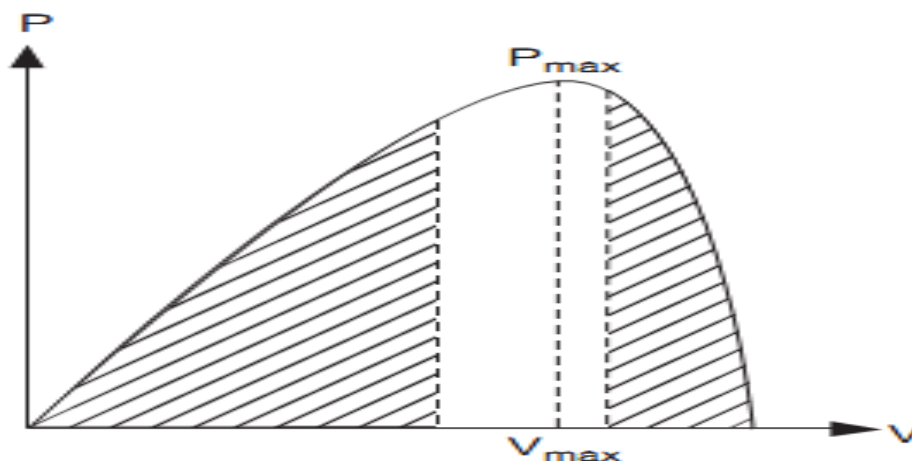


Figure 2-6: P.V characteristic of the Photovoltaic cell [7]

CHAPTER THREE

3.1. Historical Development of wind Energy

Wind energy is one of the oldest sources of energy used by mankind analogous only to the use of animal force and biomass [23]. And Throwback to olden days unlike to now a days wind energy application are more targeted in providing mechanical energy instead of Generating electricity. The power of the wind has been utilized for at least 3000 years [24], this is mainly for purpose of grinding grain or pumping water and also for sailing ship the wind has play vital role.

As we have noticed above until the twentieth century wind power was used to provide power to pump water from the ground and to grinding grain. Later on wind mills were improved and design to multi-bladed farm windmill originated in USA. The first wind mill to generated electricity in the rural U.S. was installed in 1890 [25]. However, for much of the twentieth century there was small interest in using wind energy other than for battery charging for distant dwellings. And windmill which is generating electricity commonly referred to as wind turbines or wind generator.

In wind power history the most dynamic shift was happen in early 1970s when oil priced shock the world market. After this the renaissance of wind power to the world begins and main emphasis become to produces electrical energy rather than providing mechanical energy. The first wind turbines for electricity generation had already been developed at the beginning of the twentieth century. The technology was improved step by step from the early 1970s. By the end of the 1990s, wind energy has re-emerged as one of the most important sustainable energy resources [24].

3.2. Wind Resource Potential of the Country

Ethiopia being located near the equator, its wind resource potential is very much limited. There are few promising windy areas in Ethiopia located alongside the main east African Rift Valley, the North Eastern escarpment of the country near Tigray regional state and the eastern part of the country in other word near North east of the Somali regional state [26].

Based on the recent collaboration work Between Ethiopian government and the Chinese government prepared Solar and wind master plan for the entire country, this the work has very important in identifying the gross amount and distribution of wind and solar energy resources of entire the country. At the end the study indicate that Ethiopia has a potential of 1,350 GW of wind energy [27]. When we look at the status of wind energy practice for our day today life is not that much satisfactory, and previously there are 100 wind pumps are operating in the country, providing drinking water for cattle and humans. In the Zuway region alone, 67 such wind pumps provide drinking water for more than 120,000 people [28]. However the recent progress on renewable energy such as wind has a promising future in the country and these progress flourishing and some of wind farm has built and integrated with the national grid system and adding power and reliability to the main grid system. Currently there are two wind farm were built near Adama known as Adama Wind Farm I with installed capacity of 51MW and Adama Wind Farm II of 153MW and the other one were built near mekelle and known as Ashegoda Wind Farm with installed capacity of 120MW per year and both of them has started generating. Until these two big wind projects, the wind resource development in Ethiopia was perhaps the least of all renewable energy resources that were given any attention in Ethiopia. Very recently and most interestingly investigation has been going on to build the next wind farm near to Dire Dawa known as Aysha wind farm.

The available information regarding the wind energy resource base of Ethiopia identifies two distinct zones with homogenous periodicity that is separated by the rift valley. The first zone covers most of the highland plateaus. In this zone the wind speed exhibits two well-defined maxima occurring between March and May and between September and November. In the second zone, which covers most of Ogaden and Eastern lowlands, the wind on average attains maximum velocity between May and August. Average wind velocities for the first zone and second zone are estimated at 7.6 m/s and 6.9 m/s respectively [29].

3.3. Wind Energy Conversion System

Modern wind turbine comprises of the principal components such as the tower, the yaw, the rotor and the nacelle, which houses the gear box and the generator. The tower holds the main part of the wind turbine and keeps the rotating blades at a height to capture sufficient wind power. The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists three blades despite of there are two bladed wind turbines also. The yaw mechanism is used to turn the wind turbine rotor blades in direction of the wind. The gearbox transforms the slower rotational speeds of the wind turbine to higher rotational speeds on the electrical generator side. Electrical generator will generate electricity when its shaft is driven by the wind turbine, whose output is maintained as per specifications, by employing suitable control and supervising techniques [25].

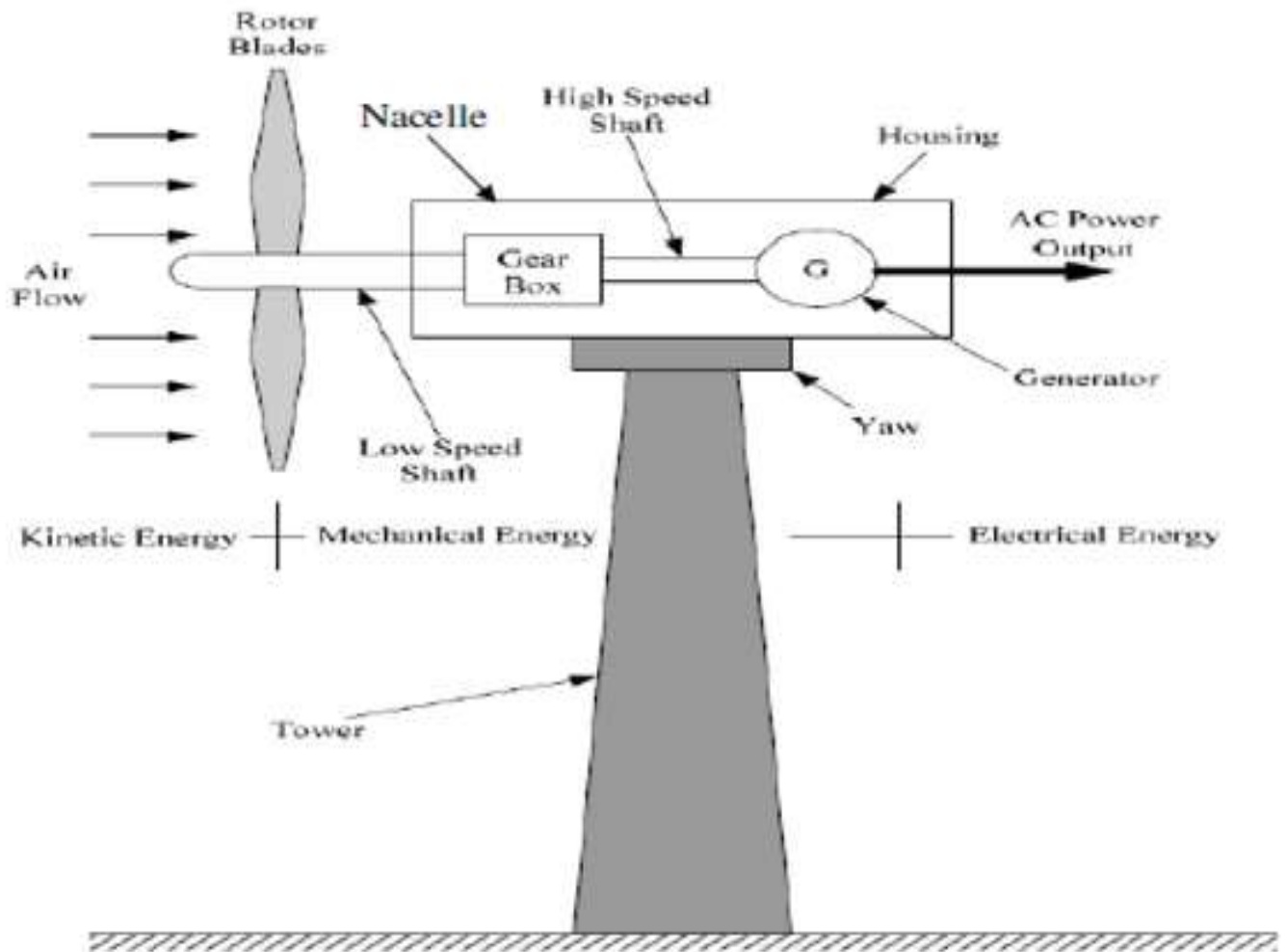


Figure 3.1: Block diagram of wind energy conversion system [30]

3.4. Wind Turbines Power Regulation Systems

Power Control is required to control the power output within allowable fluctuations for avoiding turbine damage and stabilizing the power output. There are three commonly used types of power control in the industry [31].

- ▶ Stall Control
- ▶ Pitch Control
- ▶ Active Stall Control

Stall Control: It is the simplest; the most robust and cheapest control method. The aerodynamic design principle is to increase the angle at which the relative wind strikes the blades (angle of attack) and to reduce the induced lifting force at the moment the wind speed becomes too high.

Stall controlled wind turbines have their rotor blades bolted onto the hub at a fixed angle. The fixed-blade pitch is chosen so that the turbine reaches its maximum or rated power at the desired wind speed [32].

Pitch Control: the pitch control mechanism is usually hydraulically operated. An electronic controller, which depends on the output power, sends a signal to the blade pitch mechanism so as to turn the rotor blades out of the wind to the exact degree required and to keep the rotor blades at the optimum angle for maximized output at all wind speeds. In pitch control mechanism the rotor blades are rotated around their longitudinal axis.

Active Stall Control: in this method the blade is actively controlled by pitching the blades. At low wind speeds, the blades are pitched similar to a pitch-controlled wind turbine, in order to achieve maximum efficiency. At high wind speeds, the blades go into a deeper stall by being pitched slightly into the direction opposite to that of a pitch-controlled turbine.

3.5. Wind Turbine

A wind turbine is a machine that converts the kinetic energy from the wind into mechanical energy. If the mechanical energy is directly used by machinery, such as pumping water or grinding stones, the machine is called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator. In the next topic will discuss more about classification of wind turbines and their merits & demerits.

3.5.1. Classification of Wind Turbine

Depending on the position of the rotor axis with respect to the direction of wind, two distinctly different design configurations are available for a wind turbine, the horizontal axis configuration and the vertical axis configuration. Both are known as horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) correspondingly.

Among the two configuration horizontal axis wind turbine are most commercial applicable in wind energy world.

3.5.1.1. Vertical Axis Wind Turbine (VAWT)

Vertical axis wind turbine is also known as the Darrieus rotor turbines after the French engineer who invented them in the 1920s. The axis of rotation of vertical axis wind turbine (VAWT) is vertical to the ground contrasting the horizontal counterpart and almost perpendicular to the wind direction. These types of wind turbine have very low starting torque and this may be a critical issue for certain application. The VAWT can take wind from any direction. Hence complicated yaw devices can be disregarded. the vertical axis rotors have the great advantage of not having to be turned in to the wind stream as the wind direction changes, because their operation is independent of wind direction, vertical axis machine are called panemones(from Greek words meaning “all wind”).



Figure 3.2: Vertical Axis wind turbine [33]

There are many advantages associated with the vertical axis wind turbine. Among those advantages some of them are listed below.

- ➔ In vertical axis wind turbine the generator and gear box can be placed at the ground level and may not need a tower for the machine.
- ➔ It is Omnidirectional and requires no yaw mechanisms to continuously orient itself toward the wind direction.
- ➔ Its vertical drive shaft simplifies the installation of the gear box and electrical generator on the ground, making the structure simpler and easier one.
- ➔ They can require less structural support because hefty components like gear box and generator can be situated at the ground level. This configuration also eases installation and maintenance. There is low stress on tower.

