Feasibility Study of an off- Grid Hybrid PV/Wind Power Generation System for Health Clinic at Samara University

Kedija Jelaludin Nuru

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

Presented in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Power Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

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Advisor: Tefera Terefe (PhD.)

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Kedija Jelaludin have read and evaluated her thesis entitled "**FEASIBILITY STUDY OF AN OFF-GRID HYBRID PV/WIND POWER GENERATION SYSTEM FOR HEALTH CLINIC AT SAMARA UNIVERSITY"** and examine the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power Engineering.

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Internal Examiner	Signature	Date
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External Examiner	Signature	Date

DECLARATION

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

Kedija Jelaludin ________________

Student Name Signature

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

13/September/2019

Dr. Tefera T. Y. (Assistant professor)

Name of Advisor

Date of Submission:___/___/______

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONOMYS

A	Rotor swept area [m^2]
A_i	Anisotropy index
A_m	Area of single module [m^2]
CC	Cycle charging
COE	Cost of Energy
CFL	Compact fluorescent lumps
C	The scale parameter in [m/sec]
C_p	Fraction of wind power extracted by the wind rotor [%]
CAES	Compressed air energy storage
C_B	Capacity of battery [Ah]
DOD	Depth of discharge [%]
$(DOD)_{max}$	Maximum depth of discharge of battery [%]
DC	Direct Current
E	Equation of time [hr]
F_1	Fuel curve intercept coefficient [units/hr/kW]
F_O	Rated Capacity in [kW]
HRES	Hybrid Renewable Energy System
HOMER	Hybrid Optimization Model for Electric Renewable
H_m	Site elevation [m]
I_{SC}	Short circuit current [A]
KWh/day.m^2	Kilowatt hour per day square meter
NASA	National Aeronautics and Space Administration
NPC	Net present cost
RF	Renewable fraction
RES	Renewable Energy System

ABSTRACT

Environmental and economic problems that caused by over-dependence on fossil fuels have increased the demand and request for green energy produced by alternative renewable sources. At the Health Clinic of Samara University there is a frequent power interruption, and this causes a problem in the working area of the site, especially in the more power sensitive in the emergency room and the laboratory room. When power is interrupted it may become a cause for the death of many infants, pregnant mothers, patients in the emergency rooms and others. Thus, the main purpose of this thesis work, is the feasibility study of PV-Wind hybrid energy system with diesel generator as a backup and battery bank as storage to electrify for Health Clinic at Samara University. The feasibility study of this thesis is analyzed using Hybrid Optimization Model for Electrical Renewable (HOMER) software. The paper utilized meteorological data obtained from National Meteorological Agency of Ethiopia and NASA to estimate the solar and wind energy potentials of the site. Primary load demand of the site is 212 kWh/day, peak load of 24 kW, deferrable energy is about 3.5 kWh/day, and deferrable peak load of 800W was involved during optimization of the power system. Well known HOMER software modeling tool has been used to design the off-grid system of the site. Since, the Wind and solar energy are considered as primary sources to supply electricity directly to the load and to charge the battery bank when excess generation is happened. However, in peak demand times diesel generator could also be engaged. During the design of this power system set-up, the simulation and optimization was done based on the electricity load, climatic data sources, economics of the power components and other parameters in which the Net Present Cost (NPC) has to be minimized to select an economic feasible power system. The simulation results show many different feasible system configurations with different level of total NPC have been obtained from the HOMER Software. From the overall system simulation results containing the PV-wind-diesel generator-battery-converter setup shows a COE of $0.091/kWh and a total net present cost (NPC) of $91,217 has been proposed to the site. This set up system has no capacity shortage and no unmet electric load. Although the proposed system has relatively higher the levelized cost of energy (COE) than the national tariff of Ethiopia ($0.018/kWh), but it is the lower range of global electricity tariff. In my point of view, the energy shortage at the national level, resistance to deforestation, clean energy development and expansion of power generation, it is a highly recommendable solution.

Keywords: *COE, deferrable load, HOMER, NPC, Off-grid power System*

CHAPTER ONE
INTRODUCTION

1.1 Background

It is a well-known fact that in many developing countries and less developed countries, a significant proportion of the population lives without usable electrical power. Ethiopia is one of developing countries with more than 80% of its population's lives without usable electricity [1]. The more noticeable benefits of usable electric power include: improved health care, improved education, better transportation systems, improved communication systems, a higher standard of living and economic stability. Unfortunately, many of the rural areas of Ethiopia has not benefited from these uses of electricity in the same proportion as the more populated urban areas of the country. A major limitation to the development of many rural communities has been the lack of this usable electricity. Due to the remote location, and the low population densities of the rural communities the traditional means of providing power has proven too expensive, undependable, difficult to maintain, and economically unjustifiable. Consequently, many of these communities remain without electricity and may never receive grid power from the utility [1].

The availability of reliable and efficient power supply at an affordable cost is very crucial for the economic growth and development of a country. Thus, the search for reliable, long- lasting sources of energy have been an ever-challenging task to mankind. This research is more urgent than today than ever before, due to the heavy dependence of modern life on energy especially in desert area like Samara city. Nowadays, electric power interruption becomes a serious problem throughout the city. The number of power outages in Samara City from day to day is very high and it takes a very long time for service restoration due to this every aspect of business and day to day activity of residential is negatively affected especially in the Health Clinic at Samara University that has power sensitive loads [2].

At present a special energy supply to selected areas is becoming a big challenge; requiring reliable power supply even they are grid connected. To avoid problems caused by Manmade, environmental and weather uncertainties, the reliability of a continuous production of power from renewable sources is increased by considering the possibility of integrating various sources creating hybrid energy system and this greatly reduces the intermittence and uncertainties of energy production.

The 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 [1]. Such a system often includes some kind of storage to satisfy the demand during the periods in which the renewable sources are not available and to decrease the time shift between the peak load and the maximum power produced and power conditioning unit and controller to convert and control one form of energy to other. As the present international trend in remote area electrification is to utilize renewable energy resources; solar, wind, biomass, and micro hydro power systems can be seen as alternatives. Among these, wind and solar energy systems in stand-alone or hybrid forms are thought as ideal solution for rural electrification due to abundant solar radiation and significant wind distribution availability nearby the rural community in Ethiopia .Ethiopia lies in the sunny belt between northern latitudes of 3^o and 15^o, and thus the potential benefits of renewable energy resources such as solar and wind energy can be considerable. As mentioned in [2] the total annual solar radiation reaching the territory is of the order of over 200 million tones oil equivalent (toe) per year, over thirteen folds the total annual energy consumption in the country.

The same author mentioned in [2] that the total wind resource potential across Ethiopia amounts to 42 million tone per year, which also exceeds gross energy consumption by about three fold. Temporal and spatial variations in wind resource distribution over Ethiopia are significant, with the most attractive sites located toward the eastern and northern regions where average annual wind speed typically exceeds 3.5 m/s. So far, this vast renewable energy resources are not exploited sufficiently in the country, primarily due to the lack of scientific and methodological know how as regards planning site selection and technical implementation. A further constraint prohibiting their utilization the real potential of these resources are not well-known, partly because of the lack of research emphasis in developing these technologies, and partly because of the insufficient resource data base.

Thus, the main purpose of this thesis is a hybrid renewable power generation system integrating these vast solar and wind resources is designed and modeled, to electrify for Health Clinic at Samara University.

1.2 Statement of the Problems

It is known that there is heavy dependence of modern life on energy especially in desert area like Samara city. At the Health Clinic at the Samara University, there is a frequent power interruption and this causes a problem in the working area of the Health Clinic. When power is interrupted, it may become a cause for the death of many infants, pregnant mothers, patients in the emergency rooms and others.

Even though the Health Clinic has an old small capacity generator as a backup supply, this manual generator doesn't solve the problem as needed. In addition to the above problem the noisy sound and smoke of the generator by itself is also causing an additional illnesses and disturbance in the patient's treatment rooms and the working environment of the Clinic in general. The existing diesel generator in the Clinic operates manually and this is also causing a problem during emergency cases. Hence under this context, conducting feasibility study of alternative hybrid solar/wind renewable energy system will be implemented for the Health Clinic at Samara University to increase the power reliability of the clinic.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this thesis is feasibility Study of an off- Grid Hybrid PV/Wind with diesel generator as aback up and battery bank as storage system of Power Generation System for Samara University Health Clinic.

1.3.2 Specific Objective

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

- ✓ To study the solar photovoltaic and wind energy potential of the study area.
- ✓ To select appropriate solar modules, wind turbines, diesel generator and batteries depending on the energy demand.
- ✓ Simulation of the hybrid PV-Wind renewable energy system with HOMER Software

1.4 Contributions of the Thesis

The frequency of power interruption at the selected Health Clinic is reduced due to the implementation of the proposed hybrid PV/Wind and diesel generator as a backup system.

In the Health clinic, the interruption of power affect human life and sensitive medical materials, these and related issues will be minimized as a result of this research.

1.5 Limitations of the Study

During working thesis there is always a limitation: the first limitation is lack of cooperation to get necessary and relevant information and recorded data from the workers in the selected site and other offices.

1.6 Outline of the Thesis

The thesis is organized into six chapters which are briefly summarized below.

Chapter one**,** presents the introduction, background, objectives, problem statements, the significance of study, contribution of the study and methodology followed in the thesis work. In addition, it provides the outline of the thesis. The second chapter discusses the theoretical frameworks of the solar energy systems, PV installation methods, solar PV types, radiation incident to the PV surface, solar sources potentials, PV module and array, PV modeling methods. This chapter also covers basic theory of wind turbines and its components, classification of wind turbines and wind turbines power control mechanisms. Finally, different literature review for the application of renewable energy options have been conducted for the access of renewable energy resource potentials and stand-alone hybrid systems have been presented in chapter two. In the Chapter three of the thesis, the potential resources assessment and electricity load estimation of the study area based on primary and secondary data gathering has been studied. Optimization of the hybrid system which incorporates methodology of the optimization, the climatic input data, cost values of all components, economic inputs, constraint inputs, and sensitivity values are discussed in Chapter four. Simulation results of optimization analysis, sensitivity analysis, and discussions are given in Chapter five.

Finally in Chapter Six, the general conclusions and recommendations concerning results of the simulation of the thesis works have been presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 Basic Theory of Solar Photovoltaic Systems

Photovoltaic system is the most well-known method of converting solar energy directly into electrical energy using semiconductor cells. Today's photovoltaic cells are mainly manufactured from a semiconductor material called crystalline silicon, which is available abundantly in the earth's crust and is free of toxicity. Modules made of by combining crystalline silicon cells are very durable, reliable; noise free and fuel free equipment's to produce electricity. Solar energy is the solitary source to power PV which is infinite. Photovoltaic cells have the capability of transforming 1/6 of solar resources into electric energy. PV systems are free of moving parts and are also environmental friendly. The lifetime of PV cells can end with greater than 30 years [4]. PV systems provide electricity to remote areas where there is no access to utility grid, thus elevates the life value of the community. In a PV cell there are two doped semiconductor layers, P-type (hole) and N-type layer (electron) which is separated to each other by a junction. A spontaneous electric field is developed at the boundary which defines the direction of the current flow across the junction. In order to get electricity from a PV, the sunlight should penetrate a glass cover and antireflection coating. The model developed to harness solar energy was basically from the western, planed constructing centralized electricity generation and transmitting electricity by transmission wires to the consumers. Energy efficiency of solar photovoltaic is calculated as the power output from the PV divided by the solar radiation emitted to the solar array area.

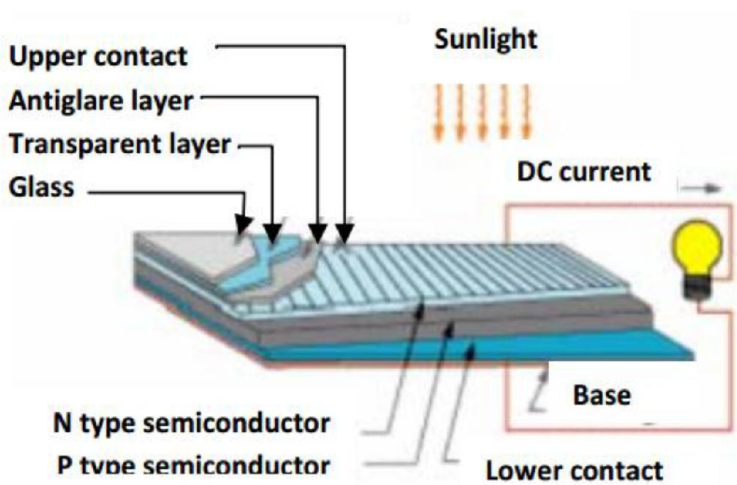


Figure 2.1: Typical PV Cell [4]

2.1.2 Types of Solar PV Cells

Different materials are used to make PV cells, with silicon obtained from sand is being the main material used for and it is available in the earth's crust. The electricity generation depends on the size of the PV cell, the conversion efficiency, and sunlight intensity of the local area. Based on [4] the material from which it is made and the means of manufacturing, PV cells of silicon material are classified into the following.

Mono-crystalline PV Cells: are made from uncontaminated silicon single crystals, cut-off from ingots. It has a dark color and along all its corners is trimmed; this is one clear difference from the poly-crystalline panels. This type of PV cell is the efficient one since it is made from one crystal but the most expensive too. It functions better in areas where low energy sources are required. This technology is the first generation of all PV cells and has high heat resistant ability. The disadvantage with this technology is that it consumes more time to manufacture. The means of production of mono-crystalline silicon is first heating high purity of silicon into super saturated state, second inserting seed crystal into the molten silicon. Then lastly slowly pulling the seed crystal out of the melted mono-crystalline with the aid of Czochralski mechanism to get silicon ingot; moreover, slicing the crystal in to pieces to make the cells then to modules and arrays. This technology has the ability to convert 1000W/m^2 solar radiation to around 140W of electricity in PV cell surface area of 1m^2 [5].

Polycrystalline PV Cells*:* It is made from combination of smaller quantities of silicon crystal blocks. They are considered as the most widely used cells nowadays. Such PV cells are inefficient than the single crystalline cells due to the reason that they are not grown from single crystals but from a combination of many crystals. They perform better than the mono-crystalline in slightly shaded conditions. This technology has the ability to convert 1000W/m^2 solar radiation to around 130W of electricity in PV cell surface area of 1m^2 [5]. The production of this type of cells is more efficient than mono-crystalline. Molten silicon has to be placed into blocks, which are then cut into slabs to make the crystals. Size of poly-crystalline solar panel is larger than mono-crystalline panel to get the same wattage because mono-crystalline is more efficient per area than multi-crystalline. So when comparing the two PV panels in terms of size to get high power output, single crystalline is good in usefulness.

Thin Film PV Cells: These types of cells are not made from real crystals rather the silicon is deposited on stainless steel, plastics or glass to form the solar module. These types of PV cells are much less efficient than the above two but the production process costs less. The inefficiency shows that larger panels of this type required producing same power as the mono or polycrystalline panels. They have efficiency from 5% to 13% and their lifespan is about 15-20 years.

2.1.3 The PV Module and PV Array

Individual PV solar cells are the fundamental building blocks of the solar panel. In general, PV cells are smaller in size and produce about one watt power. An individual solar cell produces a voltage of 0.5 to 0.6V. In order to get sufficient output voltage, PV cells are connected in series to form a PV module. PV systems are frequently functioned at multiples of 12 volts; modules are usually designed for optimal operation in these systems. While PV cells are connected in series, the output current remains the same but the output voltage will be the total summation of all cells formed the module. Schematic diagram on how PV cells connect to form module as well as modules to form array is shown in figure 2.2.

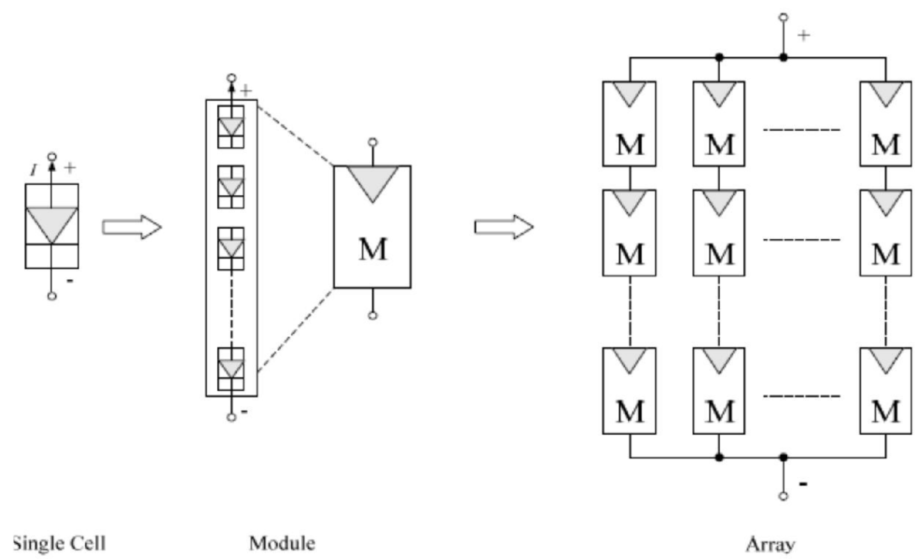


Figure 2.2: Schematic Diagram for Cell, Module and PV Array [5]

The power rating of solar panel depends on the number of solar cells and the size of the panel. When the PV cells are assembled as module, they can be illustrated as having a nominal operating cell temperature (NOCT). NOCT is the temperature of PV cell when operating at an open circuit at a temperature of 20 ^{0}c with air mass of 1.5, irradiance G = 800 W/m^2 and a wind speed less than 1m/s [6], [7]. When, modules have to be connected together to form an array as indicated in figure 2.2. Arrays connected in series result higher voltages where as the ones connected in parallel has higher current. When modules are connected in parallel they produce large power at the same voltage due to the increment of current, in a similar fashion when modules are connected in series; it is enviable to provide each module maximum power production at the same current due to the increment of voltage. When deciding to install solar panels, it is important to take into consideration the shading effects faced to the panels during the peak sun hours. The shading effect causes to the reduction of power production and it may even damage the cells. Generally, it is advisable to install PV panels free of trees, buildings, and other obstacles. The second important parameter to consider during solar panel installation is temperature. The heating up of solar panels cause a loss of power because solar cells efficiency is decrease as temperature increases. The mounting system of the panels should allow the air circulation system during the hot sun hour to cool the solar panel.

2.1.4 Solar PV Installation Methods

Solar energy exploitation depends on the tracking system that mounts the PV panel. The tracking system is basically applied to direct the panel to the direction of the sun light which enhances the radiation that strikes the surface of the PV module. Most PV arrays are typically mounted with no tracking systems. There is possibility to track the radiation of the sun for the power output maximization. Solar tracking systems are basically categorized according the number of axes of tracking and the time with which the adjustment is to be made. Below are the techniques to be considered during the design of the PV system [8], [9].

No tracking: Photovoltaic Panels are mounted at a fixed slope and azimuth; moreover it is the simplest and cheapest method. Preferable to orient the panel to the equator (south in the northern hemisphere) usually the angle of tilt is equal to the latitude of the specific site under study. A small increase and decrease from the latitude will be better for the winter and summer sun tracking respectively.

Horizontal axis monthly adjustment: This type of tracking system, it rotates horizontally from east to west direction. The angle of inclination of the PV is adjusted on the beginning of every month so that the beam strikes at 90 degree to the PV panel when sun is overhead.

Horizontal axis weekly adjustment: This type of mounting system, its axis of rotation is from east to west direction. The PV angle of tracking (slope) is adjusted on the first day of the week, thus solar radiation is at 90 degree to PV at noon of the corresponding day. The PV module slanted towards parallel the ground.

Horizontal axis daily adjustment: Axis of rotation is about a horizontal east-west direction to track the solar radiation. The slope is adjusted each day so that the sun's rays are at 90 degree to PV at noon of the corresponding day.

Horizontal axis continuous adjustment: It is a type of PV mounting system in which slope of photovoltaic is adjusted continuously and rotation is about a horizontal east-west axis. The slope is adjusted continually in order to minimize the angle on incidence.

Vertical axis continuous adjustment: PV axis of rotation is about a vertical with respect to the ground surface. The slope is fixed, but the azimuth is continually adjusted to minimize the angle of incidence.

Two axes: The panels are rotated about both to east-west and from north-south having two pivots to rotate. However, it is the most expensive method.

2.1.5 Solar Terminologies

According to Dan Chiras [10], the solar energy reached each year to the earth’s surface is roughly 10k times the total energy consumed by human. As sunlight passes through the earth’s atmosphere some of it absorbed, some is scattered and some passes through the molecules in the atmosphere. Solar energy that reaches the earth surface is solar radiation. Nuclear reactions occur in the sun as a result hydrogen is converted into helium with a process called fusion. This reaction caused for the release of large amount of radiation, where its temperature reaches about 15 million degree Celsius [10]. It is part of this energy that strikes the earth’s surface. The magnitude of solar irradiance which strike on the surface of the earth depends on latitude, climatological location parameters like air pressure, cloudiness, etc. Some of the direct applications of solar energy are to heat, to pump, and to desalinate water. Solar energy can be converted in to electricity using different conversion technologies, among which photovoltaic and solar thermal are the basics. Photovoltaic technologies convert the incoming solar insolation directly into electricity. Whereas, solar thermal technologies initially heats water then directs to mechanical systems such as steam turbines to generate electricity. This technology uses mirrors to concentrate the incoming solar energy, it captured in the form of heat. Taking an account for the PV systems and sunshine, it is necessary to take a note of the following important concepts.

Irradiance: It is the power density of the sun, measured in W/m^2. At night and on sunrise times, irradiance is often zero and increases respectively then reaches at its highest value around noon. It again decreases from noon to sunset and dropping to zero at night.

Irradiation: It is the time integral of power density of the sun (irradiance), measured in kWh/m^2.

Air mass: A parameter that influences the quantity of irradiance that is incident on the earth's atmosphere.

Solar constant: The amount of solar radiation incident on the earth's atmosphere at a vertical angle of air mass (AM=0), and its magnitude is about 1367 W/m^2.

Global solar radiation: The total summation of the sunbeam and diffuse radiations. In case of horizontal laid surfaces, global solar radiation is the summation of vertical radiation and diffuse radiation. This is part of the constant solar radiation that hits the ground.

