JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

DESIGN AND MODELING OF HYBRID PV-MICRO HYDROPOWER GENERATION: A CASE STUDY ON JIMMA ZONE, MENKO TOLI, SERBO WOREDA.

BY

GETNET ZEWDE

A THESIS SUBMITTED TO JIMMA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR the DEGREE OF MASTER OF SCIENCE IN ELECTRICAL POWER SYSTEM ENGINEERING

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Certification

The thesis entitled Design and Modeling of Hybrid PV-Micro Hydropower Generation: Case Study Jimma Zone, Menko Toli, Serbo Woreda submitted by Getnet Zewde to Jimma University in partial fulfillments for the degree of M.Sc. in Electrical Power Engineering is hereby recommended for final evaluation and examination.

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Declaration

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

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Abstract

Renewable energy technologies offer clean abundant energy gathered from self-renewing resources such as the sun, micro hydro, etc. Nowadays, due to the ever increasing demand of electricity, renewable energies are becoming the best option for electrification especially for rural areas. This thesis presented the performance analysis and design study of hybrid renewable energy combining micro-hydro and photo-voltaic system in the case study of Menko Toli Kersu kebele, Serbo Woreda. Optimized design of a Photo-Voltaic (PV) array system and micro hydro Hybrid Electric Power System has been modeled with the aid of HOMER software.

Primary and secondary data had been collected for the success of this thesis work. Solar sun shine hour, minimum and maximum temperature data had been collected from the Ethiopian meteorology agency. With standard empirical formula, the collected sunshine hour data have been changed to solar radiation. The result from empirical formulas was compared with NASA and SWERA data. The selected area has 5.13kWh/m^2/d amount of annual average solar radiation, which shows the area is rich of solar energy. Primary river flow data had been taken for modeling the existing micro-hydro power at Menko Toli River. The river has an annual average flow rate of 1.131m^2/s. HOMER software had been used for modeling optimized result of the hybrid power generation system.

On these studies, 500 households had been studied with a total annual consumption of 31,911 kWh/yr Electric Energy. The study included primary school and clinic, which serve the community.

From the HOMER software optimization result, 10KW PV, 14KW hydro, 14KW converter and 32 battery string had been selected as an optimized option for electrifying Menko Toli , with an initial capital cost $55,200, total net present cost of $76,128 and COE of $0.045. In the study all combinations of hybrid sources for the HOMER software have been observed for cost effective design. System performance evaluation had been done as per the standard requirements. The study found that a combination of PV with micro-hydro power generation is the best option for electrifying MenkoToli with a cost effective way.

Key word: PV. Micro-hydro, HOMER, Optimization

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1. List of frequently used abbreviations and symbols

1.1. Abbreviations

HRES	Hybrid renewable energy systems
MHP	Micro Hydro power
EEPCO	Ethiopia Electric Power Corporation
GIS	Geographical Information System
GPS	Global Positioning System
HOMER	Hybrid Optimization Modeling for Electrical Renewable
MoWE	Ministry of Water & Energy
NASA	National Aeronautics and Space Administration
NMSA	National Meteorological Service Agency
NGO	Nongovernmental Organization
HPGS	Hybrid power generation system
SWERA	Solar and Wind Energy Resource Assessment
PV	Photo volatile
HHs	House holds
SNNP	South Nation and nationality people
FIT	Feed-in tariff
COE	Cost of energy
NPC	Net present cost
TNPC	Total net present cost
DNI	Direct Normal Irradiance
O&M	Operating and Maintenance
SPV	Solar Photovoltaic
TV	Television
REHPP	Renewable Energy Hybrid Power Plant
RERP	Renewable Energy Resources Potential
TV	Television
ALPHASOL	alpha solution

1.2 List of symbols

a	Regression coefficient
b	Regression coefficient
A_A	Catchment area for the analogue catchment
A_T	Catchment area for the unguaged catchment T
h	Elevation of the location above sea level (km)
H	Effective pressure head of water across the turbine (m)
H	Monthly average daily global solar radiation (MJ/m2)
Ho	Monthly average daily extraterrestrial radiation on a horizontal surface MJ/m2)
i	Day of the month
k	Scaling constant or function
n	Monthly average daily number of hours of bright sunshine
n_d	Day number starting from January 1
N	Maximum possible daily hours of bright sunshine
N-type	Negative (electron) type
P-type	Positive (proton) type
Q	Flow rate (m3/s)
QX_A	Flow in the analogue catchment A
QX_T	Flow in the target unguaged catchment T
G_{sc}	Solar constant, 1367W/m^2
δ	Declination angle
φ	Latitude of the location (°)
ρ	Air density (kg/m3)
ρ	Density of water (kg/m3)
η	Overall water turbine's efficiency
g	Acceleration due to gravity (m/s^2)

CHAPTER ONE

INTRODUCTION

1.1 Background

The development of energy sector is a driving engine for promoting country's economy and the improvement of the living standard of the people. Access to modern energy, especially in rural, remote areas would help significantly to reduce poverty, to get better health care and education, to facilitate modern communication and information systems. Further, it will reduce city migration and depletion of fossil fuel resources and deforestation as well as pollutant gas emission to the environment. The development of renewable energy based on locally available resource should play a key role in this regard.

Ethiopia has a long tradition of using water driven mills. These mills are mainly used for grinding of grains in rural areas. More than 1000 of such mills were operational during the last century **[1]**, Most of them were abandoned without leaving any sustainable alternatives.

Ethiopia is one of the developing countries where more of the population lives without access to electricity up to 2015. The World Bank International Development Association data indicated that only 35% of the total population have access to electricity **[2].** Ethiopia has a huge renewable energy (micro-hydro power, solar, biomass and wind energy) potential that has not been used for rural electrification **[3],** the more noticeable benefits of usable electric power include: improved health care, improved communication system, a higher standard of living and economic stability. Unfortunately, many of the rural areas of Ethiopia haven't 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 have 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 **[4].**

The Small town of Menko Toli, a village, is one of those rural areas which have no access to electricity. The community requires electricity for house equipment like TV, Radio player, lighting and other. A hybrid PV and micro Hydro power generation system is proposed to supply electricity to a model community of more than 2,500 people and 630 households in the base year 2014. The hybrid power generation system (HPGS) is a system aimed at the production and utilization of electrical energy coming from more than one source, provides that at least one of them is renewable such as a system often includes some kinds of storage in order 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. Power conditioning unit and controller to convert and control one form of energy to another **[5].**

The hybrid renewable for different regions and locations, climatic conditions, including solar irradiance, temperature and so forth, are always changing. In order to efficiently and economically utilize renewable energy resources of solar and micro hydro energy applications, the optimum much design sizing is very important for solar and micro hydro power generation systems with battery banks. The sizing optimization method can help to guarantee the lowest investment with reasonable and full use of the PV system and micro hydro system and battery bank, so that the system can work at optimum conditions with optimal configuration in terms of optimization techniques of hybrid PV and micro hydro systems sizing have been reported in the literature using the HOMER optimization software. A stand-alone off grid solar and micro hydropower system consists of a charging system, battery storage system, and a power conversion system **[6].**

In this research a comparative analysis and feasibility of solar energy for rural electrification for selected site in Ethiopia is analyzed. Moreover, hybrid design of PV and micro hydro has been modeled with the aid HOMER software so that to reach rural areas which are far from the main grid system.

1.2 Problem Statement and Motivation

Most of rural areas of Ethiopia are not yet given electrification process and 85% of the country's population spread in this region. Ethiopian communities believe that electrification is the only duty of the Ethiopia electric power corporation **[1].** Hence, electrification process, electrifying these remote rural areas is becoming cumbersome to cover with electricity by extension of grid system. Moreover since tremendous amount of electrical energy is binge produced by EEPCO is becoming difficult to distribute the power to remote villages due to economical, technological and developmental[1] constraint power from EEPCO. It is not sufficient to supply both rural and urban needs of electrification. Therefore, other sources of electrical power have to be identified so that the electric demand of the people is satisfied. This study will assess the electric demand of Menko Toli, Serbo Woreda, and identify potential renewable energy alternatives that best suits the area.

Currently on this site, there is micro-hydro with a capacity of generating 15kw of power, even though, the demand of the population is beyond this capacity. Therefore, the ever increasing load demand of the Menko Toli will stress upon the generators and dramatically decrease the life span of the project because of efficiency problem.

1.3 Hypothesis

Since Menko Toli I remote rural area connecting to grid has to be revised both by $EEPC_O$ and the private sector economical, technological development analysis.

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective of this research is to design optimized hybrid micro-hydro and solar energy system using HOMER software for Menko Toli, Serbo Woreda.

1.4.2 Specific Objectives

- To assess the solar energy potential of the site and get the preliminary data for the hybrid power generation.
- To assess and estimate the electrical energy consumption for the community around the site.
- To design battery and convertor for the hybrid energy system.
- To design parts of the hybrid system.
- To make optimization analysis and economic feasibility of the system.

1.5 Scope of the Study

- The study only focuses on solar and micro hydro energy resource assessment of the locality without including other renewable resource of the site Menko Toli Wereda.

[1] Technology driven varies development derive advancement requires special study

Design optimized hybrid existing of micro-hydro and solar energy system using HOMER software and economic feasibility are also determined.

- This thesis will not cover the practical implementation.

1.6 Justification of the hybrid Study

The current population of Menko Toli is about 2,500 and 630 households. However 130 households widely scattered, 500 households Based on basic necessitates of power for lighting and household purposes, and at least 64W is required per household; which amounts to 31,525W for the total households in the site. Furthermore, the demands for water mill, wood work machine, and other home appliances can be nearly 14,500W. However, the installed Micro Hydro power generates only 15KW. Hence, it's apparent that the demand and existing service are incompatible.

As depicted in Figure 1.1, the existing hydro-power provides dual functionality: serves as a water mill during day time and generates electricity for lighting during night. The alternation is mainly because of the limited power it generates; as it can't provide service to both requirements at the same time. To enhance the power supply additional energy source utilization in an integrated way is needed. Therefore, this research focuses on hybridizing the existing Micro Hydro Power with PV.

Figure 1.1 Generators of micro hydropower and Water Mill

1.7 Significance of the study

Currently the Ethiopian government gives much emphasis for reaching rural areas with electrification to meet the five year strategic plan of the country to eliminate poverty in a sustainable way. In line with this, this study will give a profound design detail of hybrid system consisting of micro hydro and solar photovoltaic system for remote areas which are far from the main grid system. The study also gives direction for planner and concerned bodies so that other similar research works to be conducted in other parts of Ethiopia

The study integrates the existing source of power in the Menko Toli; i.e., the micro-hydro, with solar to enhance the reliability and efficiency of the overall system. A hybrid system composed of solar with micro hydro is the predominate source, especially for countries like Ethiopia which are surrounded by mountains since it is the only easy way to generate electricity in theses type of areas as it is possible to get a head and tail for micro hydro power generation system **[2],** the cost of Photo-Voltaic and hydro power generation lies in the form of upfront capital expenditures whereby the operation and maintenance is low.

1.8 Limitation of the Study

There are some limitations that have been faced in this study. One of the limitations is economical limitation, because of the budget allowed by the Jimma University is not enough for this work and it is difficult to visit many micro hydro power sites. The ALPHASOL Energy solution and assessment was only done for the month of February, based on which it not possible to accomplish a holistic design for all year. Due to this, I had to determine the complete data for feeding the HOMER software. Even though the path to the site is comfortable for transportation during all seasons, there is no regular move of vehicles from Serebo to it. So it makes difficult to get flow rate data on time.

1.9 Description of study area

The research project area is located at about 325 km south west of Addis Ababa, on Kersa River, which is located in the Kersa Woreda Jimma Zone, Oromia Region at an altitude of 1775m. It tribute by the Birbisa River, that originates from the highlands of the Northeast.

Kersa is bordered on the south by Dedo, on the southwest by Seka Chekorsa, on the west by Mana, on the north by Limmu Kosa, on the northeast by Tiro Afeta, and on the southeast by Omo Nada . Towns and cities in Kersa include Jimma, the zone's capital, and Serbo. The altitude of this Woreda ranges from 1740 to 2660 meters above sea level, Serbo found in Jimma woreda extends between $7^0$44.44' North latitudes and $37^0$00.14' East longitudes. It is located in the south-western part of Oromia. Jimma bordered with East Wallega zone in the

North, with East Shawa zone and Southwest Shawa zone in North East, with SNNP region in the South East and South part, and with Iluababor zone in the West **[7].**

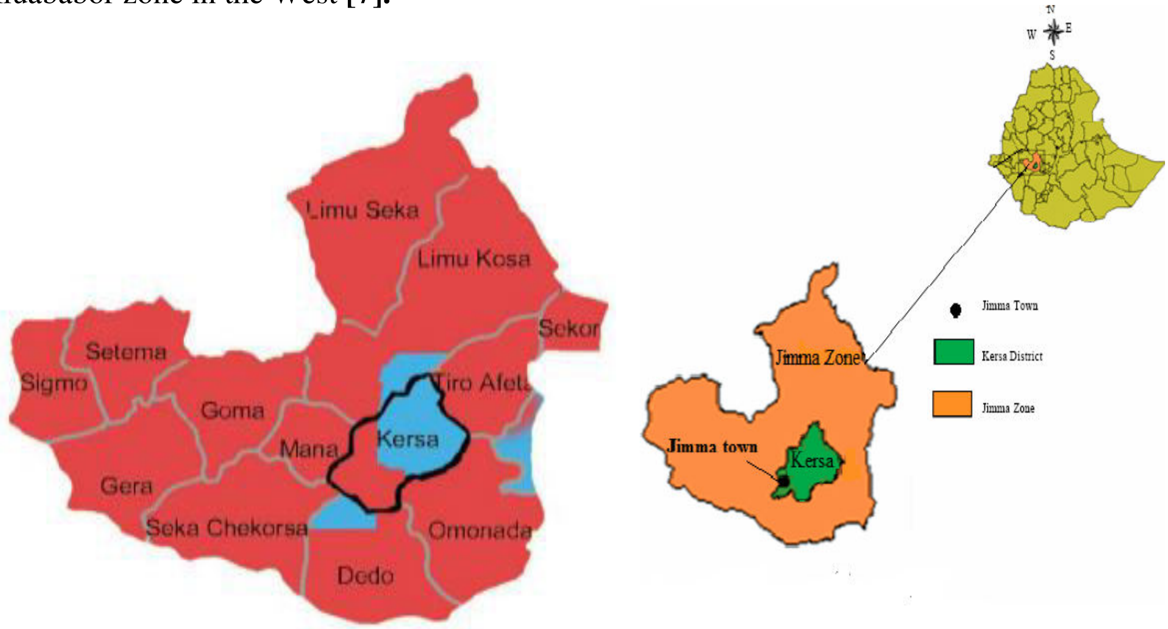


Figure 1.2 Location Map of the study area

The site is located over Jimma – Serbo (18km) asphalt road, taking about 3km away from the main road. The community on the site has constructed a traditional watermill by diverting large amounts of water from the Kersa River through a 1200m long rectangular earth canal. The water from the canal, then, passes via a traditional penstock to impinge on a turbine with a head of about 10m. Then, the turbine is used for the watermill rotation.

The site has a good access of transportation, which is available in all seasons. The village is out of the grid line, and is most unlikely to acquire electricity from EEPCo in the near future. The settlement of the society around the site is scattered within 2.5Km radius of Menko Toil.

1.10 LITERATURE REVIEW

The literature work that is available with a focus area of hybrid PV-micro hydro power generation plants. There are same literature works which are related to hybrid PV-micro hydro power generation technical and financial perspective that have paramount linkage and importance to the current work we are planning to accomplish. From the available literatures, it was possible to compile the most related and latest information in an order which is from general to specific. The logical linkage of these publications with the current work is also discussed in the following couple of pages.

Mohammed ZakirHossain and **A.K.M. Sadrul I Islam [8];** presented a Paper about PV-Wind Hybrid system modeling for remote rural application. A PV-wind hybrid model has been developed to simulate a stand-alone power system with battery storage. The model has been applied to a typical consumer peak load of one KW at a remote community in Bangladesh. Using the model, different parameters are evaluated for one-year of full operation of the system. An economic analysis has also been undertaken to assess the feasibility of such at the location considered.

Riza Muhida et al 2001 [9]; the 10 years operation of a PV-micro-hydro hybrid system in Taratak, Indonesia photovoltaic-micro-hydro system has been installed at Taratak, Indonesia since June 10, 1989. The system is being developed in Indonesia to obtain optimal result by combining the advantages of both energy conversion systems. The photovoltaic works as a dominant part in this hybrid system. However, the micro-hydro sub-system works to compensate the inconvenience found in the photovoltaic. This research is done only for 10 years, on my study the expectation life span will be more than 10 years.

Deepak Kumar Lal et al 2011 [10]; this paper presents a hybrid power generation system suitable for remote area application. The concept of hybridizing renewable energy sources is that the base load is to be covered by largest and firmly available renewable source(s) and other intermittent source(s) should augment the base load to cover the peak load of an isolated mini electric grid system. The study is based on modeling, simulation and optimization of renewable energy system in rural area in Sun Dargarh district of Orissa state, India. The model has designed to provide an optimal system configure ration based on hour-by-hour data for energy availability and demands. Various renewable/alternative energy sources, energy storage and their applicability in terms of cost and performance are discussed. The homer software is used to study and design the proposed hybrid alternative energy power system model. The Sensitivity analysis was carried out using Homer program. Based on simulation results, it has been found that renewable/alternative energy sources will replace the conventional energy sources and would be a feasible solution for distribution of electric power for standalone applications at remote and distant locations.

M.K. Deshmukh 2006 [11]; Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. Economic aspects of these technologies are sufficiently promising to include them in developing power generation capacity for developing countries. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. The paper describes methodologies to model HRES components, HRES designs and their evaluation. The trends in HRES design show that the hybrid PV/wind and other energy systems are becoming gaining popular. The issues related to penetration of these energy systems in the present distribution network are highlighted. This paper more described modeling of Hybrid renewable energy.

Leake E. Weldemariam, 2010 [12];This work studied a hybrid power system which consists of diesel generator, PV-arrays and wind turbines with energy storing devices (battery bank) and power electronic devices to achieve an efficient and cost competitive system configuration. For the different energy sources, where some are AC sources and others DC sources, different connecting topologies are proposed in this paper. The proposed connecting configurations are compared to select the one with the best efficiency of power consumption to the consumers by considering each power sources independently. With typical AC-load profiles, solar irradiation and wind speed profiles of a typical site, the sizing approaches of each energy sources, the battery bank and power electronic devices are discussed in this paper. The hybrid system with the diesel generator has environmental effect in this study so other available renewable resource required to replacing this diesel generator.

A. Qais (et al), 2013 [13];The optimal configuration of hybrid renewable energy system is useful for ensuring enough power is generated to meet the demand with reliable and cost effective manner. This is an alternative environmental friendly approach to reduce the use of diesel generators and cost of power generation. It is also a step to support the government's intention to move towards green energy. In this paper, the hybrid of micro-hydro, solar, diesel generator, power converter and battery as back-up supply are the basic components considered in the optimal sizing and operation of hybrid renewable energy system. Based on the domestic load at Kampung Pasir Raja, Dungun, the proposed hybrid RE system is determined and analyzed by using the Hybrid Optimization Model for Electrical Renewable (HOMER) software. This paper discusses thoroughly on the best combination of hybrid renewable energy system determined based on the lowest Total Net Present Cost (TNPC). Furthermore, the results have shown that the TNPC produced by the hybrid renewable energy system is better than the conventional energy that is the diesel generator; however this study did not use Compression of grid connection.