Even if the vertical axis wind turbines have an advantage which was listed above, it has also some disadvantages and listed below.

- ➔ Normally require a guy wires attached to the top for support. This has no problem with the on shore site but it limitation to off shore site. And the wires are impractical in heavily framed areas.
- ➔ One of the major problem associated with the vertical axis wind turbine is the difficult to control the output power simply in high wind speed by changing the blade pitch this also play vital role for not to be more applicable the world right now.
- ➔ Wind speeds are very low close to the ground level, thus need of a tower is eliminated, but the wind speeds will be very low on the lower part of the rotor.
- ➔ The machine is not self-starting (e.g. a Darrieus machine will need a "push" before it starts. This is only a minor inconvenience for a ride connected turbine, however, since you may use the generator as a motor drawing current from the grid to start the machine).
- ➔ Highly loaded main bearing at the foundation, difficult to repair or replace without dismantling the whole turbine.
- ➔ The overall efficiency of the vertical axis wind turbine machines is less than in the case of a horizontal.
- ➔ Replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine. In the case of the latter, it means tearing the whole machine down.

3.5.1.2. Horizontal Axis Wind turbine (HWAT)

The common wind turbine with a horizontal axis or Propeller Type is simple in principle, but the design of complete system, especially a large one that will produce electric power economically, is complex. Not only must individual components, such as rotor, generator, tower, be as efficient as possible, but this components must function effectively in combination. This type of wind turbine currently dominates wind turbine application.

Advantage of Horizontal Axis wind Turbine

- ▶ Horizontal axis wind turbine have low cut in wind speed and easy furling.
- ▶ As compared to that the vertical one, HAWT have relatively high power coefficient.
- ▶ The main advantage of HAWTs is the good aerodynamics efficiency and versatility of application.

Disadvantage of Horizontal Axis wind Turbine

- ▶ Require the tail or yaw drive to orient the turbines towards wind direction.
- ▶ Generator and gear box of this type wind turbine situated over the tower which makes its design more complex and expensive.



Figure 3.3: Horizontal Axis Wind Turbine [33]

3.6. Distribution of wind speed

Wind speed is one of the most data needed to assess the power potential of a candidate site. Not only the average strength of wind speed in study area are the most deterministic factor but also wind speed distribution with in the regime is also critical factor in wind energy analysis and more over in selecting a site to install the wind power turbine. Interestingly, to note that the average wind speed does not coincide with most frequent wind speed is higher than the most frequent speed, except for trade winds which are relatively steady thought the time [34].

Weibull Distribution has been found to give a good representation of the variation in hourly mean wind speed over a year at many typical sites.

$$P(U) = \exp\left[-\left(\frac{U}{C}\right)^K\right] \quad (3.0)$$

Where

$P(U)$ Fraction of time for which the hourly mean wind speeds exceeds U.

C The scale factor

K The shape parameter

From the above equation what we can understand is that the fraction of time characterized by two parameter C , a scale factor, and k , shape factor which describe about the variability of mean speed.

There are two commonly used functions for fitting a measured wind speed probability distribution in a given location over a certain period of time are the Weibull and Rayleigh. The Rayleigh use one parameter, average wind speed whereas Weibull uses two parameters and, thus, represent a wider variety of wind regime. In Weibull distribution, the wind variation of the regime are characterized by two functions; probability density function (PDF) and Cumulative density function (CDF).

The probability density function can be take the form

$$p(U) = -\frac{dP(U)}{dU} = -\frac{d\left[-\left(\frac{U}{C}\right)^K\right]}{dU} \quad (3.1)$$

$$p(U) = \left[\left(\frac{K}{C}\right) * \left(\frac{U}{C}\right)^{K-1} * \exp\left[-\left(\frac{U}{C}\right)^K\right] \right] \quad (3.2)$$

For most typical sites the shape factor are $K=2$ and is special case of Weibull distribution with shape factor equal to 2 is actually a fairly typical value for many locations [25], and more commonly known as Rayleigh distribution. Substituting the values of the shape factor in the above equation 3.2 can be simplified as follow.

$$p(U) = \frac{2U}{C^2} * \exp \left[-\left(\frac{U}{C}\right)^2 \right] \quad (3.3)$$

Where $p(U)$ is Rayleigh Density Function

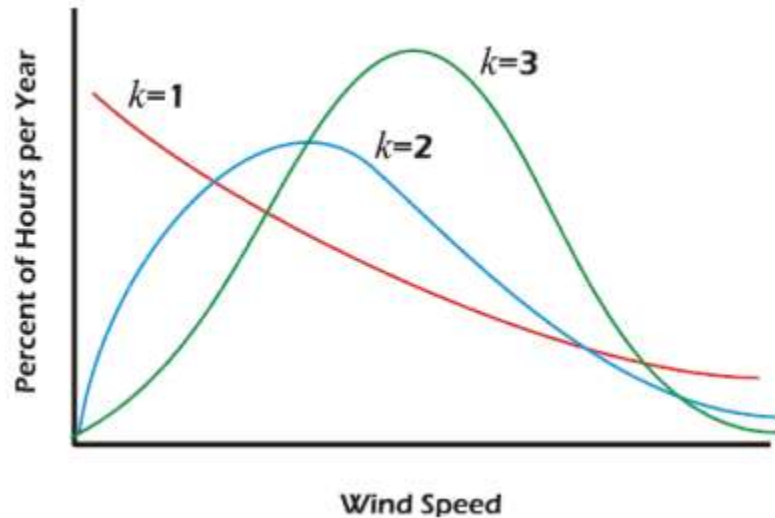


Figure 3.4: Weibull Distribution Shape Parameter [35]

Even if a Weibull distribution gives a very representation of the wind regime at many sites, this is not always the case. There are site that shows clearly different wind climate in summer and winter can be represented quite well by a double peaked “ bi-Weibull distribution” with different scale factor and shape factor in the two season such kind climatic condition can be found certain parts of California. For such case we can fraction of time for which the hourly mean wind speed exceeds U can be computed using the equation 3.4 which is shown below [36].

$$P(U) = P_1 \exp \left[-\left(\frac{U}{C_1}\right)^{k_1} \right] + (1 - P_1) * \exp \left[-\left(\frac{U}{C_2}\right)^{k_2} \right] \quad (3.4)$$

Most of the time the shape factor range in between 1 and 3 these typical value are known from practical experience and multiple observations of site where wind speed measurements have been taken , these wind types are categorized as inland, costal, and trade wind(off shore) site. Table 3-1 show below shows typical value for shape factor.

Table 3.1: Typical Shape Factor Values.

Types of Wind	Shape factor
Inland Wind	1.5 to 2.5
Costal Wind	2.5 to 3.5
Trade Wind	3 to 4

Once the shape factor k is determined, the scale factor c is can be given by

$$C = \frac{V}{\Gamma\left(1 + \frac{1}{K}\right)} \quad (3.5)$$

But this method involve the calculation of gamma function, thus there is simple approach are available which is given by

$$C = \frac{2 * V}{\sqrt{\pi}} \quad (3.6)$$

More accurately, C can be found using the expression

$$C = \frac{V * K^{2.6674}}{0.184 + 0.816 (K^{2.7385})} \quad (3.7)$$

Where: V is the average wind speed (m/s) value and Γ is gamma function.

3.7. Wind Energy System

Energy available in wind is basically the kinetic energy of large masses of air moving over the earth's surface. Blades of the wind turbine receive this kinetic energy, which is then transformed to mechanical or electrical forms or use it to do other work [34]. The kinetic energy of air of mass m moving at speed v can be expressed as.

$$E_k = \frac{1}{2} m v^2 \quad (3.8)$$

During a time period t , the mass (m) of air passing through a given blades swept area at wind speed v is:

$$m = \rho Avt \quad (3.9)$$

Where: ρ Is the density of air (kg/m^3), A Swept area of blade (m^2), m Mass of air (kg), v Velocity of wind turbine (m/s).

3.8. Rotor Swept Area

The area over which the sweeping blades can capture the wind is known as rotor area of wind turbine. The rotor area decide how much energy a wind turbine is capable to produce from wind since the rotor area increase with of the rotor diameter and rotor area can be given by

$$A = \pi r^2 = \frac{\pi}{4} D^2 \quad (3.10)$$

Where r is radius of the rotor and D diameter of the rotor;

Based on the above two equations, the wind power developed by the wind turbine is:

$$P = \frac{E_k}{t} = 1/2 \rho Av^3 \quad (3.11)$$

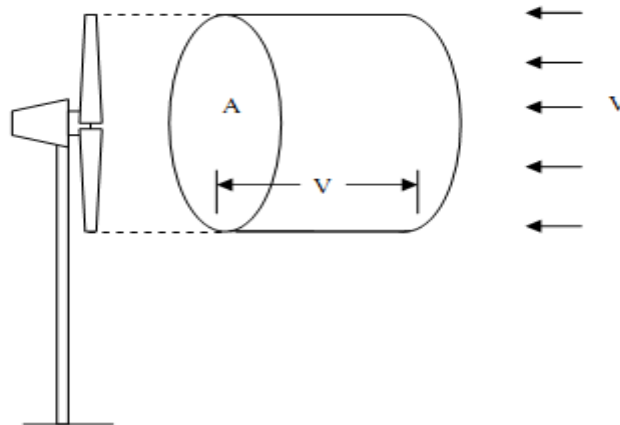


Figure 3.5: Air parcel moving towards a wind turbine [34]

The air density is a function of air pressure and temperature, which both are functions of the height above the sea level. And can be expressed in equation as follow.

$$\rho(z) = \frac{p_o}{RT} \exp\left(-\frac{gZ}{RT}\right) \quad (3.12)$$

Where $\rho(z)$ = is the air density as a function of altitude (Kg/m^3), p_o = standard sea level atmospheric density (1.225 Kg m^{-3}), R = specific gas constant for air ($287.05 \text{ JKg}^{-1}\text{K}^{-1}$), g =gravity constant (9.8 ms^{-2}), T = Temperature (K), and Z =altitude above sea level (m);

It is interesting to note that a number of energy technologies have certain fundamental constraints that restrict the maximum possible conversion efficiency from one form of energy to another. In case of wind turbine the reason behind this is that the power in wind can't be extracted completely by wind turbine.

Even though the above (equation 3.11) gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the efficiency factor and more commonly known as the coefficient of performance (C_p) in this study use the late name . It can be defined as the fraction of the free-flow wind power that can be extracted by a rotor is called the power-coefficient: thus

$$C_p = \frac{P_{wind\ turbine}}{p} \quad (3.13)$$

$$P_{wind\ turbine} = C_p * P = C_p * \frac{1}{2} \rho A v^3$$

$$C_p = 4a(1 - a)^2 \quad (3.14)$$

Where a is known as interference or perturbation factor is fractional wind speed decrease at the turbine.

The maximum value of C_p occur in the model when the value of $a=1/3$. Substituting this value in to (equation 3.14) we final get the value of $C_{p\ max}$

$$C_{p\ max} = 16/27 = 0.593$$

A maximum theoretical value of coefficient of performance (C_p) is defined by the Betz efficiency or Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. The other way of expressing of Betz law as, not all of the energy present in a stream of moving air can be extracted; some air must remain in motion after extraction. This value can't be exceeded by a rotor in free flow wind stream. In reality, the coefficient of performance is less than this limit due to various aerodynamic and mechanical losses and it thought to be in the range of 30% to 45%. Why it is not possible to generate 100% of the kinetic energy in the wind? For a wind turbine to extract 100% of the energy it would need to stop 100% of the wind. If it did this it would then stop working. Instead it extracts enough energy to still allow the wind to continue to pass through it.