Beam radiation: It is the sunbeam that reaches the earth right from the sun disk.

Diffuse radiation: It is the solar insolation that reaches the ground from the sky where its direction is changed by the atmosphere. The diffuse radiations magnitude depends on solar height, and atmospheric transparency. The higher the cloud in the sky is the higher the dispersed radiation.

Albedo radiation: It is the reflected sunlight from the ground.

Extraterrestrial normal radiation: Is the quantity of solar insolation that arrives on a surface perpendicular to the atmosphere.

Extraterrestrial horizontal radiation: is the quantity of solar radiation reaching on a flat surface positioned on top of the atmosphere. If the entire direct solar radiation source is converted into usable form of energy in the earth, it would be more than enough to supply the energy requirement of the world.

2.1.6 Equivalent Electrical Circuit of PV Cell

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 2.3 below. The following parameters call for consideration. The current I at the output terminals 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, impurities, and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to the ground. In an ideal PV cell $R_s = 0$ and $R_{sh} = \infty$. The PV conversion efficiency is sensitive to small variations in Rs, but insensitive to variations in R_{sh}. A small increase in R_s can decrease the PV output significantly I_L.

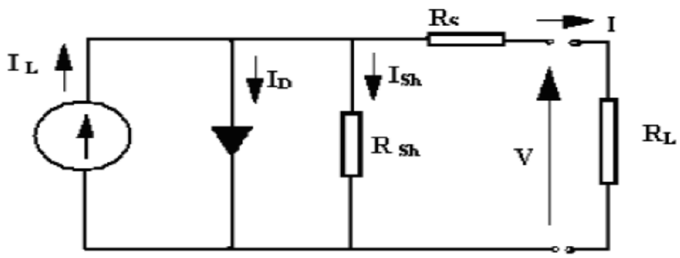


Figure 2.3: A PV cell equivalent electrical circuit [7]

The different parameters of the photovoltaic cell indicated in the equivalent circuit are expressed by the following mathematical expressions [7].

$I=I_L-I_D-I_{Sh}$ (2.1)

Where:

I: PV output current [A]

I_L: solar generated current [A]

I_D: Diode current [A]

I_{sh}: Shunt-leakage current [A]

The yield efficiency of PV panel can be greatly reduced by a small change of the internal resistance developed in the cell however there is no change of output voltage for any change of the shunt resistance [7]. Other mathematical expressions can be applied to determine the output current of the cell as follows.

$I=I_{DL}-I_O[e^{Q\cdot\frac{Voc}{KT}}-1]-\frac{\mathrm{Voc}}{\mathrm{Rsh}}$ (2.2)

In actual operating times the last term which represents the shunt current is so small compared to the solar produced and diode currents, thus it can omitted [11]. Temperature variations of the cell are considered uniform in this kind of model [12]. The open circuit voltage and the diode current are being determined as follows respectively.

$V_{oc}= V+I*R_{sh}$ (2.3)

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

$I_D=I_o\,(e^{\frac{QVD}{KT}}-1)$ (2.4)

Where:

Io: Reveres saturation current of diode [A]

Q: Electron charge [$1.6*10^{-19}$ C]

K: Boltzmann's constant [$1.38*10^{-23}$ J/ºk]

VD: Voltage of the diode [V]

T: Cell junction point temperature [k]

Similarly the short circuit current of the cell can be determined by setting the open circuit voltage as zero accordingly the short circuit and solar generated currents remained with the same magnitude. The diode saturation current (Io) is constant at constant temperature [7] and its mathematical determination is expressed as follows.

$$I_o=\left(\frac{\mathrm{Isc}}{e^{Q.VOC}}-1\right) \tag{2.5}$$

If the short circuit current of the module is known from the data sheet of the cell therefore at any solar irradiance, the cell current is given as follows.

$$I_{sc}=\left(\frac{G}{\mathrm{Go}}\right)\ \mathrm{Isc},\ G_o \tag{2.6}$$

Where:

Isc: Short circuit current [A]

G: Solar irradiance [W/m^2]

I_{sc}, Go: Short circuit current at standard test condition [A]

G_o: Solar irradiance at standard test condition [1000W/m^2]

The open circuit voltage can be determined by setting the output current to zero.

$$V_{oc}=\frac{AKT}{Q}\ \log\left(\frac{IL}{Io}+1\right) \tag{2.7}$$

The quality of PV cell is measured by the parameter called fill factor. This shows that an efficient PV will have higher values of short circuit current, open circuit voltage, and filling factor. Any solar PVs fill factor depends on the design and technology of the panel. Whichever parameter or damage that influences the fill factor also disturbs the yield power by reducing maximum current or maximum voltage or both at the same time. The output power of PV can be calculated using equation 2.8 given in [13].

$$P_{mp}=I_{mp}*V_{mp} \tag{2.8}$$

$$FF=\frac{\mathrm{VoB*Isc}}{\mathrm{Pmp}} \tag{2.9}$$

Where:

V_{mp}: PV maximum potential voltage [V]

I_{mp}: PV panels maximum current [V]

Pmp: PV panels maximum power [V]

FF: Fill factor

Furthermore, the output power of the PV can also be determined by considering the effect of solar irradiation and environmental temperature at the site of interest. As the expression given in [14] the mathematical expressions for the maximum current and maximum voltage given in equation 2.10 can be determined as follows.

$V_{mp}= V_{mp,ref}*P_{v,OC}\ (T_c-T_{c,ref})$ (2.10)

$I_{mp}=I_{mp,ref}*I_{sc,ref}\ (T_c-T_{c,ref})$ (2.11)

Where:

$V_{mp,\ ref}$: Potential voltage at standard condition [V]

$P_{V,\ OC}$: Open circuit temperature coefficient [V_{ov}/k]

$I_{mp,\ ref}$: PV panels maximum current at standard conditions [A]

$I_{sc,\ ref}$: PV panels short circuit current at standard condition [A]

T_C: Cell operational temperature [k]

$T_{c,\ ref}$: Cell temperature at standard conditions [k]

A typical PV module with I-V and P-V characteristics curve is shown in figure2.4.

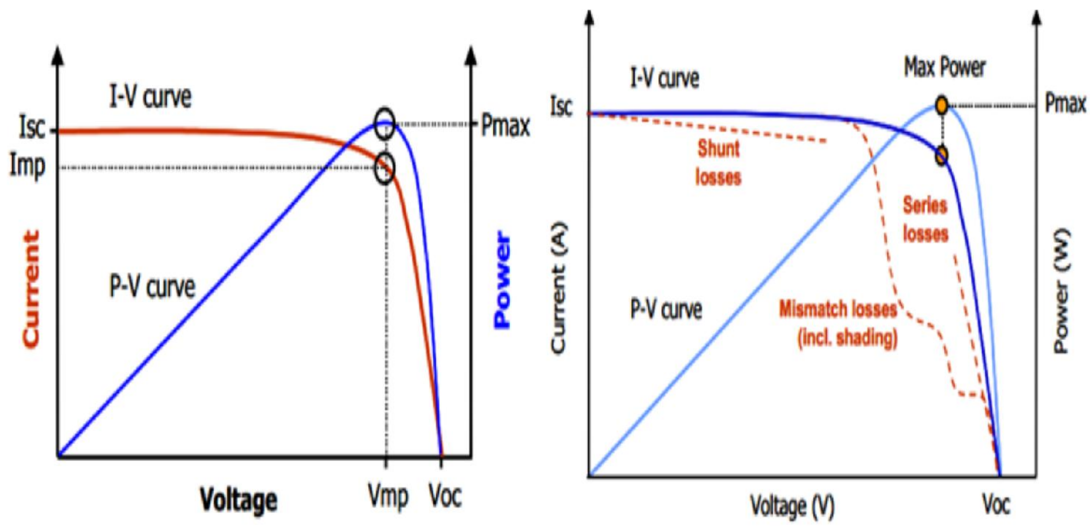


Figure 2.4: Variation of I-V Characteristic Curve of PV Cell with Categories of Different Losses [15].

Referring into figure 2.4 in the right graph, the series losses & shunt losses, and mismatch losses are resulted due to uniform soiling and non-uniform shadings of the solar PV system respectively.

2.1.7 Solar Incident Radiation Estimation

The position of the sun, the slope and the orientation of the photovoltaic surface are the most important parameters for any solar system design. Photovoltaic power output is affected by the amount of radiation reaching the surface area of the collector; however the irradiance that is incident is flat or horizontal. Thus the incident solar radiation in a tilted surface is inclined component of the radiation, which should be calculated from the global horizontal radiation. Figure 2.5 illustrates the orientation of photovoltaic system towards the sun. The angles involved in determining the amount of incident solar radiation on the surface of PV panel are described below.

Zenith angle (θz): Is the angle between the line drawn vertically and the line that connects to the sun from the vertical line. Usually this angle is 90º at sunrise and sunset times.
Solar altitude angle (α_s): It is an angle included between the line that directs to the sun and the line drawn perpendicular to this line. Its value remained at 0º during sunrise and sunset times.
Solar azimuth angle (γ_s): It is an angle that draws from south direction to the line that indicates to the sun. Its value varies from 0º when sun is overhead, -90º at sunrise and 90º at sunset.
Angle of incidence (θ): It is the angle sandwiched between the line that draws normal to PV surface and the line that points to the sun. It is the critical angle in determining the incident radiation accordingly the photovoltaic power output. For the determination of this angle, it is basic to know the following angles too.
Hour angle (ω): is defined as the angular displacement of the sun, which is east or west, of the civil meridian time zone. The earth rotates 15º per hour; furthermore this shows that at 11am and 1pm, hour angle is -15º and 15º respectively.
Surface azimuth angle (γ): is an angle that measures from south to the line that draws perpendicular to the PV panel surface. East and west orientations are negative and positive respectively. The azimuth specifies the direction towards which the panels slope. The direction into which the PV array faces is called azimuth. Zero degree azimuths depict south facing surface. So an azimuth of negative value results to a south-east facing surfaces, furthermore a surface oriented to an azimuth of 90° shows a surface facing to the west. Collector slope (β) is the angle of inclination of a surface between the PV and the horizontal plane. A 0 and 90 slopes indicate the horizontal and vertical orientations of the PV array respectively. A slope roughly equal to the latitude will typically maximize the annual PV energy production.
Declination (δ): is the angle formed between the line from the sun directed from equator and the line that directs straight to the equator. It varies by plus or minus 23.45 degrees during the year. Latitude (φ) is the angle measured from the line that draws to the center of the earth and the line directs to the equator.

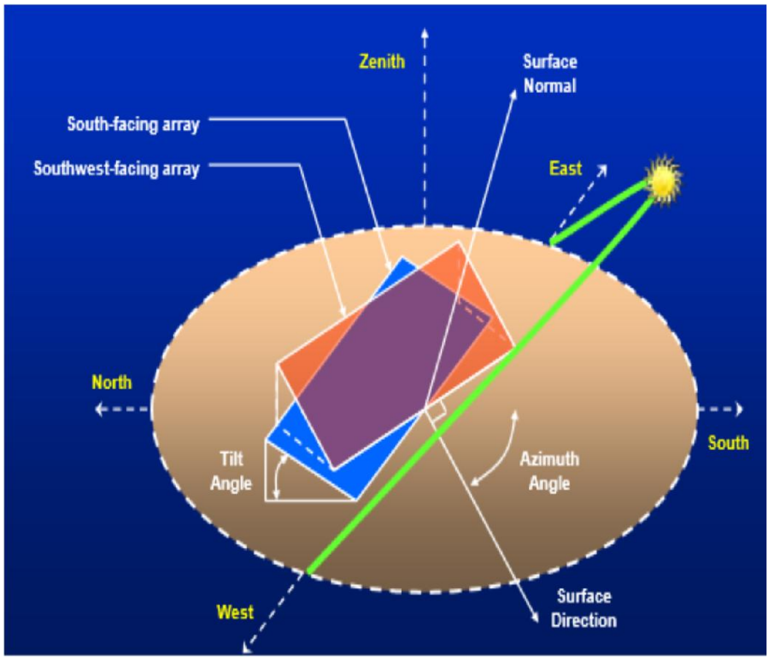


Figure 2.5: Orientation and Slope of Solar PV Module [16]

The employment of PV array may describe with inclination or slope and azimuth of the PV surface. The latitude, the time and day of the year are also parameters that relates to the sun geometry. The time of year relates to the solar declination angle. Solar declination is the latitude at which the solar beams are at 90° to the earth's surface at solar noon. All of the following equations below are presented by different authors [17], [18].

$$\delta = 23.45°\sin(360°\frac{284+n}{365}) \qquad (2.12)$$

Where:

δ: Declination angle [^{O}]

n: day of the year, 1st January as 1 through 365

The sunset hour in degrees is calculated by

$$\omega_s = \cos^{-1}\{-\tan(\emptyset)\tan(\delta)\} \qquad (2.13)$$

Where: ϕ: is the latitude [°]

δ is the solar declination [°]

$$N_s = \frac{2}{15} * \omega_s \qquad (2.14)$$

n is the day of the year which is a continuous function of time. It can be conventionally obtained from table 2.1 shown below.

Table 2.1: Recommended average days for months and values of n by months [19]

Month	N for i^{th} day of the months	For the average day of the Month		
		Date	n, date of a year	δ declination
January	I	17	17	-20.9
February	31+i	16	47	-13
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	13.15
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

Now, for a surface with any orientation, we can define the angle of incidence, meaning the angle between the sun's beam radiation and the normal to the surface, using the following equation: Calculate solar time from civil time using the following equation:

$$t_S = t_c + \frac{\lambda}{15°/\mathrm{hr}} - Z_c + E \quad (2.15)$$

Where

t_c: is the civil time in hours corresponding to the midpoint of the time step [hr.]

λ: is the longitude [°]

Z_c: is the time zone in hours east of GMT [hr.]

E: is the equation of time [hr.]

The equation of time accounts for the effects of obliquity (the tilt of the earth's axis of rotation relative to the plane of the ecliptic) and the eccentricity of the earth's orbit. HOMER calculates the equation of time as follows:

$$E=3.82[0.000075+0.001868\text{Cos}B-0.032077\text{Sin}B-0.014615\text{Cos}2B-0.04089\text{Sin}2B] \quad (2.16)$$

Where:

B is given by;

$$B = 360° \frac{(n-1)}{365} \quad (2.17)$$

$$\text{Cos}\theta=\text{Sin}\delta^*\ \text{Sin}\phi^*\ \text{Cos}\beta-\ \text{Sin}\delta^*\ \text{Cos}\phi^*\ \text{Sin}\beta^*\ \text{Cos}\gamma + \text{Cos}\delta^*\ \text{Cos}\ \phi^*\ \text{Cos}\beta^*\ \text{Cos}\ \omega+ \text{Cos}\delta^*\ \text{Sin}\phi^*\ \text{Sin}\beta^*\ \text{Cos}\ \omega+ \text{Cos}\delta^*\ \text{Sin}\beta^*\ \text{Sin}\gamma^*\text{Sin}\omega \quad (2.18)$$

Where: θ is the angle of incidence [°]

B: is the slope of the surface[°]

γ: is the azimuth of the surface [°]

ϕ: is the latitude [º]

δ is the solar declination [º]

ω is the hour angle [º]

The zenith angle is zero when the sun is directly overhead and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find an equation for the zenith angle by setting $\beta = 0°$ in the above equation (2.18), which yields:

$$\text{Cos}\theta_z = \text{Sin}\delta * \text{Sin}\phi + \text{Cos}\delta * \text{Cos}\ \phi * \text{Cos}\ \omega \tag{2.19}$$

Where:

θ_z : is the zenith angle[º]

Now we turn to the issue of the amount of solar radiation arriving at the top of the atmosphere over a particular point on the earth's surface. HOMER assumes the output of the sun is constant in time. But the amount of sunlight striking the top of the earth's atmosphere varies over the year because the distance between the sun and the earth varies over the year due to the eccentricity of earth's orbit. To calculate the extraterrestrial normal radiation, defined as the amount of solar radiation striking a surface normal (perpendicular) to the sun's rays at the top of the earth's atmosphere, HOMER uses equation (2.18) in order to estimate the solar radiation of the selected site:

$$G_{on} = G_{sc}(1 + 0.033 * Cos\frac{360n}{365}) \tag{2.20}$$

Where; G_{on}: is the extraterrestrial normal radiation [kW/m^2]

$G_{sc:}$ is the constant [1.367 kW/m^2]

n: is the day of the year [a number between 1 and 365]

To calculate the extraterrestrial horizontal radiation, defined as the amount of solar radiation striking a horizontal surface at the top of the atmosphere, HOMER uses the following equation:

$$G_o = G_{on} * \text{Cos}\theta_z \tag{2.21}$$

Where:

G_o: is the extraterrestrial horizontal radiation [kw/m^2]

G_{on}: is the extraterrestrial normal radiation [kW/m^2]

θ_z: is the zenith angle[º]

Based on the results of G_{on} obtained using equation 2.20, the total radiation incident on a horizontal surface can be calculated by

$$H_o = \frac{24*3600}{\pi} \text{Gsc}*[1 + 0.033 * Cos\left(\frac{360n}{365}\right) [\text{Cos}(\phi)*\text{Cos}(\delta)*\text{Sin}(\omega_s) + (\frac{\pi\omega s}{180})*\text{Sin}\phi*\text{Sin}\delta] \tag{2.22}$$

Where:

ϕ: is latitude of the selected area

δ: is declination angle

ω_s: is the sunset hour in degrees

The daily solar radiation is measured in joules per square meter (J/m2), however, Gsc is in watts per square meter (W/m^2).

The above equation gives the average amount of solar radiation striking a horizontal surface at the top of the atmosphere in any time step. The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. The ratio of the surface radiation to the extraterrestrial radiation is called the clearness index. The following equation defines the clearness index:

$$k_T=\frac{\overline{G}}{\overline{G}_o} \qquad (2.23)$$

Where:

$\overline{G}$: is the global horizontal radiation on the earth's surface averaged over the time step [kW/m^2]

$\overline{G}_o$: is the extraterrestrial horizontal radiation averaged over the time step [kw/m^2]

Now let us look more closely at the solar radiation on the earth's surface. Some of that radiation is beam radiation, defined as solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere. Beam radiation (sometimes called direct radiation) casts a shadow. The rest of the radiation is diffuse radiation, defined as solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast a shadow. The sum of beam and diffuse radiation is called global solar radiation, a relation expressed by the following equation.

$$\overline{G}=\overline{G}_b+\overline{G}_d \qquad (2.24)$$

Where:

$\overline{G}_b$: is the beam radiation [kw/m^2]

$\overline{G}_d$: is the diffuse radiation [kw/m^2]

The distinction between beam and diffuse radiation is important when calculating the amount of radiation incident on an inclined surface. The orientation of the surface has a stronger effect on the beam radiation, which comes from only one part of the sky, than it does on the diffuse radiation, which comes from all parts of the sky.

However, in most cases we measure only the global horizontal radiation, not its beam and diffuse components. For that reason, HOMER expects you to enter global horizontal radiation in HOMER's Solar Resource Inputs window. That means that in every time step, HOMER must resolve the global horizontal radiation into its beam and diffuse components to find the radiation incident on the PV array. For this purpose HOMER uses correlation of Erbs et al. (1982), which gives the *diffuse fraction* as a function of the clearness index as follows:

$$\frac{\overline{G}_d}{\overline{G}} = \begin{cases} 1.0 - 0.09 * kT & \text{for } k_T \le 0.22 \\ 0.9511 - 0.1604 * kT & \text{for } 0.22 < k_T \le 0.8 \\ 0.165 & \text{for } k_T > 0.80 \end{cases} \qquad (2.25)$$

For each time step, HOMER uses the average global horizontal radiation to calculate the clearness index, then the diffuse radiation. It then calculates the beam radiation by subtracting the diffuse radiation from the global horizontal radiation.

We are now almost ready to calculate the global radiation striking the tilted surface of the PV array. For this purpose HOMER uses the HDKR model, which assumes that there are three components to the diffuse solar radiation: an isotropic component which comes all parts of the sky equally, a circumsolar component which emanates from the direction of the sun, and a horizon brightening component which emanates from the horizon. Before applying that model we must first define three more factors.

The following equation defines R_b, the ratio of beam radiation on the tilted surface to beam radiation on the horizontal surface:

$$R_b = \frac{\cos\theta}{\cos\theta z} \qquad (2.26)$$

The anisotropy index, with symbol A_i, is a measure of the atmospheric transmittance of beam radiation. This factor is used to estimate the amount of circumsolar diffuse radiation, also called forward scattered radiation. The anisotropy index is given by the following equation:

$$A_i = \frac{\overline{Gb}}{\overline{\overline{G}}o} \qquad (2.27)$$

The final factor we need to define is a factor used to account for 'horizon brightening', or the fact that more diffuse radiation comes from the horizon than from the rest of the sky. This term is related to the cloudiness and is given by the following equation:

$$f = \sqrt{\frac{\overline{G}_b}{\overline{G}}} \qquad (2.28)$$

The HOMER model calculates the global radiation incident on the PV array according to the following equation:

$$\overline{G}_T = (\overline{G}_b + \overline{G}_d A_i) R_b + \overline{G}_b (1 - A_i) \left(\frac{1+\text{Cos}\beta}{2}\right) \left[1 + f\text{Sin}^3\left(\frac{\beta}{2}\right) + \overline{C}_{pg}\left(\frac{1-\text{Cos}\beta}{2}\right)\right] \qquad (2.29)$$

Where:

β: is the slope of the surface[°]

pg: is the ground reflectance, which is also called the albedo [%]

HOMER uses this quantity to calculate the cell temperature and the power output of the PV array.

2.2 Measurement of sunshine duration

Two different instruments are commonly used for measuring hours of bright sunshine in countries which have no instrument for measuring the solar irradiance directly. These are the Campbell- Stokes sunshine recorder which uses a solid glass sphere of approximately 10 cm as a lens that produces an image of the sun on the opposite surface of the sphere, and a photoelectric sunshine recorder. In the study area where the radiation data's are not available, empirical formulas can be used to estimate the average solar radiation from the hours of bright sunshine (sunshine duration). These data are available in many countries which are mainly measured by Campbell-Stokes instrument. The monthly average solar radiation then can be calculated using equation 2.30.

$$\frac{H}{Ho}=a+b\frac{n}{Ns} \tag{2.30}$$

Where ɑ and b are the regression coefficients (constants) which are dependent on the location, H is the monthly average of the daily global radiation on a horizontal surface, H_o is the average value of extraterrestrial solar radiation on a horizontal surface for each month which can be calculated from equation 2.22, n is the monthly average of bright sunshine hours per day, and N_s is the average of the maximum daily hours of sunshine which can be calculated from equation 2.14.