K.Kusakana et al, 2009 [14]; the present study investigates the possibility of using a stand-alone solar/micro hydro hybrid power system for low-cost electricity production, which can satisfy the energy load requirements of a typical remote and isolated rural area. In this context, the optimal dimensions to improve the technical and economical performances of the hybrid system are determined according to the load energy requirements, the solar and water resources and the importance of supply continuity. The proposed system's installation and operating costs are simulated using the Hybrid Optimization Model for Electric Renewable (HOMER) with the stream flow, the solar radiation and the system components costs as inputs; and then compared with those of other supply options such as grid extension and diesel generation. However this study did not use Sensitivity analysis.

1.11 METHODOLOGY

The methodologies to accomplish this thesis work will be as follows:

- Literature review: Published materials about hybrid PV and micro hydropower systems and Assessment of PV and hydropower potential of rivers will be studied.
- Problem identification and demand analyses
- Environmental assessment
- Observation scientific study tour
- Technological Assessment and validation (collaboration and load phase balancing)
- Primary data direct measuring and interview of the customer.
- Appropriate secondary data collection was made on the hydro and solar energy potentials of the desired site depending on the selected topics to undertake the thesis, the data collection is from the MoWE, NMSA, NASA and SWERA.
- Data analysis: The potential of PV-hydropower will be analyzed from the collected data.
- Design and modeling of a hybrid renewable energy system using homer software is done.
- An overall design, the research report is written including the HOMER output result.
- Conclusion and recommendations will be made based on simulation studies.

1.11.1 Data Analysis and Feasibility Study

In this research we analyze the observed data collected in 2009-2013 solar and 2010-2015 rain fall data. The result of this analysis is compared with the initial design value of PV-micro hydro power. Results of the data analysis of the system parameters obtained from operation data are shown in table 2.1 the design value of the sunshine is also shown for comparison.

The flow rate data of streams taken from ALPHASOL Modular Energy PLC & the catchment area of the Keras River is delineated from DEM data and topographic map. The sizes, the catchment area determined using Arc Map 10 GIS software the head of the stream will be measured directly from the site by using meter & GPS. The sunshine duration & solar radiation were taken from NMSA (National Meteorological Service Agency), NASA (National Aeronautics and Space) Administration) & SWERA (Solar and Wind Energy Resource Assessment). The solar data from NMSA is sunshine duration data from the nearby station and it is used to estimate the monthly average solar radiation with the angstrom type equation. Assessment and estimation of primary and deferrable loads of the society in the site is taken. The capital, operating and replacement cost, life time, etc of components are searched from local markets, websites and different literatures. Thus the stream flow rate & head of river, monthly average solar radiation, load data and market survey are prepared in suitable format for input to HOMER software. Different feasible optimal hybrid system configurations of micro hydro & solar PV are found after many repeated simulation.

1.11.2 Materials required for this study

- Google Earth &Google Map
- Software: HOMER for hybrid optimization and sensitivity analysis tool, and MS Excel for pre- and post-processing
- Digital Camera: important photos related to the study will be taken and documented.
- Standard tables and charts: to determine flow rate data, & solar irradiation in the study area
- GPS

1.12 Organization of the Thesis

This report paper is organized into six chapters-. The first chapter discusses the introduction part in which the background, motivation, objective, scope and justification, significant of the study, limitation description of the area, literature review, methodology, terms and definitions, and applicability of the research are included. In the second chapter of this report, procedure of hybrid PV-micro hydro power assessment study, basic operation of solar PV, solar energy resource assessment, estimation of the irradiance on the surface of the PV array including the major steps of the assessment are discussed. The third chapter discusses load estimation of the sit, Load (Estimation) Forecast Method, and Deferrable Load Estimation. The fourth chapter, hybrid system and input data for homer software, the fifth chapter of this report contains result and discussion of simulation both hydro and PV. In the sixth chapter, the conclusions drawn from the research work, recommended solutions and areas of study suggested for further research are included.

CHAPTER TWO
PROCEDURE OF HYBRID PV-MICRO HYDRO POWER ASSESSMENT STUDY AREA

2.1 Introduction

A photovoltaic (PV) system is able to supply electric energy to a given load by directly converting solar energy through the photovoltaic effect. The system structure is very flexible. PV modules are the main building blocks; these can be arranged into arrays to increase electric energy production. Normally additional equipment is necessary in order to transform energy into a useful from or store energy for future use. The resulting system will therefore be determined by the energy needs or loads in a particular application. PV system can broadly classify in two major groups **[15].**

a). Standalone

The stand-alone systems are usually implemented in rural and remote areas in developing countries where no access to the grid is possible. However, the low cost production and innovative ideas have led to numerous of applications in industrialized countries as well (e.g. roof top systems, PV-glazing, solar traffic lighting, solar parking ticket machines, solar chargers, telecom et al.). Stand-alone systems are usually supported by storage systems (e.g. batteries) in order to meet the load in times when the solar irradiation is not enough for the PV to cover the whole need.

b). The grid-connected systems

The grid-connected systems, which are PV systems connected to the local distribution grid and supply it with power. The connection is via an inverter that converts the DC to AC and also secures the synchronization with the grid in voltage and frequency. The PV systems can be connected directly to the public grid or first to the house grid covering the electricity demand of the house and then supplying any excess to the public grid. Most of the systems are of large-scale (above 100 kW), but small roof top on-grid systems are very common in countries with favorable feed-in tariff law. In general there is no separate energy storage beside the grid, but there are configurations that they use batteries **[16]**, to increase the PV self-consumption and with it the availability of the system and provide a better back-up mode when grid failure occurs. Nevertheless the additional benefits of those systems should balance the extra investment and maintenance cost in order to be more competitive.

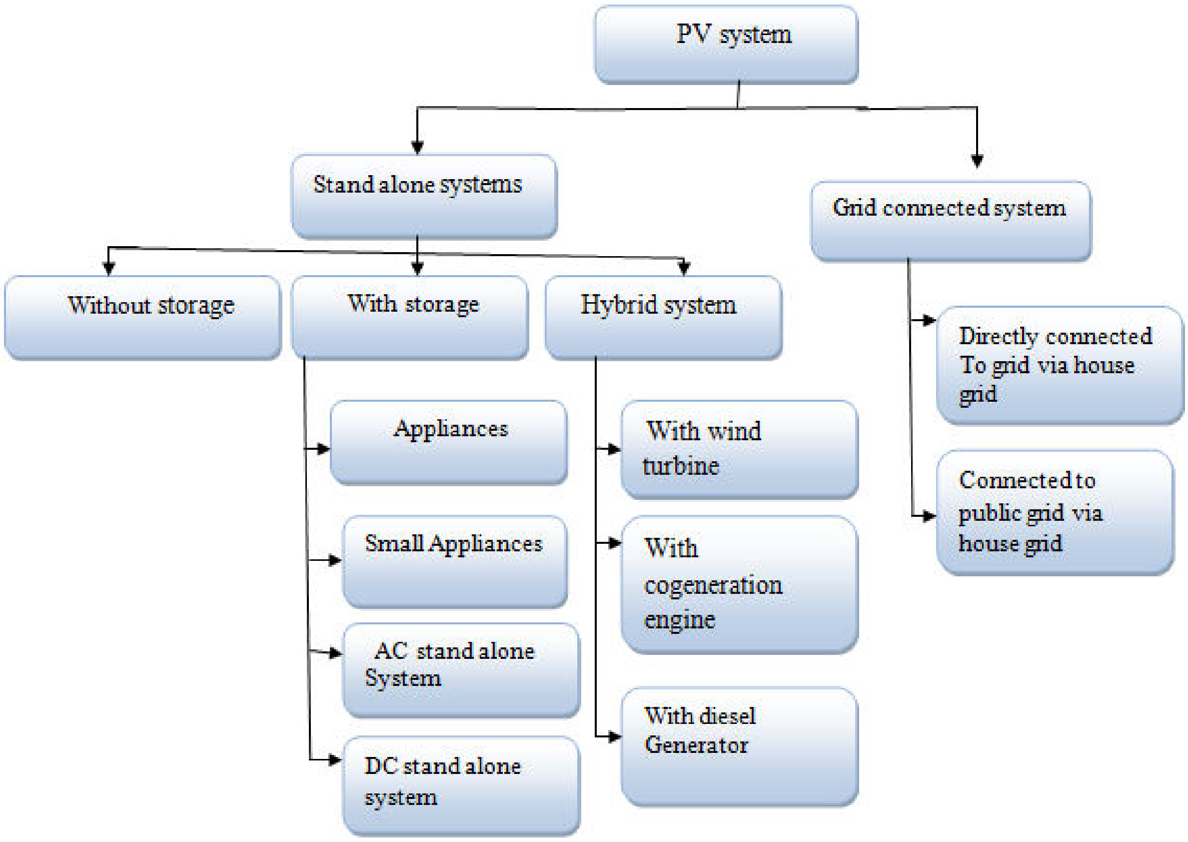


Figure 2.1: Types of PV systems (Source: **[16]**)

2.2. Basic operation of solar PV

The sun supplies energy in the form of radiation, without which life on Earth could not exist. The energy is generated in the sun's core through the fusion of hydrogen atoms into helium. Part of the mass of the hydrogen is converted into energy. In other words, the sun is an enormous nuclear fusion reactor because the sun is such a long way from the Earth only a fusion reactor. Because the sun is such a long way from the Earth, only a tiny proportion (around two-millionths) of the sun's radiation reaches the Earth’s surface.

The solar cell offers a limitless and environmentally friendly source of electricity. The solar cell is able to create electricity directly from photons. A photon can be thought of as a packet of light and the amount of energy in a photon is proportional to the wavelength of light. Figure 2.1 below shows the working mechanism of a solar cell.

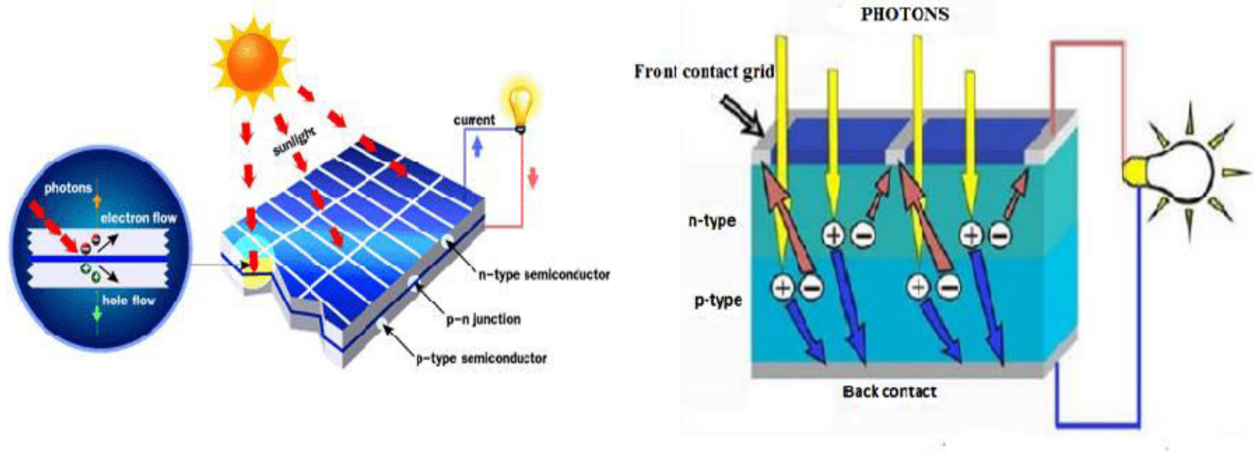


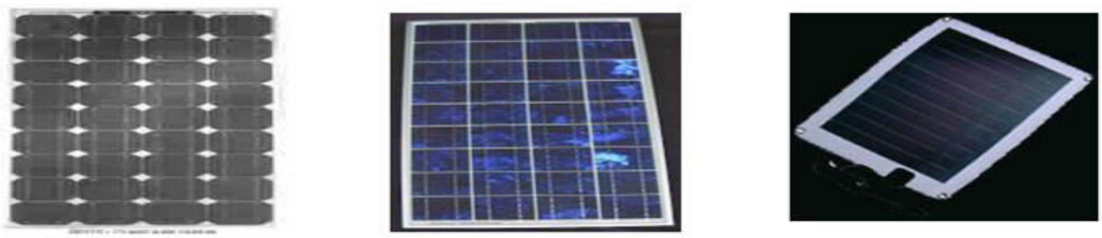
Figure 2.2 Solar cells, How They Work (Source: **[17])**

The photon's energy transfers to the valence electron of an atom in the n-type Si layer. That energy allows the valence electron to escape its orbit leaving behind a hole. In the n-type silicon layer, the free electrons are called majority carriers whereas the holes are called minority carriers. As the term "carrier" implies, both are able to move throughout the silicon layer of the solar cell, and so are said to be mobile. Inversely, in the p-type silicon layer, electrons are termed minority carriers and holes are termed minority carriers, and of course are also mobile.

When photons hit the solar cell, freed electrons (-) attempt to unite with holes on the p-type layer. The p-n junction, a one-way road, only allows the electrons to move in one direction. If we provide an external conductive path, electrons will flow through this path to their original (p-type) side to unite with holes **[18].**

2.2.1. Types of solar cells

There are three main types of solar cells used in solar system today. They are mono crystalline, polycrystalline and amorphous cells **[19].**



(a) (b) (c)

Figure 2.3 Types of solar cells

Figure (a) Mono crystalline solar cells have efficiencies of between 12 to 15% while, Figure (b) poly-crystalline solar cells have efficiencies of at most 12% and, Figure (c) amorphous solar cells 5%. Amorphous solar cells are the cheapest of all the solar cells but challenges of stability and its degradation of performance over time have not made it very popular. The efficiency of a solar cell is the ratio of the power produced by the cell to the power impinging on the cell. Reasons for the loss of efficiency include grid coverage, reflection loss and spurious absorption (some of the electrons ejected from their shell are absorbed by impure atoms in the crystal) **[19].**

2.3. Solar Module

The solar cell is the basic unit of a PV system. An individual solar cell produces direct current and power typically between 1 and 2W,hardly enough to power most applications. For example, in case of crystalline silicon solar cells with a typical area of $10 \times 10\ cm^2$ an output power is typically around 1.5 W_p, with Voc ≈0.6 V and I_{sc} ≈3.5 A. For actual usage, the solar cells are interconnected in series/parallel combinations to form a PV module **[20].**

In the outdoor environment the magnitude of the current output from a PV module directly depends on the solar irradiance and can be increased by connecting solar cells in parallel. The voltage of a solar cell does not depend strongly on the solar irradiance but depends primarily on the cell temperature. PV modules can be designed to operate at different voltages by connecting solar cells in series.

2.3.1. Connection of solar panel

Solar panels can be wired in series or in parallel to increase voltage or amperage respectively, and they can be wired both in series and in parallel to increase both volts and amps. Series wiring refers to connecting the positive terminal of one panel to the negative terminal of another. The resulting outer positive and negative terminals will produce voltage the sum of the two panels, but the amperage stays the same as one panel. Show figure 2.4.

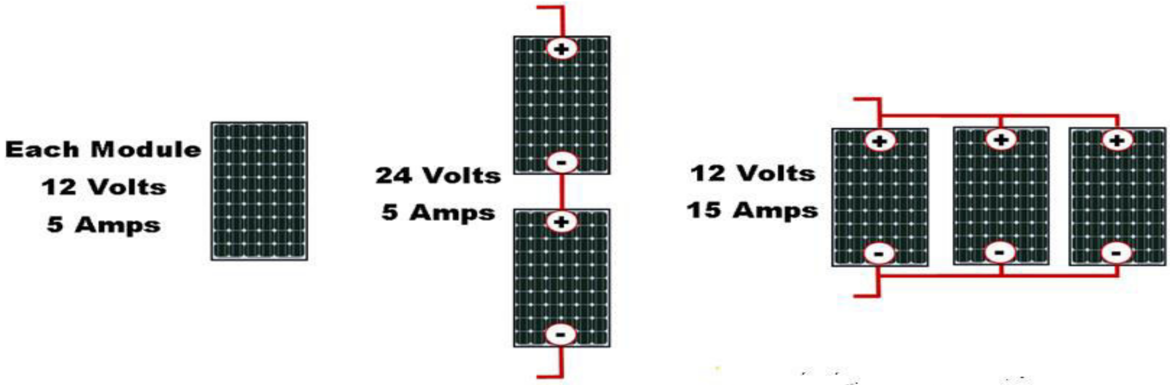


Figure 2.4 connecting types of solar panel source **[21].**

2.3.2 Advantages and Limitations of Solar Energy

Advantages of photovoltaic -PV- systems:

Photovoltaic (PV) systems provide green, renewable power by exploiting solar energy. We can use photovoltaic (PV) panels as an alternative energy source in sated hydro electricity and other electricity conventional fossil fuels. Consequently, the more we use PV panels (or other renewable energy technologies) to cover for our energy needs, the more we help reduce our impact to the environment by reducing CO2 emissions into the atmosphere. Photovoltaic (PV) panels constitute a reliable, industrially matured, green technology for the exploitation of solar energy. Photovoltaic (PV) companies give valuable warranties for PV panels in terms of both PV panel life span (years of PV life) and PV panels' efficiency levels across time. PV panels have a life span of 25 years or more, some with a maximum efficiency of 22% only **[22].**

Disadvantages of Photovoltaic (PV)

The disadvantage of Photovoltaic PV is that they produce direct electric current which must be converted to alternating current (AC) before it can be used for consumption (either to be transferred to the power grid, or directly for own consumption). To convert DC to AC, PV panel systems use inverters, expensive electronic equipment and with certain technological limitations, adding to the overall system's cost especially at larger power sizes.

One of Solar Photovoltaic (PV) panels' main disadvantage is that it delivers only in direct sunlight and it cannot store excess amounts of produced energy for later use. This is particularly important when energy is needed for the night when there is no sunlight or when weather conditions are fluctuating (e.g. sensitive to cloud shading) conditions under which PV efficiency is further decreased. Consequently, reduction in PV panel efficiency will result in a lower output (kWh) which greatly influences financial performance of PV investment.

2.3.3. Solar Irradiance

The sun is the fundamental driving force for energy in the earth's climate system. It is of crucial importance to understand fully the conditions of its arrival at the top of the atmosphere and its transformation through the earth. It is not all of the energy from the sun that reaches the earth’s surface. Rather, it is only a tinny proportion (around two-millionths) of the sun’s energy that could be available for use **[23].**

The intensity of solar radiation outside earth’s atmosphere depends upon the distance between the sun and the earth. The earth’s atmosphere also reduces the insulation through reflection, absorption and scattering. Sunlight on earth’s surface comprises a direct portion (comes from the direction of the sun) and a diffuse portion (scattered from the dome of the sky and has no defined direction). The sum of the direct and diffuse radiation is known as global radiation. The global radiation varies greatly depending upon the geographical position of the region and different seasons during a year.

The amount of solar power available per unit area is known as irradiance. Irradiance is a radiometric term for the power of electromagnetic radiation at a surface, per unit area. It is used when the electromagnetic radiation is incident on the surface. Irradiance fluctuates according to the weather and the sun’s location in the sky. This location constantly changes through the day due to changes in both the sun’s altitude (or elevation) angle and its azimuth (or compass) angle. Figure 2.5 below shows the two angles (the sun’s elevation angle and the sun’s compass angle) used to specify the sun’s location in the sky.