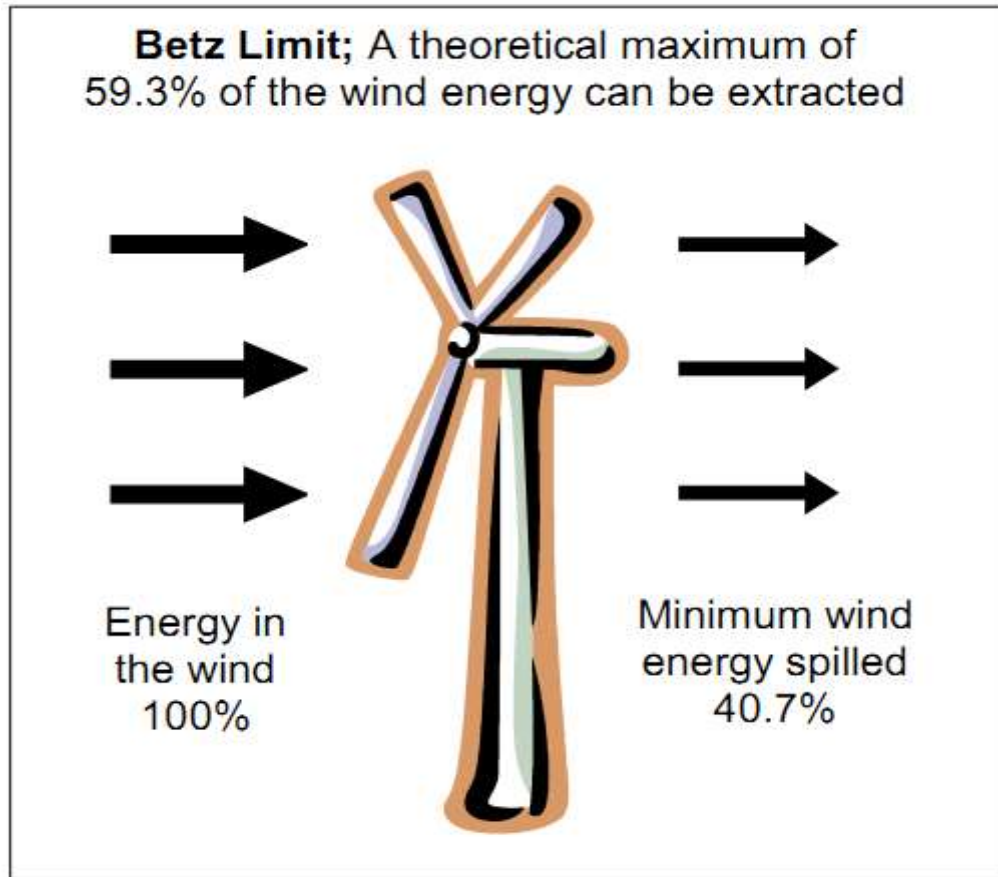


Figure 3.6: Diagrammatic Representation of Betz limit

As noted from (equation 3.11) power in wind is proportional to cube of wind velocity. Thus, it would be more preferable to place wind energy in a location with high wind velocity.

3.9. Impact of Tower Height

Throwing back, there was time where measurement of wind speed is recorded at 2m height. Thus, this measurement is accompanied by turbulence created by tree, buildings or obstructions. The wind data available at meteorological stations might have been collected from different heights. Right now, in most of the cases, the data are logged at 10 m as per recommendations of the World Meteorological Organization (WMO). This height treated as standard for anemometer height where recorded data are taken. It's known that wind speed increase with height, these is due to shear. Therefor the higher towers capture more wind power as compared to similar wind turbine at lower height. Having all says above. There should be some mechanism to determine the speed of wind at which it captures more power.

Actually there are two acceptable mathematical laws; generally speaking, both are used by many researchers to determine the vertical profile of wind speed over region of homogenous. These laws are power law and logarithmic law (log law).

This law helps to adjust the measured wind speed to the hub height. This can be done using either the logarithmic law, which assumes that the wind speed is proportional to the logarithm of the height above ground, or the power law, which assumes that the wind speed varies exponentially with height. Both mathematical laws subjected to some degree of uncertainty. For this study logarithmic law have been chosen, it is often used to extrapolate wind speed from a reference height to another height level. According to this law the ratio of velocity at two heights Z_R and Z is given below [34] [37].

$$\frac{V(Z_R)}{V(Z)} = \frac{\ln\left(\frac{Z_R}{Z_0}\right)}{\ln\left(\frac{Z}{Z_0}\right)} \quad (3.15)$$

Then the wind speed at the reference height (hub height) can be computed using equation [26] when we rearrange it.

$$V(Z_R) = V(Z) * \left[\frac{\ln\left(\frac{Z_R}{Z_0}\right)}{\ln\left(\frac{Z}{Z_0}\right)} \right]$$

Where: $V(Z_R)$ Is the wind speed at the reference height (m/sec), $V(Z)$ Is the wind speed at which the turbine hub (m/sec), Z_R Is the reference height in meter and where anemometer measurement recorded (m), Z_0 Is known as surface roughness length (0.1 is chosen) which characterizes the roughness of the ground terrain, Z Is Height where wind speed is to be determined (m), $\ln(\dots)$ the natural logarithm.

Surface roughness length or height is a parameter that characterizes the roughness of the surrounding terrain. It range between zero (surface of sea) and as high as two (town center). In table 3-2 represents the different terrain surface roughness lengths [37].

Table 3.2: Surface Roughness Lengths [37].

Terrain Description	Z_o
Very smooth, ice or mud	0.00001m
Calm open sea	0.0002m
Blown Sea	0.0005m
Snows Surface	0.003m
Lawn Grass	0.008m
Rough Pasture	0.010m
Fallow field	0.03m
Crops	0.05m
Few trees	0.10m
Many trees, Few buildings	0.25m
Forests and woodlands	0.5m
Suburbs	1.5m
City center, tall buildings	3.0m

There also another formula that wind speed on height correction is made. As you know wind speed always affected by local factor such as hills, building and topography where the wind turbine install, The formula which is shown below commonly known as the power law which is given by [37].

$$\frac{V_2}{V_1} = \left[\frac{h_2}{h_1} \right]^\alpha \quad (3.16)$$

Where: V_2 Is wind speed at the hub height of the wind turbine (m), V_1 Is wind speed at the anemometer height (m), h_2 is the hub height of the wind turbine (m), h_1 is the anemometer height of the wind turbine (m), α is the power low exponents which is known as a ground surface coefficient and it's a dimensionless parameter. Table 3.3 which is shown below provides the corresponding value of ground surface coefficient.

Table 3.3: Power law exponents α of various Terrains [25]

Terrain Type	Friction Coefficients(α)
Lake, ocean, and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops and shrubs	0.20
Country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

3.10. Wind Speed Measurement

Simply, Anemometer is a device used to measure the wind speed. Most common type of anemometer is a device with three or four arms that spin on top of a shaft. Each arm has a cup on its end. The cups catch the wind and spin the shaft. The harder the wind blows, the faster the shaft spins. A device inside counts the number of rotations per minute and the angular speed of the spinning shaft is calibrated in terms of the linear speed of the wind. A display on the anemometer shows the speed of the wind.

Based on the working principle, wind anemometer can be classified in to four and they are rotational, pressure type, thermoelectric, and phase shift anemometer. Among this classification the rotational type of anemometer is commonly applicable most parts of the world and it consists of propeller anemometer and cup anemometer. Cup type one is the most widely used in wind energy measurement right now, as the name suggest it's made of three cup type material, the cups are hemispherical or conical in shape and made with light weight material. Each cup is mounted on the horizontal arms which extend from the axis of rotation and they are just oriented in the same direction. Routinely, the anemometer is built-in with a wind vane to sense the wind direction. A data logger gathers wind speed and wind direction data from the anemometer and wind vane correspondingly.

Even though widely used type one it has some limitation and the limitations are it accelerate quickly with the wind but retards slowly as the wind cease. Due to the slow response, cup anemometers don't provide a more reliable measurement in the wind gust. However, the national metrological service agency (NMSA) and its branch use this type of anemometer.

It is very important that the measuring equipment is set high enough to avoid turbulence created by trees, buildings or other obstructions. Readings would be most useful if they have been taken at hub height where the wind turbine is going to be installed [34].

Most commonly, there are two areas to get the data required for this study. One is from national metrological service agency (NMSA) and the other is satellite based data provided by NASA through online. When there is no any metrological station at the site, the one closer to the site recommended to be chosen and the closest station is Degahabour, this station not very well organized as that of the Jigjiga branch meteorological service agency branch. However at that station only data collection is done by Jigjiga branch metrological service agency. The collected data are organized and documented by Jigjiga branch national and metrological service agency. As per the information gathered, this is done because of the lack of man power at the Degahabour met station. Having this problem in our mind, it becoming very hard to get the full data which is required for this study, thus the designer forced to pick online support data which is provided by NASA and to get the required data related to surface metrological and solar energy data available online. What it demands you is the exact geographical coordination which means latitude and longitude of the study area. The wind speed data are taken at different height regarding the turbine hub, One at 10m height and the other is at 30m height where the wind turbine to be situated. Both height measurements are taken from the ground surface.

Main determining factor for the designer to chosen satellite based wind data because of Most of the met station measurements for wind speed were taken at heights lower than the accepted standard of 10 m and over half were taken at just 2m above ground level. The measurement at 2m height may miss lead the designer while investigating the resource, to avoid such redundancy the designer shift to the satellite based data where more accurate data are available.

Table 3.4: Wind speed of the site at different height

Monthly Average Wind Speed													
Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
NASA @10m	4.54	4.26	3.56	2.71	3.63	5.74	6.04	5.62	4.46	3.07	3.72	4.34	4.30
@25m	5.44	5.04	4.27	3.25	4.35	6.88	7.24	6.73	5.35	3.68	4.46	5.2	5.16
@30m	5.62	5.19	4.4	3.35	4.49	7.11	7.47	6.96	5.52	3.8	4.6	5.37	5.33

As it is noticeable from the table 3-4 which is shown in above, when speaking relatively the peak wind speed was noted on months June, July, and August and the lowermost average wind speed is recorded on months April and October. Generally, the table designate that wind resource is abundant enough the whole year and a substantial amount of electricity could be generated using wind turbine.

3.11. Site Selection for Wind Power

The power available in the wind increase rapidly with speed, hence wind turbine should be located preferable in areas where the wind speed are strong and persistent. Although daily wind speed at a given site may be highly variable, the monthly and especially annual average speeds are remarkably constant from year to year. The major contribution to the wind power available at a given site is actually made by wind with speed above the average. Nevertheless, the most suitable site for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high.

Some of the main consideration (Technical, Economic, Environmental, social and other factor are examined before decision made to erect a generating plant on specific).

High annual average wind speed is a most basic requirement to the successful use of wind energy conversion system. The wind velocity is the critical parameter. Anemometer data is normally based on wind speed measurement from a height of 10m. For the most accurate assessment of wind power potential it is absolutely essential that anemometer data be obtain at the precise site and hub height for any proposed wind energy conversion system.

Altitude It affects the air density and thus power in wind turbine and hence the useful wind energy conversion system electric power output. Also as it well knows that, the wind tends to have higher velocities at higher altitude as we have discussed in pervious section.

Distance to road and load Center. This is another factor the system engineer must consider for heavy machinery, structure, material, blade, and other apparatus will have to travel in to any chosen wind farm project site. Similarly the nearness of the site to local center has vital role in choosing the most likely wind farm site. The near to local center has advantages and minimizing transmission line length and at the same time minimize both transmission cost and transmission power loss.

Visual Aspect One of the more obvious environmental effects of wind turbines is their visual aspects. This has more important when we concern more for aesthetic value. There is no measurable way of assessing the effect, which is essentially subjective. As with noise, the back ground is also vital important. Experience has been shown that good design and the use of subdued neutral colors “off white” is popular to minimize this effect. Thus, even if it has a less impact on the aesthetic view it should need to give attention while selecting wind farm project.

CHAPTER FOUR

Load Estimation, Hybrid System Modeling and System Components Designing

4.1. Electrical Load Estimation

Load

Load is a general term meaning either energy or power demand. Load may be classified particularly as residential, commercial, community and Deferrable, and other. Residential or Domestic customer uses energy for domestic purpose, the domestic loads which includes of lighting, radio, TV and fan; whereas commercial customer obviously use energy for commercial purpose, commercial load comprise of flour milling machine and community load which comprise of primary School (lighting, computer, printer, and fan), health post comprise of Vaccine refrigerator, VHF radio, and microscope; and mosque which include of Amplifier and lighting; and deferrable load which contain water pumps.