2.3 Solar Energy Resource of Ethiopia

Ethiopia receives 4.55 to 6.5 kWh/m^2/day annual average of solar insolation throughout the country [20, 21]. This varies significantly during the year, ranging from a minimum of 4.55kWh/m^2/day in July to a maximum of 6.55kWh/m^2/day in February and March. Other literatures describe the yearly average radiation to be in the range from 4.25 kWh/m^2 in the areas of Itang in the Gambella regional state (western Ethiopia), to 6.25 kWh/m^2 around Adigrat in the Tigray regional state (northern Ethiopia) [22].

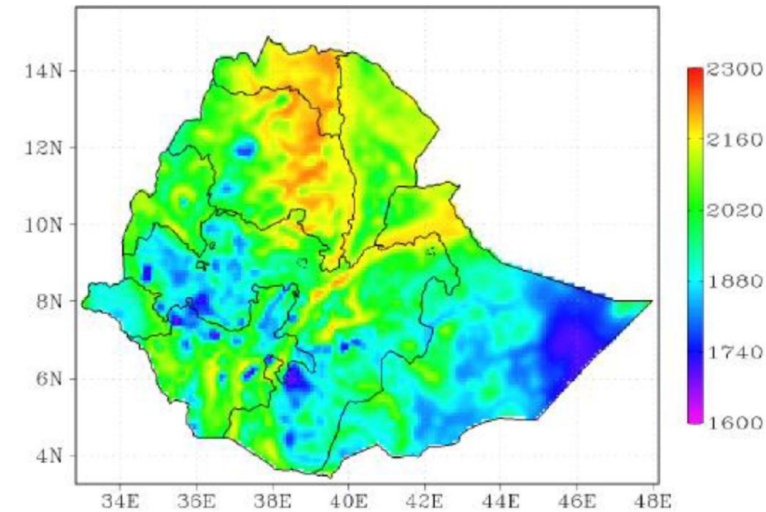


Figure 2.6: Distribution of Average Annual Total Solar Radiation of Ethiopia, kWh/ m^2 [24]

2.4 Basic theory of Wind Energy

A wind turbine is a machine that converts the kinetic energy from the wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator [25].

There are a number of different wind turbine types available. The horizontal axis turbine, (HAWT) is by far the most common type of turbine. They come in two different types: the upwind, which face the wind (tower behind rotor) and the downwind arrangement that works away from the wind (tower in front). Another kind of turbine is the vertical axis wind turbine, (VAWT) arrangement that uses drag and lift as the driving forces; the horizontal also uses drag and lift, but in other proportions.

The advantages with upwind turbines are that the tower does not act as an obstacle for the wind hitting the rotor. Despite this, the flow behind the passing blade is affected by the tower and causes a slight drop in power. When the blade passes the tower it also decreases the drag on the construction which can cause an on / off bending process causing fatigue stress. This has of course been taking into account when designing the turbine. The upwind design needs a control system that helps the nacelle turn straight to the wind. In downwind turbines, the tower shades a rotor blade each time it passes by and causes greater power losses compared to the upwind design. An advantage with downwind turbines is that the nacelle is self-adjusting and is not in need of a control system. One drawback with this is the problem with untwisting the cable inside when the nacelle has turned same direction repeatedly. The VAWT´s are not as commercial and economically competitive as the HAWT´s. Some of the VAWT types suffer from low efficiency due to design difficulties as well as the problem with operation close to the ground. Parts of the vertical turbines will therefore receive low quality winds causing power losses. To keep the construction upright it also needs to be supported with guy cables attached to the ground. The vertical turbine is not in need of yaw control, which of course is an advantage and the wind always hits the turbine tangentially [26].

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

Wind turbine single-source systems tend to produce highly variable and therefore unreliable power supply due to the irregular wind speeds. If the wind turbine is combined with other sources of a hybrid system the produced energy can become more regular improving system performance and cost effectiveness.

The Figures below shows the various wind turbine types. (a) Upwind machine (b) down wind machines (c). Vertical axis wind turbines (VAWT) accept wind from any direction.

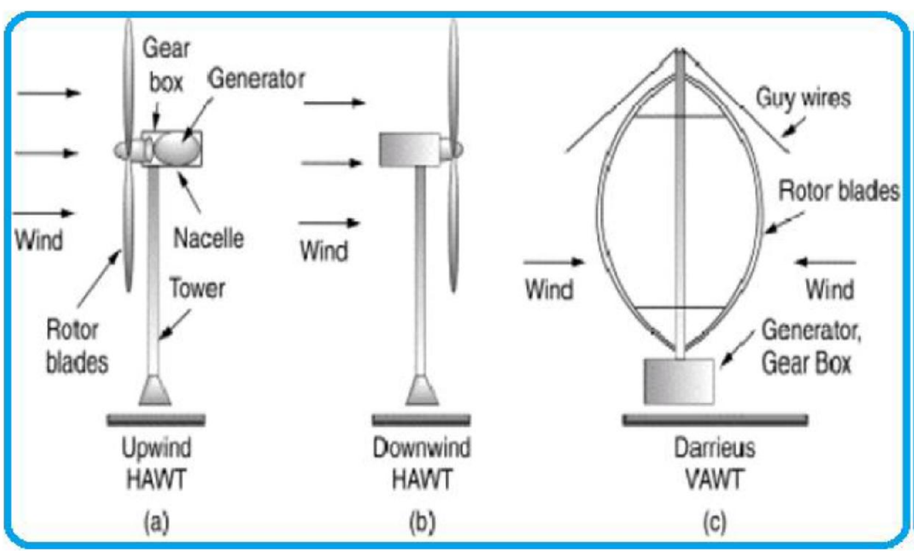


Figure 2.7: Wind turbine types and their configuration [27].

2.4.1 Wind Turbines Components

The most common turbine type is the horizontal axis wind turbine. A cut-view (Figure 2.8) helps the reader to get familiar with the components of a wind turbine.

- ✓ **Anemometer:-**Measures the wind speed and transmits wind speed data to the controller.
- ✓ **Hub:-**Hub is the connection point for the rotor blades and the low speed shaft.
- ✓ **Gear box:-**Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes specially for small scale wind turbines.
- ✓ **Generator:-**The generator is connected to the high-speed shaft and is the component of the system that converts the rotational energy of the shaft into an electrical output.
- ✓ **Tower of wind power generation:-**The tower is used to support the nacelle and rotor blades and typically made of rolled, tubular steel, and built and shipped in sections because of its size and weight. Common tubular towers incorporate a ladder within the hollow structure to provide maintenance access. Small -scale towers range in height from 24-35m and its weight depends on the material from where it is manufactured.
- ✓ **Nacelle:-**The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working rotor in emergencies.

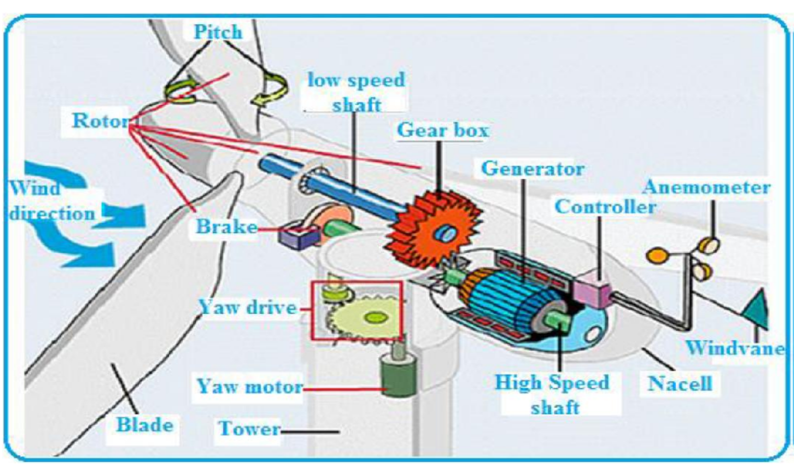


Figure 2.8: Cut-View Wind Turbine [28]

- ✓ **Controller:-**The controller starts up the machine at wind speeds of about 3.5 to 7.2 meters per sec (m/s) and shuts off the machine at about 30 m/s.
- ✓ **High-speed shaft:-**Drives the generator.
- ✓ **Low-speed shaft:-**The rotor turns the low-speed shaft at about 30 to 60 RPM.
- ✓ **Pitch:-**Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.
- ✓ **Rotor:-**The blades and the hub together are called the rotor.
- ✓ **Tower:-**Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
- ✓ **Yaw drive:-**Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.
- ✓ **Yaw motor:-**Powers the yaw drive.
- ✓ **Electronic equipment:-**Such as controls, electrical cables, ground support equipment and interconnection equipment.

2.4.2. Workings Principles of Wind Turbines

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

2.5. Wind Energy Extraction by Horizontal Axis Wind Turbine

The energy of wind is extracted by using appropriate wind turbine. The wind energy is tapped by the wind turbine which converts the kinetic energy of the wind into mechanical shaft energy. The rotational energy is converted into electrical energy through the transmission system. The transmission system consists of the rotor shaft with bearings, brake(s), an optional gearbox, as well as a generator and optional clutches. The energy available in the wind can be expressed using equation (2.31).

$P_w = \rho 1/2AV^3$ (2.31)

Where; ρ=Density of air (kg/m^3)

A = the swept area (m^2)

Pw = power in the wind (W)

v =instantaneous wind velocity (m/s)

Energy conversion from free-flowing fluid streams is limited because full energy extraction implies decrease of fluid velocity (decrease of kinetic energy of the stream), down to zero which is impossible. Some fluid may not pass through the turbine and may simply flow around it (bypass it). This limitation is expressed in terms of Betz limit defined by the power coefficient C_p as given by equation (2.32).

$$C_p = \frac{\text{Rotor Power}}{\text{Power in the Wind}} \quad (2.32)$$

The power coefficient, C_P, is a function of the axial induction factor. The optimum of this function (which is a maximum value for C_P) is 0.5926 (=16/27) [29, 30, 31]. Thus the electrical power output from the wind turbine can be expressed by equation (2.33).

$P_{wout} = \eta C_p 1/2Pav^3$ (2.33)

Where, $P_{w\,out}$ = output power of wind turbine

η= Overall efficiency of the transmission system/power train

C_p = the power coefficient

The power coefficient and efficiency of wind turbines vary greatly from manufactures to manufacturers. As a result, the power output of wind turbines vary from turbine to turbine and is given by power curve which plots the output power of a turbine against wind speed (Figure2.9).

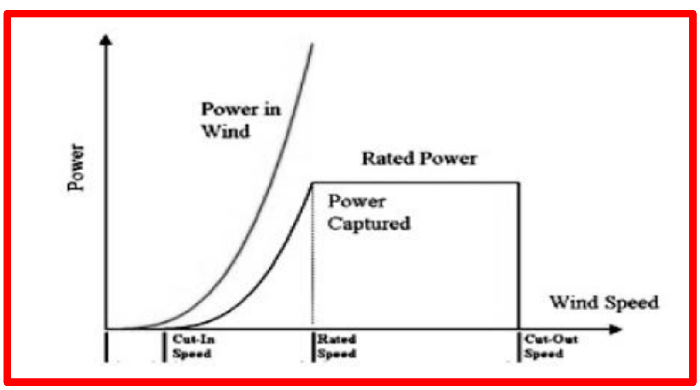


Figure 2.9: General power curve of wind turbine [31]

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

2.6. Wind Turbines Power Control Mechanism

All wind turbines are designed with some sort of power control. There are different ways to control aerodynamic forces on the turbine rotor and thus to limit the power in very high wind speeds in order to avoid damage to the turbine. There are three commonly used types of power control in the industry [23].

- Stall Control
- Pitch Control
- Active stall regulation

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

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

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

2.7. Wind Energy Resources

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

2.7.1. Wind Speed Measurement

The wind speed is measured with an instrument called an anemometer. These instruments come in several types. The most common type is a cup anemometer which has three or four cups attached to a rotating shaft. When the wind hits the anemometer, the cups and the shaft rotate. The angular speed of the spinning shaft is calibrated in terms of the linear speed of the wind. Normally, the anemometer is fitted with a wind vane to detect the wind direction. A data logger collects wind speed and wind direction data from the anemometer and wind vane respectively. It is very important that the measuring equipment is set high enough to avoid turbulence created by trees, buildings or other obstructions. Readings would be most useful if they have been taken at hub height where the wind turbine is going to be installed [25].

If the measurement of wind speed was not made at the wind turbine hub height (in this case it is 10 m) it is important to adjust the measured wind speed to the hub height. This can be done using either the logarithmic law, which assumes that the wind speed is proportional to the logarithm of the height above ground, or the power law, which assumes that the wind speed varies exponentially with height. Using the logarithmic law the wind speed at a certain height above ground level can be given as follows [28]:

$$V(z)*\ln(z_r/z_o)=V(z_r)*\ln(z/z_o) \tag{2.34}$$

Where, z_r Reference height (m)

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

z_0 =Measure of surface roughness (0.1 to 0.25 for crop land)

$v(z)$= Wind speed at height of Z m (m/s)

$v(z_r)$= Wind speed at the reference height (m/s)

Using power law the wind speed at a certain height above ground level can be given as follows [16]: $V_2=V_1(h_2/h_1)^{\alpha}$ (2.35)

Where: $V_{1=}$ is wind speed measured at the reference height h_1 (m/s),

V_2 =is wind speed estimated at height h_2 (m/s), and

α =is ground surface friction coefficient.

Table 2.2: Friction Coefficient α of Various Terrains [32]

Terrain Type	Friction Coefficient
Lake, ocean, and smooth, hard ground	0.10
Foot-high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

2.8. Wind Resource in Ethiopia

Ethiopia has exploitable reserve of 100 GW wind energy with an average speed of 3.5 to 5.5 m/s, flowing for 6 hours/day. There are two basic zones with homogenous periodicity separated by the rift valley. In the first of these, covering most of the highland plateaus, there are two well-defined wind speed maximal occurring, respectively, between March and May and between September and November. In the second zone, covering most of the Ogaden and the eastern lowlands, average wind velocity reaches maximum values between May and August [33]. Currently two projects are constructed, one Ashegoda wind park (near Mekele) of 120MW and the other Adama Wind Park of nearly 51MW.

2.9 Overview of HOMER Software

In designing power systems different decisions can be made about the configuration of the system, such as; what components to include in the system, the size and the quantity of the components and the cost of each components. Incorrect power system design can lead to shorter life of battery, increase cost of energy production, insufficient supply of electricity demand. Hybrid **O**ptimization Model for Electric Renewable (HOMER) is a computer model developed originally by the National Renewable Energy Laboratory (NREL). It has different energy generating components in its library. The user must select the components from the library to represent the architecture considered. This modeling tool uses time step from one minute to several hours. HOMER simplifies or helps the designer to compare various power systems options based on technical and economic aspects. The software answers questions like:

- ✓ What type of component to buy (solar PV, wind turbine, either both with battery or only wind and PV)
- ✓ Does the designed system would meet future growing demand
- ✓ What quantity of battery to buy
- ✓ What if fuel and other prices changes
- ✓ How to control the power system

The software also chooses between the dispatch strategies (cycle charging and load following) by making comparisons. Design and analysis of systems can be challenging task because the large combination of design options and the inclusion of uncertainties. The design complexity and uncertainty increase when renewable sources are included in the system, because they are non-dispatch able and intermittent nature. HOMER developed to overcome these challenges.

2.10 Literature Review

Different research efforts for the application of renewable energy options have been conducted for the access of renewable energy resource potentials and stand-alone hybrid systems. The following different authors were conducted for a range of hybrid systems at different times, sites and different countries; however, the methodology applied for the simulation was HOMER.

According to EM Nfah, et al [34] simulation of a standalone electricity production for the remote settlements in Cameron was conducted. The study also presented the energy requirement in rural villages is basically for lighting, radio and television entertainments. The magnitude of the energy demand is in the range of 0.2 to 1 kWh/day. They simulated and modeled four different system configurations such as; (hydro-LPG generator-battery), (solar-LPG generator-battery), (micro hydro-diesel generator-battery), (solar-diesel-battery). From the simulation result the cost of energy for different renewable energy option was found to be 0.296 \$/kWh for micro hydro hybrid system generated from a 14kW micro hydro generator, 15 kW LPG generator and 36kWh of battery storage. Furthermore, the second simulation for PV hybrid system was accounted for 18kW PV generator, 15kW LPG generator and 72kWh of battery storage, the cost of energy was obtained as 0.576 \$/kWh for remote petrol price of 0.1\$/litter and LPG price of 0.7\$/m^3. The micro hydro system proved to be the cheapest option for the southern parts of Cameroon at a minimum flow rate of 200litter/second, while the PV hybrid was the cheapest in the southern parts of the country.

A paper presented in [35] for Saudi Arabia about off grid Wind/Diesel generator hybrid power systems to cater energy for settlements in the hot coastal regions of Dhahran. This paper considered the provision of energy basically from wind energy for a model community of 100 households. As wind resources is an intermittent sources of energy and thus for the fluctuation of energy supply, wind/diesel and battery hybrid system was considered as a solution by the author.

A hybrid system containing PV/wind/micro-hydro and diesel generator simulation model was presented by [36] for Sundargarh district of Orissa state, India. Two simulations have been carried out in this case study, one with a combination of wind/solar PV and diesel generator and the second was a combination of wind/PV/small hydro and diesel generator. The authors also suggested that the wind power fluctuation and household demand variation are the only constraints influencing the system.

Elhassan, et al [37] described the design and implementation of efficient renewable energy powered energy system for household uses in Khartoum, the capital of Sudan. The simulation activity was performed for individual households and for a group of 10 to 25 households. The energy provided from PV/battery combination for the singular users was expensive than wind/PV for group of households. To list some of the costs, the COE for single home is around 49.5 SP/Wh, for 10 households it is about 25.8 SP/Wh and for 25 households is about 20.1SP/Wh.

S.Rehman et al. [38] 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 was basically to minimize the running cots of diesel generator by combining with wind turbines and accordingly to mitigate environmental pollution. Sensitivity analysis was also made by taking sensitive parameters such as wind speed which can affect the power system during its lifelong. The simulation result shows that retrofitting wind turbine to the existing diesel generator was not feasible for wind speeds less than 6m/s and fuel prices of $0.1/litter.

A study carried out by [39] to evaluate the options for off-grid electrification in the rural villages in the Kingdom of Bhutan. The study was taken place in four different places of the country. Furthermore, the demanding load was considered for lighting and communication services only. The main target of the paper was optimization of hybrid power generating units. PV/battery power generating system was the cheapest technology for Gasa and Lunana, whereas the diesel/PV/battery hybrid system was the cheapest in Getena area. Implementation of wind/battery system was better to apply in Yangtse site.

According to the paper studied by [40] which was devoted to the study of techno-economic aspects of hybrid (wind and diesel generator) schemes for a rural community in Algeria. The study was conducted to add a wind turbine to existing diesel power plant systems to reduce fuel consumption. The author concluded for wind speed below 5m/s the existing diesel operated plant with 0.05-0.179 $/liter is cost efficient than the hybrid system. The feasibility of the hybrid system assured at wind speed of 5.48m/s, maximum annual capacity shortage 0%, minimum renewable fraction 0% and $0.162/liter fuel price.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Description of the Study Area

Samara University is one of the governmental institutions established in Samara City. Samara is the capital City of Afar region and located at (11.45 °N and 41° E). Its climate circumstance falls in to sunny quarter where the temperature ranges from 27 Degree centigrade to 50 Degree centigrade.

3.2 Data Collection

The data used in the design of the hybrid components are collected directly from the site at Samara University (Health Clinic) and from Ethiopian Metrology agency, and for perfectness of the analysis these data are compared with the NASA data obtained using the latitude and longitude of the site. Data for the HOMER software input has been collected from the following sources.

3.2.1 Primary Data

These data collected directly from the site at Samara University and, are considered as a primary data, and this includes the electrical equipment's used by the clinic, as well as their daily life style of the community and daily activities related to energy consumption of Samara University Health Clinic.

The size and cost of hybrid system components is highly influenced by the size of the electric loads. Thus, correctly analyzing the load demand or profile is an important step in designing Energy generation hybrid system of the study area. Nature of operation of loads and behavior of consumers are the parameters that determine the load profile. It was very difficult to analyze the load demand profile for Samara University Health Clinic because there is not fixed formula to calculate the loads (varying from hour to hour), thus some of the loads are estimated by asking from staff members and the members of the operation and maintenance team of the Health Clinic. Generally, the main steps in estimating on how much electricity is required in a selected site is, first to list all the electrical appliances, estimate the duration these appliances are used, taking the power each appliance consumes, and for each appliance multiply the power rating in watts by consumption hour.

3.2.2 Secondary Data

The wind speed and solar radiation of the selected sites are collated from different sources such as: the national metrological service agency of Ethiopia (NMSA), National Aeronautics and

Space Administration (NASA), previous works by other scholars and others. Then the data collected from NMSA are analyzed using theoretically proved formulas. Finally the hybrid system is modeled and simulated using HOMER software based on the primary and secondary analyzed data to get the best optimized solution by considering the cost of energy (COE) and Net Present Cost (NPC) from the overall system optimization results.

3.3 Assessment of Solar Resource Potential of the Study Area

The assessment of the potential for solar radiation of the selected area is done by taking data from different sources. These are NASA, SWERA and the National metrological service agency of Ethiopia. In the first approach, the data taken from the national metrological service agency is analyzed using formulas of chapter two (i.e. equation 2.12, 2.13, 2.14, 2.20, 2.22 and 2.30) based on the sunshine duration data collected over the past three consecutive years. The sunshine duration data taken from the National Metrological agency of Ethiopia is given in Table 3.1. The measurements are taken for three consecutive years starting from 2015 G.C. As it can be seen in the table, the data's for years 2015, 2016 and 2017. Hence, only the three year data is taken to convert in to MJ/m^2 using equation 2.30. This result is then compared with the data collected from NASA and is found to be nearly equal.

