Feasibility Study of Power Generation Using Off- Grid Energy System from Micro Hydro-PV-Diesel Generator-Battery for Rural Area of Ethiopia: The Case of Indris River, Western Ethiopia

By Feyisa Bekele

A Thesis Submitted to

The Center of Energy Technology

Presented in Fulfillment of the Requirements for the Degree of Master of Science (Energy Technology)

Addis Ababa University

Addis Ababa, Ethiopia

August 2017

Addis Ababa University

Addis Ababa Institute of Technology

Center of Energy technology

This is to certify that the thesis prepared by Feyisa Bekele, entitled: Feasibility Study of Power Generation Using Off- Grid Energy System from Micro Hydro-PV-Diesel Generator-Battery for Rural Area of Ethiopia: The Case of Indris River, Western Ethiopia. It submitted in partial fulfillment of the requirements for the degree of Master of Sciences (Energy Technology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Internal Examiner: Dr. Eng. Edessa Dribsa Signature_____________ Date___________

External Examiner: Dr. Solomon T/Mariam Signature________________ Date_________

Advisor: Dr. Eng. Wondwossen Bogale Signature ________________ Date_________

Co-advisor: Tilahun Nigussie (PhD candidate) Signature _______________ Date__________

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School or Center Chair Person

Acknowledgements

First, of all my gratitude, goes to the Almighty God for his positive will and help without which the things I made here were value less. Next, I would like to thank the Energy Center of the Addis Ababa Institute of Technology, Addis Ababa University funds for this thesis. Secondly, my deepest heartfelt gratitude goes to my advisors: **Dr**. **Ing. Wondwossen Bogale** for his generosity and kindness throughout the period of my thesis work and **Tilahun Nigussie** for his unlimited help from the very beginning of selecting the title. I also need to thank the people and office of Ministry of Water & Energy of Ethiopia for their help while I was collecting stream flow data. At finally yet importantly my special appreciation goes to Tesfaye Duressa for his undisputable support throughout my stay in Addis Ababa University and my friends for their advice.

List of symbols

ρ	Density of water (1000kg/m^3)
g	Gravitational constant (9.81m/s^2).
f	Friction factors
Re	Reynolds number
v	kinematic viscosity of water
n	Manning coefficient
η_t	Turbine efficiency [%]
α_P	Temperature coefficient of power [%/°C]
γ_{pv}	Rated capacity of the PV array, meaning its power output under STC [kW]
f_{pv}	PV derating factor [%]
$\bar{G}_T$	Solar radiation incident on the PV array in the current time step [kW/m^2]
$\bar{G}_{T,\ STC}$	Incident radiation at standard test conditions [1 kW/m^2]
Υ	Azimuth of the surface
i	Real interest rate [%]
η_{batt}	Battery efficiency [%]

List of Abbreviations

AC	Alternating current
ASC	Asynchronous generators
CC	Cycle Charging
CEA	Clean energy association
CFL	Compact fluorescent lumps
COE	Cost of energy
DC	Direct Current
DG	Diesel Generator
DOD	Depth of discharge
EEP	Ethiopian Electric Power
ESHA	European small Hydropower Association
GPS	Global Position surface
HOMER	Hybrid optimization model for Renewable Energy
HYRESS	Hybrid Renewable Energy Systems for Supplying of Service
LF	Load following
MHP	Micro Hydro -power
MHS	Micro hydropower system
MoWIE	Ministry of Water, Irrigation and Energy
NASA	National Aeronautics and Space Administration
NPC	Net present cost

NGO	Non-government organization
NRER	National Renewable Energy Laboratory
PV	Photovoltaic
RE	Renewable energy
SHP	Small hydropower
SG	Synchronous generators
UEAP	Universal Electricity Access Program

Abstract

In Ethiopia, electricity supply is extremely antiquated. When compared to other African countries, electric supply system and overall electric access in Ethiopia is very low. As in most Sub-Saharan Africa countries, Ethiopia experiences huge gap to access electric supply to urban and rural areas. Accordingly, Melkey Hera village is one of a rural community situated in Western Ethiopia, and experiences problems related to access to electric supply. In this village, extension of the grid is not yet practical. Therefore, the target of this paper is to investigate the viability of a micro hydro, Photo Voltaic (PV) and Diesel Generator-battery hybrid power system options to come up with the best techno-economic and optimum configuration for supplying electricity to this village. The study conducted by an assessment of the predicted village energy demand, the available renewable energy resources, and then using the software called HOMER. The optimal off- grid system design was established to combine hydro, solar PV, battery energy storage and diesel generator. This system demonstrated to be more reliable in operation, and the most cost-effective for the required level of service. The role of energy storage in system operation also demonstrated to offer additional operational advantages in-terms of reliability and cost savings. Overall, the design results show that the majority of energy obtained is from hydropower, which accounts 79%. The PV module covers 20%, and diesel generator is only 1% of the total load consumption. The renewable fraction (RF) of the project is 99%, which implies the total energy almost obtained from renewable system only and the system is environmentally friendly. The obtained hybrid system is cost competitive with $0.133/kWh, which is somewhat good to satisfy the community needs. However, this is more than current energy price in Ethiopia, which is $0.06/kWh. If due-merit is given to the electricity deficiency of the country, this higher cost should not be given concern. However, the project requires government subsidies to make service affordable. Finally, this study identified that off grid hybrid micro hydro-PV-DG-battery bank energy system is cost effective and environmentally friendly in delivering power for rural areas far from the grid. Moreover, the study provides valuable information to the government and Non-government organization (NGO) about the renewable energy potential of the country for a rural electrification project in Ethiopia.