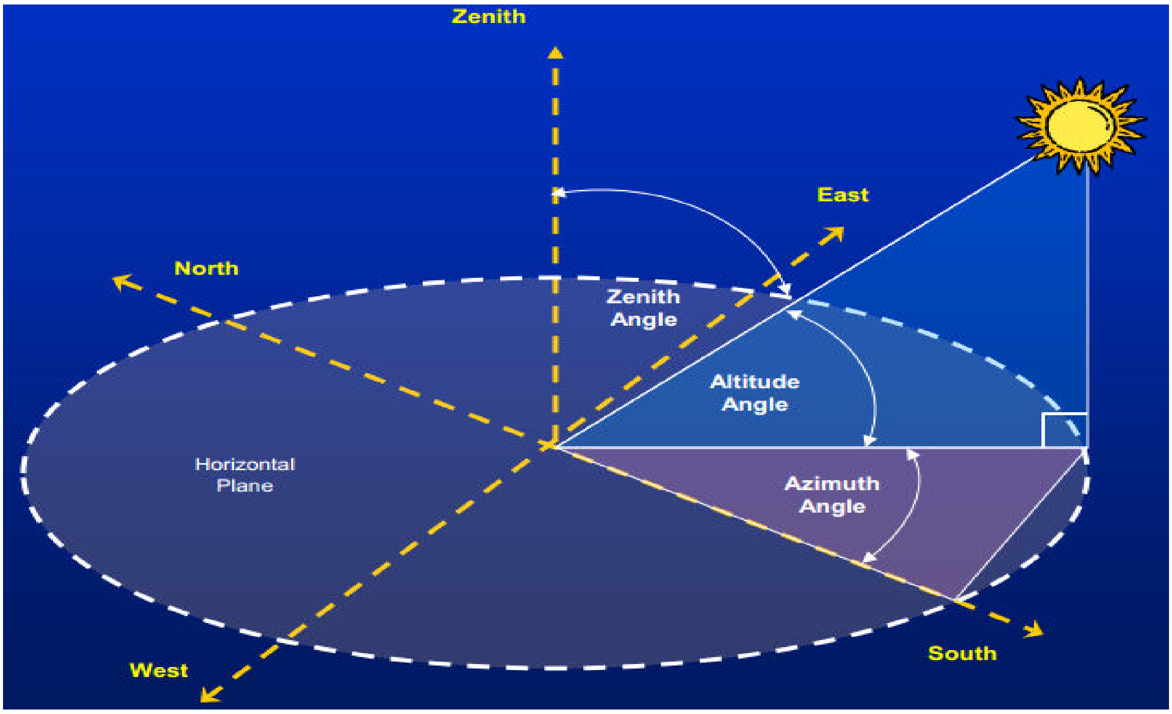


Figure 2.5 Sun's location in the sky **[24]**

2.4. Solar energy Resource assessment

Solar energy is the primary sources for all forms of energy. Solar energy measurement was taken from the average density of solar radiation incident on the earth's surface. Ethiopia has an excellent solar energy resource, with monthly global radiations ranging from 5000-7500 MW/m^2. But this value varies through time from a minimum of 5.55kWh/m^2 in February and March and with the location from 4.25 kWh/m^2 in extreme western low lands to 6.25 kWh/m^2 in north east **[25].**

In this work, all solar energy resource data collected in many of the meteorological stations (NMSA), NASA and SWERA throughout the country is the average daily sunshine hours. The available sunshine hour data from the National Meteorological Agency of Ethiopia (Jimma branch) was used to estimate the solar radiation energy of the Serbo Werda Meko Toli . Table.2.1 shows the five years average daily sunshine hours in each month for the site under study.

2.5 Installation procedure of the PV solar panels

Based on our analysis on site, we had determined the true south by using an intelligent compass from which we have calculated the orientation of the panels .since the community has got household animals and there are also wide animals, we have to elevate the solar panel minimum two matter above the grounded matter the till thing of the panels due south is 7^0. Because of the variation in the sun ‘ movement during the four season , the reaction of the solar panel should be designed and optimally assembled to achieved maximum power.

Since the reception of the surface area of the collector that is envisaged to be erected should have to be aligned to the above mentioned parameter. The reason we focus this is because the pre size amount of solar radiation striking the surface has to be determined based on the solar geometry and receiving surface characteristics.

Table.2.1 Average monthly sunshine hours of Menko Toli

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	7.73	7.53	8.19	7.13	6.71	4.93	3.9	3.66	4.5	8.13	8.38	9.06
2010	7.74	7.53	8.19	7.13	6.7	4.93	3.88	3.7	4.51	8.13	8.38	9.27
2011	7.73	7.67	8.05	7.54	7.6	6.28	3.96	4.44	5.23	6.33	7.05	8.04
2012	6.44	7.48	7.47	7.23	7.56	7.69	4.73	4.64	5.02	6.4	8.75	5.57
2013	8.24	5.05	6.95	6.42	5.6	5.95	3.4	3.8	5.25	7.67	7.32	6.55
Av.Sh	7.58	7.10	7.77	7.09	6.83	5.96	4.00	4.05	4.90	7.33	7.98	7.70

Source: [NMSA, Jimma branch]

The monthly average daily numbers of hours of bright sunshine for Menko Toli Site are the same because they have the same sunshine hour data from NMSA with Shrink as nearby station. The monthly average daily hours of bright sunshine from NMSA with Shrink as nearby station for each year and four years average data from 2009 up to 2013 are shown in figure 2.3.

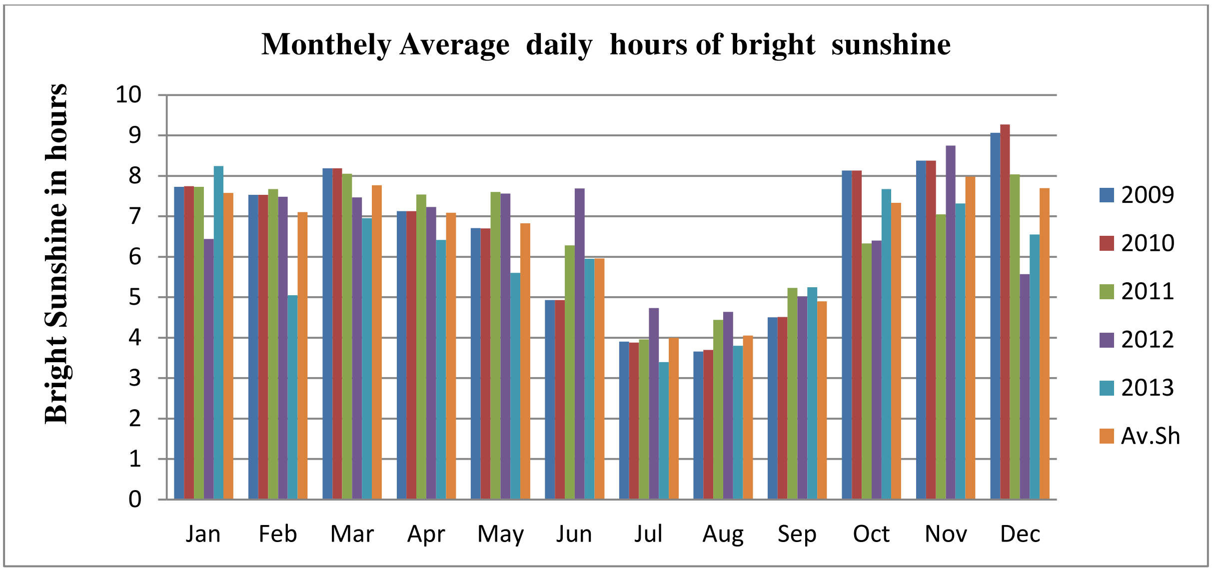


Figure 2.6 Monthly average daily numbers of hours of bright sunshine for Menko Toli Sites

2.5.1. Estimation of the irradiance on the surface of the PV array

The simple model used to estimate monthly average daily global solar radiation on horizontal surface is the modified form of the Angstrom-type equation. Solar irradiation is the amount of available solar energy on the ground surface over a specified time, expressed as kWh/m^2 or MJ/m^2. The sum of direct and diffuse solar irradiation is called global irradiation. Solar irradiation is important factor for design and operation of solar energy system because it can estimate the cost of building photovoltaic system, especially solar cells which are sold based on the area **[26].**

$$H=H_o\,((a + b\,(\tfrac{n}{N})\,)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Where

H- Monthly average daily radiation on horizontal surface (MJ/m^2).

H_o- Monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m^2).

N- Maximum possible daily hours of bright sunshine.

n- Monthly average daily number of hours of bright sunshine.

a and b are regression coefficients.

To Calculating the extraterrestrial radiation H_o ,

$$H_o=\frac{24\times360\times G_{sc}}{\pi}\left(1+0.033\times\cos\left(\frac{360\text{ nd}}{365}\right)\right)\times\left(cos\emptyset cos\delta sin\omega_s+\frac{\pi\omega s}{180}\,sin\emptyset sin\delta\right)\ldots\ldots(2.2)$$

Where:

n_d-Day number starting from January $1st$ as 1, Gsc-1367W/m², solar constant

Φ −Latitude of the location ($7^0$44.44'),

δ − Declination angle (°) and ωs− Sunset hour angle (0)

$$N = \frac{2}{15}\cos^{--}(-\tan\Phi\tan) = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.3)$$

Where:

ωs− Sunset hour angle (0),

N − the maximum possible daily hours of bright sunshine

The sunset hour angle in degrees is calculated by **[27]**

$$\omega s = \cos^{-1}(-\tan(\phi)\tan(\delta))\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Where, n is the day of the year. January first n=1to 365 days **[26].**

To Calculating the declination angle (δ)

$$\delta\,(\text{degree}) = 23.45\text{Sin}\,(\frac{360}{365}(284 + \text{nd})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.5)$$

The regression coefficients "a" and "b" are expected to improve by adding the effect of elevation, sunshine duration, and latitude together. Thus the regression coefficients "a" and "b" in terms of the latitude, elevation and percentage of possible sunshine for any location around the World (for 5°< Φ <54°) are correlated by Gopinathan with equation below **[27].**

$$a= -0.309+0.539\cos\Phi-0.0693h+0.29(n/N) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2.6)$$

$$b=1.529-1.027\cos\Phi+0.0926h-0.359(n/N)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2.7)$$

Where: h is the elevation of the location above sea level in km. For this study the data taken from site measurement with GPS and NASA gives as:

Elevation = 1844, h=1.844km and Φ=$7^0$44.44'

Where, 1kWh/ m²/d= 3.6 MJ/ m²

Table 2.2 average days for months and the declination angle

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

Table 2.3 Solar radiations analyzed from sunshine duration data for the site

Month	n_d	δ(°)	ωs (°)	N (hours)	n (hours)	$\frac{n}{N}$	a	b	H_o(kwh/ m²/d)	H(kWh/ m²/d)
January	17	-20.9	87.14	11.62	7.58	0.65	0.29	0.45	9.21	5.40
February	47	-13.0	88.27	11.77	7.10	0.60	0.27	0.46	9.85	5.38
March	75	-2.4	89.69	11.96	7.77	0.65	0.28	0.45	10.34	6.00
April	105	9.4	91.24	12.16	7.09	0.58	0.27	0.47	10.47	5.68
May	135	18.8	92.55	12.34	6.83	0.55	0.26	0.48	10.25	5.37
June	162	23.1	93.19	12.45	5.96	0.48	0.24	0.51	10.06	4.89
July	198	21.2	92.91	12.39	4.00	0.32	0.20	0.56	10.10	3.93
August	228	13.5	91.79	12.24	4.05	0.33	0.20	0.56	10.33	4.00
September	258	2.2	90.29	12.04	4.90	0.41	0.22	0.53	10.34	4.52
October	288	-9.6	88.73	11.83	7.33	0.62	0.28	0.46	9.93	5.61
November	318	-18.9	87.43	11.66	7.98	0.68	0.30	0.43	9.36	5.55
December	344	-23.0	86.82	11.58	7.70	0.66	0.29	0.44	8.98	5.21
Annual Average							0.26	0.48	9.99	5.13

The average numbers of hours of sunshine were obtained from daily measurements covering a period of 5years From Table 2.1, the overall average clear index $\frac{n}{N}$ was computed and substituted into equation 2.6 and 2.7 to obtained the values of the regression coefficients a and b as 0.26 and 0.48 respectively. The values of a and b were substituted into equation 1 which gives the model for computing the estimated global solar radiation shown in Table 2.3,. It is indicated that our model is suitable for the estimation of monthly average daily global radiation, from monthly average daily sunshine hours in the Menko Toli.

Table 2.4 Monthly average daily solar radiations from NMSA, NASA & SWERA

Date of month	**Kersa Menko Toli**		
	NMSA	**NASA**	**SWERA**
January	5.40	5.86	6.00
February	5.38	6.27	6.01
March	6.00	6.26	5.45
April	5.68	6.01	4.86
May	5.37	5.81	4.71
June	4.89	5.24	4.05
July	3.93	4.61	3.26
August	4.00	4.86	3.39
September	4.52	5.55	4.27
October	5.61	5.93	5.04
November	5.55	6.09	5.75
December	5.21	5.97	6.26
Annual Average	5.13	5.70	4.92

For this thesis the NMSA value of monthly average daily solar radiations, when compared with NASA and SWERA (Solar and Wind Energy Resource Assessment), shows no big difference. According to NMSA data, the area has average annual solar radiation potential of 5.13kWh/m^2/d, and 6.56 kWh/m^2/d as per the information in Solar and Wind Energy Resource Assessment, and 5.7 kWh/m^2/d in NASA's data center.

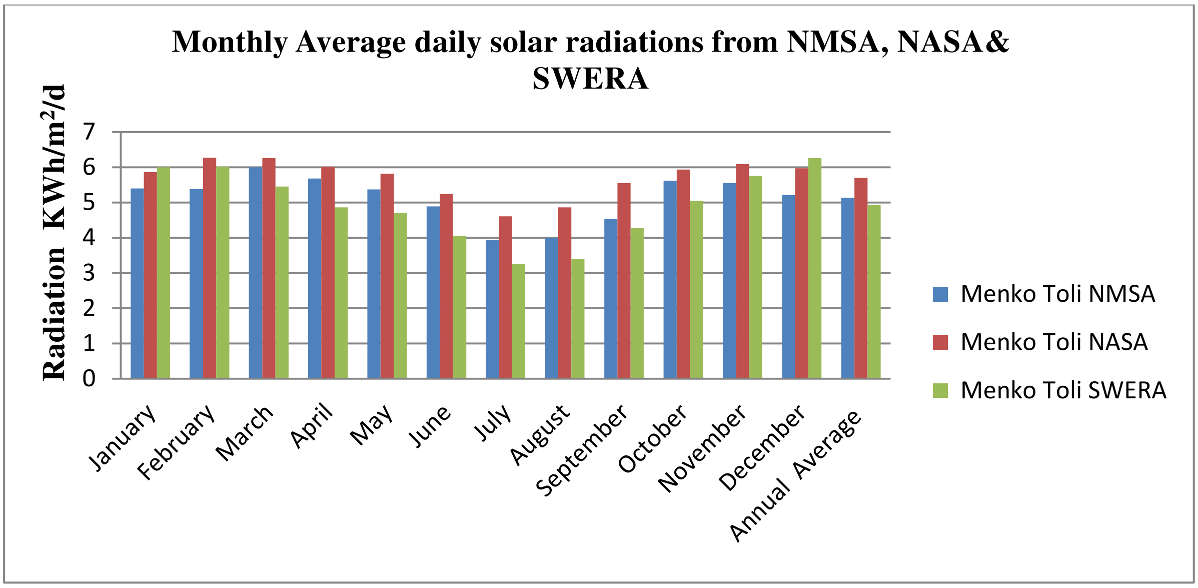


Figure 2.7 Monthly Average daily solar radiations from NMSA, NASA& SWERA

Figure 2.7 shows that in the overall average years (2009 - 2013), there were two maxima (major and minor) and two corresponding minima (major and minor). The major maximum occurred between February-April during the dry season and the minor maximum occurred between November-January. In the rainy season (May-October), we have the major minima in the months of July-August. The peak month, March,. Figure 2.7 also indicates the trend of global solar irradiation at Menko Toli, with high values during the dry season. While minimum irradiation is obtained during the rainy season, as the rain bearing clouds pervade the sky. Finally, in Figure 2.7 the monthly variation of global solar radiation and sunshine duration have same trends where the maximum values each mentioned parameter were observed in March and the minimum in July.

2.6. Basic Theory and Resource Potential of Micro hydropower

2.6.1. Introduction

Hydropower is a renewable, non-polluting and environmentally benign source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy in the moving water. The use of water falling through a height has been utilized as a source of energy since a long time. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized.

Hydropower plants range in size from large power plants that supply many consumers including industrial and commercial load to small and micro plants that provide electricity for small numbers of houses or villages. Generally, there are three different sizes that hydropower plants are based upon. Though different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is as follows **[28].**

Table 2.5 Classification of hydro power plants

Type	**Capacity**
Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 – 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	From a few hundred watts up to 5kW

2.7. Hydrological data analysis

The hydrological study undertaken for the mini hydropower project was aimed at the determination of design discharges (minimum and maximum) for a given set of return periods that were consequently utilized for design of new structures and hydropower schemes. In undertaking the hydrological study and analysis the following operations are carried out. the hydrology and hydraulic study is to determine the Economical sizes of hydraulic structures which safely evacuate design flood of without causing significant damage to the structures, river banks and adjoining settlements. Moreover the minimum flow on the river and water availability for 90% dependability.

The physical size of the whole system, especially the electro-mechanical equipments, are sized and selected by harmonizing the power demand at the end use devices with the power generated due to major site parameters that are the Head (H) and the Flow (Q) of the Kersa Micro hydropower scheme. Installed capacity of Menko Toil Micro hydropower plant Based on the main hydraulic data gathered from the site the output power of the turbine is calculated with the following basic formula. Turbine output power (P_{tur}, kW).e

$$P_{tur} = \rho \text{ x } g \text{ x } H \text{ x } Q \text{ x } \eta \text{ (kW} \quad \ldots\ldots(2.8)$$

Where:- P_{tur}- Turbine output power in kW

ρ - Density of water (1000kg/m^3)

g - Gravity (9.81 m/s^2)

H - Head in meter (m)

Q - Flow rate (m^3/s)

η - Efficiency (%)

Therefore, assuming 65 % efficiency for locally manufactured cross-flow turbine, the net head, H =11 m and water flow rate, Q=0.2 m^3/s, gravity 9.81 m/s^2 the power output (P in kW), for Menko Toli site will be 14.03 kW however the installing generator is 15kw, the diversion of turbine used 30% of the main river of Kersa .

2.8. Study of watershed characteristics of Kersa River

To obtain information on the Kersa River for mini hydropower catchments and data on relief, geomorphology, soil type, land cover and catchment parameter topographic maps, land use and land cover maps, soil and geomorphology maps, national atlas of Ethiopia as well as site visit inspection and assessment information were used. To study the watershed characteristics of the Kersa River extensive study has been done including field inventories using topographic maps. Data regarding catchment areas, i.e. watershed size and shape, stream slope, stream length and land slope were determined from topographic map, satellite data DEM 30mx30m resolution and metadata satellite imagery 15mx15m grid. **[30].**

2.8.1. Catchment area delineation

The catchment area of the Keras River is delineated from DEM data and topographic map. The sizes the catchment area determined using Arc Map 10 GIS software. (See drawing catchment area).