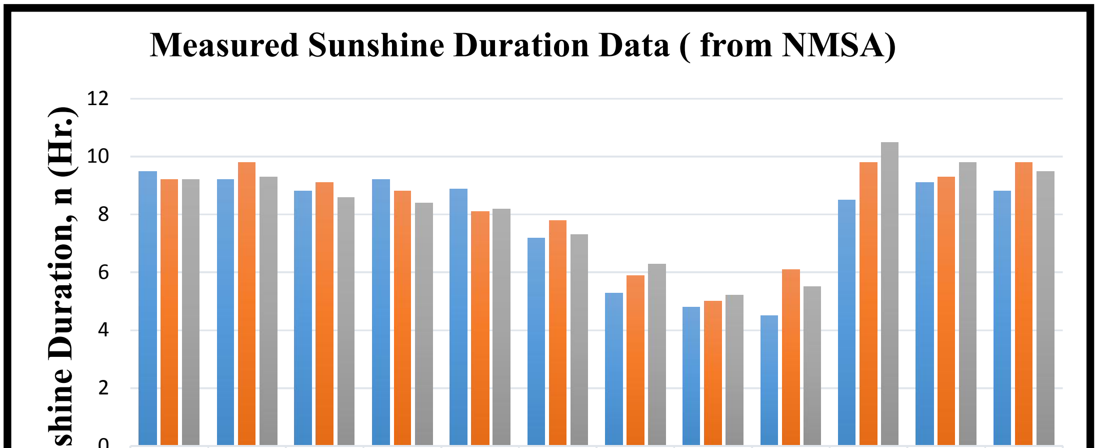
Table 3.1: Sunshine duration (n) in Hours of Samara City

Year	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	9.5	9.2	8.8	9.2	8.9	7.2	5.3	4.8	4.5	8.5	9.1	8.8
2016	9.2	9.8	9.1	8.8	8.1	7.8	5.9	5.0	6.1	9.8	9.3	9.8
2017	9.2	9.3	8.6	8.4	8.2	7.3	6.3	5.2	5.5	10.5	9.8	9.5
Average	9.3	9.4	8.8	8.8	8.4	7.4	5.8	5.0	5.4	9.6	9.4	9.4

The monthly solar radiation data for the three years with full measured hours of bright sunshine are shown in table 3.2. This table also shows monthly and annual average solar radiation in kJ/m^2 of Samara city of Afar Region.

The value for the coefficients ɑ and b which are used to calculate average solar radiation (H) varies with location, and hence the approximate values for the selected site are taken to be 0.30 and 0.50 for ɑ and b respectively [41]. Therefore, the analysis for the monthly average solar radiation is then calculated using the values of the regression coefficients and Ho which can be calculated using equation 2.8 in chapter two. The result of the analysis shown in table 3.3 is the monthly average solar radiation for the sunshine duration measured of the three years has been taken. The symbols used in table 3.3 represent the measured and calculated values which are used to analyze the extraterrestrial radiation (i.e. Ho) and the solar radiation for the location.

n and ϕ represents measured sunshine duration and the latitude angle of the area respectively. However, the symbols **δ, ωs** and Ns indicates the calculated values for declination angle, sunset angle and day length which are obtained using equations 2.12, 2.13 and 2.14 respectively.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	9.5	9.2	8.8	9.2	8.9	7.2	5.3	4.8	4.5	8.5	9.1	8.8
2016	9.2	9.8	9.1	8.8	8.1	7.8	5.9	5	6.1	9.8	9.3	9.8
2017	9.2	9.3	8.6	8.4	8.2	7.3	6.3	5.2	5.5	10.5	9.8	9.5

Figure 3.1: Measured Value of Sunshine Duration Data of three years of the Site

Table 3. 2: Measured Data of Monthly average solar radiation in kWh/m^2 for the three years from NMSA

Months	2015		2016		2017		Average H (kWh/m^2)
	Sunshine duration (Hr.)	H (kWh/m^2)	Sunshine duration (Hr.)	H (kWh/m^2)	Sunshine duration (Hr.)	H (kWh/m^2)	
Jan	9.5	6.14	9.2	6.03	9.2	6.03	6.07
Feb	9.2	6.65	9.8	6.899	9.3	6.69	6.73
Mar	8.8	6.97	9.1	7.096	8.6	6.878	6.98
Apr	9.2	7.38	8.8	7.2	8.4	7.02	7.2
May	8.9	7.02	8.1	6.68	8.2	6.72	6.8
Jun	7.2	6.44	7.8	6.7	7.3	6.49	6.54
Jul	5.3	5.515	5.9	5.77	6.3	5.94	5.74
Aug	4.8	5.43	5.0	5.52	5.2	5.6	5.52
Sep	4.5	5.18	6.1	5.885	5.5	5.62	5.56
Oct	8.5	6.62	9.8	7.17	10.5	7.47	7.09
Nov	9.1	6.26	9.3	6.34	9.8	6.54	6.38
Dec	8.8	5.85	9.8	6.22	9.5	6.11	6.06

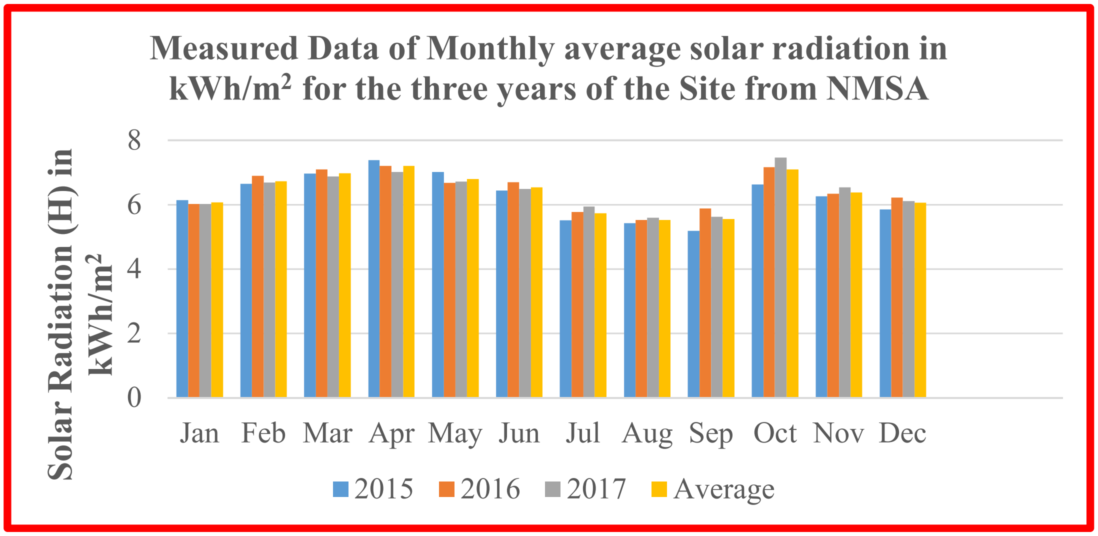


Figure 3.2: Measured Data of Monthly average solar radiation in kWh/m^2 for the three years from NMSA

Table 3.3: Analysis of Monthly average solar radiation in kWh/m^2 for the three years

Month	N	ω_s	Φ	δ	N_s	H_O (kWh/m^2)	H (kWh/m^2)
Jan	9.3	85.6	11	-20.9	11.7	8.7	6.07
Feb	9.4	87.43	11	-13.0	11.66	9.55	6.73
Mar	8.8	89.53	11	-2.4	11.9	10.4	6.98
Apr	8.8	91.84	11	9.4	12.2	10.9	7.2
May	8.4	93.79	11	18.8	12.5	10.7	6.8
Jun	7.4	94.76	11	23.1	12.6	11.0	6.54
Jul	5.8	94.32	11	21.2	12.58	10.8	5.74
Aug	5.0	92.6	11	13.15	12.3	10.97	5.52
Sep	5.4	90.43	11	2.2	12.1	10.66	5.56
Oct	9.6	88.12	11	-9.6	11.75	10.0	7.09
Nov	9.4	86.19	11	-18.9	11.49	9.0	6.38
Dec	9.4	85.27	11	-23.0	11.34	8.5	6.06
Average							**6.39**

As it can be seen in table 3.3 the monthly average solar irradiance of Samara district has maximum value on the month of April with a value of 7.2 KWh/m^2 and minimum on August with a value of 5.52 KWh/m^2. Since August is the month of the rainy season of Samara, the intensity of solar has reduced as compare with the other months of the year. The annual average solar radiation of the area is found to be 6.39 KWh/m^2, and this value indicates that the area has good potential for the implementation of photovoltaic (PV) system to give electric access to the community of Samara University Health Clinic.

Table 3.4: Monthly Average Solar Radiation in kWh/ m^2(from NASA Lat. 11.45°N, Lon. 41°E)

Months	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22 Years	6.99	6.77	6.76	6.47	6.82	6.03	5.39	5.14	5.89	7.17	7.89	7.59
Average	**6.58**											

The Table 3.4, shows the NASA data base of the study area was derived from the meteorology and energy parameters that have been recorded for 22 years by over 200 satellites. This NASA data was taken as an input for the simulation in HOMER Software for this thesis and the regarding clearance index were used. Because of, the data in NASA more or less agrees with the national average solar radiation data and the data in Metronome. NASA has estimated the 22 years annual average solar radiation incidence to a horizontal surface of the site to be 6.58 kWh/m^2/day.

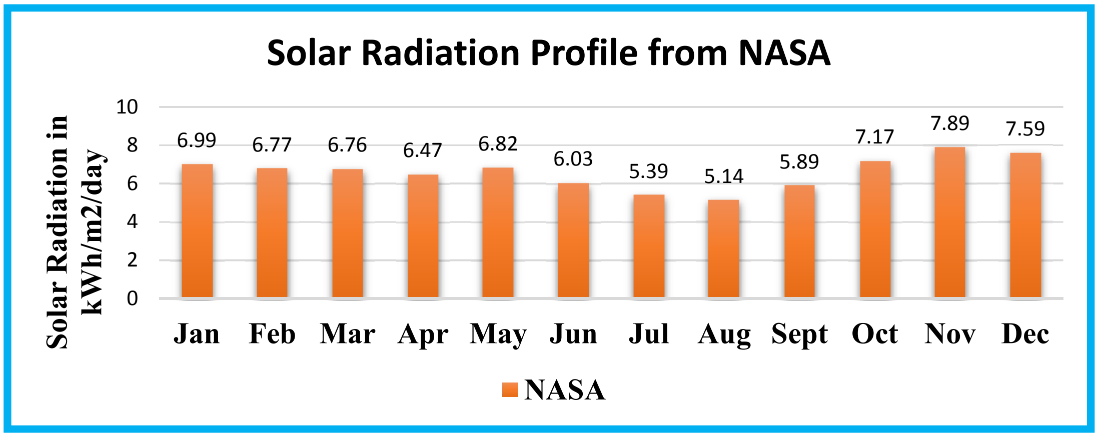


Figure 3.3: Solar radiation data of the study area from (NASA)

3.4 Wind Potential Assessment in the study Area

The resource assessment for the wind potential is done by taking the data's only from NASA. This is because of the absence of full data regarding wind speed in the National Metrological Service Agency of Ethiopia and in SWERA. Therefore, the annual average wind speed for Samara, which is located at latitude of 11.45 °N and longitude of 41° E, is found to be 3.58 m/s at a height of 10m as shown in Table 3.5. This value is used as an input to the wind resource in modeling the hybrid system.

Table 3.5: Monthly average wind speed (m/s) at the site from

10m height	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	4.11	4.01	3.68	3.03	2.95	4.04	4.41	4.08	3.29	2.70	3.14	3.56
Average	**3.58**											

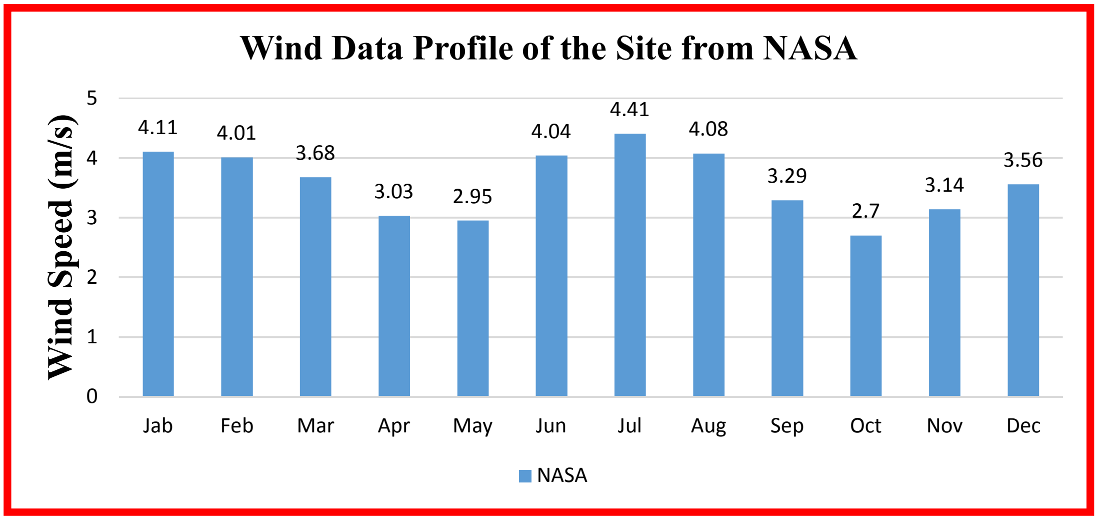


Figure 3.4: Wind Speed data of the study area from (NASA)

3.5 Electricity Load Estimation of the Site

In this thesis work, the electric load demand of the Samara University (Health Clinic) is divided in to the following two major categories like; Primary loads: which includes of (Clinic lighting, TV, DVD, desktop computer, printer, Copy machine, Celling Fan, Air conditioner, vaccine refrigerator, communication radio and microscope. The second load category is deferrable load which include the water supply of the pump to the Health clinic at Samara University. In this thesis, the primary loads and deferrable loads are considered an input to the HOMER Software.

3.5.1 Samara University Health Clinic Loads

Health clinic engaged near to a group of communities is basic service center which is equipped with simple delivery services and minor illnesses to treat surrounding communities at Samara University. The health center would expect to work as health clinic, which will serve stocking medicine, follow up of health condition of the residents including pregnant day to day health condition. The critical ailments that requires special treating will not be served in this health center rather will be referred to the nearby well equipped clinics or hospitals. The main possible appliances that draw electric power in this Samara University Health clinic are low energy light bulbs, Communication radio, television, computer, printer, laboratory microscope, celling fan, Refrigerator non-medical and vaccine freezer. The Samara University health clinic will have eight rooms including reception and toilet rooms lighted with 2 unit of 13W fluorescent lump for each room, which would work for 12 hours from 18:00-6:00 and 2 units of 40W lumps for external lighting, which would operate for 12 hours from 18:00-6:00 hours. It is also proposed to be equipped with 3 unit of 20W microscope to work for 8:00 hours per day from 8:00-12:00

on top of this from 16:00-20:00, 1 unit of 5W of communication apparatus radio assumed to work for 8:00 hours of a day from 08:00-12:00 and from 13:00-17:00, 1 unit of 100W television which is expected to work for 16:00 hours per day from 08:00-24:00 hours are also suggested for the health clinic at Samara University. Two unit of 60W vaccine freezer operating for 24:00 hours, 2 unit of 300W Refrigerator for non-medical operating for 24:00 hours, 2 unit 300W desktop computer working for 8:00 hours from 8:00-12:00 and 14:00-18:00 hour, 2 unit 330W printer working for 8:00 hour per day (2 hours printing and 6 hours standby) per day. One ceiling fan (75W) per room is also to be installed for air conditioning purpose for 24 hours. The health clinic at Samara University has one coffee house requires one 1.5 kW electric stove operating 7:00-8:00, 10:00-11:00 and 12:00-15:00, two 11W CFL lamp for the house and one 11W CFL lamp for external lighting operating 18:00-22:00 is also considered. Three unit of 5.2 kW Air conditioner (1 unit of 18,000 BTU Royal Air) to work for 10 hours (due to the desert of the site) has been installed at the Samara University Health Clinic. In addition to this, Samara University Health Clinic has some medical equipment's. Among these, 2 unit of 88 W Blood Chemical Analyzer to works for 4:00 hours of a day from 7:00-11:00 hours, 1 unit of 200 W CD4 Machine which operates for 4:00 hours of a day from 7:00-11:00 hours, 1 unit of 230 W Hematology Analyzers working for 4:00 hours from 7:00-11:00 hours.

The highest electrical energy load of the Samara University health Clinic will be gained from the Air conditioner which is 15.6 kW. Thus, the daily energy consumption by the Samara University health Clinic is 211.6 kWh and it is summarized below in Table 3.6.

3.5.2 Estimation of Deferrable Load of the Site

Deferrable load is the load that should be fulfilled after the primary load demand is supplied except in especial cases such as when water tank left empty below the required level, regardless of the time when. It is also called as secondary load, as it is not constrained with time to deliver. Some of the activities performed by the deferrable are water pumping, ice making and water heating. Loads are actually considered as deferrable due to the nature of the load they are associated with storage mechanisms. The deferrable load is prioritized after the fully satisfaction of the primary load. The storage capacity (kWh) of the pump is the electricity demanded to fill up the water storage tank because the electricity is supplied for other activities during the time of no pump operation.

In this thesis the supply of water was considered into a common central area to all eight rooms of the health clinic at Samara University, meaning there will no water pipe distribution to each room of the clinic. The aim is to cater water to the community water distribution midpoint, health clinic. In the paper [33] it is stated that the quantity of water for the health clinic is being 2.4m^3 per day. To satisfy the quantity of water for the health clinic at Samara University, size of pumps would be selected based on their power capacity and discharge rate. 2 units of pumps that draw electrical power of 550W with a discharge capacity of 45 liter/min operating for 8:00 hours per day would be installed to provide water for the community service centers (health centers). The total power drawn by the pumps is about 1.1 kW. Community services was suggested for 3 days water storage capacity and electricity consumption drained by the pumps to fill the reservoir is about 26.4 kWh.

Water provision to the central distribution reservoir for household's usage would be pumped throw 6 units of pumps with rating capacity of 550W that delivers 45litter/min of water. Pumps could run for an average of 7:00 hours per day. For this case water storage capacity for 3 days is also recommended. The energy storage capacity can be calculated as follows.

Energy storage capacity= № of pups rating capacity of pumps* storage days *running hours per day

Table 3.6: Samara University Health Clinic Electricity Consumption

Appliances	Quantity	Power Rating (kW)	Run-Time (Hr./day)	Peak Load (kW)	kWh/day
Room Lighting	16	0.013	12	0.208	2.496
External Lighting	2	0.04	12	0.08	0.96
Communication Radio	1	0.005	8	0.005	0.04
Electric Stove	1	1.5	5	1.5	7.5
Television	1	0.1	16	0.1	1.6
Desktop Computer	2	0.3	8	0.6	4.8
Printer	2	0.33	8	0.66	5.28
Laboratory Microscope	3	0.02	8	0.06	0.48
Vaccine Freezer	2	0.06	24	0.12	2.88
Refrigerator for non-medical	2	0.3	24	0.6	14.4
Air-Conditioner	3	5.2	10	15.6	156
Ceiling Fan	7	0.075	24	0.525	12.6
CD4 Machine	1	0.2	4	0.2	0.8
Blood Chemical Analyzer	2	0.088	4	0.176	0.704
Hematology Analyzer	1	0.23	4	0.23	0.92
Total					211.46

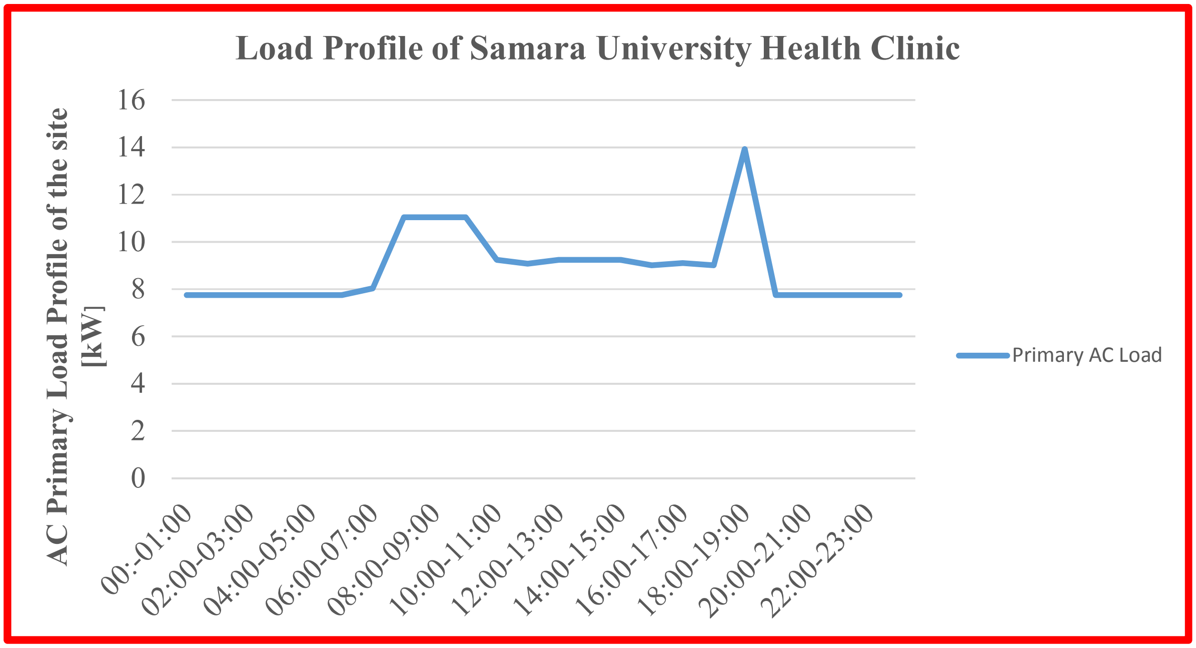


Figure 3.5: Primary Load Profile of the Site

Table 3.7: Load Summary of the Study area

AC Primary Load				Deferrable Load		
Annual Average (kWh/day)	Average (kW)	Peak Load (kW)	Load Factor	Annual Average (kWh/day)	Storage Capacity (kWh)	Peak Load (kW)
212	8.83	24	0.37	3.5	11.55	0.8

Table 3.7 indicate that, the total annual scaled average primary load of 212 kWh/day, annual peak load of 24 kW and a load factor of 0.37 is resulted from HOMER after simulation.