Keywords: *Hybrid System, Renewable Energy, HOMER, Photovoltaic, Micro Hydro, Feasibility*

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CHAPTER ONE

Introduction

This chapter of the study deals with background of the study; particularly the energy situation and energy potential in Ethiopia, the background of micro hydro and solar PV potential. The chapter also explained off-grid hybrid energy system, problem statement, objective of the study, scope of the study, significance of the study, and description of the study area.

1. Back ground of the Study

Energy requirement is becoming prerequisite to enhance income, improve quality of the people no matter where they live. Energy is one of the bases for economic growth and social progress of the people and as well as any country. The global population mostly resides in rural areas due to nature of settlement governments often cannot provide basic energy facilities for this sparsely populated regions.

International energy agency (IEA) estimates that 1.5 billion people lived without access to electricity in 2008. More than one-fifth of the world's population experiences this situation. Some 85% of those without electricity living in rural areas, mainly in sub- Saharan Africa and South Asia [1]. The rapid depletion of fossil fuels worldwide has made it necessary to reduce it dependency on nonrenewable energy sources. One way of accomplishing this is to harness the enormous potential of renewable energy sources to meet continually increasing demands for energy. However, the periodic nature of renewable energy sources is the main issue hindering their rapidly implementation. To improve the reliability and power quality of the system, energy storage and conventional generator generally used as backup system. But distributed generation using two or more renewable energy sources can also significantly increase the reliability [2].

1.1. The Energy Situation in Ethiopia

In Ethiopia, electricity supply is extremely antiquated. As compared to other African countries experience, overall electric access in Ethiopia is very low. As in most Sub-Saharan Africa countries, urban and rural access has a huge gap. Globally, Ethiopia experienced the lowest consumption rate, and its electricity consumption is 37kwh per capita per year. Only approximately 15% of populations have access to the power grid. About 89.6% of electricity in the country is consumed in urban area where approximately 50% is consumed in Addis Ababa city and 20% consumed in Adama town, the second largest town in energy consumption [3].

1.2.Micro hydro and solar PV Potential in Ethiopia

Ethiopia has significant solar, wind, biomass and biogas, hydro and geothermal energy potential, aspires to become a regional power exporter and green energy hub for eastern Africa [4]. Even though Ethiopia is ample in renewable energy resources, lack of energy supplies in rural areas in the country becomes a chronic problem. A possible reason is that these areas are either far away from the national grid and/or the people living there are sparsely populated. Extending the national grid to these areas is not up to the economic capacity of the country because of the high cost of transmission and the very low load factor in these areas. To satisfy their energy needs, these people are using kerosene, which is becoming difficult to afford and firewood, cow dung and other traditional biomass resources, which are causing deforestation and soil degradation. The Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia is working to change this scenario. In its effort, it has identified that, the use of renewable energy such as micro hydro and Photovoltaic (PV) hybrid power system as an energy source is the solution for the above problem [4].

1.2.1. Micro Hydro Power Potential

Over the last few decades, there has been a growing realization in developing countries that Micro-Hydro schemes have an important role to play in the economic development of remote rural areas, especially mountainous ones. Micro-hydro-electric power is both an efficient and reliable form of clean source of renewable energy. It can be an excellent method of harnessing renewable energy from small rivers and streams. The first step in assessing a potential water resource for hydropower is to calculate how much power can be produced. The volume of water available (flow) and the vertical distance determines the estimated power the water falls (head).The micro-hydro project designed to be a run -of-river type, because it requires very little or no reservoir in order to power the turbine. The water will run straight through the turbine and back into the river or stream to use it for the other purposes. This has a minimal environmental impact on the local ecosystem. Micro-Hydro schemes can provide power for industrial, agricultural and domestic uses through direct mechanical power or by the coupling of the turbine to a generator to produce electricity. This study is concentrated mainly at Micro-Hydro power. Ethiopia has thus a theoretical MHP potential of 100 MW with capacity ranging from 11 kW just enough to provide domestic lighting to a group of houses through a battery charging to 500 kW which can be used for small factories and to supply an independent local off-grid [6].

To harness micro hydro potential, the typical components of the micro hydropower system is known. The components of the typical MHS (Micro Hydropower System) that could be classified as civil works and power house components. The civil work components described in this section are those major components such as the intake, headrace canal, de- Sanding basin, spillway, fore bay tank, penstock pipes [7, 8].While the powerhouse components of Micro hydropower are used to convert the mechanical energy of water into electrical energy. Powerhouse consists of electro-mechanical equipment such as turbines, generator and drive systems.

Hydraulic Turbine: In a MHS, hydraulic turbine is the primary component, which converts the energy of the flowing water into mechanical energy through the rotation of the runner. The choice of particular turbine depends up on technical parameters such as design head and discharge at which the turbine is to operate as well as other practical considerations such as the availability and cost of maintenance personnel [5, 9].