Table 2.6 catchment Area Giligel Gibe and Kersa

Location	Area (Km^2)
At Giligel Gibe	2966
At Kersa	152

2.8.2. Flow duration analysis

Flow duration analysis is needed to determine the installed capacity of a hydropower project. The flow duration curve in this project is the most important because this project is planned as run of river type. Flow duration curve in Kerssa river basin was calculated by using daily run off data at Intake. The flow duration curve in Kerssa River was calculated by using data at the outlet site at Gilgel Gibe Area ratio method is used to compute the flood flow at the site of interest for this study. A peaking factor of 0.05 is employed. The estimated flow duration curve the 90% dependable discharge at Intake site **[30].**

Table 2.7.Flow duration curves

Flow duration curve at Gilgel Gibe I		Flow duration curve at Menko toli	
% Time	Flow (m^3/s)	% Time	Flow (m^3/s)
0	59.44	0	3.03
5	58.64	5	2.99
10	51.54	10	2.62
20	51.17	20	2.61
30	46.4	30	2.36
40	40.59	40	2.07
50	36.4	50	1.86
60	30.9	60	1.57
70	30.15	70	1.53
80	27.88	80	1.42
90	26.52	90	1.35
95	25.78	95	1.31
100	22.27	100	1.13

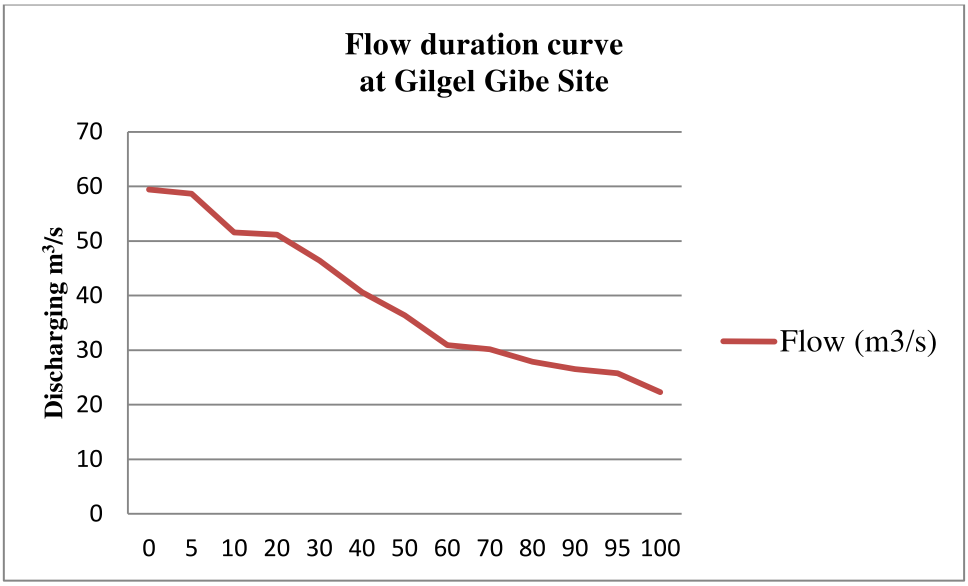


Figure 2.8 Time duration percentage Gilgel Gibe site

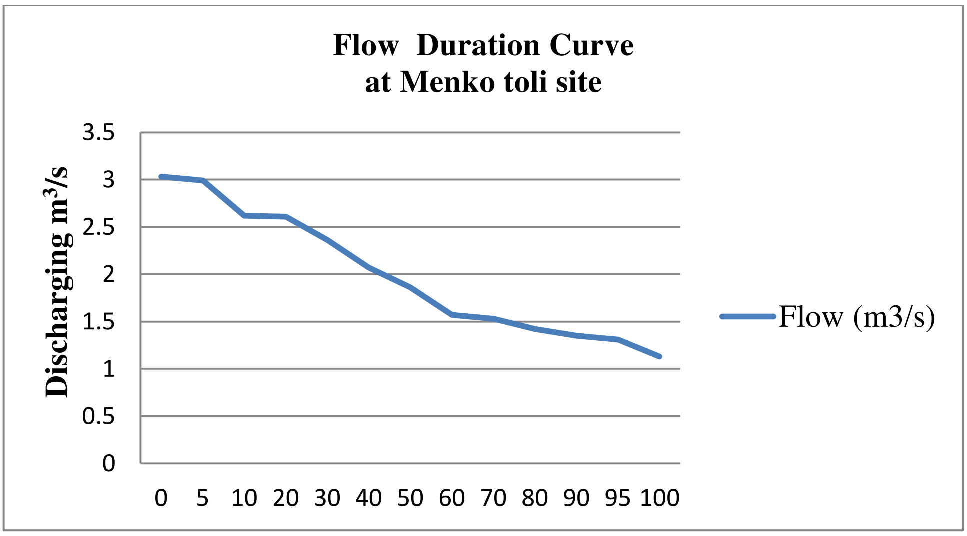


Figure 2.9 Time duration percentage for Menko Toli

2.8.3. Flow rate of the site

For the case of Menko Toli, there is gauging station. Especially for the design of all the components of MHP (Micro-hydro power) it is need to have a rainfall, water flow rate data. There is one river flow gauging station at Gilgel Gibe I River having a catchments area of $2966km^2$. Kersa River it have smallest catchments of $152km^2$ feeding site at Gilgel Gibe I gauging station

Thus to estimate the stream flow of ungauged sites, empirical method of estimation is used rather than statistical model and rainfall-runoff model for this study. Stream flow estimation for ungauged catchments by transposing gauged stream flow data from an analogue catchment is a widely use technique requiring the rescaling of the flow regime to the ungauged target catchment. These techniques all take the following form **[30].**

$$QX_T = k\left(\frac{A_T}{A_A}\right) QX_A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.8)$$

Where: QX_T = the flow in the target unguaged catchment T

QX_A= the corresponding flow in the analogue catchment A

A_T = the catchment area for the unguaged catchment T

A_A= the catchment area for the analogue catchment A

k = a scaling constant or function

Table 2.8 the Values of k as a function of land use, topography and soil type for use in Rational Method

Land use and topography	Soil Types		
	Sandy loam	Clay and silt loam	Tight clay
Cultivated land			
i) Flat	0.30	0.50	0.60
ii) Rolling	0.4	0.60	0.70
iii) Hilling	0.52	0.70	0.82
Pasture land			
i) Flat	0.10	0.30	0.40
ii) Rollin	0.16	0.36	0.55
iii) Hilling	0.22	0.42	0.60
Forest land			
i) Flat	0.10	0.30	0.40
ii) Hilling	0.30	0.50	0.60
Populated land			
i) Flat	0.40	0.55	0.65
ii) Rolling	0.50	0.65	0.80

Menko Toli site is where the logs indicated that for the pit located on the right side 1 m deep composed of reddish-brown clayey and black soils with high clay content. The other pit located on the left side 60cm deep composed of black soils with high clay content. During excavation the water came out easily beaused the soil type of Menko Toli is clay.

Table 2.9 Average monthly water flow rate at Gilgel Gibe I River **[31]**

Month	**1997**	**1998**	**1999**	**Average**
January	17.40	76.12	26.97	40.163
February	7.76	38.96	14.21	20.31
March	6.43	43.58	19.56	23.19
April	44.26	30.32	15.68	30.086
May	70.17	55.16	44.39	56.54
June	181.61	78.13	92.15	117.30
July	187.00	226.85	213.17	209.01
August	279.18	458.64	291.11	342.98
September	185.68	257.03	154.38	199.03
October	122.77	226.38	194.37	181.173
November	324.73	88.51	67.40	160.213
December	143.09	39.91	29.49	70.83
Annual	121.15	134.97	96.91	121.15

Table 2.10 Average monthly flow rate at the Menko Toli

Month	**Flow rate of Gillgle Gibe I m3/s**	**Flow rate of Menko Toil m3/s**
January	40.163	0.370
February	20.31	0.190
March	23.19	0.214
April	30.086	0.277
May	56.54	0.521
June	117.30	1.082
July	209.01	1.928
August	342.98	3.164
September	199.03	1.836
October	181.173	1.671
November	160.213	1.478
December	70.83	0.838
Annual	**121.15**	**1.131**

2.9. Advantages and Disadvantages of micro hydropower plants

2.9.1. Advantages of Micro Hydropower

Clean energy source: Hydropower does not produce greenhouse gas emissions, which are the major cause of the international concerns about environmental problems. Hydroelectricity does not involve a process of combustion, therefore it avoids polluting emissions like carbon dioxide (responsible for global warming) that otherwise would be produced by conventional energy when burning fossil fuels. MHP is a clean energy source (it does not produce waste in the rivers, or air pollution) and renewable (the fuel for hydropower is water, which is not consumed in the electricity generation process) [**32].**

Efficient energy source: It only takes a small amount of flow (as little as two gallons per minute) or a drop as low as two feet to generate electricity with micro hydro. Since MHP is a Decentralized energy source located close to the consumers, transmission losses can be reduced, although electricity can be delivered as far as a mile away to the location where it is being used.

Reliable electricity source: Hydro produces a continuous supply of electrical energy in comparison to other small-scale renewable technologies. The peak energy season is during the winter months when large quantities of electricity are required. Power is usually continuously available on demand and the energy available is predictable.

No reservoir required: Micro hydro is considered to function as a 'run-of-river' system, meaning that the water passing through the generator is directed back into the stream with relatively minimal or no impact on the surrounding ecology.

Cost effective energy solution: Building a small-scale hydro-power system can cost from \$1,000 - \$20,000 USD/kW, depending on site characteristics, power plant size and location. Maintenance costs are relatively small in comparison to other technologies **[32]**. Given a reasonable head, it is a concentrated energy source. It is a long-lasting and robust technology the life of systems can be as long as 50 years or more without major new investments (the average life considered for investment purposes however is about 30 years).

Power for developing countries: Because of the low-cost versatility and longevity of micro hydro, developing countries can manufacture and implement the technology to help supply much needed electricity to small communities and remote villages. No fuel and limited maintenance are required, so running costs are low (compared with diesel power). Localized power can be utilized for the benefit of the local economy.

2.9.2. Disadvantages of Micro Hydro

Site specific technology: In order to take full advantage of the electrical potential of small streams, a suitable site is needed. Factors to consider are: distance from the power source to the location where energy is required (this is not very common to find), stream size (including flow rate, output and drop), and a balance of system components inverter, batteries, controller, transmission line and pipelines.

Energy expansion not possible: There is always a maximum useful power output (size and flow from small streams for example) available from a given hydropower site, which limits the increase in power generation and the level of expansion of activities which can make use of the power.

Seasonal variations: In many locations the flow in a stream fluctuates seasonally and this can limit the firm power output to quite a small fraction of the possible peak output. During summer months there is likely to be less flow and therefore less power output. Advanced planning and investigations are needed to ensure adequate energy generation and power demands are met.

Environmental and ecological concerns: Micro hydropower like any energy-production activity has impacts on the local ecosystem (on the quality of river and river ecosystems, noise, landscape) the availability of electricity has got an enormous privilege in implementing innovative technology such has wood and engraving, waving etc to improve the life style of the community. All the actors if they integrate environmental concerns with their daily activity environmental conservation could be achieved.

CHAPTER THREE

ELECTRIC LOAD ESTIMATION

3.1. Introduction

Load demand statistics are the most important data for hybrid system **[33],** the power demand for a supply system is represented by the instant power required by the various electric devices simultaneously connected to the system. The size of PV panel, wind turbine, micro hydro and diesel generator to be selected is determined primarily by this power demand. The energy demand represents the length of time which the devices are connected to the system. However, the present context is that it represents the consumption. The estimated present energy demand will firstly consider the design and size of the system and secondly the view of electricity sales.

The expression loads refers to a demand for electric or thermal energy, if any. Three types of load scan be modeled using HOMER: primary load which is electric demand that must be served according to particular schedule, deferrable load which is electric demand that can be served at certain period of time, the exact timing is not important and thermal load which is demand for heat.

3.2. Load Estimation Forecast Method

To give the reader a brief idea of the methodology, that Menko Toli used for this type of estimation a short introduction on its different parts and its computation is being presented below followed by the outcome of my interview with Menko Toli customer. Based on my observation study tours, it is appropriate and demanding to implement a three-phase electrical supply system. To this end initial data from Menko was collected showing the number of potential customers for electricity, Load Quantity, for the estimation period namely one to ten years. In addition, the customers were sorted after their types such as households or restaurants. To get the estimated potential customers supplied with the required electrical power with the available MHP is not achievable, since it is mandatory to multiply with connection Factor This in turn wood demon an additional power supply unit such as PV each customer type is multiplied with a. The result of the first phase is in other words the estimated amount of customers to be connected sorted after type of customer. The second phase consists of two parts and describes each customer type.

3.3. Load Estimation

For Urban resident, activities are usually more energy intensive than rural resident activities. As a result of the ongoing rural-urban demographic shift a large increase in modern energy consumption could be expected. Consequently, per capita energy consumption is much higher in urban than rural areas. Consequently, the carrying out of rural surveys is vital for the accuracy of estimations, as assuming rural loads from an urban perspective would give a false picture of the rural demand **[34].**

Hence, that is better to take some considerations that are related to rural activities rather than using urban-rural demography. In order to obtain an accurate and objective analysis of the load situation for this study, emphases during field visit was laid on collecting data from rural areas. Information was also collected from load predictions that were found in literatures. Initial data collected from Menko Toli, and interview of local peoples during site visit.

3.3.1. Primary Loads

Primary load is electrical load that the power system must meet at a specific time. Electrical demand associated with lights, radio, TV, Enjera Methad , household appliances, computers, and industrial processes is typically modeled as primary load. If electrical demand exceeds supply, there is a deficit that is recorded as unmet load. The user specifies an amount of primary load in kW for each hour of the year, either by importing a file containing hourly data or by allowing HOMER to synthesize hourly data from average daily load profiles. When synthesizing load data, HOMER creates hourly load value based on user-specified daily load profiles. Different profiles for different months and different profiles for weekdays and weekends are specified. A specified amount of randomness can beaded to synthesize load data so that every day's load pattern is unique. In this thesis 5% hourly and daily load noise is defined to account for variability of load demand. According to Bekele G. et al. **[35],** electric load in the rural villages of Ethiopia can be assumed to be composed of lighting, radio and television, water pumps, health post and primary schools load. In this study, electricity for cooking and for flour mills is added to the load together with home radio and a TV set. Water pumps are considered as deferrable loads while the others as primary loads. As indicated previously, there are about 25000 people (500 families) without electricity. Also expected there is one flour mill in Menko Toli site and one wood work machine also considered.

3.3.2. Deferrable load

Deferrable load is electrical load that can be met anytime within a certain time span, which exact timing is not important. Water pumping and battery-charging are examples of deferrable loads because the storage inherent to each of those loads allows some flexibility as to when the system can serve them. The ability to defer serving a load is often advantageous for systems comprising intermittent renewable power sources, because it reduces the need for precise control of the timing of power production. If the renewable power supply ever exceeds the primary load, the surplus can serve the deferrable load rather than going to waste .For each month, the user specifies the average deferrable load, which is the rate at which energy drains out of the tank. The user also specifies the storage capacity in kWh (the size of the tank), and the maximum and minimum rate at which the power system can put energy into the tank. There are two main deferrable loads in the villages of Menko Toli.

- Water pump for daily use
- Pumped irrigated Menko Toli

Exception to the load profile: For the rainy months from June to October, irrigation pumps are not required to work deferrable load decrease. So the power consumption of these pumps for these months is taken to be zero and it is input to HOMER.

3.3.3. Load Estimation for Menko Toli

3.3.3.1. Primary Load Estimation for Menko Toli

In this work three ways are used to estimate the primary load: Household load , Community load, Industrial load estimate. As a first step, the estimations of electrical appliances are itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt hour per day as shown below in Table 3.1

Table 3.1 Total average energy consumption

TOTAL AVERAGE ENERGY CONSUMPTION				
Appliance	Quantity	Power (W)	House use per day	Energy W h/day
Light	500	30	4	60,000
Street light	30	25	12	9,000
Television	15	80	5	6,000
Mobile charger	300	5	2	3,000
Radio	150	20	6	18,000
Stove	10	500	3	15,000
DVD player	30	40	4	4,800
Refrigerator	27	200	24	129,600
Wood work machine	1	2500	8	20,000
Flour mill	1	12000	8	96,000
Total Energy consumption				361,400

In this work the electrical load estimation is made for 500 house hold flour mill and for small wood work shop. It was calculated based on the appliance, quantity of appliance, and the power of appliance. The appliance is divided into 8 main needs, which are light at the living room and bedroom each lamp consider 15watt energy save and outside of the house, one for each place, television and DVD and mobile charger The total average energy consumption for a house is about 361,400 kWh. To simulate the system, the approximate energy consumption for each hour is required. Table 3.2 shows the energy in kW for each appliance, all total is 24 hours. The energy consumption is for 500 houses and for one flour mill and for one small work shop.