Estimating of both the power and energy demand requirement is a crucial to effective system planning. Demand estimation is used to determine the capacity of generation, transmission, and distribution system. Energy forecasts determine the type of facility required. The electric load in the rural villages of Ethiopia can be Consider to be Comprise of lighting, radio receiver and television set, health post and primary schools load [38] In addition to this load, In this study fan added to school to have smooth teaching during hot condition.

The load determination is done for Abubeker Ahmed village with population number is 7,524 and with average number of person per household of 6.8 and the total number of households are 1,074 this data are taken from “Lanqerta Health Center”. Out of the total number of households, 185 households have the access to diesel generated electricity which is provided by the private owner. Thus, the load estimation is done by taking such number of households. The rest of households are not taking in to consideration since the scope of the thesis. In this energy system design, the designer select electrical appliance of low voltage especially electric lamp, and the lamp are energy efficient one. This is done basically to promote energy

efficient lamp and at the same time to save energy wastage instead of using incandescent lamp.

As a designer, when we chose an electrical load we have to consider many things and among from those, the most decisive thing is the purchasing power of the community and availability of the electric load in the nearby market. Recently, Ethiopia Electric Power (EEP) trying to reduce the energy wastes which was incurred due to an inefficient usage of electric load (incandescent lamp) in community especially in the lighting system. Doing this have mutual benefit both the users and supplier. Thus the designer chose energy efficient lamp instead of incandescent lamp. At the same time it promote save energy strategy.

House Hold

In Rural part of Ethiopia, the demand for electrical energy is just for their basic need and the most common domestic loads are well known and fundamentally they need for lighting, Radio, TV, and Mobile charge (due to increasing of mobile user). Each house hold expected to have three a 15W compact florescent lamp as a light bulb and a lamp for external lighting, a 5W Radio receiver, a 60W Television and a 10W mobile charge. Electric light bulbs are to be operational for six hour of a day which is between 18:00 and 24:00 in the evening; radio and TV which will operate for four hours from 18:00 and 22:00. The criteria for selecting appliance are by taking into consideration of the low energy saving standard and the purchasing power of the rural community. The daily energy consumption by per household community is calculated to be approximately 0.62 Kwh/day.

Table 4.1: Energy consumption by each household.

Household Demand					
Type	Load	Load Demand (w)	Quantity	Runtime (h/day)	Energy Consumption(kwh/day)
Household	CFL lamp	15	2	6	0.18
	Radio	20	1	8	0.16
	TV	40	1	6	0.24
	Mobile Charger	10	1	4	0.04
	Load Demand			0.1 kw	Energy Demand

A primary school proposed of 8 classrooms and individual class room will be installed by means of two 15w CFL and radio receiver with 20W rating, in addition to this the school assumed to have one computer and printer having a power rating of 60W and 635W respectively, By taking location high temperature (warmness) in to account the designer consider 45w power rating fan in each class to be installed for the purpose air conditioning system which is operated afternoon time from 13:00 – 17:00 per day, and there are days where fans might operate in morning time also but it's very insignificant as compared to that of afternoon time. Last but not least, for external lightning two CFL are considered and also two lamp for toilet. An assumption was taken that evening classes would conduct from 18:00 - 21:00 hours. During the weekends evening class will not be conducted.

The electric load in a typical health post there are three room health care facility, equipped with vaccine refrigerator “Sometimes they may have a cold box instead of refrigerator”, light bulb, stand-by communication VHF radio, microscope is suggested in [38]. Here in the health post give conduct for minor sickness though for major sickness they will referred to the adjacent Health Center and the health post not deliver a regular service, they deliver service three or four days in week for the treatment. Saturday and Sunday are off days.

The other primary loads that are present in village are load present in mosque and there are two mosques present in a village. Since all most all the community whose livings in this village is Muslim. As we know most of the loads in the mosque are primary load and they are electric lamp amplifier. As per their religion they do have small mosques; Basic loads in mosque are Amplifier for Azan (to call prayer to mosque which is mandatory during day time) and CFL lamp for lighting during praying time especially at the night time.

Table 4.2: Energy consumptions of the community load

Community load					
Type	Load	Load Demand(w)	Quantity	Runtime (h/day)	Energy Consumption(kwh/day)
Mosque	CFL lamp	15	4	5	0.3
	Amplifier	120	2	2	0.48
	Load Demand		0.3 kw	Energy Demand	0.78 kwh/day
Health Post	CFL lamp	15	3	3	0.135
	Vaccine Refrigerator	80	1	24	1.92
	Microscope	20	1	3	0.06
	Radio	20	1	8	0.16
	Load Demand		0.165 kw	Energy Demand	2.275 kwh/day
Primary school	CFL lamp	15	20	3	0.9
	Radio	20	1	8	0.16
	Computer	60	1	2	0.12
	Printer	635	1	1	0.635
	Fan	45	8	4	1.44
	Load Demand		1.375 kw	Energy Demand	3.255 kwh/day
Total Load Demand					1.84 kw
Total Energy Demand					6.31 kwh/day

As we have seen in the above table the power and energy demand of per household is 0.1 kW and 0.62kwh/day/household respectively. Then to get the total power and energy demand, it has to be multiplied with the total number of household.

For 185 household

$$\text{Total power} = 0.1 \text{ kw/household} * 185 \text{ household} = 18.5 \text{ kw}$$

And then the total energy demand can be computed as follows

$$\text{Total energy demand} = 0.62 \text{ kwh/day/household} * 185 \text{ household} = 114.7 \text{ kwh/day}$$

For that of community load

$$\text{Total Load Demand power} = 1.84 \text{ kw}$$

$$\text{Total energy Demand} = 6.31 \text{ kwh/day}$$

Now Table 4.3 which is shown below summarize whole Load Power and Energy Demand

Table 4.3: Summary table for total power demand and energy demand of the household and community.

Category	Total
Total Load Demand	20.34 kw
Total Energy Demand	122kwh/day

4.2. Hybrid System Modeling

System modeling is a foundation or base work that leads to system design and in any system design it's mandatory to model the system before going to design.

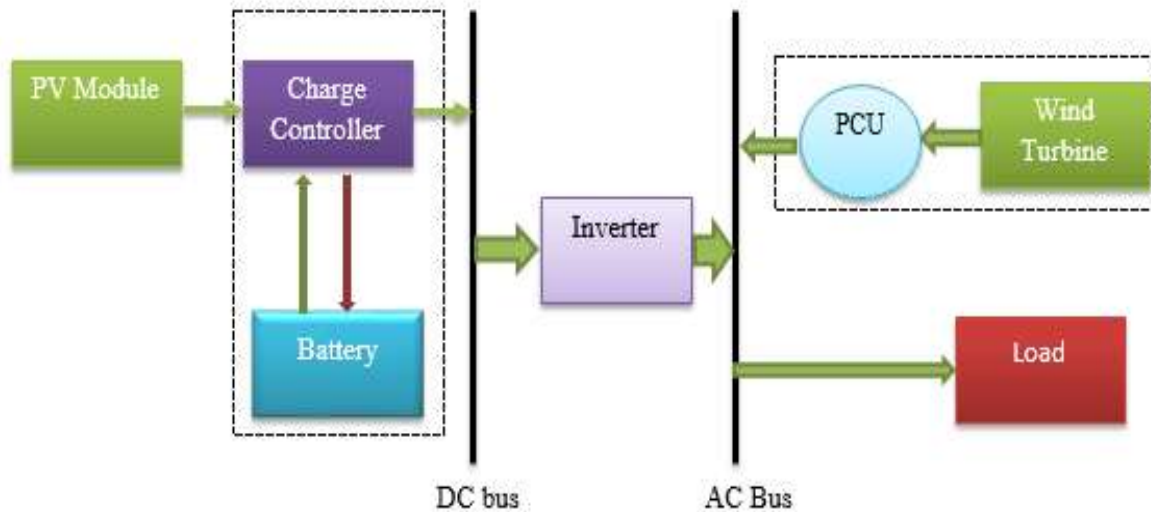


Figure 4.1: Hybrid System Modeling

4.3. System Components Design

Load Curve

The load on power stations varies from time to time. These variations during the whole day (24 hours) are recorded hourly and plotted against time on graph. This graph is called a load curve. Load curve is a graphical representation between load in kW (or MW) in proper time sequence and time in hours. It shows the variation of load on the power station.

The highest point on the load curve represents the maximum demand (peak demand) on the station on that day. The area under the load curve gives the total energy supplied on that day. And if this area is divided with the number of hours gives the average load (power) on the station.

Load profile study and determination are the first steps for the design of any electric power system. The system to be design in coming section has to supply daily load curve which is shown in Table 4.4.

Table 4.4: Daily Load Profile of the Abubeker Ahmed Village.

Time [hr] Load [KW]	0:00- 1:00	1:00- 2:00	2:00- 3:00	3:00- 4:00	4:00- 5:00	5:00- 6:00	6:00- 7:00	7:00- 8:00	8:00- 9:00	9:00- 10:00	10:00- 11:00	11:00- 12:00
Household	4.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
Community	0.15	0.15	0.15	0.18	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.4
Total [KW]	4.15	0.15	0.15	0.18	2.15	2.15	2.15	2.2	2.2	3.2	3.2	3.4

Load type (kw)	12:00- 13:00	13:00- 14:00	14:00- 15:00	15:00- 16:00	16:00- 17:00	17:00- 18:00	18:00- 19:00	19:00- 20:00	20:00- 21:00	21:00- 22:00	22:00- 23:00	23:00- 00:00
Househ'd	4.0	4.0	3.0	2.0	2.0	2.0	15.0	16.0	16.0	16.0	15.0	5.0
Commu'y	0.8	0.2	1.5	1.80	1.45	0.9	0.95	1.5	1.80	1.45	1.40	0.15
Total [KW]	4.8	4.2	4.5	3.8	3.45	2.9	15.95	17.5	17.8	17.45	16.4	5.15

From the above table of daily load distribution it is possible to develop daily load duration curve using Microsoft excel and its output become as shown in figure 4.2.

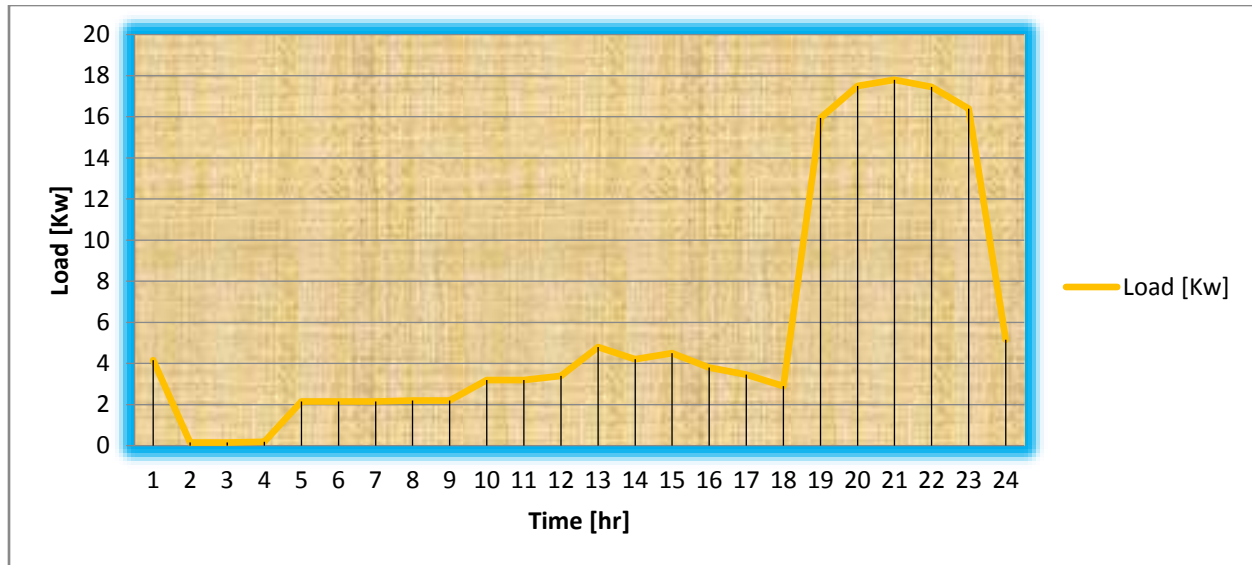


Figure 4.2: Daily Load curve for Abubeker Village

4.4. Solar System Sizing

System sizing is the process of evaluating the adequate voltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility. In system design the system shall not either oversized or undersize.