Another powerhouse component in the micro hydro system is the generator. Although this study is not overly concerned with the selection and uses of generators in the MHS (Micro Hydropower System), it is relevant to describe the basic types of generators. There are two main types of generators that are used for the hydropower production: synchronous or asynchronous generators. The synchronous generators are the main types of generators that are used in large scale of the energy production. When the output power levels are generally less than 10 MW, the asynchronous generators are widely used. The productions of these generators are also preferred as asynchronous generators because they can operate at different speeds with a constant frequency, and are cheap compared to the synchronous ones. Both of these generators have the ability to use the network connection or just work in the autonomous mode. The asynchronous generators are generally suitable for the micro hydropower generation. The offered asynchronous generator has many advantages over the ordinary synchronous generator as a source of isolated power [10]. Major components of a typical micro hydropower scheme (MHPS) are shown on the Fig,1.1 below:

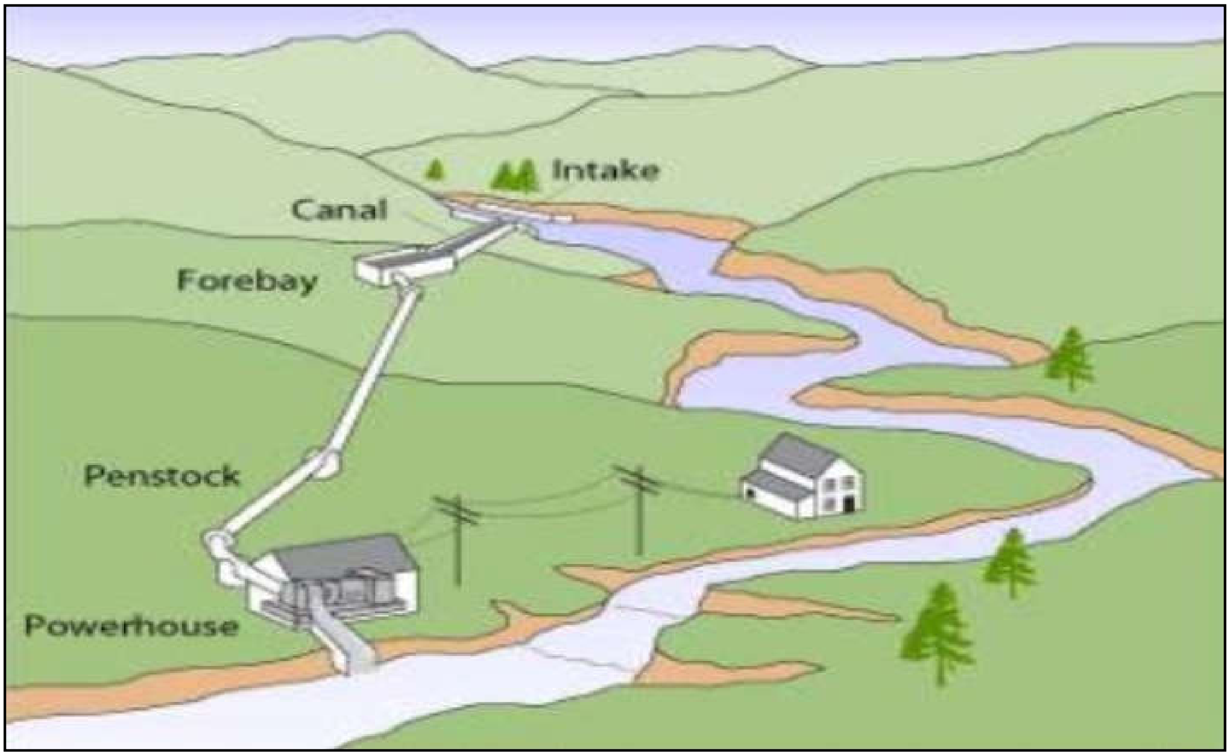

Fig.1. 1: The major components of a typical micro hydropower scheme [11]

1.2.2. Solar Photovoltaic Potential

Ethiopia has plenty of solar radiation potential. It receives a solar irradiation of 5000 – 7000 kWh/m² according to region and season and thus has great potential for the use of solar energy. The average solar radiation is uniform, around 5.2kWh/m^2/day. The values vary seasonally from 4.55-5.55 kWh/m^2/day and with location from 4.25 kWh/ m^2/day in the extreme western low lands to 6.25 kWh/ m^2/day in Adigrat area, Northern Ethiopia is still at its early stage [5].

Solar radiation that reaches the earth’s surface in a straight line called direct radiation. Sunlight scattered by cloud, dust, humidity and pollution, which is called diffused. The sum of the direct and diffuse sunlight called global-horizontal radiation. Concentrating solar technologies, which use mirrors and lenses to concentrate sunlight, rely on direct radiation, while PV cells and other solar technologies can function with diffused radiation. Photovoltaic cells do not only use the direct component of the light, but also produce electricity when the sky overcast to the average total solar energy received over the year rather than to refer to instantaneous irradiance [27]. The solar cell is the elementary building block of the photovoltaic technology that converts sunlight directly into electricity by taking the advantages of the photoelectric effect. Solar cells are made of semiconductor materials such as silicon. One of the properties of semiconductors that makes them most useful is their conductivity may easily be modified by introducing impurities into their crystal lattice [13].There are several types of solar cells from which more than 90% of the solar cells currently made worldwide consist of wafer-based silicon cells. Either they cut from a single crystal rod or from a block composed of many crystals are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Modules consisting of mono crystalline silicon PV cells reach commercial efficiencies about 21.5%, which is the highest efficiency available on the market. Another important family of solar cells based on thin-films, which are approximately 12μm thick and therefore, require significantly less active, semiconducting material. Thin-film solar cells can be manufactured at lower cost in large production quantities; hence their market share will likely increase in the future. However, they indicate lower efficiencies than wafer-based silicon solar cells, which mean that more exposure surface and materials for the installation is required for a similar performance [5].