Table 3.2 Energy Consumption for each hour daily

Hours	Energy(kw)		Hours	Energy(kw)
6 - 7 AM	7.40		6 - 7 PM	25.10
7 - 8 AM	12.40		7 - 8 PM	26.10
8 - 9 AM	15.90		8 - 9 PM	26.10
9 - 10 AM	19.90		9 - 10 PM	26.10
10 - 11 AM	19.90		10 - 11 PM	26.10
11 - 12 PM	20.10		11 - 12 AM	26.10
12 -1 PM	17.60		12 -1 AM	6.50
1 - 2 PM	20.10		1 - 2 AM	6.50
2 - 3 PM	20.10		2 - 3 AM	6.50
3 - 4 PM	20.10		3 - 4 AM	6.50
4 - 5 PM	20.10		4 - 5 AM	6.50
5-6 PM	20.10		5 - 6 AM	6.50

The outline of the energy consumption each hour is shown is Table. 3.2 From 6 to 9 am, the energy consumption is least from other time, the lamp might be off. So do the mobile Radio. Are working, so the villagers not in the house. From 9 am to 12pm, the electrical load starts to increase, but during the lunch time form 11-12pm to decrease. The flour mill wood work machine and other house holed equipment might be on. The electrical load is at the peak from 6 pm to 12 am while the electrical load from 12 pm to 6 am starts to decrease. Only some lamp at the outside of the house and Refrigerator might be on. All the consumptions are estimated due to the villagers' lifestyle. The load profile might be changed from time to time. The total population of the villager may increase. Thus, any changes are not valid for this consumption and calculation

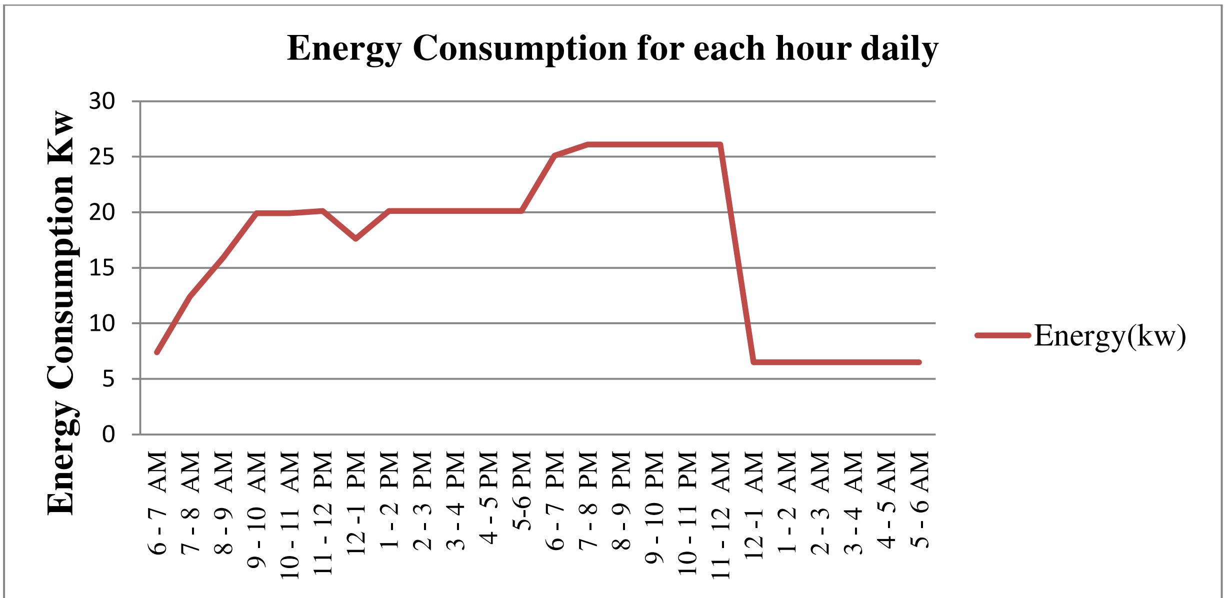


Figure 3.1 Consumption by hour for Menko Toli

CHAPTER FOUR
DESIGNING OF HYBRID SYSTEM COMPONENTS

4.1. Hybrid Power Systems

The alternative/renewable energy sources such as solar energy, wind energy and micro/small hydro-power plant have the greater potential to generate power for system utilities. The abundant energy available in nature can be harnessed and converted to electricity in sustainable and clean way to supply the necessary power to elevate the living standards of people without access to the electricity grid. If stability is concerned with available voltage and power variation, these problems can be solved by integrating the possible alternative/renewable energy sources. The concept of hybridizing renewable energy sources is that the base load is to be covered by largest and firmly available renewable source(s) and other intermittent source(s) should augment the base load to cover the peak load of an isolated mini electric grid system. The hybrid power systems which utilize renewable energy generators can be classified into two basic configurations: Series hybrid system and Parallel hybrid system **[36].** Both the systems have their own characteristics. The proposed scheme is based on parallel hybrid system, the electricity availability from each source, including the storage battery bank are sensed and controlled/fed to a common bus bar, thus providing an optimum mix of electricity from each individual source in the bus. The electricity availability from each source, including the storage battery bank are sensed and controlled/fed to a common bus bar, thus providing an optimum mix of electricity from each individual source in the bus **[37]**

4.2 Hybrid System Designing

This work present hybrid consists of a solar and micro-hydro renewable combination along a power generator which acts as the supplement. The capability of the electric power generating hybrid systems is to satisfy the power demand on the atmospheric conditions. Such conditions will define different operation modes of the system. Basically, these operation modes are determined by the energy balance between the total generation and the total demand, the combination has to be formulated for the efficient investment and operation of the system, figure 4.1more described that the blocked diagram of hybrid PV-micro hydro System.

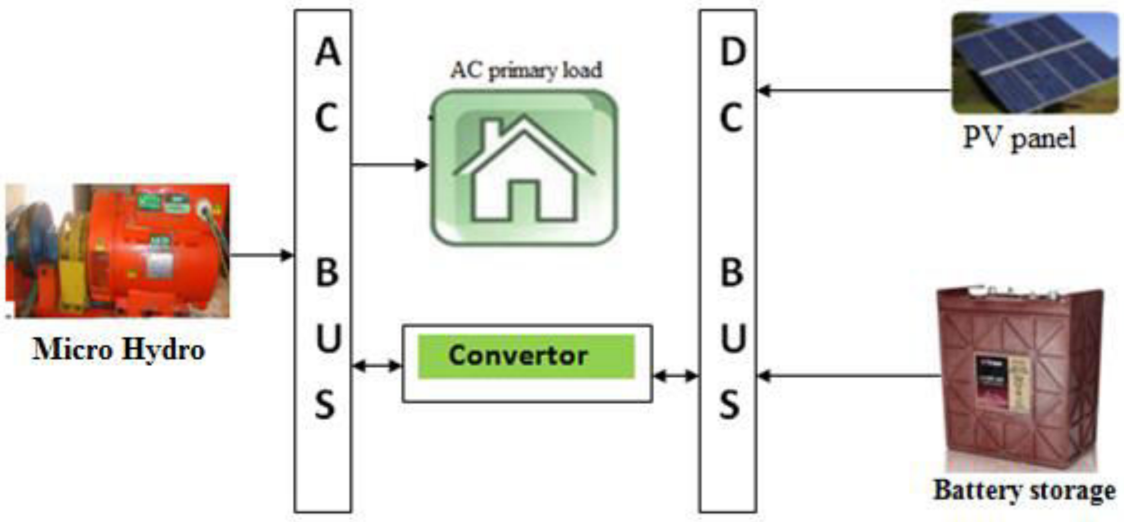


Figure 4.1 Blocked Diagram of Hybrid PV-Micro Hydro System

This can be characterized as a mixed ac/dc bus hybrid system with some energy sources connected to the dc bus and others connected to the ac bus. Usually the PV array is connected to the dc bus via a battery charge controller, which initially was of the series pulse-width modulation (PWM) type. However ac bus connection of PV is also possible with some systems. Micro hydro power is connected to the AC bus via a transfer switch integrated into the inverter/charger and the inverter/charger controls **[38]**

In this work includes both an AC/DC rectifier and DC/AC inverter. the exciting of PV is DC supply, and the exciting of micro hydro power is AC to make Hybrid . PV and battery after converts the DC to AC to connected AC bus, in block schematic diagram the power conditioner is included in the hydro turbine and PV panel. There are three power flow options in Figure 4.1 (hydro, solar and storage batteries) PV and micro hydro power are synchronized together with PV and storage battery after converting.

4.3. Introduction to HOMER

HOMER (Hybrid Optimization Model for Electric Renewable) The HOMER Micro hydropower Optimization Model is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs **[39]**

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, HOMER models the performance of a particular micro power system configuration each hour of the year to determine its technical feasibility and life-cycle cost. In the optimization process, HOMER simulates many different system configurations in search of the one that satisfies the technical con-strains at the lowest life-cycle cost. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs.

Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price. Figure 4.2 illustrates the relationship between simulation, optimization, and sensitivity analysis. The optimization oval encloses the simulation oval to represent the fact that a single optimization consists of multiple simulations. Similarly, the sensitivity analysis oval encompasses the optimization oval because a single sensitivity analysis consists of multiple optimizations **[39].**

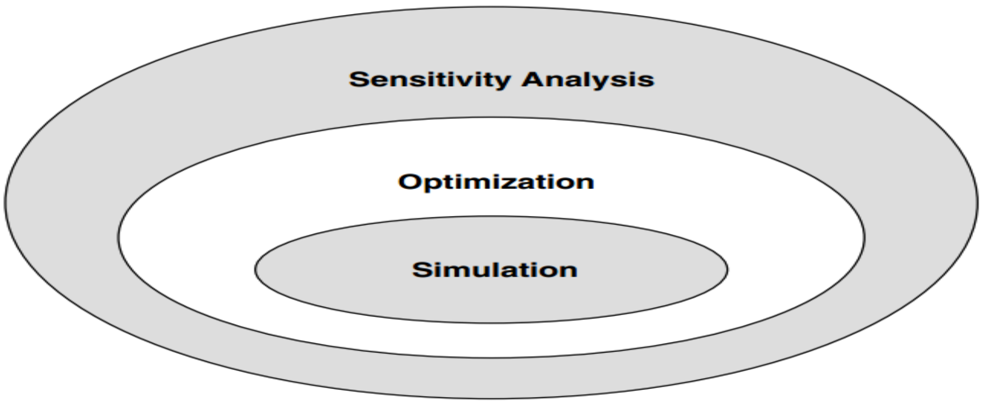


Figure 4.2 Conceptual relationships between simulation, optimization, and sensitivity Analysis. Source (**[39]**)

4.3.1. HOMER simulation

HOMER's fundamental capability is simulating the long-term operation of a micro-power system. It is higher-level capabilities, optimization and sensitivity analysis, rely on this simulation capability. The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time.

HOMER can simulate a wide variety of micro power system configurations, com-prizing any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac–dc converter, an electrolyze, and a hydrogen storage tank. The system of connected or autonomous and can serve ac electric loads. Figure 5.2 shows schematic diagrams of some examples of the types of micro-power systems that HOMER can simulate.

PV power generation

In general, the PV costs $2/W, but may be more depending on the technology used by PV arrays. The capital costs of a PV system not include: the PV array cost and other costs such as labor, installation and structure costs. Various PV arrays costs were investigated and finally a 1kW PV array cost was assumed to be $2000 in Ethiopia the replacement cost is around $1500 and operational and maintenance cost $20 per year fed for Homer software.

HOMER uses the following equation to calculate the output of the PV array:

$$P_{PV} = f_{PV} Y_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) 1 + \alpha_P (T_C \quad + T_{c,STC}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.1)}$$

Where:

Y_{PV} is the rated capacity of the PV array, meaning its power output under standard Test condition [kW]

f_{pv} is the PV derating factor [%]

$\bar{G}_T$ is the solar radiation incident on the PV array in the current time step [kw/m^2]

$\bar{G}_{T,STC}$ is the incident radiation at standard test conditions [1kw/m^2]

α_P is the temperature coefficient of power [%/°C]

T_c is the PV cell temperature in the current time step [°C]

$T_{c,STC}$ is the PV cell temperature under standard test conditions [25 °C]

Micro-hydro Power Generator

The micro hydro model in homer software designed for a exacting of water resource base of the specified head, monthly water flow rate, efficiency of the turbine , the available head of kersa 11m and the designed flow rate as 0.2m^2/s and the efficiency of turbine 65% the life time of micro hydro taken from model in simulation is 20years the designed total capacity is 14kw the initial cost of Micro hydro is $2000 and O/M cost is 2% of capital cost $639 and the total cost of $20639.

HOMER calculates uses the electrical power output of the hydro turbine using the following equation:

$$P_{hyd} = \frac{h_{hyd} . \rho_{water} . g . h_{net} . Q_{turbine}}{1000W/kW} \quad \text{.................................} (4.2)$$

Where:

P_{hyd} = power output of the hydro turbine [kW]

h_{hyd} = Turbine efficiency [%]

ρ_{water}= density of water [1000 kg/m^3]

g= acceleration due to gravity [9.81 m/s^2]

h_{net}= effective head [m]

$Q_{turbine}$= hydro turbine flow rate [m^3/s]

Battery

Battery storage is considered in the system so that when the load demand is less than the available renewable energy, the excess energy can be stored in battery storage. Battery will supply stored energy when the load demand increases in the system. Although battery storage needs regular maintenance, it is less expensive than running a generator in the long term. However, HOMER will analyze the system with different combinations, both with diesel generator and battery storage separately and will provide the optimal solution. Trojan L16P battery type was selected and the capital, replacement and operation and maintenance costs associated with it are $300, $200 and $4 respectively **[40].**

The battery wear cost is the cost of cycling energy through the battery bank. HOMER assumes there is a fixed amount of energy that can be cycled through a battery before it needs replacement (this amount of energy is called the lifetime throughput). With this assumption, the battery wear cost can be found by the following equation:

$$C_{bw} = f(x) = \left(\frac{C_{rep,batt}}{N_{batt} \cdot Q_{lifetime\sqrt{\eta_{rt}}}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.3)}$$

Where:

$C_{rep,batt}$ = Replacement cost of the battery bank[$]

N_{batt} = the number of batteries in the battery bank

$Q_{lifetime}$ = the lifetime throughput of a single battery [kWh]

h_{rt} = battery roundtrip efficiency [fractional]

In HOMER, two independent factors limit the lifetime of the battery bank: the lifetime throughput and the battery float life. In other words, batteries die either from use or from old age. HOMER calculates the battery bank life using the following equation:

$$R_{batt} = \text{MIN}\left(\frac{N_{batt} \cdot Q_{lifetime}}{Q_{thrpt}} . R_{batt,f}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.4)}$$

Where:

R_{batt} = battery bank life [yr]

N_{batt} = number of batteries in the battery bank

$Q_{lifetime}$ = lifetime throughput of a single battery [kWh]

Q_{thrpt} = annual battery throughput [KWh/yr]

$R_{batt,f}$ = battery float life[yr]

Converter

The inverter converts DC power to a regulated AC voltage and current, which is used to supply standard AC appliances. Renewable energy sources such as PV modules and wind turbines produce DC, batteries store DC power. However, the load often requires the use of AC. To convert the DC power from the batteries to AC power an inverter is used and the inverter size should be 25-30% bigger that the total watts of the DC load **[41][43].**

There are two separate criteria for identifying inverters:

- How the DC is converted to AC; and
- Output Waveform

In this work, the inverter size also select by Homer software based of the input data the DC to Ac conversion system is Solid State Inverter because our frequency 50 Hz the output wave Costs of inverters and control chargers vary based on their sizes. Often they decrease per kW when the size is increased. Different sizes of inverters and control chargers were considered in order for HOMER to simulate the system with different sizes and determine the optimal size and cost. Is Sine Wave Inverter now the day the 1kw Inverter price is 400$ in Addis Ababa.

Charge controller

The charge controller is a regulator which limits the rate of current that goes to and from the battery pack. Charge controllers are essential to prevent overcharging or completely draining a battery. Such action can reduce battery performance and the lifespan of a battery dramatically.

There are various types of charge controllers. They differ according to their sizes, displays, features and the way in which they regulate voltages. This short article focuses on the mathematical selection criteria of a charge controller based on the production capacity of solar panel and the total DC load on the system.

The solar charge controller is about 3 to 5% of the whole solar system cost. But investing in a quality controller ensures good battery management which extends battery life and reduces associated costs **[42].**

This solar charge controller performs crucial system functions such as low voltage disconnection (LVD) to protect the battery from deep discharge, and high voltage disconnection (HVD) to protect the battery from overcharging. A quality solar charge controller should have a good battery state of charge calculation (SOC) to monitor the battery status. Good battery management can be applied with the help of such functions.

Max. DC Load Current = Total DC Connected Watts / DC System Voltage.

Connected electric load

Electrical load is an electrical component or portion of a circuit that consumes electric power, The data were calculated for the total hourly basis daily electrical load requirement of a residential, the expected load consumption profile of the area is shown in Figure 4.3 The daily load requirement of the intended village group is found to be 361 kWh per day and the peak load is found to be 26.1 kW.

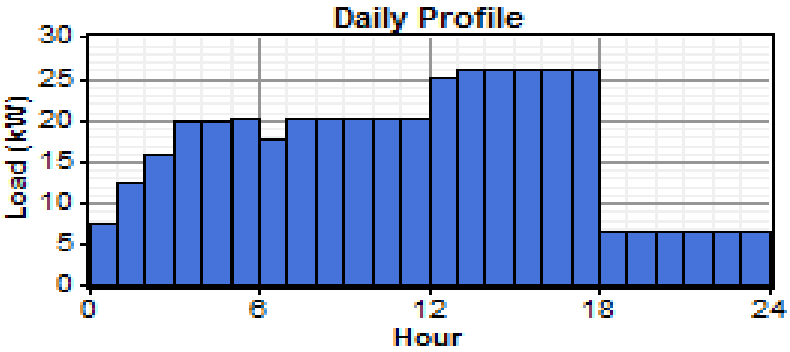


Figure 4.3 Hourly load consumption

4.4. Inputs to the software for Comparison of Grid Extension

The estimated cost only for 15kV single circuit transmission line without consideration of transformer, insulation, mounting pole, wire costs is \$5330/km. Estimated operating and maintenance cost is \$650/yr/km and EEPCO's average COE is \$0.025 /kWh for domestic and general application. Estimated transmission distances from nearby substations are about 8km, MenkoToli sites respectively. Therefore, by taking the above capital, replacement & energy cost to HOMER, grid breakeven distances are identified, calculation of breakeven grid extension distance using the following equation:

$$D_{grid} = \frac{C_{NPC.}\ CRF\left(\mathrm{i}, R_{proj}\right) - C_{power} \cdot L_{tot}}{C_{cap.}\ CRF(i, R_{proj}) + C_{om}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.5)$$

Where:

C_{NPC} = total net present cost of the stand alone –power system [\$]

CRF() = capital recovery factor

i = interest rate[%]

R_{proj} = project lifetime [yr]

L_{tot} = total primary and deferrable load [kWh/yr]

C_{power} = cost of power from the grid [\$/kWh]

C_{cap} = capital cost of grid extension [\$/km]

C_{om} = O&M cost of grid extension [$/yr/km]

Table 4.1 Size, quantity, life time and cost inputs to the software for Menko Toli

Component	Size(kW)	Capital ($)	Replacement Cost($)	O & M cost ($/yr)	Sizes (kW) considered	Quantities	Life Time
PV	1	2000	1500	20	0,5,10,11,13 14,15,16,20..	----	20
Micro hydro	14kW	20000	600	50	14	----	25
Battery L16P	360Ah	300	250	4	---	0,4,8,10,12,15, 15,20,35,4045,50	5
Convertor	1	400	300	20	0,10,13,14,15 16,20,25	----	25

The values given in the above Table 4.1 are primarily chosen based on the size of the load for the specified community. The given costs are estimated according to the current local and global price of the components. The range of sizes for the PV, hydropower and the converter and the number of batteries are the other inputs into the software which are given so as to give flexibility to the software and optimize the output results.

CHAPTER FIVE

5. RESULT AND DISCUSSION

5.1. Simulation Result:

In this section the outcome of the design of a PV-hydro power hybrid power generation system is explained; discussion about the result will presented and at the end, decision for selecting the best situation with the simulation results shall be set forward. The results of the analysis will be presented in the following paragraphs.

5.2. Optimization results

The solar energy potential of the site was fed into HOMER and this is depicted in Figure 5.1. This figure also 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 based on the data input for the analysis. Typical values for the monthly average clearness index range from 0.39 (a very cloudy month) to 0.6 (a very sunny month).

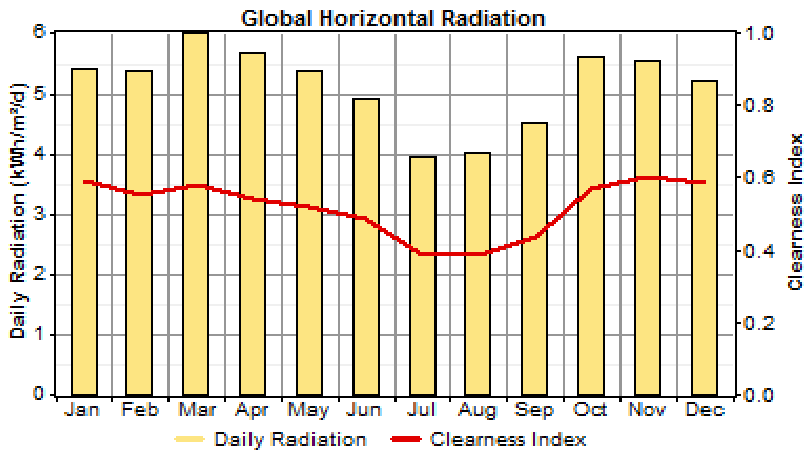


Figure 5.1 Monthly average solar resources

The result which HOMER software suggested for Menko Toli site is shown in figure 5.2 schematic figures and the simulation result is also performed. The categorized optimal result is shown in table 5.1, where different feasibility relationships are depicted. The PV/hydro/battery hybrid in the first row of the table shows a more optimized combination as compared to the Hydro/battery hybrid configuration in the second row.