Total Load of Abubeker Ahmed Village, $Total Load = 122 Kwh/day$

Assuming 30% both for losses and reserve capacity incase sudden load increase in the future. Then total energy from all sources (i.e. wind and solar energy).

$$Total Load = 122 Kwh/day * 1.3$$

$$Total Load = 158.6 Kwh/day$$

The use of two renewable sources causes the energy generation to be divided into two parts. Let's assume 70% of the daily energy demand is to be contributed by wind turbine and the remaining 30% from solar panel.

Total energy demand is 158.6 Kwh/day and 30% of total energy become

$$158.6 Kwh/day * 0.3 = 47.6 Kwh/day$$

Thus Daily energy required from solar photovoltaic array is 47.6 Kwh/day

$$E_{req} = 47.6 \text{ Kwh/day}$$

To obtain the peak power of the solar PV by dividing daily energy required by the worst month of sunshine hours, the worst month sunshine hour is 5.37 wh/day.

$$P_{peak} = \frac{\text{Daily energy required}}{\text{Minimum sunshine hours}} \quad (4.1)$$

$$P_{peak} = \frac{47.6 \text{ Kwh/day}}{5.37 \text{ wh/day}} = 8.864 \text{ KW}_p$$

$$P_{peak} = 8,864W_p$$

The current required from solar PV array can be computed by dividing the peak power by DC voltage of the system. Here DC system voltage assumed to be 48V. The current can be computed as follow

$$I_{DC} = \frac{\text{peak power}}{\text{System DC voltage}} \quad (4.2)$$

$$I_{DC} = \frac{P_{peak}}{V_{DC,system}} = \frac{8,864W_p}{48V} = 184.66A$$

$$I_{DC} = 184.66A$$

Where I_{DC} is the current from solar PV array, P_{peak} is the peak power of solar PV array, $V_{DC,system}$ is DC system voltage. E_{req} Daily energy required from solar PV array.

Based on system demand Solar PV module can be connected either in series, in parallel, or both. This is mainly depends on desire voltage or current.

The selected panel is (Mitshubishi-MF180UD4, 180-W, 24-V, 7.45-A). The specification of PV panel;

Table 4.5: Electrical Characteristics of Solar PV panel [38].

Solar PV Panel Specification	
Manufacturer	MITSUBISHI ELECTRIC
Model Name	MF180UD4
Cell Type	Poly-crystalline Silicon
Numbers of Cell	50 Cells
Maximum Power Rating STC P_{max}	180W
Open Circuit Voltage V_{OC}	30.4V
Short Circuit Current I_{SC}	8.03A
Maximum Power Voltage V_{mp}	24.2V
Maximum Power Current I_{mp}	7.45A

Number of parallel module can be determined by dividing the whole solar PV modules current by rated current of one module.

$$N_{parallel} = \frac{\text{whole module current}}{\text{Rated current of single module}} \quad (4.3)$$

$$N_{parallel} = \frac{I_{DC}}{I_{rated}} = \frac{184.66A}{7.45A} = 24.78 \cong 25 \text{ modules}$$

And the number of series module can be determined by dividing system DC voltage by solar PV module rated voltage and computed as follows,

$$N_{series} = \frac{\text{System DC voltage}}{\text{Module rated voltage}} \quad (4.4)$$

$$N_{series} = \frac{V_{DC,system}}{V_{rated}} = \frac{48V}{24V} = 2 \text{ modules}$$

Then the total modules can be calculated by simple multiplication of number of modules in series with number of modules in parallel or vice versa. And mathematically expressed as follows,

$$N_{total} = N_{parallel} * N_{series} \quad (4.5)$$

$$N_{total} = 25 * 2 = 50 \text{ modules}$$

Total modules of 50 required to supply 30% of the power demand by the Abubeker Ahmed Village.

4.4.1. Battery Bank Sizing

Before rush in to battery sizing first we have to determine how many possible days with no sun light, which is very important in sizing of battery bank. In table 4-6 which is shown below help in determine days of autonomy in particular location. Day of Autonomy usually taken as 5 to 6 days and for this case we take maximum of 6 days. Usually days of autonomy dependent on the geographical coordination of one's location and generally for any geographical location the number of autonomy can be summarized as follows in table format.

Table 4.6: Autonomy Days for any specific geographical location.

Autonomy Days For Specified Latitude	
Latitude	Days of Autonomy
0°-30°	5-6
30°-50°	10-12
50°-60°	15

The amount of energy storage required is equal to the multiplication of total energy demand to be covered by solar PV and number of autonomy days. Taking maximum days is six.

$$E_{stored} = \text{Daily energy required} * \text{Days of autonomy} \quad (4.6)$$

$$E_{stored} = 47.6 \text{ Kwh/day} * 6 \text{ days}$$

$$E_{stored} = 285.6 \text{ Kwh}$$

This amount of energy required if there was no sun light for six days which will increase the reliability of the system.

Depth of discharge is important factor for the battery. It refers to how much capacity will be used from the battery. Most Battery systems are designed for regular discharges of up to 40 to 80 percent. For safety, the result obtained above is divided by the maximum allowable level of discharge.

$$E_{safe} = \frac{E_{stored}}{MOD} = \frac{E_{stored}}{\text{Depth of discharge}} \quad (4.7)$$

Taking the depth of discharge of most battery is 60%

$$E_{safe} = \frac{285.6 \text{ Kwh}}{0.6} = 476 \text{ Kwh}$$

So far it has been determined how much energy to be stored in the battery banks. Thus, now the selection of battery made and the battery selected is described in table 4.7.

Table 4.7: Electrical Characteristics of Battery.

Selected Battery Specification	
Battery Name	Surette 12MD375P
Nominal Voltage	12V
Nominal Capacity	375Ah

Based the data which is listed in above table 4.7 it is possible to determine the capacity of battery bank and can be computed as follows.

The capacity of battery bank required in Ampere-hours can be evaluated by dividing safe energy stored by the DC voltage of single battery.

$$C = \frac{E_{safe}}{V_{battery}} \quad (4.8)$$

$$C = \frac{476 \text{ kwh}}{12V} = 39.666 \text{ KAh}$$

$$C = 39,666Ah$$

Then, the total numbers of batteries is obtained by dividing capacity of battery bank by nominal capacity of individual battery.

$$N_{b,series} = \frac{V_{DC}}{V_{rated}} \quad (4.9)$$

$$N_{b,series} = \frac{V_{DC}}{V_{rated}} = \frac{48V}{12V} = 4 \text{ batteries}$$

$$N_{battery} = \frac{\text{Capacity of battery banks}}{\text{Nominal Capacity of single}} \quad (4.10)$$

$$N_{battery} = \frac{C}{C_{battery}} = \frac{39,666Ah}{375Ah}$$

$$N_{battery} = 105.776 \cong 106 \text{ Batteries}$$

Where C is capacity of battery bank, $C_{battery}$ is nominal capacity of single battery, $N_{battery}$ is the number of batteries, $V_{battery}$ is the nominal voltage of selected battery.

Number of series battery can be computed by dividing system voltage by battery Nominal voltage of single battery.

$$N_{b,series} = \frac{\text{System DC voltage}}{\text{Nominal voltage}}$$

Then number of parallel path is obtained by dividing the total number of batteries by number of batteries connected in series.

$$N_{b,parallel} = \frac{N_{battery}}{N_{series}} \quad (4.11)$$

$$N_{b,parallel} = \frac{106 \text{ batteries}}{4 \text{ batteries}} = 26.5 \cong 26 \text{ parallel paths}$$

4.4.2. Sizing of voltage Controller

A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor F_{safe} .

Based on selected controller (Xantrex C- 40, 48V, 40A) [40]. Then the rated current of the voltage controller ($I_{Controller}$) can be obtained as;

$$I_{controller} = (I_{sc})_{pv,module} * N_{b,parallel} * F_{safe} \quad (4.12)$$

$$I_{controller} = 8.03A * 26 * 1.25 = 261A$$

Number of controller required for the system

$$N_{controller} = \frac{I_{controller}}{\text{Amper of each controller}} \quad (4.13)$$

$$N_{controller} = \frac{261A}{40A} = 6.525 \cong 7 \text{ controllers}$$

Thus, based on the above result the system require at least seven voltage controller the system.

4.4.3. Sizing of the Inverter

An inverter inverts the Direct Current (D.C.) to an Alternating Current (A.C.). The output of solar PV array is direct current and the loads to be powered are alternating current; therefore

there should be inversion systems which can invert the DC to AC. The soul purposes of an inverter it to do inversion.

For stand-alone systems, the inverter must be large enough to handle the total amount of watts that will be using at one time; the inverter size should be 25-30% bigger than total watts of appliances. In case appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting [39].

Solar PV systems contribute 30% of the load energy demand of the Abubeker Ahmed Village.

Thus

$$\text{Inverter rating} = 6.102 \text{ kw} * 1.25 = 7.6275 \text{ kw} \cong 8 \text{ kw}$$

Any inverter with rating power of 7.6kw or more is selected for this system. The inverter needed must be able to handle about 76275-W at 220-Vac. Latronics standalone inverter area also abbreviated as LS series, LS-7048, 7000-W, 24-Vdc, 230-Vac $\pm 4\%$, output frequency 50Hz $\pm 0.1\%$, output waveform is true sin wave.

4.5. Wind Turbine Sizing and Selection

Power that can be extracted by wind determine using equation 3.11

$$P_{wind} = 1/2 * \rho AV^3$$

Where P_{wind} is the power extracted by wind turbine, V is the average wind speed of the site, A is the swept area of the rotor diameter, ρ is the air density and its value at sea level is 1.225 kg/m³ at normal atmospheric pressure.

The swept area of the rotor diameter can be obtained from the equation 3.10 which is shown below.

$$A = \pi r^2 = \frac{\pi}{4} D^2$$

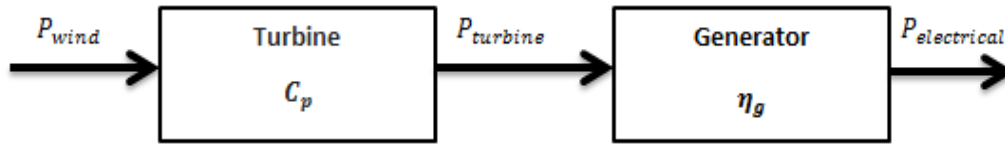


Figure 4.3: Wind electric System

The electrical power output from wind turbine can be obtained from equation 3.13; this might not work for wind turbine with gear box system.

$$P_{turbine} = C_p * P_{wind}$$

$$P_{turbine} = C_p * \frac{1}{2} * \rho AV^3 = \frac{1}{2} * C_p \rho AV^3$$

Finally the electrical power output from wind turbine system become as;

$$P_{electrical} = \eta_g * P_{turbine}$$

$$P_{electrical} = \frac{1}{2} * \eta_g * C_p * \rho AV^3$$

Where C_p is coefficient of performance which has equal to 0.593, η_g is efficiency of the generator.

Once the power to be supplied by solar photovoltaic generation is determined, the next step will be determining the power to be supplied by the wind turbine and rotor diameter of it. Known that wind turbine produce instantaneous power production and for this reason wind turbine size will be determine using average power of daily energy demand. The average power of Abubeker Ahmed village is 5.814 kW.

Thus the electrical power required from wind turbine output is 5.814KW

$$P_{electrical} = 5.814 \text{ KW}$$

Because of two reasons, the first reason is Betz law limit (means that wind turbines can never be better than 59.3% efficient) and the secondly, inefficiency in the generator. The electrical power extracted from the available wind is very smaller. Having saying this we can develop inequality equation.

$$P_{wind} > P_{turbine} > P_{electrical}$$

Having the above inequality equation, it possible to develop equality equation as;

$$P_{turbine} = P_{wind} * C_p$$

$$P_{electrical} = P_{turbine} * \eta_g$$

Taking coefficient of performance value as 0.593 and assuming good quality generators may have full load efficiency of 0.87.