The PV cells converts sunlight directly into electricity by taking advantage of the photoelectric effect. When photons in sunlight strike the top layer of a PV cell, they provide sufficient energy to knock electrons through the semiconductor to the bottom layer by making a separation of electric charges on the top and bottom of the solar cell. Figure 1.2 shows the operation and principles of converting sunlight into electricity. Connecting the bottom layer to the top with a conductor completes an electrical circuit and allows the electrons to flow back to the top by creating an electric current and enabling the cycle to repeat with more sunlight [12]

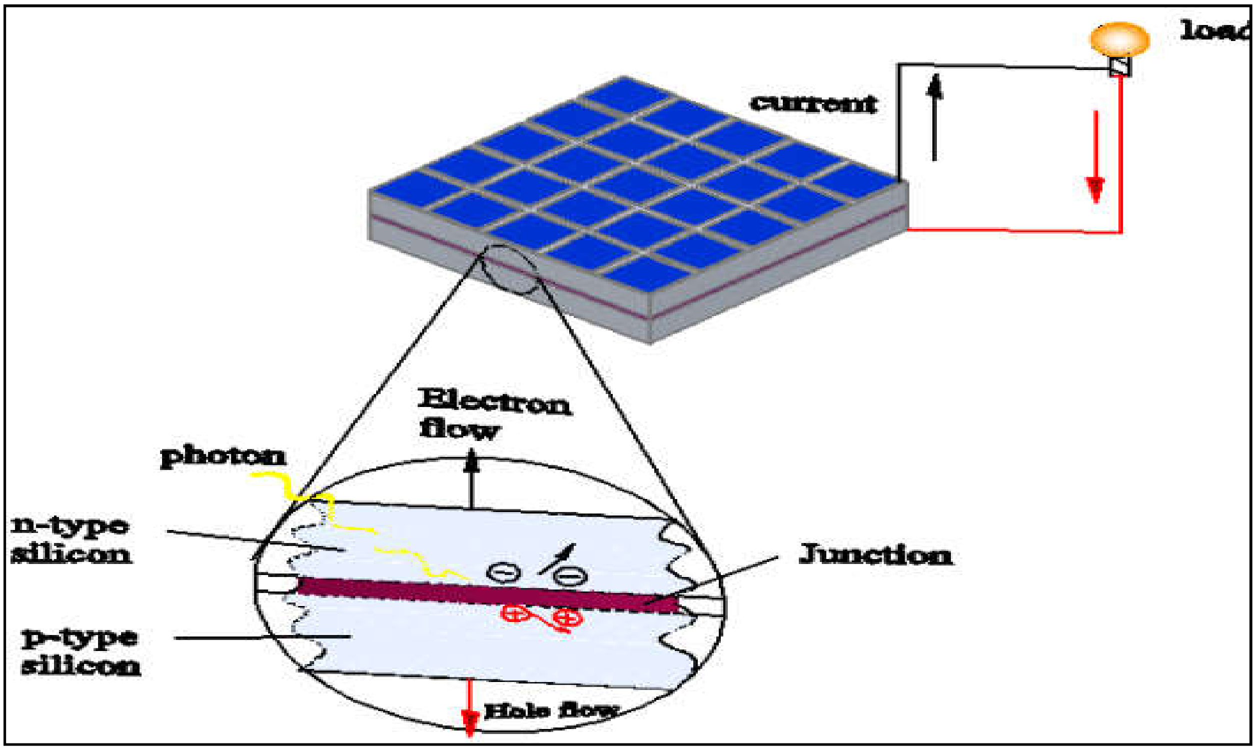

Fig.1.2: Basic operation of photovoltaic system [12]

Generally, the renewable energy potentials stated above have various advantages to solve energy crises in rural community of Ethiopia as well as worldwide nevertheless they have some demerits. For example, a system using solar energy alone will face the problem of unavailability of optimum amount of solar radiation during nighttime or cloudy weather condition. Again using a wind power system will face a problem in meeting the load demand in a less windy climate. And using a hydropower system alone will be unable to meet the load demand if the force of water flow is not optimum. Considering all these factors, here a hybrid energy system consisting of solar energy, wind power and hydropower should be taken into account. Due to significant fluctuation in wind speed magnitude for high cut-in speed ranging, the wind system cannot deliver power at a constant load. Therefore, over sizing of the Wind system becomes necessary to achieve reliability, which causes the design to become expensive [14]. Optimum designing is very essential for PV /hydro/Battery hybrid system. By incorporating diesel generator with renewable energy system, diesel generator is able to increases the electricity supply during sudden increase in energy demand. Alternatively, when the batteries capacity decreases, facilities face no supply interruption. Hence, Hydro/PV/DG/Battery have become feasible alternatives for power production by using computer simulation techniques available nowadays, the optimum system configurations can be obtained by comparing the performances and energy production costs of different configurations of wind power, PV and hydropower hybrid generating systems.

The purpose of this study is to check the viability of Micro Hydro, PV, DG and Battery hybrid system. This study helps to minimize environmental pollution, deforestation and soil degradation. Due these people are using firewood, cow dung and other traditional biomass resources and kerosene, which are becoming difficult to afford and the rural community can get electricity access by this study. Moreover, this study provides important information to the government and Non- government organizations (NGO) about the energy potential of technology in the village for a rural electrification project in Ethiopia. Furthermore, it can serve as a base to conduct similar study activities for other sites.