CHAPTER FOUR

OPTIMIZATION OF HYBRID POWER GENERATION SYSTEM USING HOMER SOFTWARE

4.1 Introduction

The main renewable sources of energy considered in this thesis are solar and wind. Diesel generator as backup and battery bank as energy storage systems are employed in the energy system due to the intermittent nature of the renewable sources. The wind turbine and diesel generator produces AC type voltage as they are alternating in nature, whereas the PV panels output is DC type. Bidirectional converter is fitted in this configuration which is basically used to charge the battery by changing the alternating current type load into DC, moreover supplies alternating current type electricity back from battery to AC load consumers. All loads required by consumers are AC type. Some of the input values into the software are expressed in size and in quantity. Wind turbines and batteries are the power system components which vary in quantity, and solar PV, diesel generator and converter are other components that vary in size. This chapter is to illustrate the input variables that will help for optimization and modeling of the system and to brief some resulted value related to the inputs. Detail of the components of the power system and the electricity load of the Samara University Health Clinic has already explained in the previous chapters.

4.2 Modeling of Hybrid Energy System with HOMER

HOMER software is used as a tool to accomplish in this thesis work. As earlier, the main objective of the study is to design and model hybrid PV–Wind based standalone power generation systems to meet the load requirements of the Samara University Health Clinic specified earlier. A schematic diagram of the standalone hybrid power supply system sought is shown in figure 4.1 and its representation by HOMER is shown in Figure 4.2. The power conditioning units are DC-DC and AC-DC converters, with the sole purpose of matching the PV and wind turbine generated voltages to that of the bus voltage at the DC Centre. The AC load is of both primary and deferrable types.

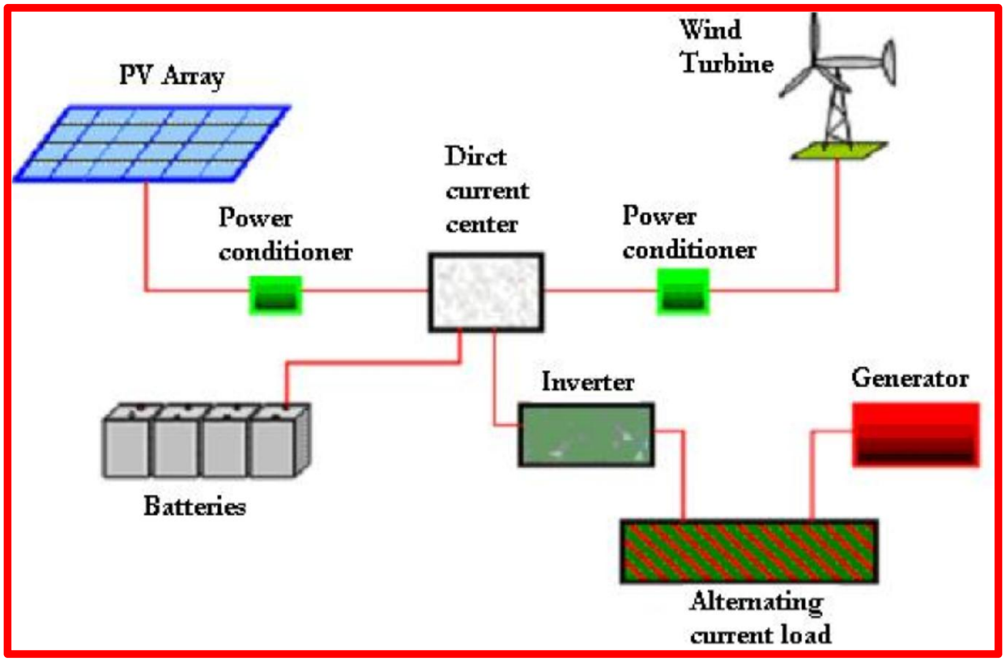


Figure 4.1: Modeling of Stand-alone hybrid PV/Wind Power Generation System

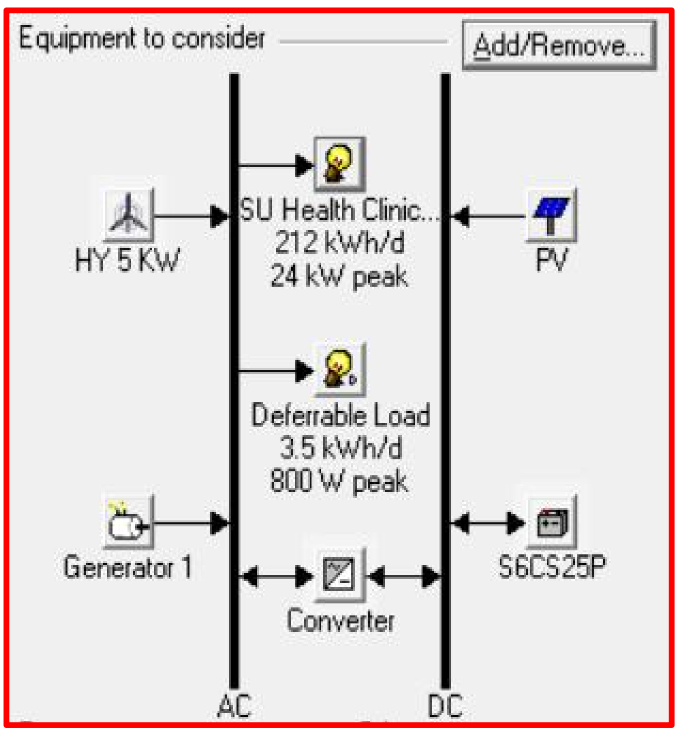


Figure 4. 2: HOMER diagram for the hybrid PV-wind –generator-battery-converter set-up

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

4.3 Electricity Load Input to the HOMER

Next to the selection of the components technology from the library of HOMER software, the electricity load is the first to be entered in to the modeling tool. The primary load input, which was determined in chapter three in section 3.5.1, has entered on hourly basis (24 hours data) and there after the software modeled the peak load.

Moreover it also synthesized the monthly load from the 24 hour input data. In this thesis the primary electricity load described as inputs has categorized into the following; the weekend load, the load for August, January and July, and the load for the rest of the months. Whereas the deferrable load needs to be described as average monthly basis. The diurnal variation of the primary load profile of the community is depicted in Figure 4.3 generated by HOMER after inserting the 24 hour load data. Most of the appliances employed in study area operate with alternating current voltages and hence AC loads were suggested in the load estimation in chapter three. The load profiles have almost the same daily demands, peak demands, average demands, base demands.

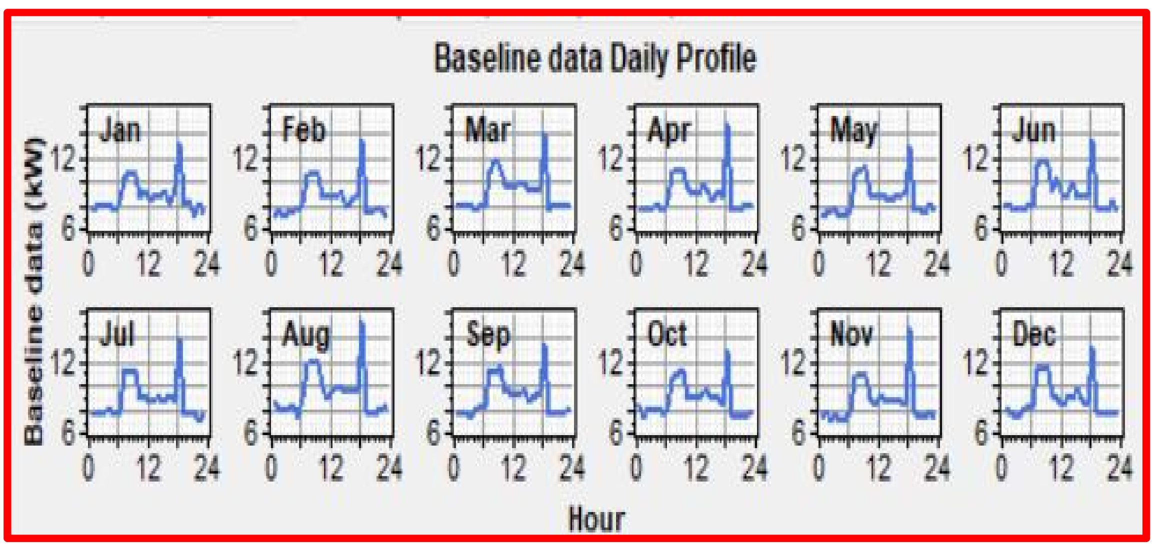


Figure 4.3: Diurnal Variation of Primary Load Profile of the Site

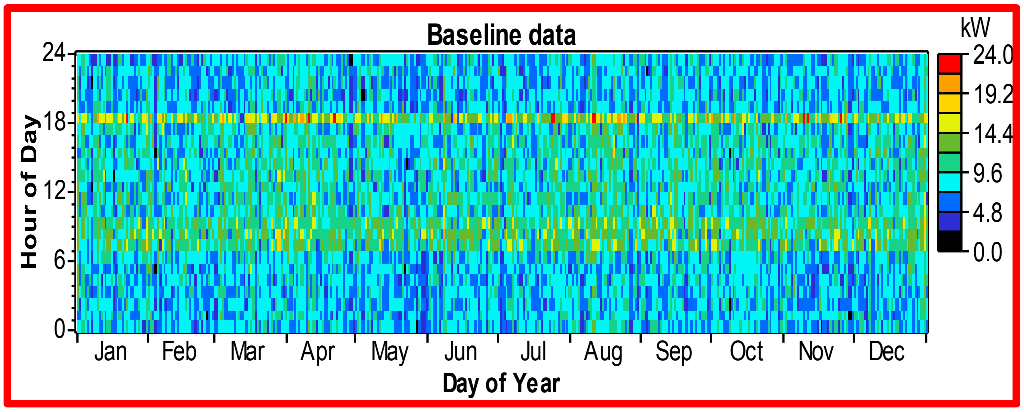


Figure 4.4: Data-Map of the Monthly Primary Load Profile of the Site

The primary load demand of the study area is also indicated in figure 4.4 the electricity load profile varies during the day. The load is rises during the morning time from 7:00-10:00 hours and at the night time from 18:00-19:00 hour took the maximum power demand than other hours.

4.4 Resource Assessment input to the HOMER

The term resource applies to anything coming from outside the system that is used by the system to generate electric power. That includes the four renewable resources (solar, wind, hydro, and biogas) as well as any fuel used by the components of the system. Renewable resources depend extremely on location. The solar resource depends strongly on latitude and climate, the wind resource on large-scale atmospheric circulation patterns and geographic influences, the hydro resource on local rainfall patterns and topography, and the biomass resource on local biological productivity. Moreover, at any one location a renewable resource may exhibit strong seasonal and hour-to-hour variability. The nature of the available renewable resources affects the behavior and economics of renewable power systems, since the resource determines the quantity and the timing of renewable power production. The careful modeling of the renewable resources is therefore an essential element of system modeling.

In this thesis work solar and wind renewable resources are used to generate electric power at Samara University Health Clinic.

Solar Resources: The solar resource raw data inputting to the HOMER software is the average global horizontal radiation measured in 10 minute time interval over 22 years from the NASA data base of the study area. On top of the solar resources data the latitude and longitude of this area would also be used as an input. The time zone is another parameter to be set. The study area is located at latitude: 11.45 N, longitude: 41 E, and with time zone of GMT +3:00. In order to get how much power is generated by the solar PV it requires inputting measured solar resources data in units of kW/m^2 into HOMER software.

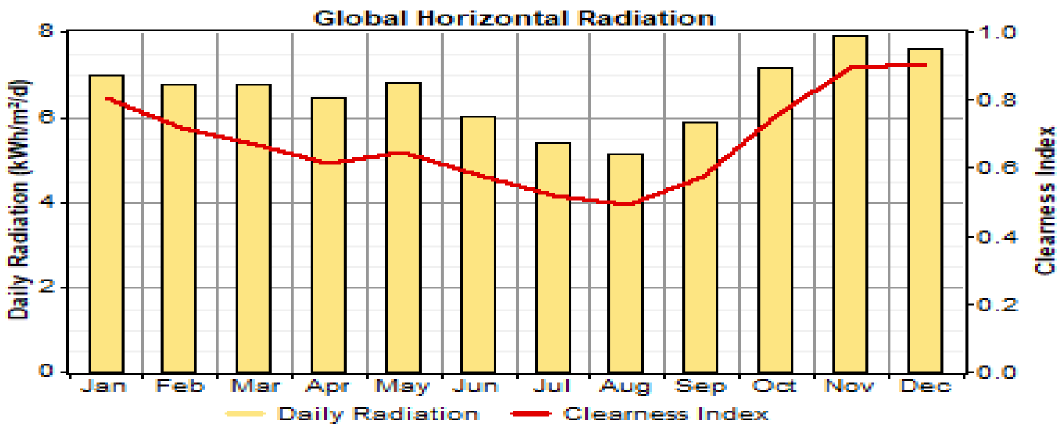


Figure 4.5: Monthly Average Solar Radiation of the Site [NASA]

Figure 4.5 shows the clearness index, the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere, which HOMER generated from global solar radiation for the analysis. Typical values for the monthly average clearness index range from 0.491 (a cloudy month) to 0.905 (a very sunny month).

Wind Resources: Similar to the solar sources data the wind speed was also measured at the same area in the same year from NASA data base. Wind speed was measured at 10 meter height data used in this thesis works. The time interval of data measurement was 10 minutes at 10 meter height. Share of electricity generated by wind turbine is calculated by the software, thus 10 minute wind speed data was inputting into HOMER for the determination of energy production from wind sources. In addition to the wind speed resources the altitude above sea level, the anemometer height are the required inputs too. The anemometer height, which is the height above ground at which the wind speed data were measured, has been defined. The elevation of the site above sea level, which is used to calculate the air density according to equations 2.34 and 2.35, is also defined.

The Weibull shape factor is a measure of the distribution of wind speeds over the year. The autocorrelation factor is a measure of how strongly the wind speed in one hour tends to depend on the wind speed in the preceding hour [42]. For complex topography the autocorrelation factor is (0.70 - 0.80) while for a uniform topography the range is higher, (0.90 - 0.97). A typical range for the autocorrelation factor is 0.8 – 0.95 [42]. An average value of 0.85 is used in this thesis because the selected areas are of averagely uniform topography. The diurnal pattern strength is a measure of how strongly the wind speed tends to depend on the time of day [42]. Typical values for diurnal pattern strength range from 0 to 0.4. A value of 0.25 has been selected for calculations. The hour of peak wind speed is the hour of the day that tends, on average, to be the windiest throughout the year. The typical range for the time of peak wind speed is 14:00-16:00 [42]. This has also been observed in the available raw data for some of the months. In addition to this, the software has been run for different times between 14:00 and 18:00, the results have been checked against the measured data and the time of 15:00 has been chosen for the calculations.

The monthly average wind speed for site, together with other related data, such as values of Weibull parameter k, diurnal pattern, autocorrelation, etc., was fed into HOMER. Figure 4.6 shows the wind speed resource data measured at 10 m height.

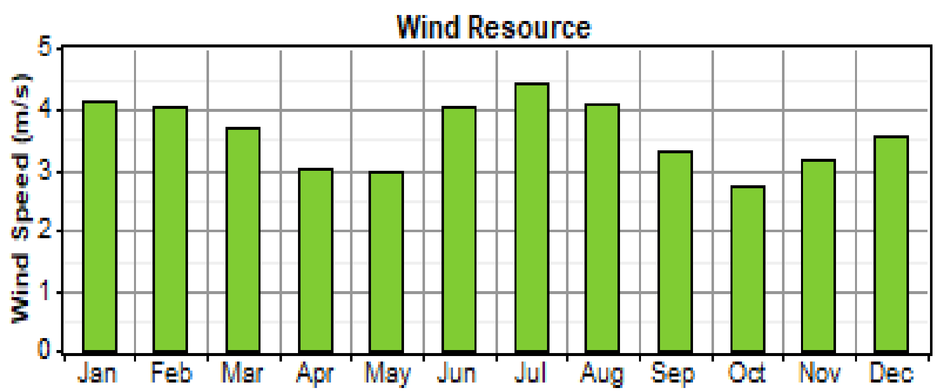


Figure 4.6: Monthly Average Wind Speed at 10 Meter [HOMER]

4.5 Materials Cost and Size Specifications of Hybrid System Components

The basic criterion related to the selection of the power system components in this thesis work is the cost of components, as the main purpose of the work is searching the optimum power system configuration that would meet the demand with minimum NPC and COE. The estimation of the components cost was made based on the current cost available on market.

Initial capital cost of components: It is the total installed cost deployed to purchase and install the component at the commencement of the project.

Operation and Maintenance cost (O & M cost): It is the cost accounted for maintenance and operation of the system. The entire scheme components considered in this thesis has different operation and maintenance costs. Miscellaneous O&M costs considered by HOMER are like emission penalties, capacity shortage penalty and fixed operation and maintenance costs.

Replacement cost: This is the cost required to replace wear out components at the end of its life cycle. This cost is different from initial cost of the component, due to the following reasons. At the end of its lifecycle not all of the spares of the component need to replace, Costs from donors may eliminate or can reduce initial cost, however replacement cost may not account travel costs but initial costs do.

4.5.1 Solar PV Size and Cost

After surveying different products focusing on the cost provided the following panel was chosen. The reason for choosing the product from the stated company is due to its low cost delivered as long as efficiency is not a big concern here. The solar panel considered was a 1kW, which is with 4 number of solar module having 250 W capacities from Trina-solar Company. The selected panel was poly-crystalline silicon made which is known as TSM 250-PA05 model with an efficiency of 14 to 15 %, the price varied from \$1.16 to \$1.31/watt [43]. In this thesis work the installation cost is taken as 40% of the PV price and replacement cost is taken as 70% of initial capital cost taking into account the reduction of PV cost trends. The author considered the current installation cost of PV the average value (\$3000/kW) of the upper and lower limit values and the other input costs, sizes and lifespan of the PV are displayed in Table 4.1.

Table 4.1: Size and Cost of PV Panel

PV Size (KW)	Capital Cost ($)	Replacement Cost ($)	O & M Cost ($/year)	PV life (years)	Sizes Considered (KW)
1	1200-4500	860	0	25	0,5,10,15,20,25,30,35,40,45,50,55,60,100,150

There is no any tracking system considered in this thesis, thus the system is modeled as fixed tracking mount at ground. Derating factor is a term accounted for both PV systems efficiency and charge controller efficiency since charge controller is not being designed by HOMER. This factor is to be subsidized for dust, high temperature, shading, wiring losses, and so on. The size of the PV panels input in to HOMER is in kW, not in m^2, thus its efficiency is not taken into account as an input also. The azimuth angle or orientation and angle of inclination of the PV panel are the two important factors that should be considered during solar system design. For sufficient amount of electricity generation at the study area the ideal orientation of solar PV is due south, but however it is also possible to face south-east or south-west, there will actually small loss due to the shift of west or east of south. The following parameters were considered for modeling of the power system like; the derating factor was taken as 85%, ground reflectance was also considered as 20%, slope 11.45 (latitude of the location) and azimuth 0^0 (south orientation).

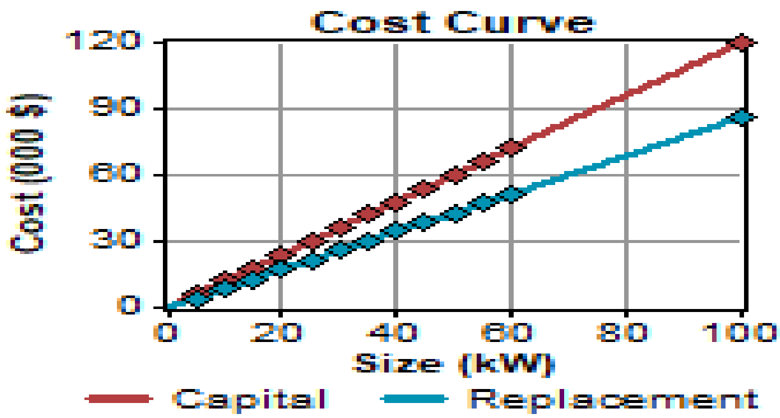


Figure 4.7: Cost Curve of Solar PV [HOMER]

4.5.2 Wind Turbine Size and Cost

A wind turbine is a device that converts the kinetic energy of the wind into ac or dc electricity according to a particular power curve, which is a graph of power output versus wind speed at hub height.

Each hour, the power output of the wind turbine is calculated in a four-step process. First, the average wind speed for the hour at the anemometer height is determined by referring to the wind resource data. Second, the corresponding wind speed at the turbine's hub height is calculated using either the logarithmic law or power law. Third, the power output of wind turbine is calculated at that wind speed referring to its power curve assuming standard air density. Fourth, that power output value is multiplied by the air density ratio, which is the ratio of the actual air density to the standard air density.

In addition to the turbine's power curve and hub height, the expected lifetime of the turbine in years, its initial capital cost in dollars, its replacement cost in dollars, and its annual O&M cost in dollars per year has been specified.

The primary criterion for the selection of the wind turbine is its cost. The wind turbines have been selected from different sources; the various wind turbine websites and those suggested by the HOMER program itself based on their costs. Other selection criteria used are: the type of current they generate (ac or dc), how low the cut-in wind speed is, and for what application the wind turbine be used for. The cut-in wind speed is another is primary criterion, if not import than cost, as the wind resource at the site is not very high. The type of current they generate, whether ac or dc, is also considered as it have impacts on the size of the inverter. As the load equipment's assumed for the Health Clinic at Samara University is of an ac type a wind turbine that generates ac current has been chosen. As the aim of the research is to supply electric energy to remotely located communities at Samara University Health Clinic, the wind turbines selected should be those which are applicable for home or off grid applications.