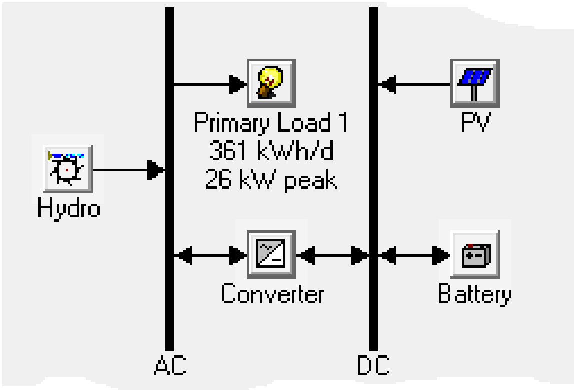


Figure 5.2 the propoesd scheme of hybrid energy generation for the study area in HOMER softwer model.

HOMER simulates system configurations with all of the combinations of components that were individual in the component input. HOMER performs the basis of the NPC (net present cost). The strategy taken in this simulation is to ensure the power generator provide enough power to meet the demand. The renewable energy sources in collaboration with the micro hydro and PV generators were evaluated to determine the feasibility of the system. The method is also simulated in order to estimate its operational characteristics, the annual electrical energy production, sensitivity case, annual electric consumption, annual electric production, excess electric energy, capital storage and cost sheet of optimization system as shown figure 5.3&5.4.

Table 5.1 HOMER categorized simulation results for specific site

	PV (kW)	Hydro (kW)	Battery	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	10	14.0	32	14	$ 55,200	1,637	$ 76,128	0.045	1.00	0.00
		14.0	240	14	$ 97,600	3,850	$ 146,818	0.087	1.00	0.00

The first rank overall optimization result (row 1) in table 5.1 has 32 lead acid Trojan battery, 14kW convertor, 10kw PV and 14kW hydro power. For this set-up, the initial capital cost $55,200 the total net present cost (NPC) is $76,128, the cost of energy (COE) is $0.045/kWh, contribution from renewable resources is 100%, and therefore this setup could be a good choice for implementation. Figure 5.3 shows the monthly average electrical production of this system detail.

Table 5.2: Some simulation results captured from overall optimization result for Menko Toli

No	PV (kW)	Hydro (kW)	Battery	Converter (kW)	Initial capital	Ope & M co($/yr)	Total NPC($)	COE ($/kWh)	Tot. Ele Prod kWh/yr
1	10	14.0	32	14	55,200	658	76,128	0.045	166,501
2	10	14.0	32	15	55,600	678	76,784	0.046	166,501
3	10	14.0	32	16	56,000	698	77,440	0.046	166,501
4	10	14.0	32	13	54,800	827	77,890	0.046	166,501
5	11	14.0	32	14	57,200	678	78,236	0.046	168,018
6	11	14.0	32	15	57,600	698	78,891	0.047	168,018
7	11	14.0	32	16	58,000	718	79,547	0.047	168,018
8	11	14.0	32	13	56,800	847	79,998	0.047	168,018
9	10	14.0	32	20	57,600	778	80,062	0.047	166,501
10	10	14.0	48	14	60,000	722	80,851	0.048	166,501

Table 5.2 gives some of the main information about the system and the corresponding sizes and quantities of each component is indicated accordingly. The most optimum combination is the first row of each of the previous tables; which includes PVs, micro-hydro, battery storage and inverter. The total net present value of the system and energy cost per kWh are insensitive as compared to the other combinations. The second best combination is the second row in all the previous tables and is comprised of PVs, micro-hydropower, battery storage, and inverter. The impact of changing only the size of inverter and net present cost are different from the first row.

System Architecture: 10 kW PV, 14 kW Hydro, 32 Trojan L16P-, 14 kW Inverter, 14 kW Rectifier

Total NPC: $ 76,128
Levelized COE: $ 0.045/kWh
Operating Cost: $ 1,637/yr

Cost Summary | Cash Flow | Electrical | PV | Hydro | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	15,172	9
Hydro turbine	151,329	91
Total	166,501	100

Consumption	kWh/yr	%
AC primary load	131,911	100
Total	131,911	100

Quantity	kWh/yr	%
Excess electricity	30,431	18.3
Unmet electric load	0.000202	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	1.00

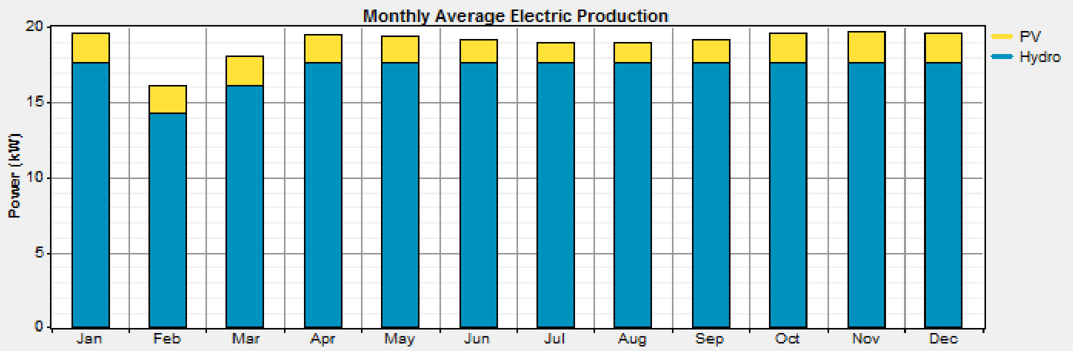
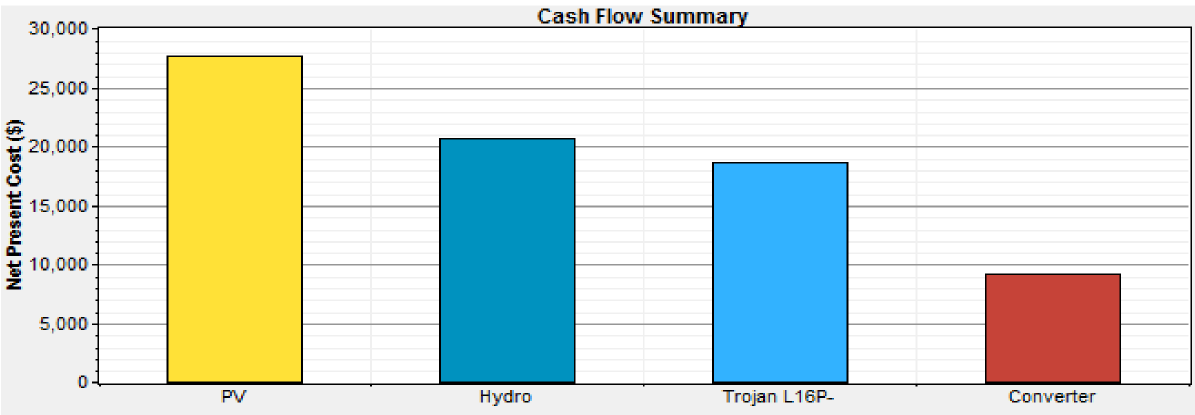


Figure 5.3: Monthly Average Electric Production of the selected hybrid system

From figure 5.3 above one can see that the total electrical production that is produced by all the renewable sources amounts to 166,501 kWh/yr; which encompasses 15,172kWh/yr or 9% from solar, and 151,329kWh/yr from hydro electric production, which covers large amounts of electric production.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	20,000	6,259	2,557	0	-1,165	27,651
Hydro	20,000	0	639	0	0	20,639
Trojan L16P-	9,600	7,773	1,636	0	-350	18,659
Converter	5,600	0	3,579	0	0	9,179
System	55,200	14,032	8,411	0	-1,515	76,128

Figure 5.4 Cost sheets of the components in the first optimum system

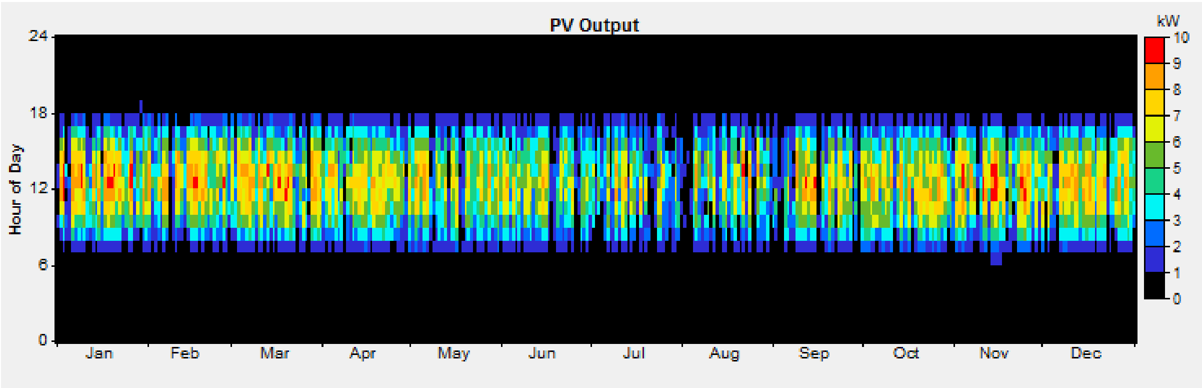


Figure 5.5 Annual electric energy productions by PV system

Figure 5.5 depicts the variation of sunlight available throughout the hours of the day, with the lowest values registered in the first and the last hours of the day and the available peak near midday. It also demonstrates the change in hours of the day throughout the year.

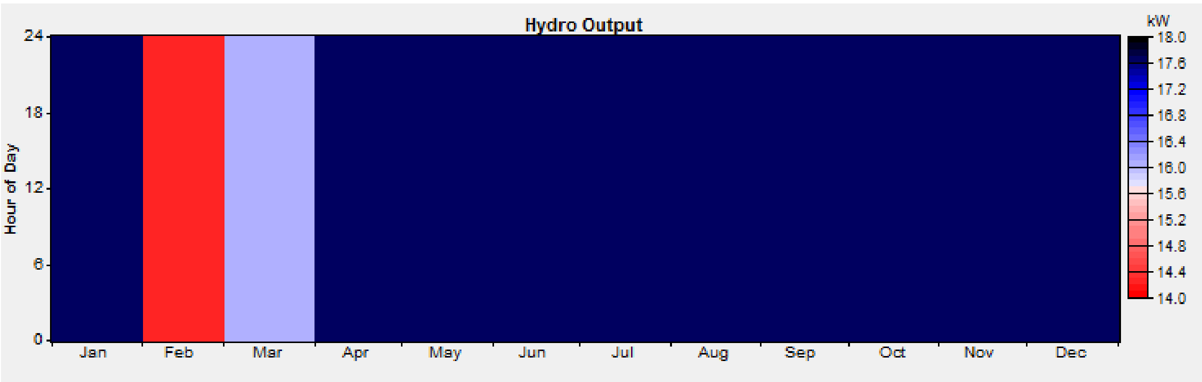


Figure 5.6 Annual electric energy productions by hydro power system

From Figure 5.6 one can learn that the potential electric generation over various months of the year with the lowest amount expected to be near February.

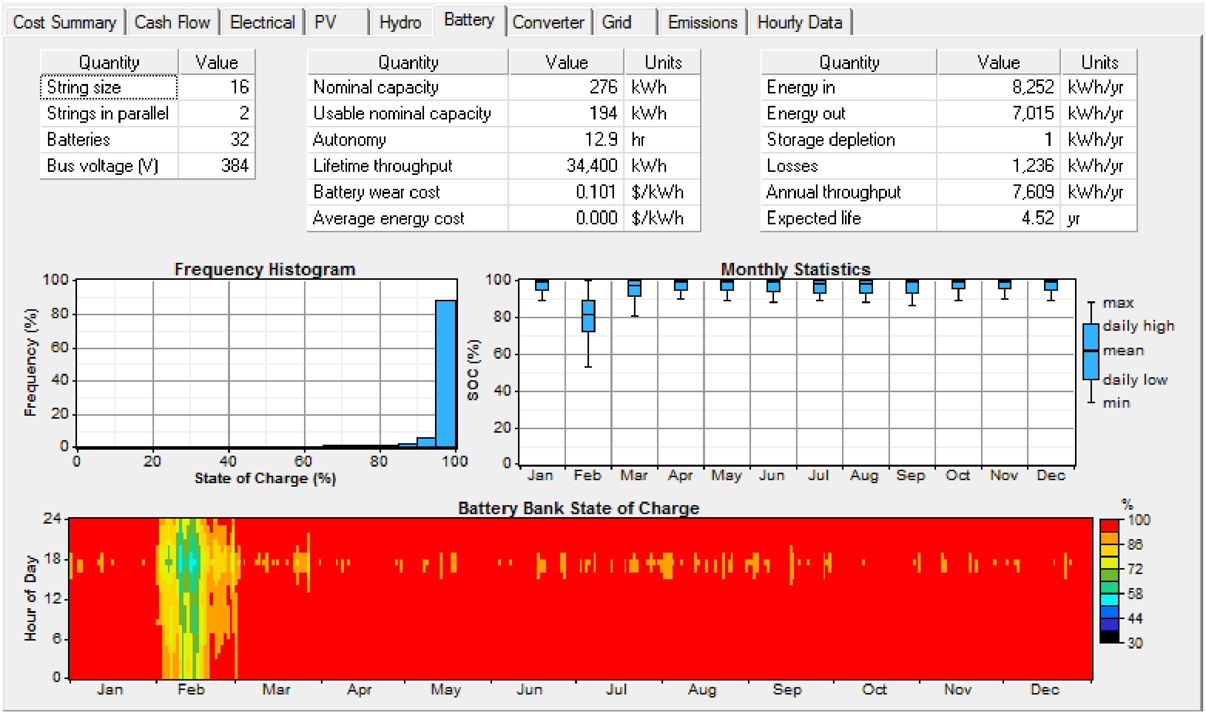


Figure 5.7 Annual Statistical result of battery system

As indicated in Figure 5.7, the battery is fully discharged in due of delivering power to loads because of the minimum generation capacity in hydro-electric component of the system during the same month. It's also evident here that the battery becomes operational during 12:00-18:00pm hours of the day to compensate the unavailability of sunshine.

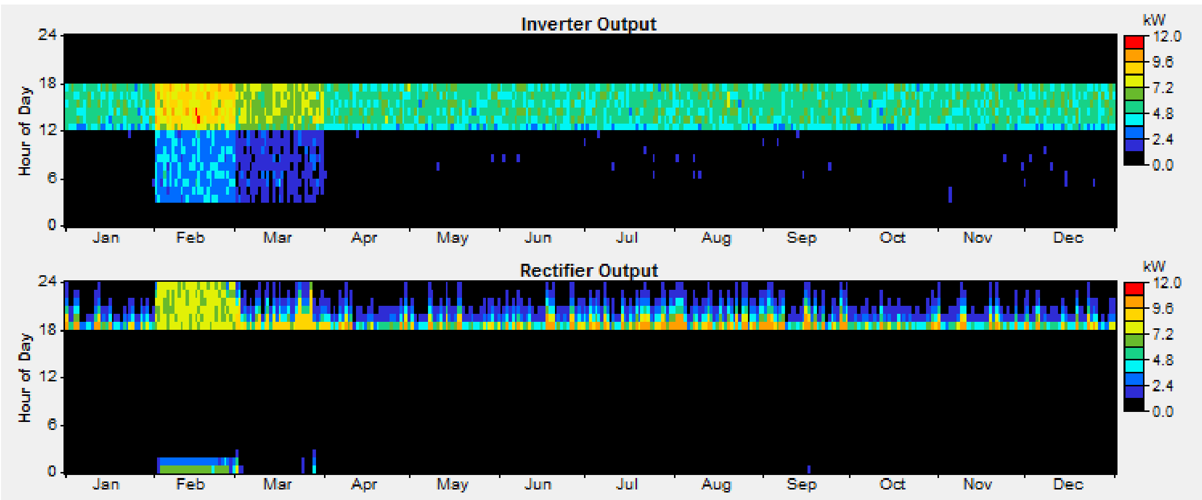


Figure 5.8 Annual Statistical result of convertor system

As indicated in Figure 5.8 the convertor is fully functional in due of delivering power to loads from 12-18pm during the pick load, also from February to march convertor is fully functional due to of decreasing of flow of water highly using PV and battery .

5.3 Sensitivity result for Meneko Toil site

Figure 5.9 shows the results of a sensitivity analysis over a range of load sizes and annual average solar radiation. The model assumes seven values for the average size of the electric load and five values for the annual average global solar radiation. The axes of the graph correspond to these two sensitivity variables. Both colors in the graph indicate these sensitivity cases, and the color of each diamond indicates the optimal system type for that sensitivity case. At an average load of 361kWh/day and an average solar radiation of 5.3kWh/day the optimal cost is $76,128 using the optimal system type of hydro/PV/battery. At an average load of 360kWh/day and the same stream flow rate, the optimal system type is found to be hydro/PV/battery. HOMER uses two-dimensional linear interpolation to determine the optimal system type at all points between the diamonds. The graph in Figure 5.9 shows that for the assumptions used in this analysis, hydro–battery systems are optimal for very small systems, as the load size increases the optimal system type changes to hydro/PV/battery used,

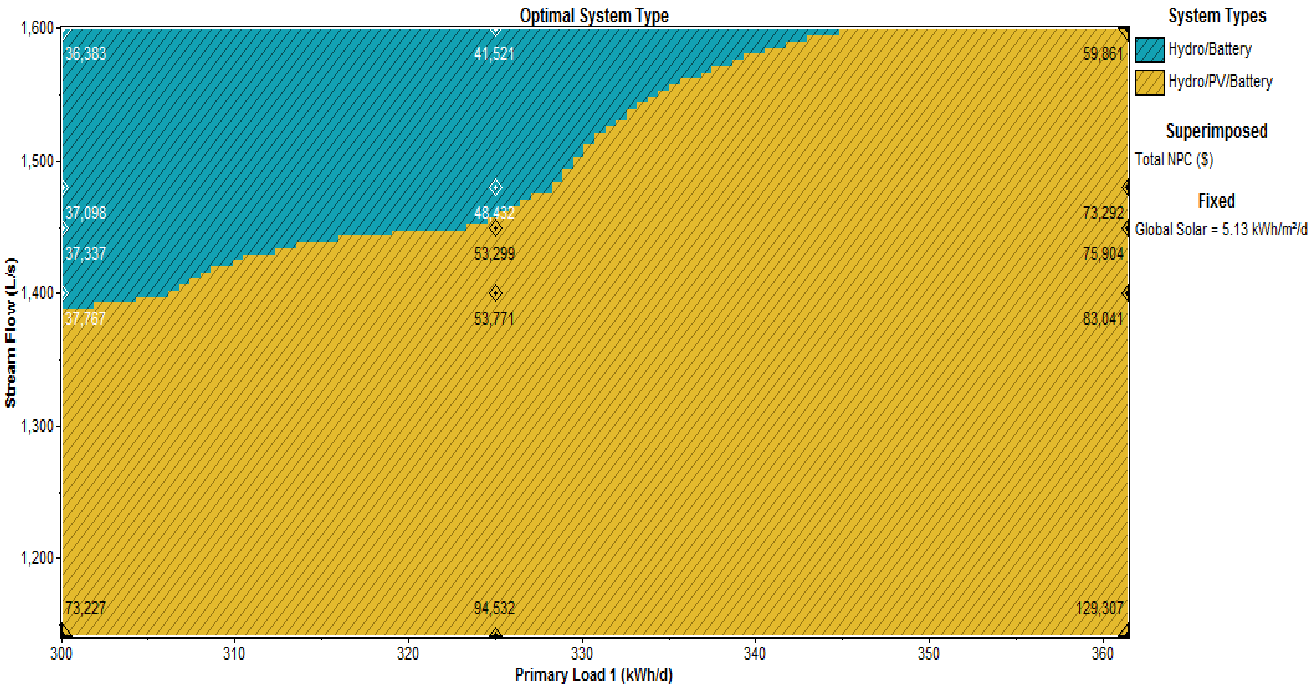


Figure 5.9 Sensitivity result to show the NPC for variable primary load and stream flow for selected site

The solutions present in the optimization space of Figure 5.9 are shown Obviously, the higher costs correspond to systems based on steam flow increasing if it is used hydro/battery and lower costs correspond to the solutions associated with higher primary load is decreasing if it using Hydro/PV/battery not optimum. In the intermediate region, the costs are distributed in horizontal bands, so depending on the stream flow more than the primary load.