1.1. Problem Statement

Even if Ethiopia has a huge potential of renewable energy (hydro, wind, solar, geothermal and biomass), the country is suffering from energy crises throughout characterized by frequent blackouts and interruption. Due to limited energy production, there are places; especially around remote areas, energy is not available/accessed and the people around are living in serious problem of access to electricity supply. A possible reason is that either these areas are far away from national grid or community settlements are sparsely populated. Extending national grid to those areas is not up to the economic capacity of the country because of the high costs of transmission and very low load factor in the areas. However, electrification of the rural communities is very essential to bring socio economic development of the rural community and the country at large. Based on universal electrical access program (UEAP), the Ethiopian Government owned utility "EEP" to extend the national electricity grid to towns and villages preferably with minimum of 5000 households. The high contribution of the Ethiopia government is because the extension of the grid to villages with less than 5,000 inhabitants is economically not feasible for EEP [3].

Melka Hera village is one of the rural communities situated in Western Ethiopia. In the village, the extension of the grid is not yet practical. Due the electricity services in the village, community-lacked necessities such as light, education, reliable roads etc. in spite of having year round flow river crossing it; the name of river is Indris. To satisfy their energy needs, these people use kerosene, which is becoming difficult to afford because of the high and day-by-day increasing price of kerosene; and firewood, cow dung and other traditional biomass resources which are causing deforestation and soil degradation. Moreover, the village has small population (about 505 Households), which is sparsely distributed and inaccessible location, and far from the central grid.

1.2. Objectives of the study

To accomplish this thesis work, the following general and specific objectives are designed.

1.2.1. General objective

The general objective of the study is investigating the viability of a micro hydro -PV- DG-Battery hybrid for rural electrification at a selected site.

1.2.2. The Specific Objectives

This study attempted to deal with the following specific objectives:

i. Assess the current power demand and forecast the load growth of the community around the village,

ii. Determine the renewable energy potential of the village; Micro hydro and solar radiation potential.

iii. Design power generation system of the area.

iv. Evaluate the technical and economic feasibility of the hybrid system for power generation at selected site.

1.3. Scope of the Study

The study focuses to check the technical and economic viability of a standalone Micro Hydro-PV-DG-battery hybrid energy for Melka Hera village. This study shall gather, and analyze important data and select the most suitable system configuration. This study only focuses on the feasibility of Micro Hydro/PV/DG/Battery hybrid energy system among renewable energy systems like biomass energy and geothermal energy systems, which are not available at the study area. Moreover, due to significant fluctuation in wind speed magnitude for high cut-in speed ranging, the wind system cannot deliver power at a constant load. This paper work does not cover the practical implementation of the project and the distribution system rather than generation system.

1.4. Significance of the Study

Ethiopian government has given great attention to provide electricity for rural area of the country and devised mechanism called universal electric assess program (UEAP) to make available fast connection of the rural area. This paper focuses on feasibility study for power generation from Micro hydro/PV/ Diesel generator/ Battery storage hybrid, off- grid energy system for Ethiopia rural area. The study has many advantages for rural community of the village and the country. Policy makers and concerned bodies can use this study as real problem solving approach for similar related projects and rural electrification. This study utilizing abundant renewable energy sources like solar hydro in solving electrification challenges. The supply of cheap electricity from renewable energies as main sources of power production has direct energy with poverty elevation in the country. Therefore, hybrid energy system is the best solution for this isolated area due to international policy and emissions reduction.

Generally, this has benefits to create new job opportunities to simplify rural life and to create good job atmosphere. This study will give solution by providing 24-hour electricity services to the community of Melka Hera village if Ethiopia and other concerned body/governmental or non-governmental organizations work for the practical implementation of the project.

1.5. Description of the Study Area

Melka Hera is located in Toke Kutaye Woreda, West Shewa, Oromia region, Ethiopia. One of the selected water resources for hydroelectric generation is, “Indris River” for the communities living in the village called “Melka Hera village”. Its geographical coordinates are 08° 51.603’ north, 37° 43.927' East and 2379m elevation.