Known that, $P_{electrical} = 5.814 \text{ KW}$

The others two, wind power and output power from turbine can be obtained as follows

$$P_{turbine} = \frac{P_{electrical}}{\eta_g} = \frac{5.814 \text{ KW}}{0.87} = 6.68 \text{ KW}$$

$$P_{wind} = \frac{P_{turbine}}{C_p} = \frac{6.68 \text{ KW}}{0.593} = 11.26 \text{ KW}$$

Using equation (4.18) the rotor diameter of wind turbine is find and which will be selected for the village to be electrified.

$$P_{wind} = 1/2 * \rho AV^3$$

The only unknown parameter in the above equation is the swept area of the wind turbine to be selected and can be obtained as;

$$A = \frac{2 * (P_{wind})}{\rho * V^3} = \frac{2 * (11.268 \text{ KW})}{1.225 \text{ Kg/m}^3 * (5.33 \text{ m/sec})^3} = 121.49 \text{ m}^2$$

Using equation (3.10), knowing the area, it is possible to determine the rotor diameter;

$$A = \pi r^2 = \frac{\pi}{4} D^2$$

$$D = \sqrt{\left(\frac{4 * A}{\pi}\right)} = \sqrt{\left(\frac{4 * 121.49m^2}{\pi}\right)} = 12.437m$$

So the diameter of rotor will be 12.437m. Any wind turbine with rotor diameter of 12.437m or more could be the best wind turbine for this system design. There are different types of wind turbine are available in the market with different rotor diameter and types of output. Among the different categories of wind turbine one which is best for the design result could be selected.

After long survey a wind turbine with rotor diameter of 12m is chosen. And its detail specification explains in table 4.8.

Table 4.8: Wind turbine technical parameter [39].

Wind Turbine Specification	
Model	BFD 12-20KW wind turbine
Rotor Diameter(m)	12
Blade Quantity	3
Start-up wind Speed(m/s)	3
Working wind speed (m/s)	3.0-35
Security Wind Speed(m/s)	50
Generator Type	Permanent Magnet Three phase AC generator
Rated Power	20KW
Max. Power	35

4.6. Cost Analysis of Grid Extension

Power is transmitted to the end users through distribution lines. This is mainly done either by extending the national grid from a near-by substation or from an overhead medium voltage (MV) distribution line. The voltage level of the outgoing feeder from which the tapping is to be made could be 15Kv, 19Kv or 33Kv. Among this the 33kv line then the tapping voltage level should be taken as 33kv to be constructed. Since top most priority should be for tapping from 33Kv.

Due to the recently occurring wooden pole shortage and MV line network constructed with wooden pole with poor quality (because of the unique conditions of the area), UEAP has started using Concrete as major network construction pole types. Unlike to that of wooden poles, Concrete poles cannot be affected by insects, it's durable, and has good resistance to wind, fire and moist areas. Therefore concrete poles are the most preferred.

There are main activities done by UEAP when they extend grid system and the activities are surveying, excavation, pole erection, pole top configuration and stringing of conductor. The main MV-line shall be constructed with Aluminum Alloy Conductor AAAC 95 mm² and the T-offs with AAAC 50 mm² is used for the 33Kv line.

Therefore, to give electric access to the 185 households, health post, mosque, kebele administration and primary school from the national grid found nearby, it needs extension of 64 km MV line and erection of one transformers with a rating of 1x100KVA. Hence, the cost is analyzed using an interlinked spread Microsoft excel sheet used by the UEAP; and the result obtained is as shown in table 4-9. The total cost includes material, transportation and labor cost. The investment cost is therefore obtained to be 9,050,279.96 Ethiopian birr and its corresponding US dollar value is 389,259.35.

Description of work Construction of 64Km 33KV with concrete pole, erection of 1X100KVA transformer

Table 4.9: Cost estimation for grid extension.

DESCRIPTION	SALARY AND WAGE	ALLOWANCE	TRANSPORT	MATERIAL	TOTAL
33KV LINE EXTENSION	1,277,692.60	1,561,624.28	779,930.46	3,563,594.88	7,182,842.22
0 X50KVA ERECTION	0.00	0.00	0.00	30,513.71	30,513.71
0 X200KVA ERECTION	0.00	0.00	0.00	0.00	0.00
1 X100KVA ERECTION	2,589.10	3,164.46	3,371.28	71,964.61	81,089.45
0 X25KVA ERECTION	0.00	0.00	0.00	0.00	0.00
3 X LOAD BREAK SWITCH	4,723.65	5,773.35	3,699.00	51,886.67	66,082.67
0 X AUTORECLOSURE	0.00	0.00	0.00	0.00	0.00
LV LINE EXTENSION	90,612.67	110,748.82	102,225.92	563,411.78	866,999.19
TOTAL	1,375,618.02	1,681,310.91	889,226.66	4,281,371.65	8,227,527.23
INTEREST TO BE CAPITALIZED					
OVER HEAD COST (10%)					822,752.72
TOTAL COST					9,050,279.96
RECHARGABLE/RECOVERABLE AMOUNT (*Contributions)					
NET TOTAL					9,050,279.96

4.7. Summary input to the HOMER software

Table 4.10: Input to the HOMER software.

	PV Modules	AC Wind Turbine (BFD 12- 20KW)	Battery (26CS25P)	Converter
Size(kW)	1	20	1,156 Ah	7
Capital(\$)	2,000	20,000	1,170	6,190
Replacement cost(\$)	2,000	20,000	1,170	6,190
O&M cost (\$/yr.)	5	100	5	0
Size considered	0,10,20,30,40, 45,50,60,70,80, 90,100	_____	_____	0, 7,10,15,18, 20,24,36
Quantities Considered	_____	0,1,2,3,4,5	0,8,16,35,38,40,45 50,55,60,65,70,75,80	_____
Life time (yrs.)	20	20	9,645 Kwh	15

CHAPTER FIVE

5.1. Simulation Result and Discussion

HOMER simulates many different system configurations, discards the infeasible ones (those that do not satisfy the user-specified constraints), ranks the feasible ones according to total net present cost, and presents the feasible one with the lowest total net present cost as the optimal system configuration.

It's quite obvious that from optimization result one can observe, size of different components in each system configuration and their symbols, Initial capital cost, operating and maintenance cost, cost of energy, renewable fraction, total net present cost, and shortage capacity.

HOMER Software displays the optimization results are generated in two forms; an overall form in which the top ranked system configurations are listed according to their net present cost (NPC) and in a categorized form where only the least cost system configuration is considered for each system type. Table 5-2 shows the resulting list of feasible combinations of system components in the overall form. Since the list for the overall result is long, part of it has been truncated keeping only those of greatest interest. The complete table is given in the Appendix (Table 5-2). From the simulation result, different optimum and feasible system configurations with different level of total NPC are obtained.

The overall simulation table is too long to put it here. So, only a selected part is shown in Table 5-1 and the listed outputs of the overall optimization have little variation in the COE (\$0.004\$/kWh to \$0.01/kWh) for the first three most feasible results. The system ranked first has a very good renewable fraction (which is 100%) and lowest Levelized COE \$0.275/kWh but, with 64.4% excess electricity per year. System set ups ranked second and third has higher cost of energy as compared to the first one but most astonishingly the system ranked in the third has 36.6% excess electricity per year, this means almost by half reduction in excess electricity production as compared to that of system ranked first and second. Therefore, the set up ranked in the third is the winning candidates for implementation.

The configuration shown in third row of the overall optimization result where the system contain Solar PV, wind turbine and battery, solar PV-wind hybrid system with an initial

capital cost of \$ 120,336 operating cost of 3,002 \$/year, Total net present cost of \$154,768 and Levelized cost of energy per kilowatt hour of this hybrid system is 0.285\$/KWh.

Table 5.1: The overall optimization result.

Rank	PV (KW)	BFD 12- 20	Battery	Converter(KW)	Dispatch strategy	Initial Capital cost	Operating cost (\$/yr.)	Total NPC (\$)	Cost of energy (\$/KWh)	Renewable Fra
1.	10	2	35	15	LF	124,214	2,570	153,696	0.275	1
2.	0	3	35	15	LF	124,214	2,620	154,270	0.279	1
3.	10	1	45	20	LF	120,336	3,002	154,768	0.285	1
4.	0	2	45	20	LF	120,336	3,052	155,342	0.286	1
5.	20	1	35	18	LF	126,867	2,569	156,331	0.281	1
6.	10	2	35	18	LF	126,867	2,619	156,905	0.279	1
7.	0	3	35	18	LF	126,867	2,669	157,478	0.283	1
8.	20	1	38	15	LF	127,724	2,656	158,184	0.284	1
9.	20	1	35	20	LF	128,636	2,601	158,470	0.285	1
10.	10	2	38	15	LF	127,724	2,706	158,758	0.283	1
11.	10	2	35	20	LF	128,636	2,651	159,043	0.282	1
12.	10	1	45	24	LF	123,873	3,067	159,046	0.293	1
13.	0	3	38	15	LF	127,724	2,756	159,331	0.286	1
14.	0	3	35	20	LF	128,636	2,701	159,617	0.287	1
15.	0	2	45	24	LF	123,873	3,117	159,620	0.293	1

Like the rest of optimal systems, this optimal system also uses 100% renewable energy and these promote Ethiopia's Climate- Resilient Green Economy. The cash flow summary for hybrid system and system cost break down per year for hybrid system is shown in figure 5.1 and System report for the third cost effective system in Table 5.2.

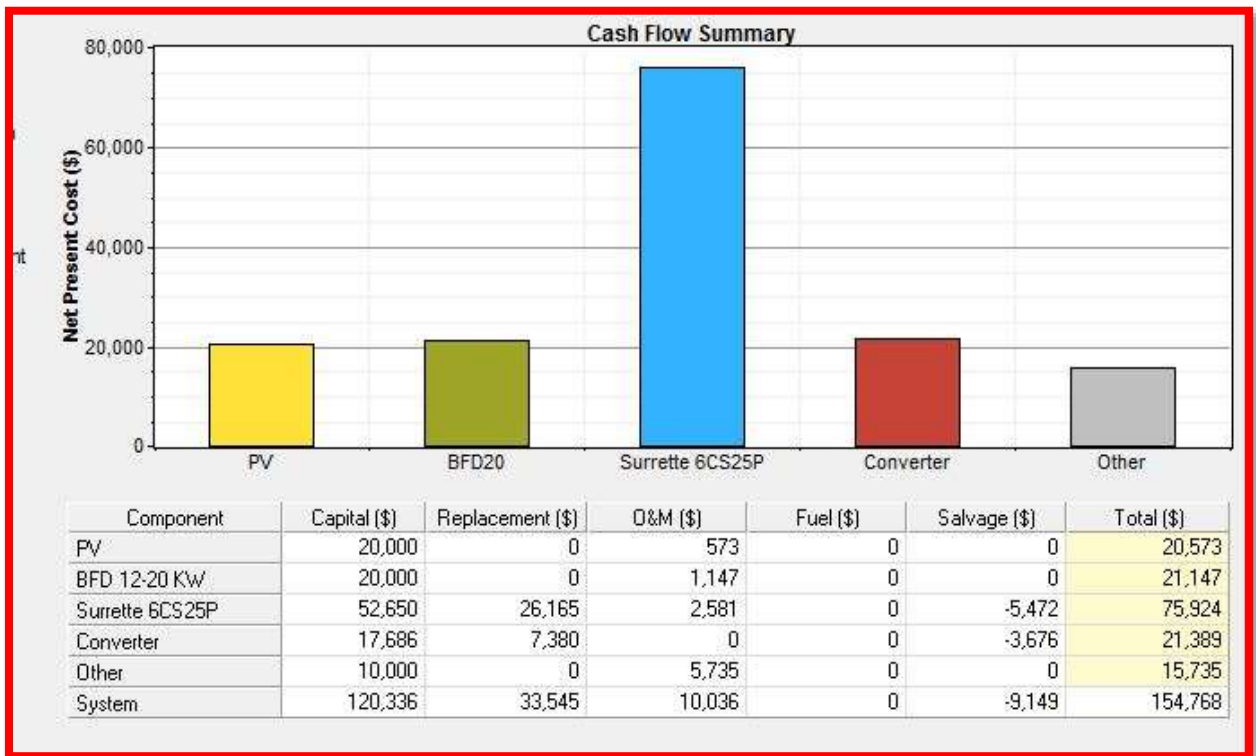


Figure 5.1: Cost summary for the third cost effective system, 3rd row in table 5.1

Table 5.2: System report for the second cost effective system, 3rd row in Table 5.1

System Architecture		Annual Electric Energy Production (KWh/yr)			Annual Electric Energy Consumption (KWh/yr)		
PV Array (KW)	10	PV array	19,183	22%	AC primary Load	48,793	100%
Wind turbine	1	Wind Turbine	67,925	78%	Total	48,793	100%
Battery S6CS25P	45	Excess Electricity	31,405	36.1%	Capacity Shortage		9%
Inverter	20	Unmet Load	3,458	6.8%	Sensitivity Case		
Rectifier	20	Capacity Shortage	4,732	9.3%	Solar Data	6.47 KWh/m ² /d	
Dispatch Strategy	LF	Renew Fraction	100%		Wind Data	5.33 m/sec	
Cost Summary							
Total Net Present Cost (\$)		\$154,768					
Levelized Cost of Energy (\$/KWh)		0.285					
Operating Cost (\$/yr)		3,002					

Monthly Average Electric Production from different components of the wind/PV/battery hybrid system is shown in figure 5-2 of the total primary energy required for Abubeker Ahmed village. Majorly wind turbine produced 67,625 KWh which cover 78% of the total energy production while solar PV produced almost 19,183 KWh which contribute 22% of total energy produced. Although an excess energy of 31,405 KWh is produced and this can be used to electrify the community which does not get even diesel based electricity. But a capacity shortage of only 4,732KWh (9.3%) was experienced during a year. This capacity shortage can't affect the system since some amount load shedding could be applicable per year.