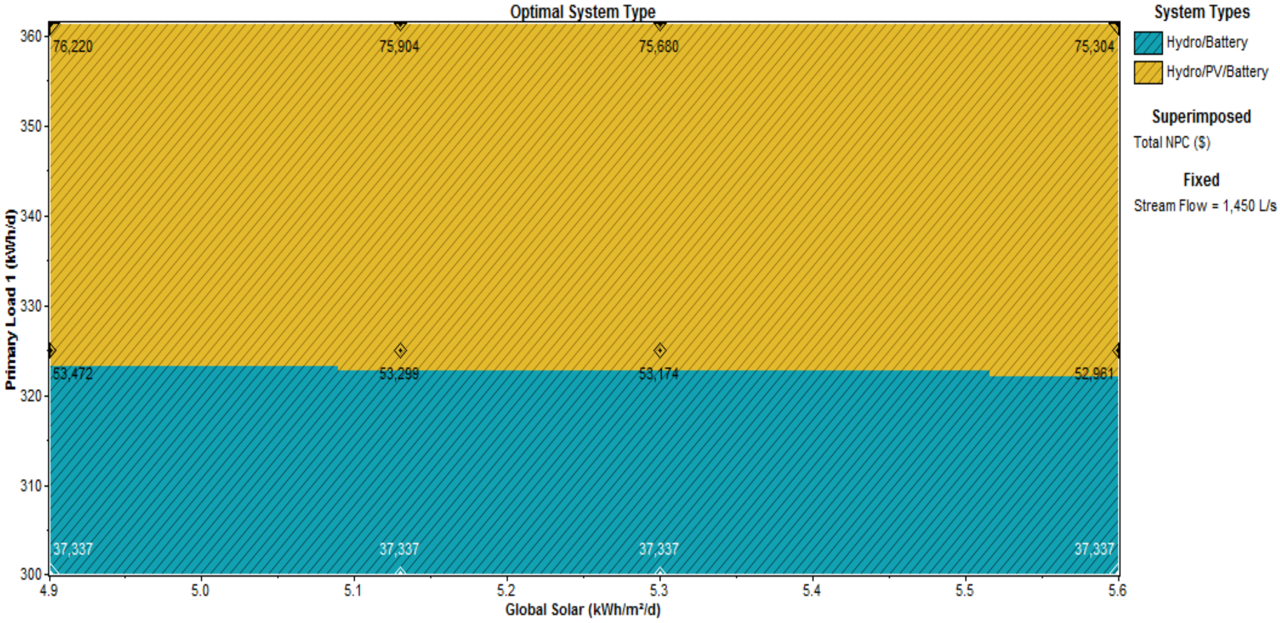


Figure 5.10 Sensitivity result to show the NPC for variable primary load and global solar radiation for selected site

Figure 5.10 shows that the solutions corresponding to primary load is increased and solar radiation is decreased, the recommended combination to be used is hydro/PV/battery because of the fact that the optimal cost is least. However the primary load is decreasing and solar radiation is increasing the green color region slightly larger is better to use recommend Hydro/battery because net present cost is less.

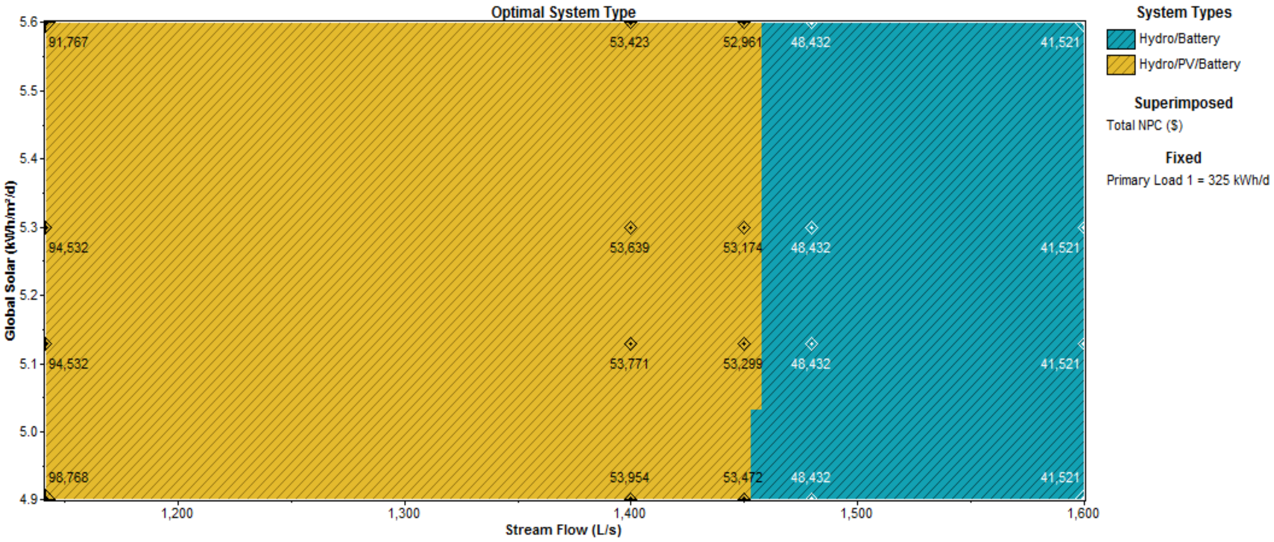


Figure 5.11 Sensitivity result to show the NPC for variable global solar radiation and stream flow for selected site.

Figure 5.11 shows that for Sensitivity result to show the NPC for variable global solar radiation and stream flow the assumptions used in this analysis, hydro–battery systems are optimal for green reign, as the load size increases the optimal system type changes to hydro/PV/battery used,

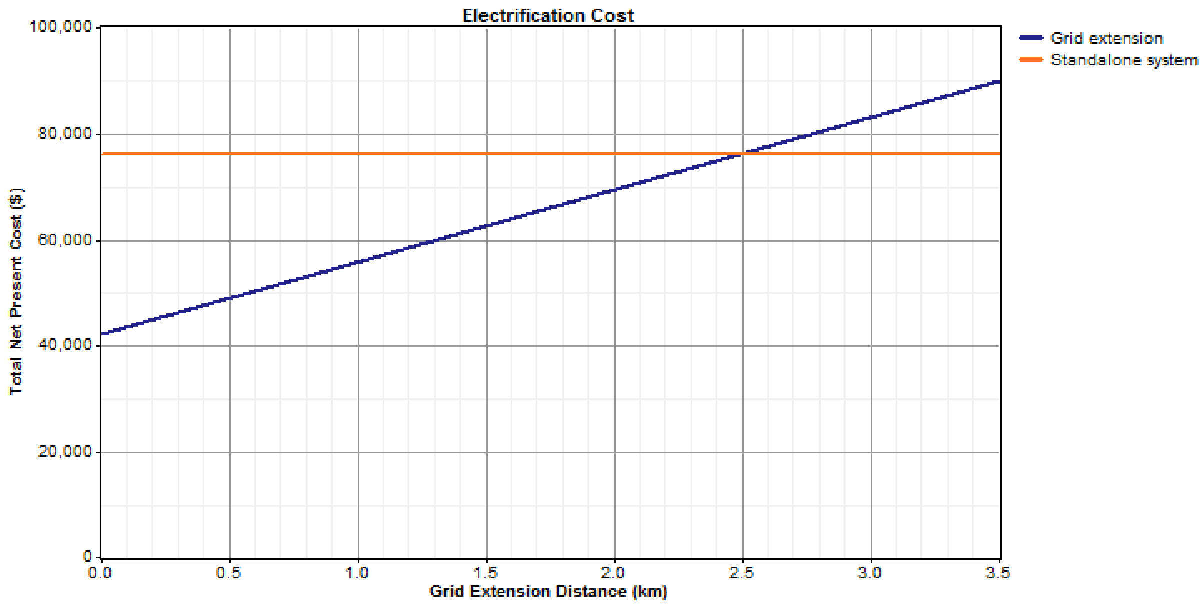


Figure 5.12 Breakeven grid extension distance in the first optimal system for Kersa Toli

From above figure 5.12 showing that the evaluation costs[2] of the PV and micro hydro hybrid system with the grid extension in terms of breakeven grid extension distance certain at 2.49 km meeting point between the grid extension cost in blue and the stand-alone cost in red. For the selected site, the shortest distance from the grid to the load centre is about 8km consequently the hybrid system is more economical than a grid extension.

Table 5.3 Summarized system report of the first optimal system for Menko Toli site

System Architecture		**Annual electric production**			**Types of Loa**	**Annual electric consumption (kWh/yr)**	
Hydropower	14kw	Type	kWh/yr	%	AC primary load	31,911	100%
PV	10kw	Hydropower	151,329	91	Total	131,911	100%
Battery	32 Trojan	PV	15,172	9			
Inverter	14kW	Excess electricity	30,431	18.3	Cost Summary		
Rectifier	14kw	Unmet load	0.000202	0	Total NPC	$76,128	
					COE	$0.045Kwh	

This research uses first iteration of overall optimization results, however if the demand load is increased in the future then by using the appendix table data of iteration it is possible to find the appropriate values of component's based on the load.

[2] It is advisable to consult EEPCO officials on the police of electrification process remote rural areas of Ethiopian

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. Conclusion

This paper discussed the optimization and operational strategy of hybrid renewable energy system. The main target of this thesis is to show that renewable energy can play a satisfying role in providing electricity to rural communities. Integrating available renewable energy and designing as a hybrid power system minimizes the cost of the system and energy per kWh in the long term.

The hybrid system devised in this research work gives an insight into the advantage of off-grid electric power generation as compared to its counterpart, the grid system. Based on actual parameters of the area, Menko Toli and the surroundings, the analytical procedures undertaken provided conclusive and promising results in terms of capital and other related costs with the comparable supply ratings. For a load distance of greater than 2.49km, a grid supply is not feasible to employ. For the selected site (8km away from the grid) the proposed hybrid supply option, composed of 10kW PV and 14kW micro-hydro has a COE of $0.045 per kWh, which is much less than the capital cost for grid system. For this specific site, for a load distance of greater than 2.49km, a grid supply is not feasible to employ. For the selected site (8km away from the grid) furthermore the renewable energy source potential of the site amounts to 15,172 kWh per year from PV and 152,329 kWh per year from Hydro. This is an essential and environmental friendly energy source that needs to be exploited at an optimum cost. For instance, the net present cost (NPC) that needs to be expended to realize this project is $76,128, which is much less than the grid cost (refer to Figure 5.12).

In conclusion, this study shows that developing a hybrid power system is more cost effective and suitable for rural communities where renewable energies are available; the result of this study encourages private investors and local community members, especially in Ethiopia, to take advantage of renewable energy and be convinced that there is sustainability in investing in hybrid power systems.

6.2 Recommendation

Ethiopia has a large potential renewable energy sources for rural electrification through the off grid system. However, the feasibility of its implementation should be based on given distances from the grid system. For example, this research indicates that a supply from the grid is not feasible for loads which are more than 2.49km away from the grid, which is the case for the site under consideration here. Hence, a site-specific study is important before the choice of applying either of the supplies.

It is shown in the results of this research that the first row is recommended for implementation as it requires much less financial investment in the long term and yields a low cost of energy per kWh. The current population of Menko Toli is about 2,500. But the installed Micro Hydro power generates only 15kw. This power is not sufficient for fulfilling the need of this population for electricity and flour mill. They need a water mill replaced by an Electrical System. To update the power supply additional energy source utilization is needed. Therefore, this gives an alternative approach to design satisfy the demand with an optimized and cost-effective way.

These alternative energy sources with systematic design are highly preferable for countries like Ethiopia, where there is abundant potential of the renewable energy sources. There are, however, formidable challenges like low purchasing power of the rural people and unfavorable public attitude towards the private sector. It is thus recommended that the government, non-governmental organizations and the public make combined efforts to overcome these challenges by using more flexible approaches to improve the current terrible state of rural electrification in Ethiopia.

Furthermore, this thesis shows only one selected site of Ethiopia and it doesn’t represent all areas of the country. Thus future works should use these beginnings as a benchmark and extrapolate similar activities to other sites and make the rural people beneficial and the system in Menko Toli can also be upgraded by using biomass power generation as plenty of resources are available for it.

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APPENDICES

Appendix A:

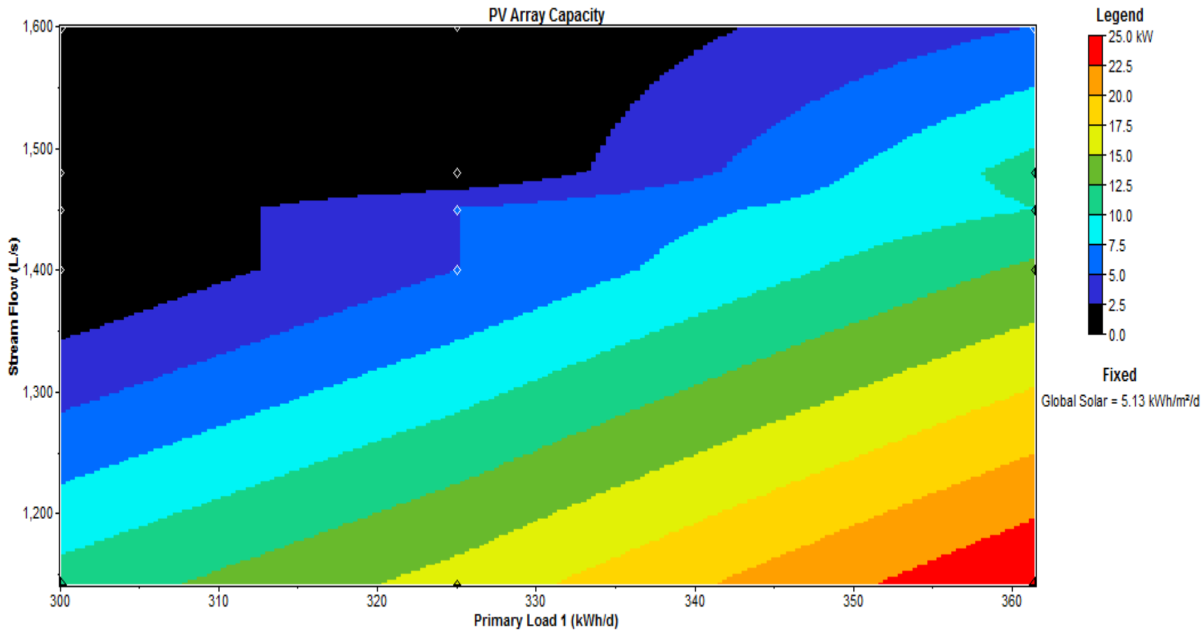

Figure A.1 PV array capacity and stream flow Vs primary load

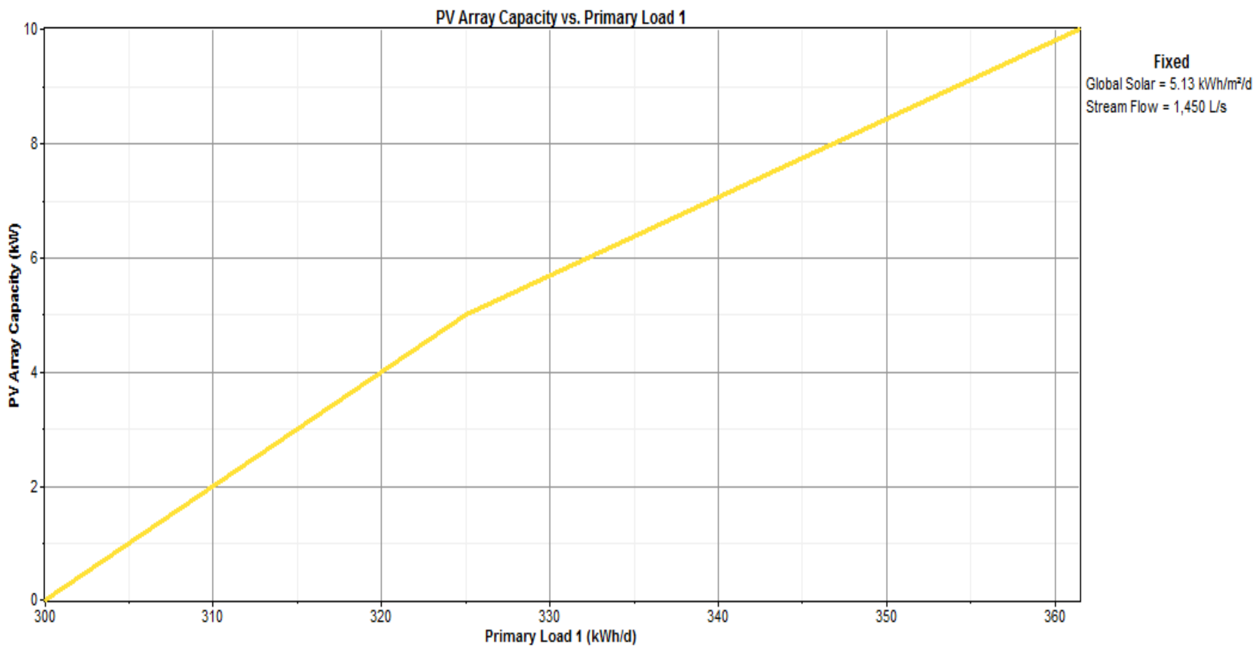

Figure A.2 PV array capacity and PV Vs primary load

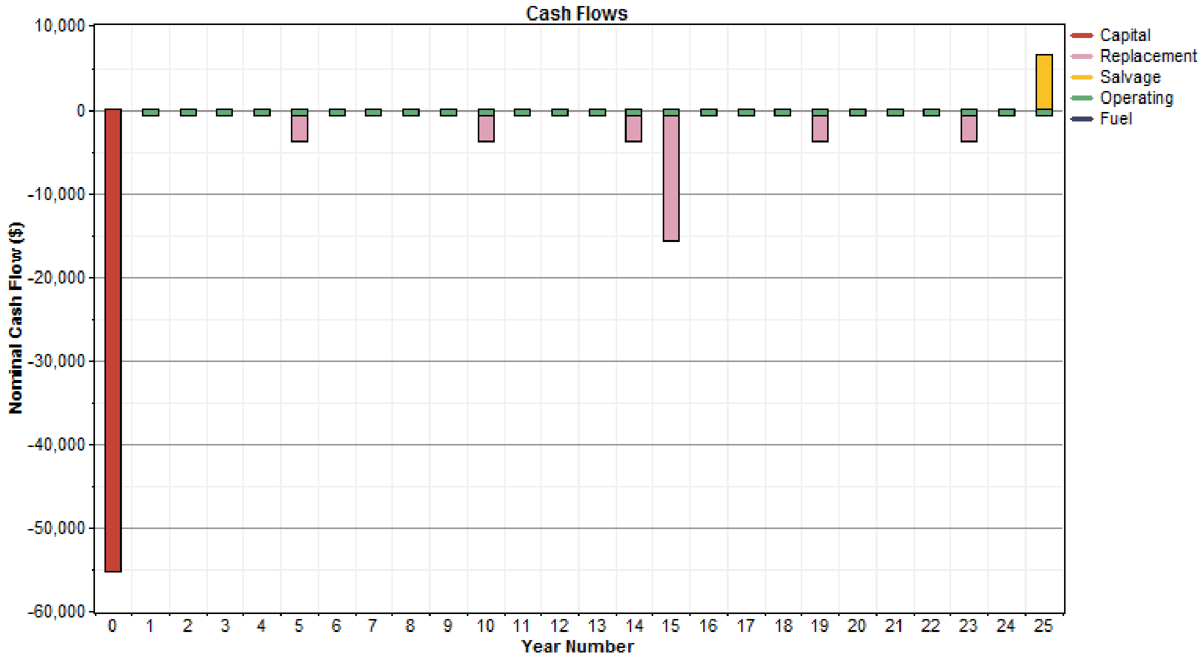

Figure A.3 Cash flows

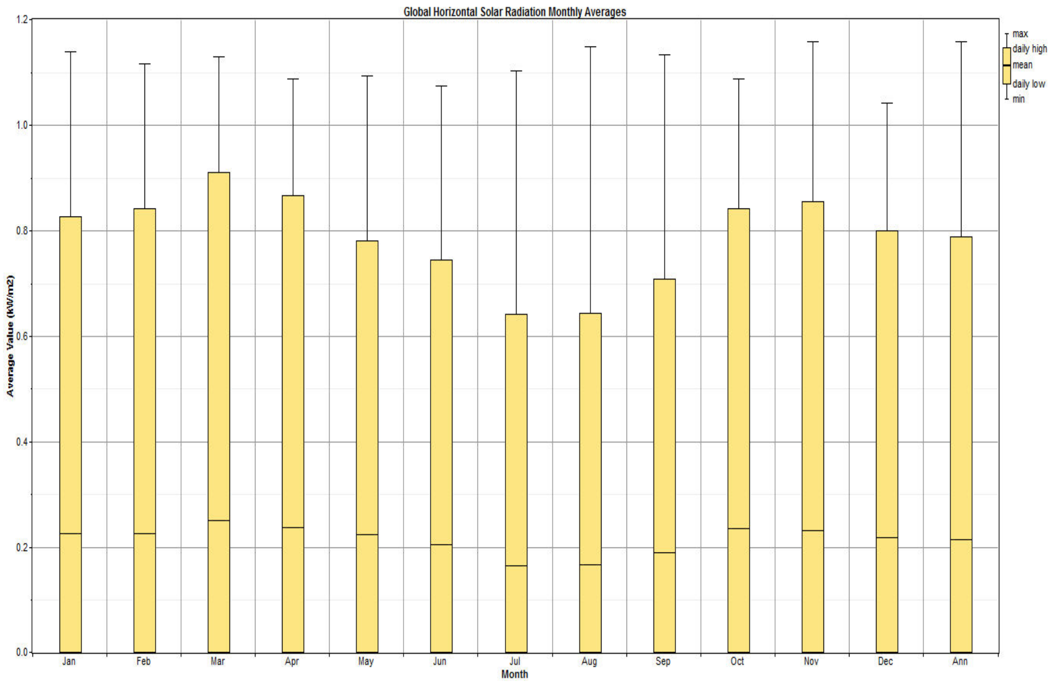

Figure A.4 Global Horizontal solar radiation monthly Averages

Appendix B:

Overall Optimization Results

S.No.	PV (kW)	Hydro (kW)	Battery	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Tot. Ele Pro.kWh/yr
1	10	14.0	32	14	55,200	658	76,128	0.045	166,501
2	10	14.0	32	15	55,600	678	76,784	0.045	166,501
3	10	14.0	32	13	54,800	759	77,440	0.046	166,501
4	10	14.0	32	16	56,000	698	77,890	0.046	166,501
5	11	14.0	32	14	57,200	678	78,236	0.046	168,018
6	11	14.0	32	15	57,600	698	78,891	0.047	168,018
7	11	14.0	32	13	56,800	779	79,547	0.047	168,018
8	11	14.0	32	16	58,000	718	79,998	0.047	168,018
9	10	14.0	32	20	57,600	778	80,062	0.047	166,501
10	10	14.0	48	14	60,000	722	80,851	0.048	166,501
11	10	14.0	48	15	60,400	742	81,507	0.048	166,501
12	10	14.0	48	13	59,600	823	82,163	0.048	166,501
13	10	14.0	48	16	60,800	762	82,170	0.049	166,501
14	11	14.0	32	20	59,600	798	82,318	0.049	168,018
15	13	14.0	32	14	61,200	718	82,613	0.049	171,052
16	15	14.0	16	14	60,400	694	82,743	0.049	174,087
17	11	14.0	48	14	62,000	742	82,754	0.049	168,018
18	14	14.0	16	14	58,400	896	82,974	0.049	172,570
19	10	14.0	32	25	59,600	878	82,984	0.049	166,501
20	13	14.0	32	15	61,600	738	83,198	0.049	171,052
21	15	14.0	16	15	60,800	714	83,341	0.049	174,087
22	11	14.0	48	15	62,400	762	83,399	0.049	168,018

23	13	14.0	32	13	60,800	819	83,409	0.05	171,052
24	15	14.0	16	13	60,000	795	83,630	0.05	174,087
25	11	14.0	48	13	61,600	843	83,640	0.05	168,018
26	14	14.0	16	15	58,800	916	83,853	0.05	172,570
27	13	14.0	32	16	62,000	758	84,054	0.05	171,052
28	15	14.0	16	16	61,200	734	84,065	0.05	174,087
29	13	14.0	16	14	56,400	1,130	84,080	0.05	171,052
30	14	14.0	16	13	58,000	998	84,296	0.05	172,570
31	11	14.0	48	16	62,800	782	84,505	0.05	168,018
32	14	14.0	16	16	59,200	936	84,509	0.05	172,570
33	10	14.0	48	20	62,400	842	84,516	0.05	166,501
34	13	14.0	16	15	56,800	1,150	84,746	0.05	171,052
35	13	14.0	16	13	56,000	1,231	84,785	0.05	171,052
36	14	14.0	32	14	63,200	738	84,960	0.05	172,570
37	16	14.0	16	14	62,400	714	85,078	0.05	175,604
38	11	14.0	32	25	61,600	898	85,176	0.051	168,018
39	13	14.0	16	16	57,200	1,170	85,448	0.051	171,052
40	10	14.0	64	14	64,800	786	85,602	0.051	166,501
41	14	14.0	32	15	63,600	758	85,734	0.051	172,570
42	16	14.0	16	15	62,800	734	85,832	0.051	175,604
43	14	14.0	32	13	62,800	839	86,252	0.051	172,570
44	16	14.0	16	13	62,000	815	86,257	0.051	175,604
45	10	14.0	64	15	65,200	806	86,390	0.051	166,501
46	14	14.0	32	16	64,000	778	86,487	0.051	172,570
47	10	14.0	64	13	64,400	887	86,677	0.051	166,501
48	16	14.0	16	16	63,200	754	86,688	0.051	175,604

49	13	14.0	32	20	63,600	838	86,840	0.051	171,052
50	15	14.0	16	20	62,800	814	86,913	0.051	174,087
51	10	14.0	64	16	65,600	826	86,918	0.051	166,501
52	11	14.0	48	20	64,400	862	86,938	0.051	168,018
53	14	14.0	16	20	60,800	1,016	87,132	0.052	172,570
54	13	14.0	48	14	66,000	782	87,364	0.052	171,052
55	15	14.0	32	14	65,200	758	87,430	0.052	174,087
56	11	14.0	64	14	66,800	806	87,443	0.052	168,018
57	10	14.0	48	25	64,400	942	87,763	0.052	166,501
58	13	14.0	16	20	58,800	1,250	88,064	0.052	171,052
59	13	14.0	48	15	66,400	802	88,086	0.052	171,052
60	15	14.0	32	15	65,600	778	88,099	0.052	174,087
61	13	14.0	48	13	65,600	883	88,419	0.052	171,052
62	15	14.0	32	13	64,800	859	88,742	0.052	174,087
63	11	14.0	64	15	67,200	826	88,754	0.052	168,018
64	11	14.0	64	13	66,400	907	89,012	0.052	168,018
65	13	14.0	48	16	66,800	822	89,075	0.053	171,052
66	15	14.0	32	16	66,000	798	89,110	0.053	174,087
67	14	14.0	32	20	65,600	858	89,192	0.053	172,570
68	11	14.0	64	16	67,600	846	89,205	0.053	168,018
69	16	14.0	16	20	64,800	834	89,525	0.053	175,604
70	10	14.0	64	20	67,200	906	89,531	0.053	166,501
71	14	14.0	48	14	68,000	802	89,536	0.053	172,570
72	16	14.0	32	14	67,200	778	89,812	0.053	175,604
73	13	14.0	32	25	65,600	938	89,879	0.053	171,052
74	15	14.0	16	25	64,800	914	89,955	0.053	174,087

75	11	14.0	48	25	66,400	962	89,966	0.053	168,018
76	14	14.0	16	25	62,800	1,116	90,197	0.054	172,570
77	14	14.0	48	15	68,400	822	90,410	0.054	172,570
78	16	14.0	32	15	67,600	798	90,468	0.054	175,604
79	14	14.0	48	13	67,600	903	90,534	0.054	172,570
80	16	14.0	32	13	66,800	879	91,123	0.054	175,604
81	14	14.0	48	16	68,800	842	91,190	0.054	172,570
82	16	14.0	32	16	68,000	818	91,364	0.054	175,604
83	13	14.0	16	25	60,800	1,350	91,377	0.054	171,052
84	13	14.0	48	20	68,400	902	91,574	0.054	171,052
85	15	14.0	32	20	67,600	878	91,641	0.054	174,087
86	11	14.0	64	20	69,200	926	91,697	0.054	168,018
87	15	14.0	48	14	70,000	822	92,228	0.055	174,087
88	14	14.0	32	25	67,600	958	92,291	0.055	172,570
89	16	14.0	16	25	66,800	934	92,388	0.055	175,604
90	10	14.0	64	25	69,200	1,006	92,814	0.055	166,501
91	15	14.0	48	15	70,400	842	92,883	0.055	174,087
92	15	14.0	48	13	69,600	923	93,061	0.055	174,087
93	13	14.0	64	14	70,800	846	93,539	0.055	171,052
94	15	14.0	48	16	70,800	862	93,716	0.055	174,087
95	14	14.0	48	20	70,400	922	93,746	0.056	172,570
96	16	14.0	32	20	69,600	898	93,813	0.056	175,604
97	13	14.0	64	15	71,200	866	93,990	0.056	171,052
98	13	14.0	64	13	70,400	947	94,372	0.056	171,052
99	13	14.0	64	16	71,600	886	94,643	0.056	171,052
100	13	14.0	48	25	70,400	1,002	94,655	0.056	171,052

101	15	14.0	32	25	69,600	978	94,665	0.056	174,087
102	16	14.0	48	14	72,000	842	94,823	0.056	175,604
103	11	14.0	64	25	71,200	1,026	94,976	0.056	168,018
104	20	14.0	16	14	70,400	794	95,159	0.056	181,673
105	16	14.0	48	15	72,400	862	95,321	0.056	175,604
106	16	14.0	48	13	71,600	943	95,814	0.057	175,604
107	20	14.0	16	15	70,800	814	95,826	0.057	181,673
108	14	14.0	64	14	72,800	866	95,977	0.057	172,570
109	16	14.0	48	16	72,800	882	96,162	0.057	175,604
110	20	14.0	16	13	70,000	895	96,427	0.057	181,673
111	15	14.0	48	20	72,400	942	96,470	0.057	174,087
112	20	14.0	16	16	71,200	834	96,481	0.057	181,673
113	14	14.0	64	15	73,200	886	96,921	0.057	172,570
114	14	14.0	64	13	72,400	967	96,995	0.057	172,570
115	14	14.0	48	25	72,400	1,022	97,024	0.057	172,570
116	16	14.0	32	25	71,600	998	97,091	0.058	175,604
117	13	14.0	64	20	73,200	966	97,137	0.058	171,052
118	14	14.0	64	16	73,600	906	97,588	0.058	172,570
119	5	14.0	128	14	74,000	942	98,236	0.058	158,915
120	16	14.0	48	20	74,400	962	98,591	0.058	175,604
121	15	14.0	64	14	74,800	886	98,599	0.058	174,087
122	5	14.0	128	15	74,400	962	98,892	0.059	158,915
123	20	14.0	16	20	72,800	914	99,093	0.059	181,673
124	5	14.0	128	13	73,600	1,043	99,246	0.059	158,915
125	15	14.0	64	15	75,200	906	99,440	0.059	174,087
126	15	14.0	48	25	74,400	1,042	99,548	0.059	174,087

127	15	14.0	64	13	74,400	987	99,760	0.059	174,087
128	5	14.0	128	16	74,800	982	99,875	0.059	158,915
129	14	14.0	64	20	75,200	986	99,902	0.059	172,570
130	20	14.0	32	14	75,200	858	99,998	0.059	181,673
131	15	14.0	64	16	75,600	926	100,273	0.059	174,087
132	13	14.0	64	25	75,200	1,066	100,353	0.059	171,052
133	20	14.0	32	15	75,600	878	100,531	0.06	181,673
134	20	14.0	32	13	74,800	959	101,187	0.06	181,673
135	20	14.0	32	16	76,000	898	101,356	0.06	181,673
136	16	14.0	64	14	76,800	906	101,637	0.06	175,604
137	16	14.0	48	25	76,400	1,062	101,878	0.06	175,604
138	16	14.0	64	15	77,200	926	102,011	0.06	175,604
139	5	14.0	128	20	76,400	1,062	102,170	0.061	158,915
140	16	14.0	64	13	76,400	1,007	102,371	0.061	175,604
141	20	14.0	16	25	74,800	1,014	102,525	0.061	181,673
142	15	14.0	64	20	77,200	1,006	102,667	0.061	174,087
143	16	14.0	64	16	77,600	946	103,038	0.061	175,604
144	14	14.0	64	25	77,200	1,086	103,118	0.061	172,570
145	20	14.0	32	20	77,600	978	103,809	0.062	181,673
146	16	14.0	64	20	79,200	1,026	105,290	0.062	175,604
147	5	14.0	128	25	78,400	1,162	105,449	0.063	158,915
148	20	14.0	48	14	80,000	922	105,592	0.063	181,673
149	15	14.0	64	25	79,200	1,106	105,803	0.063	174,087
150	20	14.0	48	15	80,400	942	106,248	0.063	181,673
151	20	14.0	48	13	79,600	1,023	106,296	0.063	181,673
152	20	14.0	48	16	80,800	962	106,903	0.063	181,673

153	20	14.0	32	25	79,600	1,078	106,952	0.063	181,673
154	25	14.0	16	14	80,400	894	107,088	0.064	189,258
155	16	14.0	64	25	81,200	1,126	107,354	0.064	175,604
156	25	14.0	16	15	80,800	914	107,607	0.064	189,258
157	25	14.0	16	13	80,000	995	108,058	0.065	189,258
158	25	14.0	16	16	81,200	934	108,070	0.065	189,258
159	20	14.0	48	20	82,400	1,042	108,568	0.065	181,673
160	5	14.0	160	14	83,600	1,070	108,725	0.066	158,915
161	25	14.0	16	20	82,800	1,014	109,381	0.066	189,258
162	10	14.0	128	14	84,000	1,042	109,526	0.066	166,501
163	20	14.0	64	14	84,800	986	109,831	0.067	181,673
164	11	14.0	16	14	52,400	3,682	110,230	0.067	168,018
165	5	14.0	160	15	84,000	1,090	111,884	0.067	158,915
166	10	14.0	128	15	84,400	1,062	112,004	0.067	166,501
167	25	14.0	32	14	85,200	958	112,062	0.067	189,258
168	5	14.0	160	13	83,200	1,171	112,416	0.067	158,915
169	20	14.0	48	25	84,400	1,142	112,540	0.067	181,673
170	10	14.0	128	13	83,600	1,143	112,717	0.067	166,501
171	20	14.0	64	15	85,200	1,006	112,804	0.067	181,673
172	11	14.0	16	15	52,800	3,702	112,823	0.067	168,018
173	5	14.0	160	16	84,400	1,110	113,072	0.067	158,915
174	20	14.0	64	13	84,400	1,087	113,196	0.067	181,673
175	10	14.0	128	16	84,800	1,082	113,373	0.067	166,501
176	11	14.0	16	13	52,000	3,783	113,479	0.067	168,018
177	25	14.0	32	15	85,600	978	113,508	0.067	189,258
178	25	14.0	32	13	84,800	1,059	113,646	0.067	189,258

179	20	14.0	64	16	85,600	1,026	113,727	0.067	181,673
180	11	14.0	16	16	53,200	3,722	113,824	0.068	168,018
181	25	14.0	32	16	86,000	998	114,134	0.068	189,258
182	11	14.0	128	14	86,000	1,062	114,178	0.068	168,018
183	25	14.0	16	25	84,800	1,114	114,585	0.068	189,258
184	11	14.0	128	15	86,400	1,082	114,827	0.068	168,018
185	11	14.0	128	13	85,600	1,163	115,282	0.069	168,018
186	5	14.0	160	20	86,000	1,190	115,482	0.069	158,915
187	10	14.0	128	20	86,400	1,162	115,818	0.069	166,501
188	11	14.0	128	16	86,800	1,102	115,996	0.069	168,018
189	20	14.0	64	20	87,200	1,106	116,138	0.069	181,673
190	11	14.0	16	20	54,800	3,802	116,350	0.069	168,018
191	25	14.0	32	20	87,600	1,078	116,589	0.069	189,258
192	11	14.0	128	20	88,400	1,182	116,757	0.07	168,018
193	5	14.0	160	25	88,000	1,290	118,761	0.071	158,915
194	10	14.0	128	25	88,400	1,262	119,097	0.071	166,501
195	25	14.0	48	14	90,000	1,022	119,274	0.071	189,258
196	20	14.0	64	25	89,200	1,206	119,417	0.071	181,673
197	11	14.0	16	25	56,800	3,902	119,628	0.071	168,018
198	25	14.0	32	25	89,600	1,178	120,035	0.071	189,258
199	25	14.0	48	15	90,400	1,042	120,073	0.071	189,258
200	25	14.0	48	13	89,600	1,123	120,357	0.071	189,258