Based on the selection criteria mentioned above, different wind turbines have been tested by running the simulation several times. From those wind turbines which were candidates for this application, the HY-5 type has been found to be the best in terms of the cut-in wind speed and also in respect to other criteria mentioned earlier. This wind turbine was obtained from those wind turbine website (www.huayingwindpower.com) owned by Hulk Energy Machinery [10]. The turbine is a 5 kW turbine commonly available on the market such as the one for which the power curve is given in Figure 4.8.

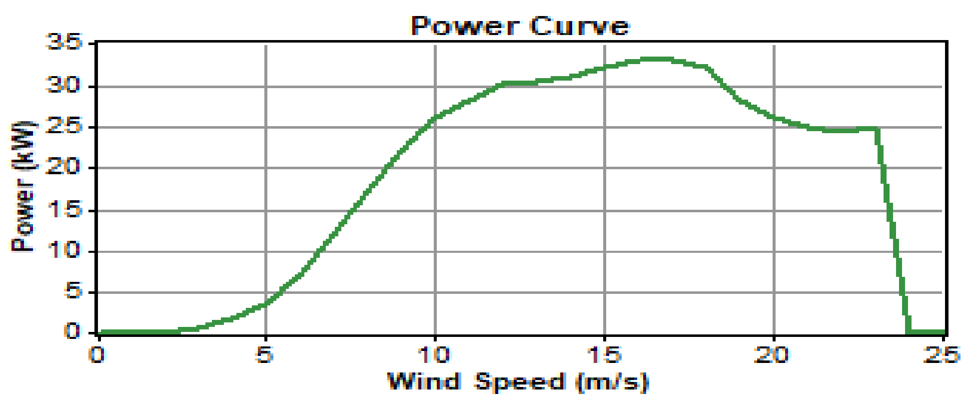


Figure 4.8: Power Curve of HY-5 KW type Wind Turbine [HOMER]

In this thesis installed cost of wind turbine was taken about $1026/kW and replacement cost of the wind turbine considered in this case is about 67% of capital cost after 20 year service life. In addition to this, the operation and maintenance cost is taken as 2% of capital cost per year is also considered in this thesis works. Below in Table 4.2 wind turbine parametric inputs into HOMER are given.

Table 4.2: The Wind Turbine Parametric Inputs into HOMER

Capacity (KW)	Capital Cost ($)	Replacement Cost ($)	O & M Cost ($/year)	Life (years)	Tower height (m)	Quantity
5	5130	3420	103	25	25	0,1,2,3,4,5,10,20

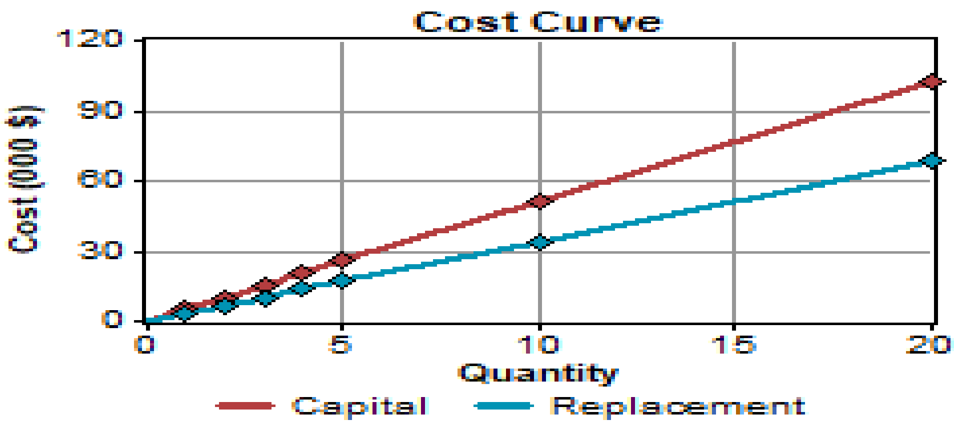


Figure 4.9: Cost Curve of Selected Wind Turbine

4.5.3 Cost and Sizes of the Battery

Like the other hybrid power system components, input parameters inserting into the HOMER software are cost and number of batteries. Note the following definitions; the battery rated/nominal capacity is the quantity of energy discharged from battery. Minimum state of charge of batteries is the state of charge below which the battery is never discharged to prevent from damage. From 30-50 percent is the recommended minimum state of charge. Round-trip battery efficiency is the energy flow into the battery that can be extracted for later use. Lifetime throughput is the energy quantity that circulated in the battery through its lifelong. The storage battery Surret 6CS25P selected in the proposed system from the manufacturer Rolls/Surret, which is given in HOMER tool library. Since, this type of battery used in the selected Samara University Health Clinic site with 4 batteries in one string of 24 Volt. Thus, the selected battery has the following characteristics obtained from the modeling tool. The nominal capacity of the selected battery is 1156Ah (6.94kWh) with nominal voltage of 6V for single battery and the amount of energy stored in a single battery is 6.94kWh, maximum charge current is 41A, lifetime throughput of 9645 kWh was considered, minimum state of charge is accounted for 40%, round-trip battery efficiency is taken as 80%. Replacement cost for battery is assumed about 67% of its capital cost.

- ✓ Capital Cost of Batteries:$833/battery
- ✓ Replacement Cost: $555/battery
- ✓ Operation and Maintenance Cost: $15/year
- ✓ Quantities of Batteries considered: 0,1,4,8,12,16.20,24,32

The battery bank's capital and replacement costs in dollars, and the O&M cost in dollars per year have been specified. Since the battery bank is a dispatchable power source, its fixed and marginal cost of energy is calculated for comparison with other dispatchable sources. Unlike the generator, there is no cost associated with ''operating'' the battery bank so that it is ready to produce energy; hence its fixed cost of energy is zero. For its marginal cost of energy, the sum of the battery wear cost (the cost per kWh of cycling energy through the battery bank) and the battery energy cost (the average cost of the energy stored in the battery bank) are used. The battery wear cost is calculated as [HOMER, ver. 2.68 Beta].

$$C_{bw}=\frac{Crep,batt}{Nbatt\ {*}Qlife{*}\sqrt{\eta rt}} \tag{4.1}$$

Where:

$C_{rep,\ batt}$, is replacement cost of the battery bank ($) and η_{rt} is battery roundtrip efficiency (%).

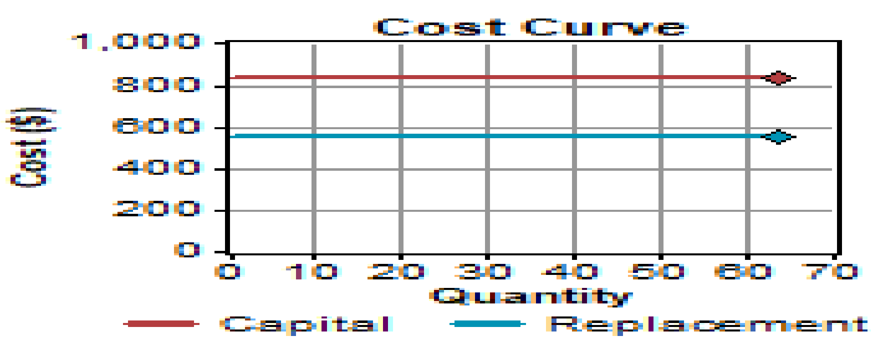


Figure 4.10: Cost curve for the proposed battery at selected site [HOMER]

4.5.4 Diesel Generator Size and Cost

Diesel generators are available in a wide range, however different suppliers cater different cost evidences and this makes challenging to compare. Diesel generators do not allow running at less than the minimum load ratio of 30%. Generators operations lifetime is measured in hours. Since generators lifetime depend on fuel quality and operating conditions this makes difficult to get lifetime data. The well-known engines used to produce electricity are internal combustion engines of which diesel engines last long than gasoline powered engines [9]. Frequent load variation results in the poor performance of generator and larger fuel consumption and higher O&M cost accordingly higher cost of energy would be obtained. In this thesis, after surveying of various diesel generator suppliers, the selected one is from Cummins, supplied by Guangzhou Kanghai M&E Equipment Co.Ltd. Generator size is among the input sizes to consider working with wind and solar PV to meet the load requirement in the case of no wind flows and no sunshine times. Thus range of size of the generator could be less than the peak load demand as it would function in collaboration with the renewable sources and battery bank. The choice of diesel generator accounts the constraints of power delivering capacity, the load type, cost efficiency and fuel consumption. The cost of diesel generators available in the market varies from $250 to $450/kW. The selection of a particular generator size deliberates the constraint of both cost effectiveness and capacity of delivering the required power. The optimal and appropriate capacity of generator could be picked after simulation. In this paper the cost of generator was suggested as $450/kW, thus the related costs are listed as follows.

- ✓ Capital cost was taken as $9000
- ✓ Replacement cost: $9000
- ✓ Sizes of Gen set considered are: 0,6,10,15,20,25,30
- ✓ The minimum load ratio of 30% of rated load was accounted
- ✓ Operation and maintenance cost was around $0.5/hr.

4.5.5 Power Converter Size and Cost

A converter needs to maintain flow of energy between AC and DC power system components. The rated power of the inverter should be equal to or larger than the peak load but since the load will supply both from the renewable and non-renewable, even below the peak would be installed.

Converter sizes considered are: 0, 10, 15, 20, 30, 35kW; Capital cost of converter is taken as $700, replacement cost is about $550 which is 79% of the capital cost, efficiency of converter is around 90% and the lifetime of the converter will end for 15 years.

4.6 Other Inputs that Affect Power System Optimization

4.6.1 Economics Inputs

HOMER is provided also with economic inputs window, thus to get the Total Net Present Cost (NPC) of the system. Economic input parameters include like project lifetime, annual real interest rate, capacity shortage penalty, fixed capital cost, and system fixed O&M cost. System fixed capital cost is the cost that engaged at the beginning of the project implementation. Despite of the size and scheme architecture, the system fixed capital cost and O&M cost are considered as fixed values. Though these values have an effect on the NPC of each system however it affects them all at the same rate, thus they have no effect on the power system ranking. In this thesis; fixed capital cost, fixed O&M cost and capacity shortage penalty was taken as zero.

Real interest rate is the difference between inflation rate and nominal interest rate. HOMER discounted the capital cost of each components of the power system in to annual cost by amortizing the lifelong time of the components using real interest rate. It does not consider inflation; rather it assumes prices will rise at the same rate during the life long period of the power system. To compare the economics of the power system configuration with renewable and non-renewable sources of energy, the modeling tool would consider the following additional inputs. The lifetime of the off-grid power system is designed to end for 25 years long with generating capacity to meet the demand and the annual real interest rate is taken as 6% that is used to calculate the NPC of the project.

4.6.2 Constraint Inputs

Constraint is a condition set by the power system designer in which the power providing scheme should satisfy to be feasible. An infeasible power system is a system that does not meet the constraints set by the modeler. It should be noted that capacity shortage is a power shortfall made between the needed operating capacity and system actual operating capacity of the scheme at certain time period. The needed operating capacity includes the surplus demand and operating reserve loads. The operating reserve is safety margin for excess electrical energy generating capability that ensures reliable provision of electricity, despite of the load, solar and wind fluctuations. HOMER is smart enough to calculate the capacity shortage of any power system architecture per annum. Excess electricity is produced due to either excess generation of power from renewable sources above load demand beside to this when battery bank is fully charged so unable to store the produced energy. For this thesis paper case the following constraint inputs are considered and no thermal load is accounted for this site of interest. Maximum annual capacity shortage of 0.1%, minimum renewable fraction 50%, operating reserve, as percentage of hourly load 10% and annual peak load of 0%, operating reserve, as percent of renewable output, solar power output: 25% and wind power output of 50%.

4.6.3 Emission and System Control Parameters

In Ethiopia, there is no framework that leads to penalizing rules for emission. Although emission penalty is already applied in the developed world, however as the African continent is considered as unindustrialized continent emission penalty is not adopted yet. In this thesis no emission penalty is considered at all for the system. The power flow control mechanism is an important input parameter for the power system. The control strategy is simple when the hybrid system includes PV, wind and battery components, however it becomes complex when generator is included in the hybrid system, as it is important to know how to charge batteries and how to supply the power either from the batteries or from generator.

Cycle charging: batteries are to be charged to the set point state of charge when the system starts to charge with no interruption until it will reach the set point state of charge. It helps to reduce the generator number of start cycles, charge and discharge cycles of the battery bank and also the time the battery waste at minimum state of charge.

Load following (zero charging strategy): this means batteries do not get charged by the diesel generator, it gets maximum charging time when renewable sources gets higher, meaning when generated power is greater than the load demand.

Set-point state of charge (SOC) 80%: This would help to minimize the operation cost of the power system however during the load following strategy this percentage would be zero.

Table 4.3: Summarized Inputs to the HOMER Software

Materials	PV Module (KW)	Wind Turbine	Diesel Generator	Battery (Surrete 6CS25P)	Convertor
Size (KW)	1	5	15	1,156 Ah	1
Capital ($)	1200-4500	5130	9000	833	700
Replacement ($)	860	3420	9000	555	510
O & M Cost ($/year)	0	103	0.5	15	100
Sizes Considered (KW)	0,5,10,15,20, 25,30,35,40, 45,50,55,60,100,150	______	0,6,10,15, 20,25,30	________	0,10,15,20 30,35
Quantities Considered (KW)	__________	0,1,2,3,4, 5,10,20	________	0,1,4,8,12, 16,20,24,32	_______
Life Time	25 years	25 years	20,000 hrs.	9,645 kWh	15 years

For the analysis, diesel is considered for the generator fuels with prices used are 0.5, 0.64 and 1.2 US dollars per liter. The current diesel price considered in Ethiopia is 0.64 USD per liter (15-July-2019). Inverter and rectifier efficiencies are assumed as 90%. The project life time is 25 years, and the interest rate is assumed to be the present rate, 6%. The HOMER software generates the results which are a list of feasible power supply systems sorted according to their net present cost. Furthermore, sensitivity variables, such as the range of wind speeds, range of radiation levels, PV panel price, and diesel price are supplied, and then the software is tuned for optimum results.

4.7 Sensitivity Variables

The modeling tool permits to take an account for future dynamic changes, meaning increasing or decreasing demands, renewable and non-renewable resources fluctuations. Sensitivity parameters chosen by the modeler would tell how sensitive the power system is for each change of the input variables. The benefit of putting sensitivity analysis is to define the uncertainty pertaining with the power system, when the modeler is not quite sure about the values of the components considered choosing several parameters to ensure the likely range and see how the system changes. When considering large number of sensitivity variables, it should be noted that the computational time of HOMER takes too much to complete the simulation which is very challenging to the software. The computational time depends on the quantity and sizes of the power system components and the sensitivity number of variables. Thus, this all combinations prolongs the running time, which is the limitation of the software. Although the accuracy of simulation result increase with the increase of the number of sensitivity variables, computational time is long and it requires larger memory computer. Taking the limitations into account in this thesis work the sensitivity cases are given in Table 4.4.

Table 4.4: Sensitivity Analysis Variables

Samara University Health Clinic Load (KWh/day)	Wind Speed (m/s)	Diesel Prices ($/L)
212 and 350	3.58, 4.00	0.5, 0.64, 1.2

CHAPTER FIVE
RESULT AND DISCUSSION

This chapter would give the details of the optimization results for the selected hybrid power system of a typical Samara University Health Clinic. The system was designed with the help of HOMER with no given much concern to the efficiency of the components.

HOMER software is used for simulating the hybrid system containing PV-Wind and diesel generator and storage battery as a backup. To get optimal combination of the hybrid components which could be implemented as a hybrid system model, the simulation model was run repeatedly by varying parameters that have a controlling effect over the output. These parameters are given in Table 4.3. Besides, variable of wind speed and prices of PV modules have been used for sensitivity analysis.

The software displays the result for the inputs in either an overall form in which the top ranked system configurations are listed according to their net present cost(NPC) or in categorized form in which only the most cost effective configuration is considered from each system type. Table 5.1 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 A-1). From the simulation result, different optimum and feasible system configurations with different level of total NPC are obtained. From Table 5.1, the levelized COE ranges from \$0.091/kWh to \$0.100/kWh.

The current energy tariff of Ethiopia is \$0.06/kWh. Global electricity tariff varies in a wide range. For instance, Canada has an energy tariff of \$0.0618/kWh while Denmark has \$0.33/kWh [58]. All feasible system types shown in both Table 5.1 and Table 5.8 below have a levelized COE slightly higher than the national tariff. However, they are within the range of global tariff.

5.1 Systems Optimization Result

Table5.1: Truncated Top ranked Overall Optimization Results from HOMER

Sensitivity Results | Optimization Results

Sensitivity variables

SU Health Clinic Load (kWh/d) 212 | Wind Speed (m/s) 3.58 | D Price ($/L) 0.64 | PV Capital Multiplier 0.6

Double click on a system below for simulation results.

PV (kW)	Wind	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	D (L)	Gen (hrs)
35	3	6	64	15	LF	$ 55,523	2,792	$ 91,217	0.091	1.00	0.00	1,146	206
40	2	6	64	15	LF	$ 53,993	2,941	$ 91,587	0.091	1.00	0.00	1,514	264
45	2	6	64	15	LF	$ 57,593	2,745	$ 92,682	0.092	1.00	0.00	1,226	222
40	3	6	64	15	LF	$ 59,123	2,662	$ 93,157	0.093	1.00	0.00	956	178
30	4	6	64	15	LF	$ 57,053	2,846	$ 93,439	0.093	1.00	0.00	1,075	195
35	4	6	64	15	LF	$ 60,653	2,701	$ 95,178	0.095	1.00	0.00	861	163
50	2	6	64	15	LF	$ 61,193	2,676	$ 95,405	0.095	1.00	0.00	1,125	208
45	3	6	64	15	LF	$ 62,723	2,616	$ 96,163	0.096	1.00	0.00	887	168
40	2	6	64	20	LF	$ 57,493	3,031	$ 96,244	0.096	1.00	0.00	821	126
35	3	6	64	20	LF	$ 59,023	2,955	$ 96,796	0.096	1.00	0.00	557	88
25	5	6	64	15	LF	$ 58,583	2,994	$ 96,860	0.096	1.00	0.00	1,142	201
45	2	6	64	20	LF	$ 61,093	2,802	$ 96,915	0.096	1.00	0.00	485	75
30	5	6	64	15	LF	$ 62,183	2,792	$ 97,877	0.097	1.00	0.00	845	158
35	3	10	64	15	LF	$ 57,923	3,137	$ 98,024	0.097	1.00	0.00	1,700	196
40	4	6	64	15	LF	$ 64,253	2,651	$ 98,138	0.098	1.00	0.00	788	153
40	3	6	64	20	LF	$ 62,623	2,796	$ 98,365	0.098	1.00	0.00	324	53
55	2	6	64	15	LF	$ 64,793	2,647	$ 98,636	0.098	1.00	0.00	1,082	203
30	4	6	64	20	LF	$ 60,553	3,023	$ 99,197	0.099	1.00	0.00	506	81
40	4		64	20	CC	$ 64,153	2,742	$ 99,208	0.099	1.00	0.00		
40	4		64	20	LF	$ 64,153	2,742	$ 99,208	0.099	1.00	0.00		
50	2	6	64	20	LF	$ 64,693	2,715	$ 99,406	0.099	1.00	0.00	357	57
50	3	6	64	15	LF	$ 66,323	2,589	$ 99,424	0.099	1.00	0.00	848	163
40	3	10	64	15	LF	$ 61,523	2,979	$ 99,601	0.099	1.00	0.00	1,469	174
50	3		64	20	CC	$ 66,223	2,639	$ 99,961	0.100	1.00	0.00		
50	3		64	20	LF	$ 66,223	2,639	$ 99,961	0.100	1.00	0.00		
30	4	10	64	15	LF	$ 59,453	3,178	$ 100,080	0.100	1.00	0.00	1,611	186
30	3	10	64	15	LF	$ 54,323	3,584	$ 100,138	0.100	0.99	0.00	2,351	261

Looking at some of the set up listed above on the truncated overall optimization result form from Table 5.1, we find the following remarkable results. The most cost effective system, i.e. the system with the lowest net present cost, is the PV-wind turbine-generator-battery converter set-up with the generator operating under a load following (LF) strategy (a dispatch strategy whereby the generator operates to produce just enough power to meet the primary load; lower-priority objectives, such as charging the battery bank or serving the deferrable load, is left to the other renewable power sources such as Wind and Solar). For this set-up, the total net present cost (NPC) is $91,217, the cost of energy (COE) is 0.091 $/kWh, contribution from renewable resources is 100%, the amount of diesel oil used annually is 1,146 liters and the generator operates for 206 hours per year.

In this set-up, there is an excess electricity generation of 12%, no unmet electric load and no capacity shortage. The presence of excess electricity generation is not bad since equipment's efficiency was not considered from the initial point. It is also accounted for the operating reserve and the capacity shortage considered by the designer and it may be due to excess generation from renewable sources moreover unable to store by the batteries as a result of batteries fully charged. This could be a best choice for implementation.

The system set-up in the 1st row of table 5.1 is the most cost efficient (based on NPC and COE) system composed of with 35 kW PV, 3 units of wind turbines 5kW each, 6kW diesel generator, 64 units of batteries and 15kW converter. The power regulation mechanism is load following strategy. The summary of the monthly electricity generation trend is given in figure 5.1 below. The largest monthly electricity generation from wind sources is occurred in the whole months except October, as a result electricity generation from diesel generator is minimum almost the whole year, but this reduction is not only contributed from wind sources but from solar sources too.