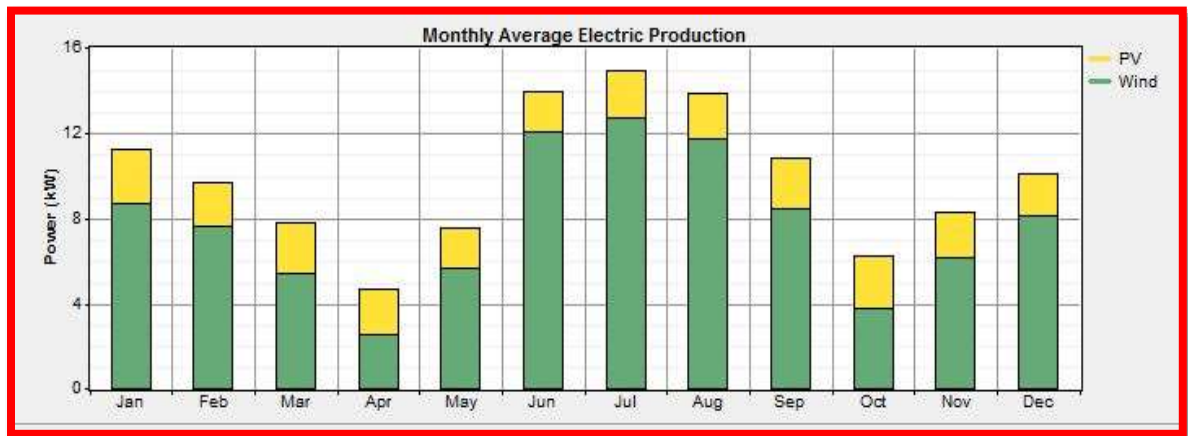


Figure 5.2: Contribution of power units for Abubeker Ahmed village.

Table 5-3 represents optimization results in a categorized form. As explained in above discussion, HOMER display optimization result in two form these are either in overall form or categorized form. The first two results (in Table 5.3) of categorized forms have been discussed in the overall form. As result, simply jump to the third row and in this case, the total NPC of the optimized result ranked third is 226,947\$ which is 73,251\$ higher than the total NPC of the optimized result ranked first in the categorized form, but the excess electricity production much lower than the optimized result in ranked first. Its Levelized cost of energy (COE) is 0.415 \$/KWh. System with solar photovoltaic only is perceived to have high Levelized cost of energy. This set up contain no wind turbine, all the energy production come lone from solar Photovoltaic. As we could observe from the above tables (see table 5.1 and 5.2) that the PV/wind /battery system is better in levelized cost of energy and total net present cost.

Table 5.3: Optimization result in categorized form

Rank	PV (KW)	BFD 12- 20	Battery	Converter(K W)	Dispatch Strategy	Initial Capital cost	Operating cost (\$/yr.)	Total NPC (\$)	Cost of energy (\$/KWh)	Renewable Fraction
1.	10	2	35	15	LF	124,214	2,570	153,696	0.275	1
2.	0	3	35	15	LF	124,214	2,620	154,270	0.279	1
3.	40	0	65	18	LF	181,967	3,922	226,947	0.415	1

The monthly average electric production for this set up is given in figure 5.3 and whereas more detail information about the system is given in Table 5.4

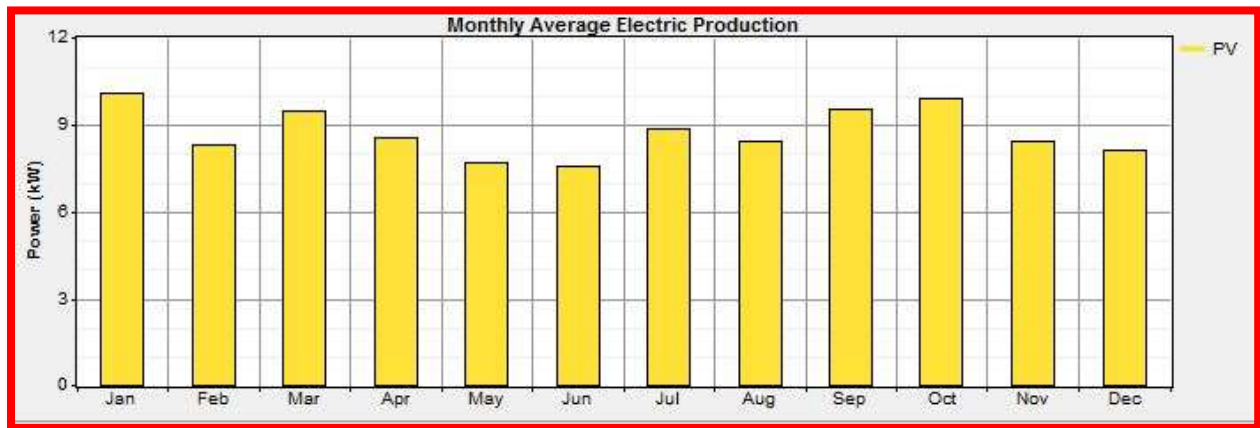


Figure 5.3: Monthly average electric production for Abubeker Ahmed Village

Table 5.4: System report for the second cost effective system, 3rd row in Table 5.3

System Architecture		Annual Electric Energy Production (KWh/yr)			Annual Electric Energy Consumption (KWh/yr)		
PV Array (KW)	40	PV array	43,700	100%	AC primary Load	48,700	100%
Wind turbine	0	Wind Turbine	0	0%	Total	48,280	100%
Battery S6CS25P	65	Excess Electricity	14,745	19.2%	Capacity Shortage		9.6%
Inverter	18	Unmet Load	3,035	6.0%	Sensitivity Case		
Rectifier	18	Capacity Shortage	4,874	9.6%	Solar Data	6.47 KWh/m ² /d	
Dispatch Strategy	LF	Renew Fraction	100%		Wind Data	5.33 m/sec	
Cost Summary							
Total Net Present Cost (\$)		\$181,967					
Levelized Cost of Energy (\$/KWh)		0.415					
Operating Cost (\$/yr)		3,922					

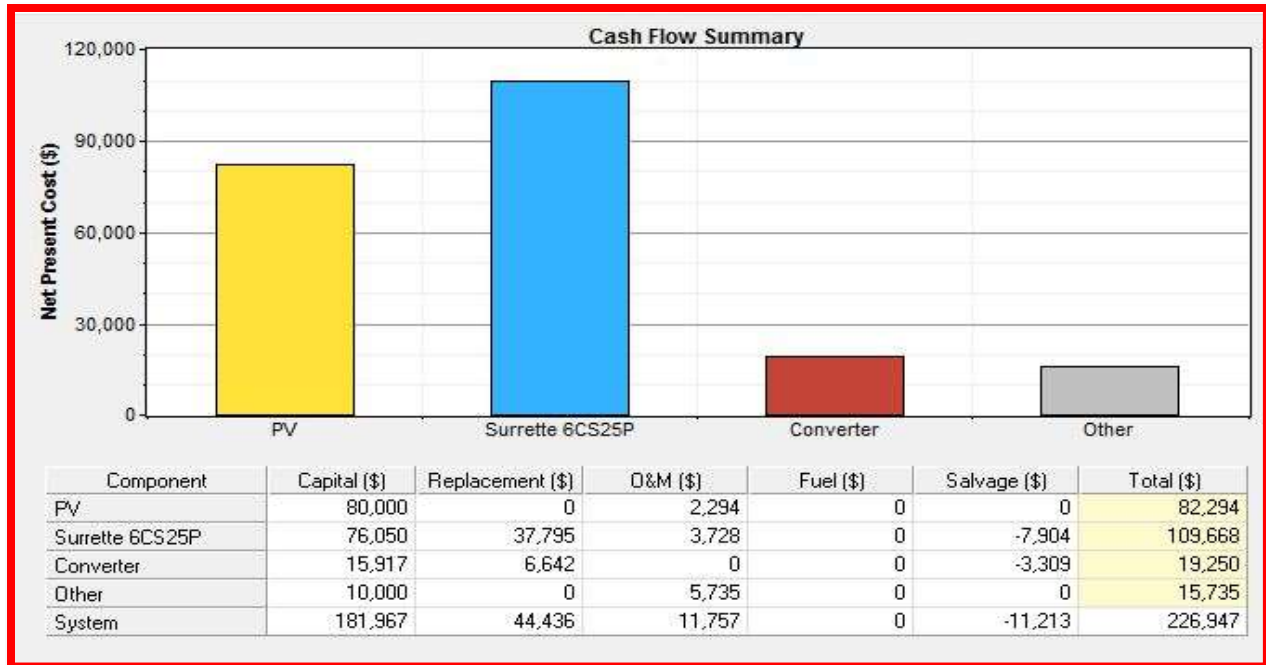


Figure 5.4: Cost summary for the second most effective system, 3rd row in table x-3

5.2. Comparison of Grid Extension with Standalone (Off Grid)

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.

In addition to Simulation, optimization and Sensitivity analysis, HOMER also used to compare the investment cost of the hybrid system against the cost required for extending the grid. As a result, it is found that the hybrid system is cost effective for an area which is found at a distance greater than 15.4 Km in other word the breakeven grid extension distance from the existing grid found In the nearby. Therefore, the standalone system is the optimal solution of power supply for the towns since the net present cost of grid extension much higher than standalone.



Figure 5.5: Break even grid extension distance obtained using HOMER software.

CHAPTER SIX

Conclusion and Recommendation

6.1. Conclusion

In this thesis, feasibility study and design of renewable energy resources of Abubeker Ahmed village for electrification of 185 household is carried out. The potential of both solar energy and wind energy resource assessment is done. Concerning solar energy potential there is no recorded solar radiation data at both federal and regional office NMSA, instead only sunshine hour data was available. Thus empirical formula which are able to incorporate the available sunshine hour data and provide the solar radiation. At the end the result obtained from the empirical formula were cross checked against satellite based data which was found from NASA. However, the wind energy data are taken from NASA. This is due to there was no fully recorded data. And it also compare cost of hybrid system against the cost required to electrify the village by extending the grid using interlinked Microsoft office excel spread sheet prepared by UEAP.

HOMER software was used as an aid for modeling and simulation of the PV-wind hybrid system. HOMER has proved a valuable tool in this study especially because of its ability to simulate numerous components and load combinations. The hybrid arrangement is then simulated using HOMER software in order to select the best optimized result. The feasibility study for the hybrid setup is based on the outcomes of the wind and solar energy potentials at the specific site. In the results, numerous alternative feasible hybrid arrangements, with almost the same level of contribution by the renewable resource and different total net present cost are obtained.