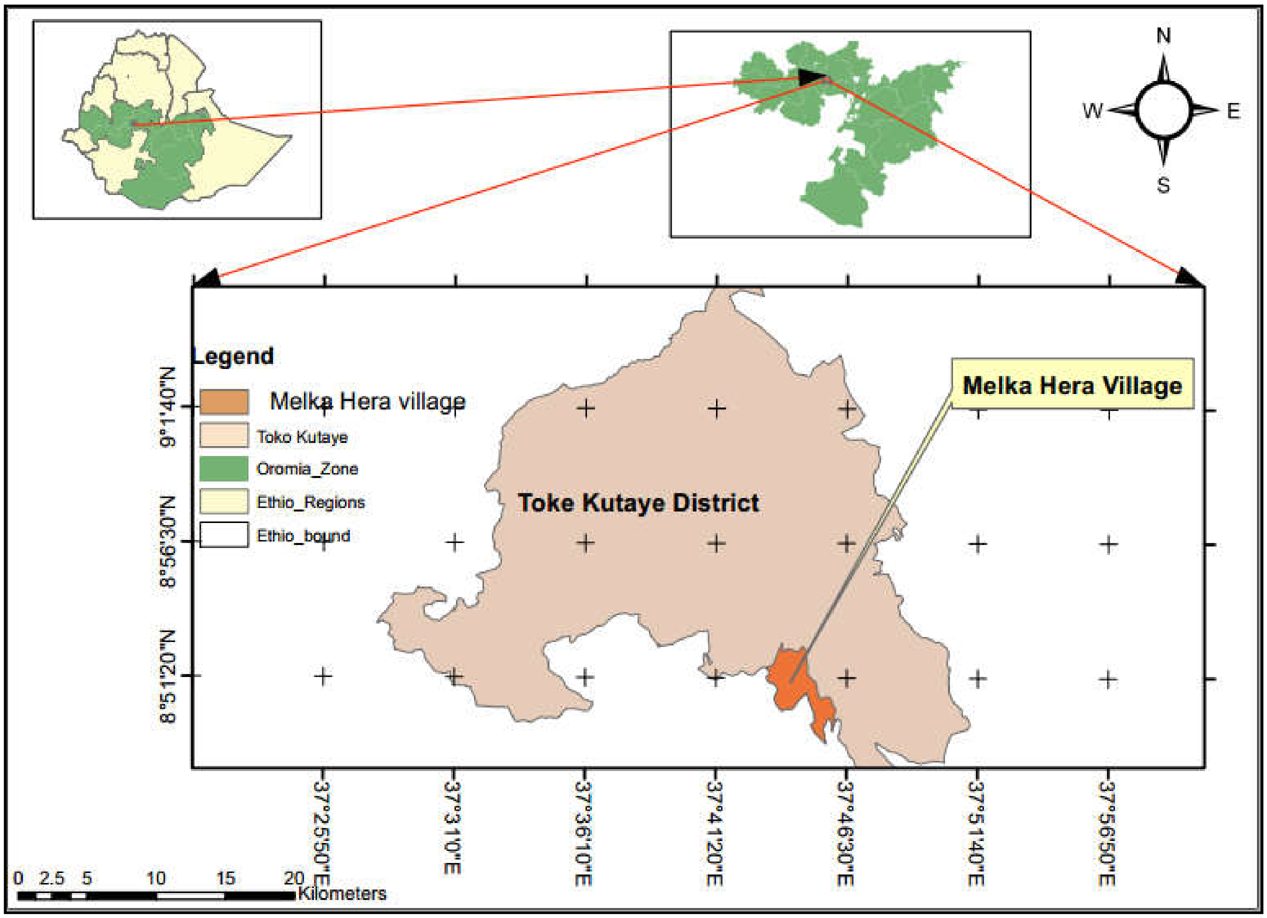

Fig.1.3: map of the study area, from arc GIS software

1.6. Outline of the Thesis

This thesis organized into six chapters. **The first chapter focuses on** background of the study. Particularly, it deals with the energy situation, energy potential in Ethiopia and the background of the micro hydro and solar PV potential. In addition, this chapter also explained off-grid hybrid energy system, problem statement, objectives of the study, scope of the study, significance of the study and description of the study area**. Chapter two** covers literature reviews of the study on hybrid energy system, hybrid system architecture and software tool. **Chapter three** covers the methodology that include primary and secondary data collection, Energy demand assessment, energy potential assessment of the site like micro hydro resource and solar energy resources were discuses. In this part, selection of hybrid system Components and costs are included**. Chapter four** deals with Hybrid system designing, System analysis with HOMER requires information on the resources, economic constraints. Input information like village load demand renewable resources, component technical details and costs, constraints, controls, and type of dispatch strategy. **Chapter five** presents results and discussion. Finally, **chapter six** presents conclusions and recommendation of this thesis.

CHAPTER TWO

Literature Review

Many researches were carried-on in hybrid stand-alone power generation all over the world and in Ethiopia. Different papers used different Technology options and ways to evaluate the deferent configurations of renewable energy resources, such as solar energy, wind energy, small hydropower and their hybrid configurations. As many studies' result shows, they have been published for deferent form of applications; some of the papers are reviewed in the following paragraphs.

Simulation of a standalone electricity production for the remote settlements in Cameron was studied by *EM Nfah, et al.*[15], the study focused on the energy requirement in the selected rural area. The analysis shows that the magnitude of the energy demand was in the range of 0.2 to 1 kWh/day. Four different system configurations simulated and modeled. Such configurations are (hydro/diesel generator/battery), (solar/diesel generator/battery), (hydro/diesel generator/battery), (solar/ diesel generator/battery). Based on the simulation result the cost of energy for different renewable energy option was 0.296 €/kWh, which generated from a 14kW Micro Hydro generator, 15 kW diesel generator and 36kWh of battery storage. Furthermore, the second simulation for PV hybrid system was accounted for 18kW PV generator, 15kW diesel generator and 72kWh of battery storage, the cost of energy was obtained to be 0.576 €/kWh for remote petrol price of 0.1€/litter and LPG price of 0.7€/m^3. The author concluded that micro hydro system proved to be the cheapest option.