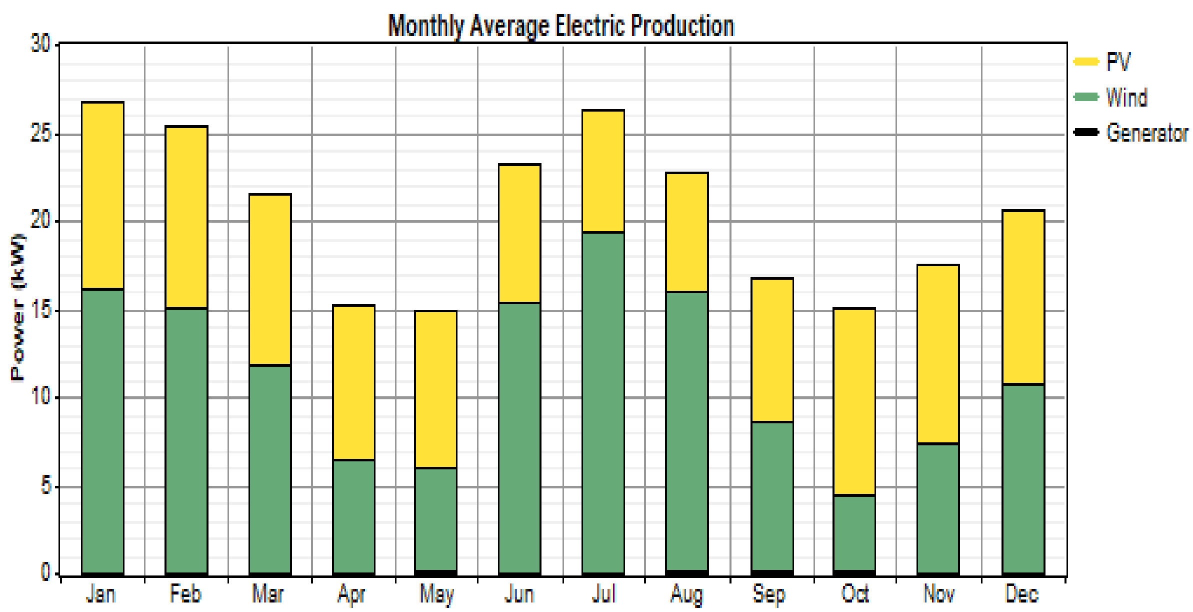


Figure 5.1: Share of Electricity Generation from the Optimum System, 1st row in table 5.1.

The electricity generation by individual power units of the hybrid system and consumptions by primary AC and deferrable load are given in figure 5.2. PV array power production accounts for 44% (79,438kWh/year) whereas wind turbine accounts for only 55% (99,722kWh/year), and diesel generator accounts for 1% (530kWh/year) of total electricity produced by the hybrid scheme. As generation of electricity from wind sources is higher than any other scheme incorporating in the hybrid structure, hence it is considered as the base load of the hybrid assembly.

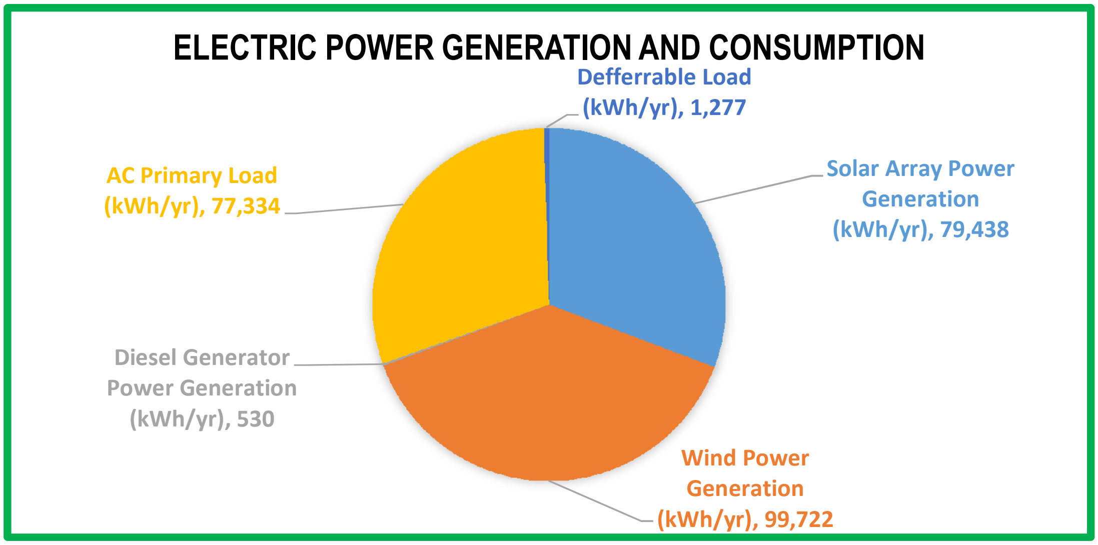


Figure 5.2: Power generation and consumption, from the Optimum System, 1st row in table5.1.

The total power production of this power system setup is 179,690kWh/year, whereas the total electric power consumption of the AC load is about 77,334kWh/year that is 98% of the electricity produced by the hybrid scheme and the remaining 1,277kWh/year (2%) is for deferrable load. Looking into the magnitudes of the power production and consumption of figure 5.1, there is surplus of electricity. Although an excess electricity of 21,562kWh/year was produced, which is 12% of the total energy generated but a capacity shortage of 97.9kWh was experienced during the year**.** Actually this power system architecture indicates that it would enable to cater the demand growth of the community at Samara University Health Clinic in the future. This excess electricity can provide to neighboring villages or introduce small businesses at Samara University to increase the load factor of the power system; consequently the cost of electricity will decrease also.

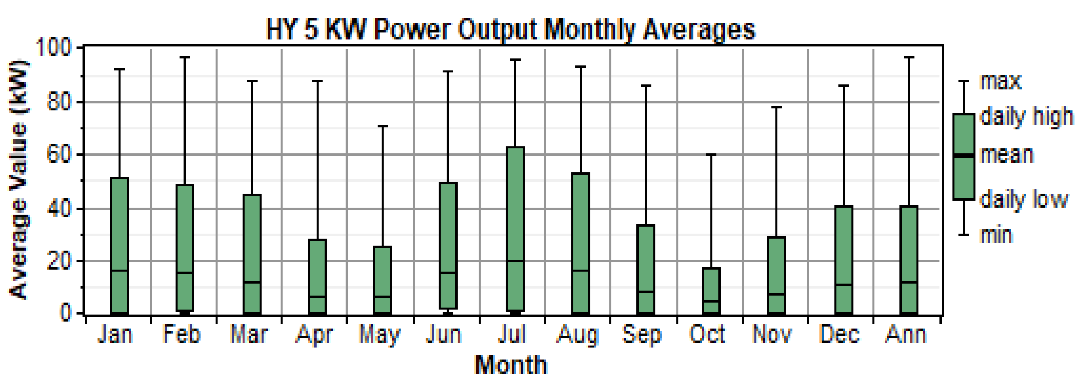


Figure 5.3: Wind Turbine Power output, from the Optimum System, 1st row in table 5.1.

Table 5.2: Wind Turbine Scheme Result

Quantity	Value	Unit
Total rated capacity	15	kW
Mean output	14.4	kW
Maximum output	96.6	kW
Wind penetration	129	%
Hours of operation	7,261	Hr/yr
Levelized cost of Energy	0.0152	$/kWh

The distribution of electricity production by the wind turbines is depicted in figure 5.3 and Table 5.2. As noticed the energy production by wind turbines is relatively higher in summer season this is normally due to the higher wind flow as solar radiation gets lower. Maximum wind power output above 60kW is registered during the whole months except October.

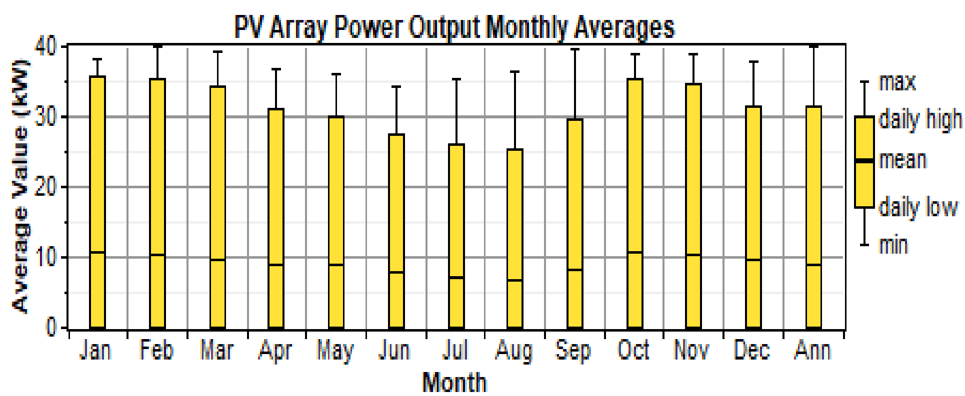


Figure 5.4: PV Power output, from the Optimum System, 1st row in table 5.1.

Table 5.3: PV Scheme Simulation Result

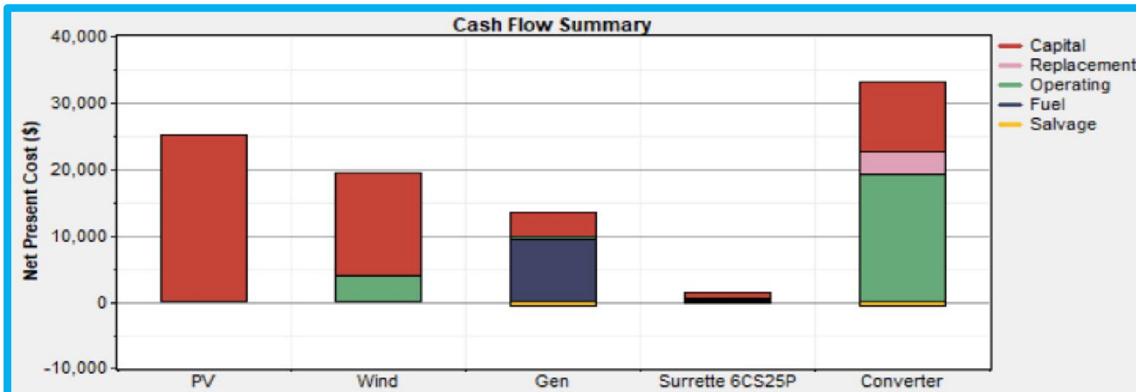
Quantity	Value	Unit
Total rated capacity	35	kW
Mean output	9.1	kW
Maximum output	39.9	kW
PV penetration	103	%
Hours of operation	4,381	Hr/yr
Levelized cost of Energy	0.0248	$/kWh

Figure 5.4 and Table 5.3, depicted the share of electricity generation via solar PV. As noticed from the figure 5.4, electricity generation is higher at the times of high solar radiation striking the earth's surface, of which February is the month that gets the largest amount of irradiation.

Table 5.4: Summarized System report for the most cost effective system, 1st row in Table 5.1

System architecture		**Sensitivity case**		**Annual electric energy production (KWh/year)**			**Annual electric energy consumption (KWh/year)**			**Emission (kg/year)**	
PV	35KW	Diesel Price ($/L)	0.64	PV	79,438	44%	Primary load	77,334	98%	CO2	16.9
Wind turbine	3HY-5kW	Wind speed Average	3.58 m/s	Wind turbine	99,722	55%	Deferrable load	1,277	2%	CO	0.229
Gen.1	6KW	Primary Load (kwh/d)	212	Gen.1	530	1%	Total	78,611	100%	Unburned hydrocarbons	0.0115
				Total	179,690	100%					
Battery S6CS25P	64	PV Capital Cost Multiplier	0.6	Excess electricity	21,562	12%	**Cost summary**			Particulate matter	0.0229
Inverter	15KW	PV Replacement Cost Multiplier	0.6	Unmet load	46.1	0%	NPC	$91,217		SO2	6.2
Rectifier	15KW			Capacity shortage	97.9	0%	COE	0.091 $/KWh		NOx	0.0229
Dispatch Strategy	LF										

It is clearly marked in figures 5.5, although the initial cost of diesel generator has incurred low cost to purchase which is about 6% of the total capital cost, however due to higher use of fuel the fourth cost draws from the diesel generator.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	25,200	0	0	0	0	25,200
HY 5 KW	15,390	0	3,950	0	0	19,340
Generator 1	3,600	0	527	9,377	-623	12,881
Surrette 6CS25P	833	413	192	0	-119	1,319
Converter	10,500	3,442	19,175	0	-641	32,477
System	55,523	3,855	23,844	9,377	-1,382	91,217

Figure 5.5: Cost summary for the most cost effective system, 1st row in Table 5.1

Another attractive most cost effective system in terms of NPC is row 2 in Table 5.1, with system architecture that is similar COE the above stated system. It is composed of 40kW PV, 2 units of wind turbines 5kW each, 6kW diesel generator, 64 units of batteries, 15kW converter and generator operating under Load following (LF) strategy. The NPC for this setup is $91,587 and the COE is 0.091$/kWh. The generator used diesel oil annually is 1,514 Litter and the corresponding generator operation time is 264 hours per year. In this set up excess electricity generation is 7%, no unmet electric load and no capacity shortage and this set up can be a good choice also to implement. Figure 5.6 shows the monthly average electrical system is also given in Table 5.1.

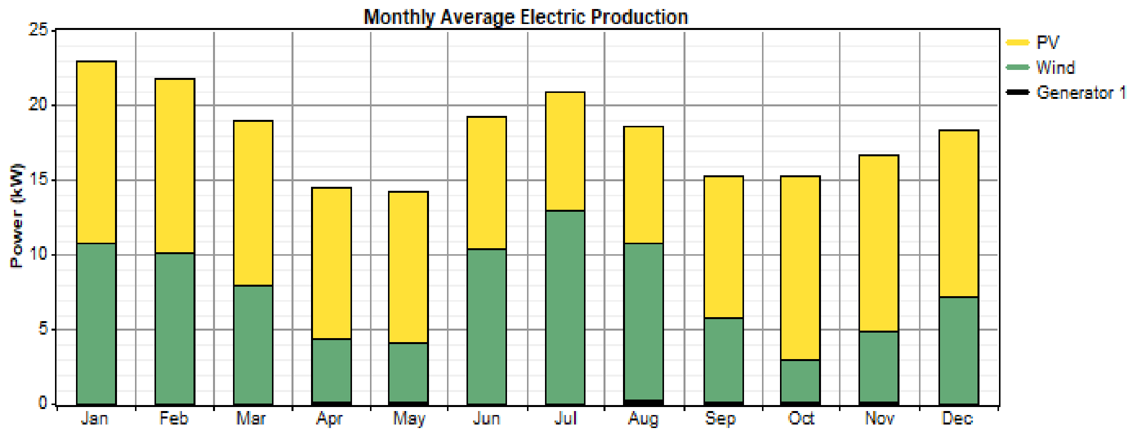
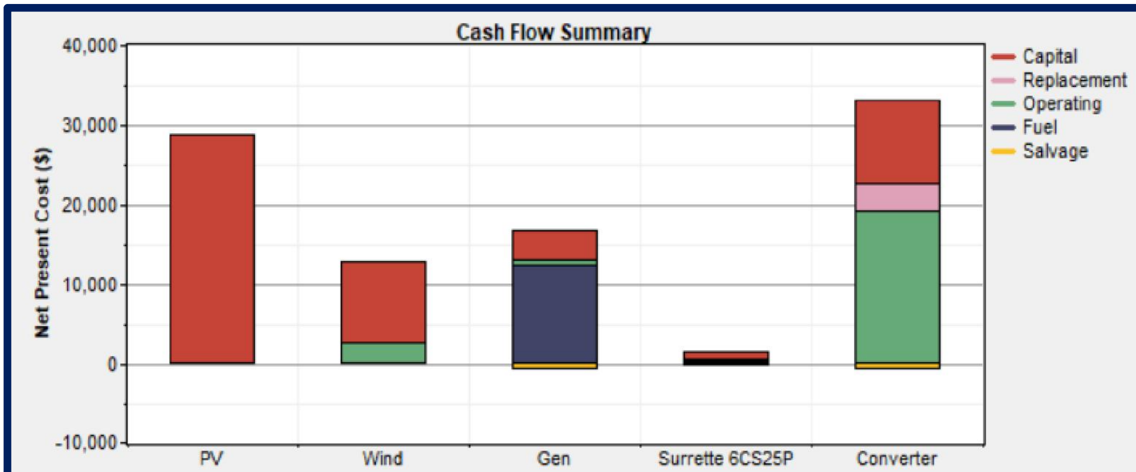


Figure 5.6: Contribution of the power generation unit for the second most cost effective system, 2nd row in Table 5.1

The simulation results showed that this power system setup has annual electricity production of 157,998Wh/year. The power generation offered from PV array is the largest as presented in the above graph which is about 57%, followed by the Wind turbines which is accounted for 42% of total generation. The AC served load is accounted for 77,310kWh/year. Excess electricity obtained from this scheme is about 11,060kWh/year, which is accounted for 7% of the total energy produced. Essentially this power system architecture indicates that it would enable to supply the demand growth of the community at Samara University in the future, however it is the excess electricity produced in account of the operating reserve and the capacity shortage of introduced into the system by the modeler. This excess electricity can provide to neighboring ICT rooms, or introduce small businesses at Samara University to increase the load factor of the power system; consequently the cost of electricity will decrease also.

Table 5.5: Summarized System report for the most cost effective system, 2nd row in Table 5.1

System architecture		**Sensitivity case**		**Annual electric energy production (KWh/year)**			**Annual electric energy consumption (KWh/year)**			**Emission (kg/year)**	
PV	40KW	Diesel Price ($/L)	0.64	PV	90,786	57%	Primary load	77,310	98%	CO_2	22.3
Wind turbine	3HY-5kW	Wind speed Average	3.58 m/s	Wind turbine	66,481	42%	Deferrable load	1,277	2%	CO	0.303
Gen.1	6KW	Primary Load (kwh/d)	212	Gen.1	730	1%	Total	78,587	100%	Unburned hydrocarbons	0.0151
				Total	157,998	100%					
Battery S6CS25P	64	PV Capital Cost Multiplier	0.6	Excess electricity	11,060	7%	**Cost summary**			Particulate matter	0.0303
Inverter	15KW	PV Replacement Cost Multiplier	0.6	Unmet load	70	0%	NPC	$91,587		SO_2	8.19
Rectifier	15KW			Capacity shortage	155	0%	COE	0.091 $/KWh		NO_x	0.0303
Dispatch Strategy	LF										



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	28,800	0	0	0	0	28,800
HY 5 KW	10,260	0	2,633	0	0	12,893
Generator 1	3,600	0	675	12,384	-562	16,097
Surrette 6CS25P	833	413	192	0	-119	1,319
Converter	10,500	3,442	19,175	0	-641	32,477
System	53,993	3,855	22,675	12,384	-1,321	91,587

Figure 5.7: Cost summary for the most cost effective system, 2nd row in Table 5.1

Down in the list, the third most cost effective system, row 3 in Table 5.1, is the same system type with that of first row. For this set-up the total net present cost (NPC) is $92,682, the cost of energy (COE) is 0.092$/kWh, the generator used diesel oil 1,226 Litters/year and the diesel generator operates for 222 hours in the year. This system has excess electricity generation of 5%, no unmet electric load and no capacity shortage. The monthly average electric production for this setup is shown in Figure 5.8 and Table 5.6 gives the most import information about the system. The cost breakdown supported by a bar-graph for this set-up is also given in Figure5.9.

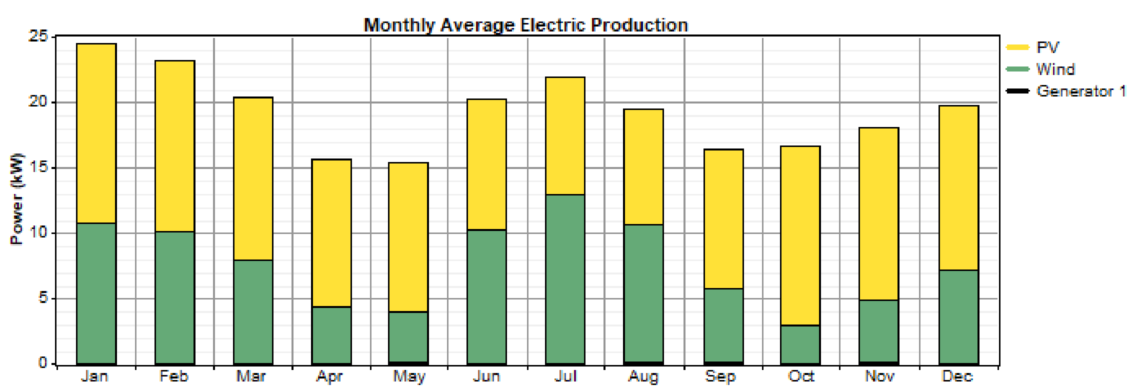
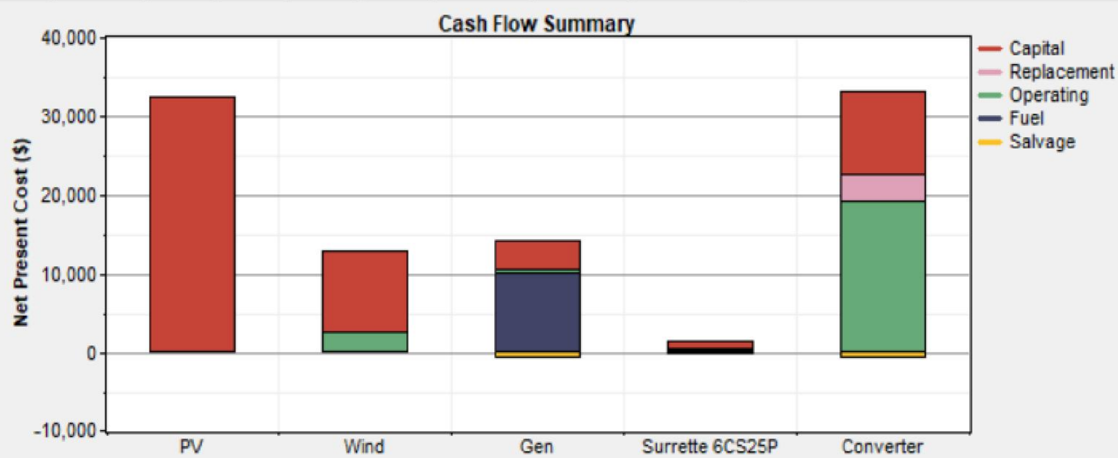


Figure 5.8: The monthly average electric production for 3rd row, in table 5.1

Table 5.6: Summarized System report for the most cost effective system, 3rd row in Table 5.1

System architecture		**Sensitivity case**		**Annual electric energy production (KWh/year)**			**Annual electric energy consumption (KWh/year)**			**Emission (kg/year)**	
PV	45KW	Diesel Price ($/L)	0.64	PV	102,134	60%	Primary load	77,343	98%	CO2	18
Wind turbine	2HY-5kW	Wind speed Average	3.58 m/s	Wind turbine	66,481	39%	Deferrable load	1,277	2%	CO	0.245
Gen.1	6KW	Primary Load (kwh/d)	212	Gen.1	561	1%	Total	78,620	100%	Unburned hydrocarbons	0.0123
				Total	169,176	100%					
Battery S6CS25P	64	PV Capital Cost Multiplier	0.6	Excess electricity	8,460	5%	**Cost summary**			Particulate matter	0.0245
Inverter	15KW	PV Replacement Cost Multiplier	0.6	Unmet load	37	0%	NPC	$92,682		SO2	6.64
Rectifier	15KW			Capacity shortage	87	0%	COE	0.092 $/KWh		NOx	0.0245
Dispatch Strategy	LF										



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	32,400	0	0	0	0	32,400
HY 5 KW	10,260	0	2,633	0	0	12,893
Generator 1	3,600	0	568	10,031	-606	13,593
Surrette 6CS25P	833	413	192	0	-119	1,319
Converter	10,500	3,442	19,175	0	-641	32,477
System	57,593	3,855	22,568	10,031	-1,365	92,682

Figure 5.9: Cost summary for the most cost effective system, 3rd row in Table 5.1

As mentioned earlier, the price variation for diesel oil, considered in this study, is between $0.5 and $1.2. To know what the situation would look like if the current diesel price reached the highest level considered, the first few lines of the optimization results are given in Table 5.7.