The levelized COE ranges from \$0.275 per kwh to \$0.343 per kwh. This cost is slightly higher than the current energy tariff within the country. Despite the country tariff has been subsidized by the Ethiopian government. However, according to the recent conferences held new energy tariff are going to be introduce soon.

Even though the proposed system require fairly higher cost of energy than the current national energy tariff. Taking into consideration of high energy demand, rural electrification,

deforestation, climate change, implementation of eco-friendly technology and achievement of CRGE country strategy, changing the live hood status of the rural community, thus implementation of renewable clean energy source development is a key potential prioritized area of recommendation to be implemented.

Finally the novelist suggested that standalone solar PV-wind hybrid system is economically feasible and more even environmentally friendly to replace the existing diesel-only supply system for the proposed village.

6.2. Recommendation

Final the following recommendation are made out of this study, the recommendation are generally for policy maker and governmental organization.

- The government, the private sector and non-governmental organization should step-up their effort towards renewable energy production to meet the electricity demand of the rural community.
- In spite of huge renewable energy potential of Ethiopia, still a very small amount of it used but if properly exploiting these potential of renewable of the country the generation of clean and renewable electric power also allows for a given development of other sector of the economy, moreover, via electricity exports, Ethiopia can share its green developments to other countries in the region while contributing positively to its trade balance.
- Even though the main target of this study to replace the existing diesel generator electricity supply for Abubeker Ahmed village. This doesn't mean it cover all the community in village of Ethiopia Somalia region thus further study should be make consideration those people who doesn't even get diesel generator electricity.
- Solar energy potential of the site is determined based on the data taken from Jigjiga branch of National Metrological Service Agency since only sunshine hour data are available to determine the potential of the area. It would be super powerful for the researcher if NMSA provide the direct measurement of solar radiation. And similar problem counter with wind speed measurement in some part. It would be more power full if the measurement taken at hub height of the wind turbine and recorded data to be at least two or three successive year.

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Appendix

Appendix: Overall Optimization Result

Rank	PV (KW)	BFD 12- 20	Battery	Converter(KW)	Dispatch Strategy	Initial Capital cost	Operating cost (\$/yr.)	Total NPC (\$)	Cost of energy (\$/KWh)	Renewable Fraction
1.	10	2	35	15	LF	124,214	2,570	153,696	0.275	1
2.	0	3	35	15	LF	124,214	2,620	154,270	0.279	1
3.	10	1	45	20	LF	120,336	3,002	154,768	0.285	1
4.	0	2	45	20	LF	120,336	3,052	155,342	0.286	1
5.	20	1	35	18	LF	126,867	2,569	156,331	0.281	1
6.	10	2	35	18	LF	126,867	2,619	156,905	0.279	1
7.	0	3	35	18	LF	126,867	2,669	157,478	0.283	1
8.	20	1	38	15	LF	127,724	2,656	158,184	0.284	1
9.	20	1	35	20	LF	128,636	2,601	158,470	0.285	1
10.	10	2	38	15	LF	127,724	2,706	158,758	0.283	1
11.	10	2	35	20	LF	128,636	2,651	159,043	0.282	1
12.	10	1	45	24	LF	123,873	3,067	159,046	0.293	1
13.	0	3	38	15	LF	127,724	2,756	159,331	0.286	1
14.	0	3	35	20	LF	128,636	2,701	159,617	0.287	1
15.	0	2	45	24	LF	123,873	3,117	159,620	0.293	1
16.	10	1	50	18	LF	124,417	3,195	161,066	0.295	1
17.	20	1	38	18	LF	130,377	2,704	161,393	0.288	1
18.	20	1	40	15	LF	130,064	2,746	161,559	0.289	1

19.	0	2	50	18	LF	124,417	3,245	161,639	0.295	1
20.	10	2	38	18	LF	130,377	2,754	161,966	0.286	1
21.	10	2	40	15	LF	130,064	2,796	162,132	0.288	1
22.	0	3	38	18	LF	130,377	2,804	162,540	0.291	1
23.	0	3	40	15	LF	130,064	2,846	162,706	0.292	1
24.	20	1	35	24	LF	132,173	2,666	162,748	0.292	1
25.	10	1	50	20	LF	126,186	3,227	163,204	0.299	1
26.	10	2	35	24	LF	132,173	2,716	163,321	0.290	1
27.	20	1	38	20	LF	132,146	2,736	163,532	0.291	1
28.	0	2	50	20	LF	126,186	3,277	163,778	0.299	1
29.	0	3	35	24	LF	132,173	2,766	163,895	0.295	1
30.	10	2	38	20	LF	132,146	2,786	164,105	0.290	1
31.	0	3	38	20	LF	132,146	2,836	164,679	0.294	1
32.	20	1	40	18	LF	132,717	2,794	164,767	0.292	1
33.	10	2	40	18	LF	132,717	2,844	165,341	0.292	1
34.	0	3	40	18	LF	132,717	2,894	165,914	0.296	1
35.	20	1	40	20	LF	134,486	2,827	166,906	0.296	1
36.	10	4	16	18	LF	144,637	1,962	167,142	0.305	1
37.	10	2	40	20	LF	134,486	2,877	167,479	0.295	1
38.	10	1	50	24	LF	129,723	3,292	167,482	0.307	1
39.	20	1	38	24	LF	135,683	2,801	167,809	0.299	1
40.	0	3	40	20	LF	134,486	2,927	168,053	0.300	1
41.	0	2	50	24	LF	129,723	3,342	168,056	0.307	1
42.	10	2	38	24	LF	135,683	2,851	168,383	0.297	1
43.	0	3	38	24	LF	135,683	2,901	168,956	0.302	1
44.	10	4	16	20	LF	146,406	1,994	169,281	0.309	1

45.	10	1	55	18	LF	130,267	3,421	169,502	0.309	1
46.	20	1	45	15	LF	135,914	2,971	169,995	0.302	1
47.	0	2	55	18	LF	130,267	3,471	170,075	0.309	1
48.	10	2	45	15	LF	135,914	3,021	170,568	0.302	1
49.	0	3	45	15	LF	135,914	3,071	171,142	0.305	1
50.	20	1	40	24	LF	138,023	2,891	171,184	0.303	1
51.	10	1	55	20	LF	132,036	3,453	171,640	0.313	1
52.	10	2	40	24	LF	138,023	2,941	171,757	0.303	1
53.	10	1	45	36	LF	134,484	3,260	171,880	0.317	1
54.	0	2	55	20	LF	132,036	3,503	172,214	0.313	1
55.	0	3	40	24	LF	138,023	2,991	172,331	0.307	1
56.	0	2	45	36	LF	134,484	3,310	172,453	0.317	1
57.	20	1	45	18	LF	138,567	3,020	173,203	0.304	1
58.	10	4	16	24	LF	149,943	2,059	173,558	0.317	1
59.	30	1	35	15	LF	144,214	2,570	173,696	0.311	1
60.	10	2	45	18	LF	138,567	3,070	173,777	0.305	1
61.	20	2	35	15	LF	144,214	2,620	174,270	0.306	1
62.	0	3	45	18	LF	138,567	3,120	174,350	0.309	1
63.	10	3	35	15	LF	144,214	2,670	174,843	0.307	1
64.	20	1	45	20	LF	140,336	3,052	175,342	0.308	1
65.	0	4	35	15	LF	144,214	2,720	175,417	0.311	1
66.	20	1	35	36	LF	142,784	2,859	175,581	0.315	1
67.	10	2	45	20	LF	140,336	3,102	175,915	0.309	1
68.	10	1	55	24	LF	135,573	3,517	175,918	0.320	1
69.	10	2	35	36	LF	142,784	2,909	176,155	0.313	1
70.	0	3	45	20	LF	140,336	3,152	176,489	0.313	1

71.	0	2	55	24	LF	135,573	3,567	176,492	0.321	1
72.	0	3	35	36	LF	142,784	2,959	176,728	0.318	1
73.	30	1	35	18	LF	146,867	2,619	176,905	0.314	1
74.	20	2	35	18	LF	146,867	2,669	177,478	0.309	1
75.	10	1	60	18	LF	136,117	3,646	177,938	0.323	1
76.	10	3	35	18	LF	146,867	2,719	178,052	0.311	1
77.	20	1	50	15	LF	141,764	3,197	178,431	0.316	1
78.	0	2	60	18	LF	136,117	3,696	178,511	0.323	1
79.	0	4	35	18	LF	146,867	2,769	178,625	0.315	1
80.	30	1	38	15	LF	147,724	2,706	178,758	0.317	1
81.	10	2	50	15	LF	141,764	3,247	179,004	0.316	1
82.	30	1	35	20	LF	148,636	2,651	179,043	0.318	1
83.	20	2	38	15	LF	147,724	2,756	179,331	0.314	1
84.	0	3	50	15	LF	141,764	3,297	179,578	0.319	1
85.	20	2	35	20	LF	148,636	2,701	179,617	0.313	1
86.	20	1	45	24	LF	143,873	3,117	179,620	0.315	1
87.	10	3	38	15	LF	147,724	2,806	179,905	0.315	1
88.	10	1	60	20	LF	137,886	3,678	180,076	0.327	1
89.	10	3	35	20	LF	148,636	2,751	180,190	0.314	1
90.	10	2	45	24	LF	143,873	3,167	180,193	0.316	1
91.	10	1	50	36	LF	140,334	3,486	180,316	0.330	1
92.	0	4	38	15	LF	147,724	2,856	180,478	0.319	1
93.	20	1	38	36	LF	146,294	2,995	180,643	0.321	1
94.	0	2	60	20	LF	137,886	3,728	180,650	0.327	1
95.	0	4	35	20	LF	148,636	2,801	180,764	0.319	1
96.	0	3	45	24	LF	143,873	3,217	180,767	0.320	1

97.	0	2	50	36	LF	140,334	3,536	180,889	0.330	1
98.	10	2	38	36	LF	146,294	3,045	181,216	0.320	1
99.	20	1	50	18	LF	144,417	3,245	181,639	0.317	1
100.	0	3	38	36	LF	146,294	3,095	181,790	0.325	1
101.	30	1	38	18	LF	150,377	2,754	181,966	0.320	1
102.	30	1	40	15	LF	150,064	2,796	182,132	0.322	1
103.	10	2	50	18	LF	144,417	3,295	182,213	0.319	1
104.	20	2	38	18	LF	150,377	2,804	182,540	0.317	1
105.	20	2	40	15	LF	150,064	2,846	182,706	0.320	1
106.	0	3	50	18	LF	144,417	3,345	182,786	0.323	1
107.	10	3	38	18	LF	150,377	2,854	183,113	0.319	1
108.	10	3	40	15	LF	150,064	2,896	183,279	0.320	1
109.	30	1	35	24	LF	152,173	2,716	183,321	0.325	1
110.	0	4	38	18	LF	150,377	2,904	183,687	0.323	1
111.	20	1	50	20	LF	146,186	3,277	183,778	0.321	1
112.	0	4	40	15	LF	150,064	2,946	183,853	0.324	1
113.	20	2	35	24	LF	152,173	2,766	183,895	0.320	1
114.	20	1	40	36	LF	148,634	3,085	184,017	0.326	1
115.	30	1	38	20	LF	152,146	2,786	184,105	0.324	1
116.	10	2	50	20	LF	146,186	3,327	184,351	0.322	1
117.	10	1	60	24	LF	141,423	3,743	184,354	0.334	1
118.	10	3	35	24	LF	152,173	2,816	184,468	0.322	1
119.	20	4	16	15	LF	161,984	1,964	184,507	0.336	1
120.	10	2	40	36	LF	148,634	3,135	184,591	0.325	1
121.	20	2	38	20	LF	152,146	2,836	184,679	0.320	1
122.	0	3	50	20	LF	146,186	3,377	184,925	0.326	1

123.	0	2	60	24	LF	141,423	3,793	184,928	0.334	1
124.	0	4	35	24	LF	152,173	2,866	185,042	0.326	1
125.	10	5	16	15	LF	161,984	2,014	185,080	0.335	1
126.	0	3	40	36	LF	148,634	3,185	185,164	0.330	1
127.	10	3	38	20	LF	152,146	2,886	185,252	0.322	1
128.	30	1	40	18	LF	152,717	2,844	185,341	0.324	1