Terefe J.[16],studied the design of a hybrid electric power generation system utilizing both wind and solar energy for supplying a cluster of three micro and small enterprises (MSEs) working on wood and metal products at the Welenchity site. The work was begun by investigating wind and solar energy potentials of the desired site, compiling data from different sources and analyzing them using HOMER software. According to the results obtained through the analysis, the site has abundant solar energy potential and the wind energy potential. It is unquestionably high enough to be exploited for generating electric energy using wind turbines with low cut-in wind speed and the design of a standalone PV-wind hybrid power generating system has proceeded based on the promising findings of these two renewable energy resource potentials, wind and solar. The author concluded that, a wind-solar hybrid energy system would be cost effective if there is reduction in component cost by installation of many of this hybrid system in a farm thereby lowering the investment cost per kilowatts. Its availability, sustainability and environmental friendliness make it a desirable source of energy supply. However, the author should indicate an option how the high initial capital cost reduced or replaced by locally available alternative energy source like Micro hydro, which is the cheapest in the investment cost increasing the affordability of the hybrid system and the most environmentally friendly renewable energy system.

According to *Iswor Bajracharya* [17], Assessment of Run-Of-River (ROR) Hydropower Potential and Power Supply Planning was studied. The primary objectives of this dissertation are to assess the theoretical ROR potential of hydropower the rivers in Nepal and power supply modeling to develop power generation and expansion plan for the period 2015 to 2030. Long-range energy alternative planning (LEAP) was selected for power supply modeling as it is the widely used energy-modeling tool around the world for integrated energy planning and supply side management. The author concluded that the theoretical run-of-river hydropower potential was estimated by developing the hydrological model for the three major river basins of Nepal: the Kosi, the Narayani and the Karnali basin. In this study, the power supply model was developed using the hydro as the major source of energy for three projected electricity demand cases: base case, medium growth and high growth electricity demand. Besides hydro, solar PV and wind power was also incorporated. This study covers only the power supply side. The effect of demand side management on power supply could not be studied.

According to *Berihun G.* [18], “modeling and simulating of a micro hydro-wind hybrid power generation system for rural area of Ethiopia” presented by using HOMER software. His objective was to design a hybrid system cost competitive to supply energy for remote villages for a model community of 660 households with one primary school two churches one mosque and one health center. He discussed two option, Wind/Micro hydro hybrid and Standalone Micro hydro system. According to him, the COE most favorable wind/micro hydro hybrid system is \$0.112/kWh. Moreover, COE of standalone micro-hydro system is \$0.035/kWh. He concluded micro hydro system is the most economical and can only satisfy the energy demand of the village and technically feasible option. However if he include solar resources, which incurs lower capital cost relative to wind system in the hybrid configuration, his hybrid system may be cost effective.

Zelalem G.[19], studied techno economic assessment of solar PV/diesel hybrid power system for a hypothetical rural school by using HOMER software to supply peak load of 11kW for 24 hours per day. In his study, he has compared only diesel supply system to that of solar PV/diesel hybrid system with battery bank and he showed that the hybrid system is cost effective and environmentally friendly since the solar PV covers around 95% of power demand and the diesel generator is used to cover only 5% of power demand. In addition, he has conducted sensitivity analysis considering uncertainty in two variables: solar radiation and diesel fuel price. Here the study only considered power supply for the school, teachers' resident, barber and optimum design and mobile charging shops for income generation of the school and the study did not consider the nearby community.

Optimum planning of hybrid energy system using HOMER for rural electrification was studied by *Mahmud.et al.*[20]**.** This paper presented the efficient system of sustainable renewable energy for domestic use and its total cost for the off-grid area; taking Sandip-para as model which is in Raujan upzila of Chittagong district. Methodology of this study is collecting the basic data of solar radiation, wind speed and other required. The author concluded that, using hybrid power generations came forward due to high prices of generating power from oil and also due to the limited availability of such kind of non-renewable sources. Hybrid system can optimize the power supply especially in off-grid rural areas. However, it is still considered expensive and difficult to combine various energy sources together. The author is identified problems but his credentials and associations are not clearly noted.

Duffie, J.A. and Beckman, W.A. [21], Studied the combination of PV/wind/Micro-hydro and diesel generator simulation model, by using HOMER software for Sundargarh district of Orissa state, India. Two simulations were performed in this case study, one with a combination of Wind/Solar PV and diesel generator and the second with combination of Wind/PV/small hydro and diesel generator. The authors also suggested that the wind power fluctuation and household demand variation are the only constraints influencing the system. From the author's suggestion, PV/Micro hydro system is more reliable economical than Wind/PV/ Micro hydro system.

In Kenya Hybrid Energy System for Off- Grid Rural Electrification was developed by *Clint* [22],the purpose of this study develop a hybrid energy system comprised of wind turbines, diesel generators and batteries to provide electricity for an off - grid rural community of 500 households, one school, one medical center and an irrigation system. He used HOMER software tool to simulate the hybrid system and analyze the results. At 40m hub height and 1.2 USD per liter of diesel, excess electricity was generated in the optimal simulations that indicate connecting such energy systems to national electricity grid is economically viable.

Yohannes T.[23], studied application of micro hydro-PV off- grid hybrid energy system using HOMER software (hybrid optimization model for electrical renewable) as optimization and sensitivity analysis tool. The author concluded that, Off-grid (Micro Hydro/PV/Battery) hybrid system is technically and economically feasible and Environmentally Friendly Configuration. And from the optimal simulation result the most cost effective system, the system with the lowest net present cot, is the PV micro hydro battery converter configuration the cost of energy (COE) is 0.044$/kWh, and renewable resources fraction is 99% from this we can easily observe that almost the total portion of energy production is from renewable energy sources. This setup could be a good choice for implementation because the system is almost from renewable energy sources. However, the author included DG in the design section for backup system regardless of including in the title. The author recommended, the study done is on one randomly selected village of Guder Wereda administration in Oromia region and it does not cover all around the region of Ethiopia. Future researchers should extend such a research work in other potential sites and make the rural people beneficial with renewable energy resource. From the author's recommendation, since the energy supply for rural area of Ethiopia is the chronic problem to solve fundamental services like health care education, water supply, Communication, transport etc, Supplying electricity for the village is the prerequisite.