Table 5.7: The first few lines of the optimization results for a diesel price of $1.2

Sensitivity Results | Optimization Results

Sensitivity variables

SU Health Clinic Load (kWh/d) 212 | Wind Speed (m/s) 3.58 | D Price ($/L) 1.2 | PV Capital Multiplier 0.6

Double click on a system below for simulation results.

PV (kW)	Wind	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	D (L)	Gen (hrs)
40	4		64	20	CC	$ 64,153	2,742	$ 99,208	0.099	1.00	0.00		
40	4		64	20	LF	$ 64,153	2,742	$ 99,208	0.099	1.00	0.00		
35	3	6	64	15	LF	$ 55,523	3,434	$ 99,421	0.099	1.00	0.00	1,146	206
50	3		64	20	CC	$ 66,223	2,639	$ 99,961	0.100	1.00	0.00		
50	3		64	20	LF	$ 66,223	2,639	$ 99,961	0.100	1.00	0.00		
40	3	6	64	15	LF	$ 59,123	3,198	$ 99,998	0.099	1.00	0.00	956	178
45	2	6	64	20	LF	$ 61,093	3,074	$ 100,387	0.100	1.00	0.00	485	75
40	3	6	64	20	LF	$ 62,623	2,977	$ 100,685	0.100	1.00	0.00	324	53
35	3	6	64	20	LF	$ 59,023	3,267	$ 100,782	0.100	1.00	0.00	557	88
30	4	6	64	15	LF	$ 57,053	3,448	$ 101,131	0.101	1.00	0.00	1,075	195
35	4	6	64	15	LF	$ 60,653	3,183	$ 101,344	0.101	1.00	0.00	861	163
45	2	6	64	15	LF	$ 57,593	3,432	$ 101,460	0.101	1.00	0.00	1,226	222
50	2	6	64	20	LF	$ 64,693	2,916	$ 101,965	0.101	1.00	0.00	357	57

The result in a categorized form, where only the least cost effective system is considered for each system type, is given in Table 5.8. The setup in the first row is the same as that listed in Table 5.1 and has been discussed earlier.

The set up the second row in Table 5.8 has the most cost effective system than the other rows and supplying 100 % from renewable resources. It comprises with 40 kW PV, four units of Wind turbine each rating 5kW, 64 units of Batteries and 20 kW Converter. The NPC and COE for this set up are $99,208 and 0.099$/kWh respectively.

The net present costs for this set-up is 8% more than that of the setup with 100 % renewable contribution listed in first row in Table 5.1. However, this set-up could also be considered as options if issues discussed earlier are given consideration; the issues of future price trends of the components which constitute the system and also the rapidly rising diesel price as well as the issues of environmental protections and global warming.

Table 5.8: Optimization results in a Categorized form

Sensitivity Results | Optimization Results

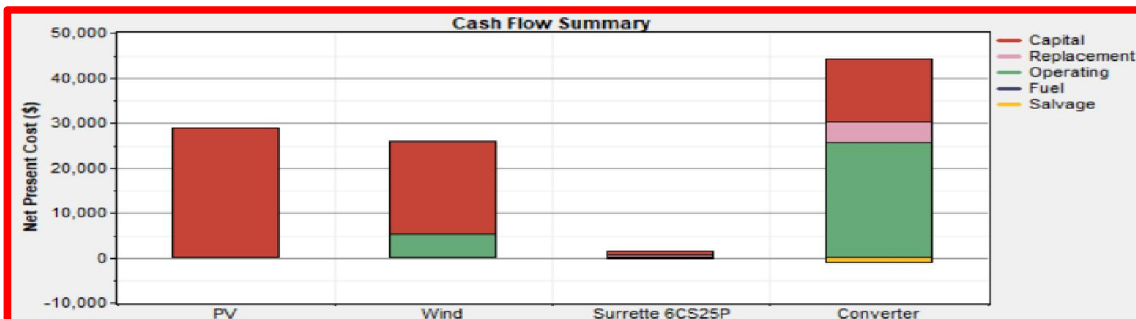
Sensitivity variables

SU Health Clinic Load (kWh/d) 212 Wind Speed (m/s) 3.58 D Price ($/L) 0.64 PV Capital Multiplier 0.6

Double click on a system below for simulation results.

	PV (kW)	Wind	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	D (L)	Gen (hrs)
	35	3	6	64	15	LF	$ 55,523	2,792	$ 91,217	0.091	1.00	0.00	1,146	206
	40	4		64	20	CC	$ 64,153	2,742	$ 99,208	0.099	1.00	0.00		
	100		10	64	20	LF	$ 92,833	4,333	$ 148,228	0.147	0.99	0.00	3,080	300
		10	15	64	15	LF	$ 71,633	8,597	$ 181,536	0.181	0.99	0.00	8,658	614

Figure 5.10, shows the summary of the NPC under the categorized form of the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	28,800	0	0	0	0	28,800
HY 5 KW	20,520	0	5,267	0	0	25,787
Surrette 6CS25P	833	413	192	0	-119	1,319
Converter	14,000	4,590	25,567	0	-854	43,302
System	64,153	5,003	31,025	0	-973	99,208

Figure 5.11: Cost Summary for the categorized most cost effective system

Table 5.9: Summarized System report for the categorized most cost effective system

System architecture	
PV	40KW
Wind turbine	4HY-5kW
Battery S6CS25P	64
Inverter	15KW
Rectifier	15KW
Dispatch Strategy	LF

Sensitivity case	
Diesel Price ($/L)	0.64
Wind speed Average	3.58 m/s
Primary Load (kwh/d)	212
PV Capital Cost Multiplier	0.6
PV Replacement Cost Multiplier	0.6

Annual electric energy production (KWh/year)		
PV	90,786	41%
Wind turbine	132,963	59%
Total	223,749	100%
Excess electricity	46,990	21%
Unmet load	65.5	0%
Capacity shortage	115	0%

Annual electric energy consumption (KWh/year)		
Primary load	77,324	98%
Deferrable load	1,277	2%
Total	78,600	100%
Cost summary		
NPC	$99,208	
COE	0.099 $/KWh	

Emission (kg/year)	
CO_2	0
CO	0
Unburned hydrocarbons	0
Particulate matter	0
SO_2	0
NO_x	0

5.2 Sensitivity Result

Sensitivity analysis was also carried out and figure 5.12 shows the variation of PV capital cost multiplier against diesel price for a fixed average wind speed of 3.58 m/s (measured at 10 meters height) and average solar radiation of 6.58 kWh/m^2/day. In the figure, the net present cost of the most cost-effective set-up for a particular set of diesel and PV prices is also included.

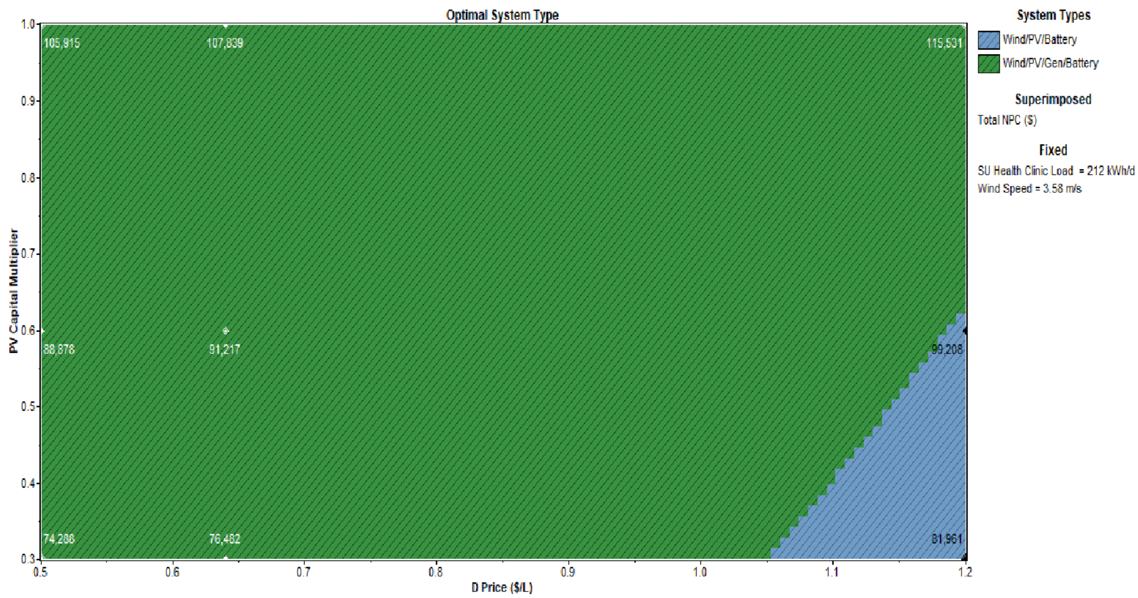


Figure 5.12: Sensitivity of PV cost to diesel price with some important NPCs labeled

In this Figure 5.12, it can be seen that the wind/PV plays big role in supplying energy to the Samara University Health clinic. At this point, it must be known that this is not due to more availability of wind potential than solar energy potential; rather it is because of wind turbine used. The wind turbine used in the design of the system is one with small cut-in wind speed, 2m/s, and also have small capital cost when compared to majority of turbines in the market.

From Figure 5.12, it is observed that for a diesel price of higher than 1.05$/L with PV cost multiplier less than 0.626 Wind/PV/Battery/Converter systems is favorable while for diesel price less than 1.05$/L Wind/PV/Generator/Battery/Converter system is favorable for all PV capital cost multipliers.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this thesis, feasibility study of hybrid PV/Wind energy system with diesel generator as backup and battery bank as energy storage systems for supplied electricity to Samara University health clinic has been conducted. Before the design of the hybrid system was started, the wind energy and solar energy potentials of the area under study had been studied. Then, based on these potentials, a design of a standalone electric power supply system for a model community has been conducted.

Solar radiation of the site is calculated from 2015 to 2017 G.C daily sunshine hour data using empirical formulas taken from NMSA of Ethiopia and is 6.39kWh/m^2/day. This result is compared with the data collected from NASA and it is found to be nearly the same. Consequently, for this study the NASA solar radiation is used for modeling the hybrid system. The Study of monthly average wind speed potential of the site is based on the data obtained from NASA at 10 matters anemometer height is used to synthesize hourly wind speed data using HOMER Software. The analysis of the renewable energy resources data has been carried out by HOMER software. From the results, the wind energy potential of the site is found to be considerable, although it may not be sufficient for a large independent wind farm; it is viable option if incorporated into other energy conversion systems such as PV, diesel generator and battery. The results also confirmed the availability of huge utilizable solar energy at the site.

In this Thesis work, the primary loads and deferrable loads as an input to the HOMER Software has been considered. Because of, the nature of the load of the study area (Samara University Health Clinic).The primary peak demand of 24 kW, a deferrable peak demand of 3.5 kW and a storage capacity of 19.4 kWh has been estimated for the site.

For the study area, different feasible system configurations with different level of total NPC are obtained. The levelized COE ranges from $0.091/kWh to $0.100/kWh. This cost is slightly higher than the current energy tariff within the country of Ethiopia ($0.06/kWh), but, it can be said that the maximum COE determined here is at the lower range of global electricity tariff.

In this thesis works, have taken the average wind speed of 3.58 m/s , current diesel price 0.6$/L and a PV capital cost of $1200/kW, different system configurations/types are found as feasible options for the site. One feasible system from the site can be taken to make-up the overall system capable of supplying the electric power to Samara University Health clinic.

From the overall system simulation results containing the PV-wind-diesel generator-battery-converter setup shows a COE of \$0.091/kWh and a total net present cost (NPC) of \$91,217 has been proposed to the site. This set up system has excess electricity generation of 12%, no capacity shortage and no unmet electric load. Although the proposed system has a relatively higher COE than the national tariff of Ethiopia, in view of the energy shortage at the national level, resistance to deforestation, clean energy development and expansion of power generation, it is a highly recommendable solution.

Finally, the Sensitivity analysis was also carried out with the variation of PV capital cost multiplier against diesel price for a fixed average wind speed of 3.58 m/s and average solar radiation of 6.58 kWh/m^2/day. From the result it is observed that for a diesel price of higher than 1.05\$/L with PV cost multiplier less than 0.626 Wind/PV/Battery/Converter systems is favorable while for diesel price less than 1.05\$/L Wind/PV/Generator/Battery/Converter system is favorable for all PV capital cost multipliers.

6.2 Recommendations

Most of the time data handling in our country is very weak, this makes finding relevant data very difficult. So I recommend the concerned governmental body to give a due attention for such research works.

The study only focused on one selected site of Samara University Health Clinic and it doesn't cover all the compound of University buildings. So, the future researchers should expand this research work in other sites of the University and make the community beneficiary with renewable energy resource.

6.3 Future Works

In this work the hybrid combination of solar and wind turbines are implemented as a backup system to the main commercial AC power. Different combination of the available energy resources can be used as a future work.

This work focuses on a Health Clinic found in Samara University, and if we really need to start the efficient utilization of renewable energy resources, we should start it on schools and hospitals, and someone who is interested in energy efficient utilization technologies can design his/her own system model for any remote area site.

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Appendix A

Table A-1: Overall Optimization results from HOMER Software

PV (Kw)	Wind	Gen.1 (kW)	Battery	Conv. (kW)	Dispatch	Initial Capital	Operating Cost($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
35	3	6	64	15	LF	$55,523	2,792	$91,217	0.091	1.00
40	2	6	64	15	LF	$53,993	2,941	$91,587	0.091	1.00
45	2	6	64	15	LF	$57,593	2,745	$92,682	0.092	1.00
40	3	6	64	15	LF	$59,123	2,662	$93,157	0.093	1.00
30	4	6	64	15	LF	$57,053	2,846	$93,439	0.093	1.00
35	4	6	64	15	LF	$60,653	2,701	$95,178	0.095	1.00
50	2	6	64	15	LF	$61,193	2,676	$95,405	0.095	1.00
45	3	6	64	15	LF	$62,723	2,616	$96,163	0.096	1.00
40	2	6	64	20	LF	$57,493	3,031	$96,244	0.096	1.00
35	3	6	64	20	LF	$59,023	2,955	$96,796	0.096	1.00
25	5	6	64	15	LF	$58,583	2,994	$96,860	0.096	1.00
45	2	6	64	20	LF	$61,093	2,802	$96,915	0.096	1.00
30	5	6	64	15	LF	$62,183	2,792	$97,877	0.096	1.00
35	3	10	64	15	LF	$57,923	3,137	$98,024	0.097	1.00
40	4	6	64	15	LF	$64,253	2,651	$98,138	0.098	1.00
40	3	6	64	20	LF	$62,623	2,796	$98,365	0.098	1.00
55	2	6	64	15	LF	$64,793	2,647	$98,636	0.098	1.00
30	4	6	64	20	LF	$60,553	3,023	$99,197	0.099	1.00
40	4		64	20	CC	$64,153	2,742	$99,208	0.099	1.00
40	4		64	20	LF	$64,153	2,742	$99,208	0.099	1.00
50	2	6	64	20	LF	$64,693	2,715	$99,406	0.099	1.00
50	3	6	64	15	LF	$66,323	2,589	$99,424	0.099	1.00
40	3	10	64	15	LF	$61,523	2,979	$99,601	0.099	1.00
50	3		64	20	CC	$66,223	2,639	$99,961	0.100	1.00
50	3		64	20	LF	$66,223	2,639	$99,961	0.100	1.00
30	10	4	64	15	LF	$59,453	3,178	$100.080	0.100	1.00
30	3	10	64	15	LF	$54,323	3,584	$100,038	0.100	0.99
35	5	6	64	15	LF	$65,783	2,697	$100.254	0.100	1.00
45	2	10	64	15	LF	$59,993	3,156	$100.335	0.100	1.00
35	3	10	64	20	LF	$61,423	3,067	$100,633	0.100	1.00
35	4	6	64	20	LF	$64,153	2,855	$100,644	0.100	1.00
45	2	10	64	20	LF	$63,493	2,907	$100,649	0.100	1.00
40	2	10	64	20	LF	$59,893	3,212	$100,958	0.100	1.00
35	4	10	64	15	LF	$63,053	2,994	$101,321	0.101	1.00
45	3	6	64	20	LF	$66,223	2,749	$101,366	0.101	1.00
45	4	6	64	15	LF	$67,853	2,624	$101,400	0.101	1.00
40	3	10	64	15	LF	$65,023	2,858	$101,557	0.101	1.00
60	2	6	64	15	LF	$68,393	2,618	$101,858	0.101	1.00
35	5		64	20	CC	$65,683	2,845	$102,055	0.102	1.00
35	5		64	20	LF	$65,683	2,845	$102,055	0.102	1.00
35	2	10	64	15	LF	$52,793	3,858	$102,113	0.102	0.99
55	2	6	64	20	LF	$68,293	2,672	$102,444	0.102	1.00
45	3	10	64	15	LF	$65,123	2,923	$102,489	0.102	1.00

50	2	10	64	20	LF	$67,093	2,780	$102,625	0.102	1.00
55	3	6	64	15	LF	$69,923	2,566	$102,727	0.102	1.00
30	4	10	64	20	LF	$62,953	3,114	$102,755	0.102	1.00
45	4		64	20	CC	$67,753	2,742	$102,808	0.102	1.00
45	4		64	20	LF	$67,753	2,742	$102,808	0.102	1.00
50	2	10	64	15	LF	$63,593	3,073	$102,872	0.102	1.00
30	3	10	64	20	LF	$57,823	3,528	$102,919	0.102	1.00
25	5	6	64	20	LF	$62,083	3,205	$103,048	0.103	1.00
25	4	10	64	15	LF	$55,853	3,705	$103,215	0.103	1.00
35	4	10	64	20	LF	$66,553	2,884	$103,41	0.103	1.00
40	4	6	64	20	LF	$67,753	2,795	$103,484	0.103	1.00
55	3		64	20	CC	$69,823	2,639	$103,564	0.103	1.00
55	3		64	20	LF	$69,823	2,639	$103,561	0.103	1.00
40	5	6	64	15	LF	$69,383	2,674	$103,562	0.103	1.00
30	5	6	64	20	LF	$65,683	2,973	$103,691	0.103	1.00
25	5	10	64	15	LF	$60,983	3,343	$103,719	0.103	1.00
30	5	10	64	15	LF	$64,583	3,071	$103,843	0.103	1.00
40	4	10	64	15	LF	$66,653	2,930	$104,106	0.104	1.00
35	2	10	64	20	LF	$56,293	3,748	$104,208	0.104	0.99
45	3	10	64	20	LF	$68,623	2,791	$104,304	0.104	1.00
50	3	6	64	20	LF	$69,823	2,714	$104,520	0.104	1.00
35	3	5	64	20	LF	$64,423	3,154	$104,744	0.104	1.00
45	2	15	64	20	LF	$66,493	2,995	$104,780	0.104	1.00
60	1	6	64	20	LF	$66,763	2,975	$104,799	0.104	1.00
50	4	6	64	15	LF	$71,453	2,614	$104,870	0.104	1.00
40	3	15	64	20	LF	$68,023	2,900	$105,098	0.105	1.00
55	2	10	64	20	LF	$70,693	2,722	$105,492	0.105	1.00
40	5		64	20	CC	$69,283	2,845	$105,655	0.105	1.00
40	5		64	20	LF	$69,283	2,845	$105,655	0.105	1.00
50	3	10	64	15	LF	$68,723	2,892	$105,692	0.105	1.00
60	2	6	64	20	LF	$71,893	2,647	$105,735	0.105	1.00
35	5	10	64	15	LF	$68,183	2,939	$105,757	0.105	1.00
35	5	6	64	20	LF	$69,283	2,867	$105,927	0.105	1.00
55	2	10	64	15	LF	$67,193	3,031	$105,937	0.105	1.00
40	2	15	64	20	LF	$62,893	3,372	$105,998	0.105	1.00
60	3	6	64	15	LF	$73,523	2,545	$106,063	0.105	1.00
40	4	10	64	20	LF	$70,153	2,810	$106,073	0.105	1.00
35	3	15	64	15	LF	$60,923	3,542	$106,205	0.106	1.00
50	4		64	20	CC	$71,353	2,742	$106,408	0.106	1.00
50	4		64	20	LF	$71,353	2,742	$106,408	0.106	1.00
30	5	10	64	20	LF	$68,083	3,000	$106,438	0.106	1.00
50	2	15	64	20	LF	$70,093	2,844	$106,446	0.106	1.00
25	4	10	64	20	LF	$59,353	3,691	$106,536	0.106	1.00
45	4	6	64	20	LF	$71,353	2,764	$106,681	0.106	1.00
30	4	15	64	20	LF	$65,953	3,189	$106,716	0.106	1.00
35	4	15	64	20	LF	$69,553	2,917	$106,846	0.106	1.00
25	5	10	64	20	LF	$64,483	3,337	$107,140	0.107	1.00
60	3		64	20	CC	$73,423	2,639	$107,161	0.107	1.00
60	3		64	20	LF	$73,423	2,639	$107,161	0.107	1.00