Bizuayehu T.[24],developed hybrid PV/Wind/Battery power system to replace the existing Diesel power electricity for Kebri Dehar and Degehabur towns of Ethiopia. Both towns are remotely located from the national grid. He identified two power supply systems as an options; hybrid (standalone Solar/Wind/Battery) system and extending new transmission line from nearest substation of the national grid to the selected towns. In addition, he designed for both options using the HOMER simulation program as a design tool. The simulation results shows that composed of solar/wind/battery was the best option with the cost of generating energy found 0.422 $/kWh and 0.441$/kWh for Kebri Dehar and Dagahabur towns respectively. Whereas the simulation result for the grid extension of energy cost are 1.172 and 0.869 $/kWh for Kebri Dehar and Dagahabur towns respectively. According to the software result the grid connected option was found to be not economical feasible solution comparing with hybrid system.

A research conducted by *Leak. E Woldemaria* [25], entitled" Genset Solar Wind hybrid power system of off-grid power generation for rural application. The hybrid system comprises of generators set PV –array and wind turbine with storage and power electronics device presented in his paper. His study intended to promote an efficient and cost competitive system configuration of hybrid power system to improve the life of the rural community not yet connected to the central grid. He concluded that renewable energy sources and/or their hybrid configuration are cost competitive although the huge capital investment of the renewable energy resources is the major limitation. According to my suggestion, he should indicate an option how the high initial capital cost can be reduced or replaced by locally available alternative energy source like MHPS.

Even though the authors stated above was used HOMER to realize their study, the hybrid system setups were studied using different load demands, applications, study area as well as climatic data. Some of the research supplied in areas have no electricity at all whereas, in others areas diesel generator are used to produce energy. However, every hybrid power system was designed in a different manner based on the available climatic data, number of households, and community load profiles. In most of the study, the electricity to be provided, has to be supplied for large number of households, which has to be applied for lighting, baking, communication, school, health service and small commercial business. In addition, almost all of the above scholar's paper shows the hybrid system either only using PV/wind excluding one of Hydro/PV/Wind/Hybrid energy system. Therefore, enough research work is not available which shows PV with Micro-Hydro-DG. This was considered in this paper to investigate the viability of the project. This system configuration would be best of all due to the Ethiopia have plenty of solar resource and huge amount of Hydro potential in almost many parts of the country. To get continuous supply of electricity mostly to meet the peak load demand, diesel generator is the best solution.

Unlike the previous studies, the focus of this study was to assess the technical and economic feasibility of standalone *Micro Hydro- PV- DG- Battery hybrid* energy for Melka Hera village by using HOMER software. The study helps to provide valuable information to the government and Non-government organization (NGO) about the potential of technology in the country for a rural electrification project. As a result, the concerned body would be able to minimize environmental pollution, deforestation and soil degradation. Furthermore, this study can be used as a benchmark to conduct similar study activities for the other areas.

2.1. The Application of HOMER Software

HOMER is a micro-power optimization-modeling tool, which was developed by the National Renewable Energy Laboratory (NREL) of the United States Department of Energy (DOE) for the Village Power program. The software tool has the capability to determine the system configuration, system components and sizing, cost and availability of resources and the large number of technology options available. Its main advantage over other hybrid energy system design software is that it can easily help simplify complex hybrid energy design and provide inform decision on difficult situations. HOMER simulated the operation of the system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric and thermal energy demand in the hour to the energy that the system can supply in that hour, and calculated the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER will be used to decide for each hour how to operate the generators and whether to charge or discharge the batteries. For each system configuration under consideration, HOMER will perform these energy balance calculations and then determines whether a configuration is feasible [64]. This means it checks whether the proposed system meet the electric demand under the given conditions, and it estimates cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest. The software has the capability to perform system optimization. HOMER performs three principal tasks: simulation, optimization and sensitivity analysis based on the raw data given. Fig.2.1 shows how simulation, optimization and sensitivity analysis are interrelated. The oval figure enclosed in another oval figure shows that one optimization consists of multiple simulation and one sensitivity analysis consists of multiple optimizations [64].

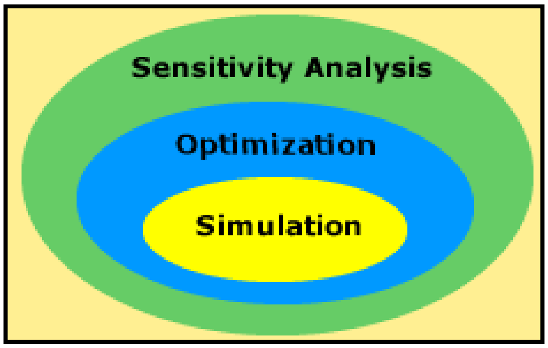

Fig.2.1: Interactions between simulation, optimization and sensitivity analysis [26]

Simulation: It compares the energy supply from the system and the load demand in 1 hour, of the 8,760 hours. During this time it decides either to use load following or dispatch strategy to operate batteries and generator. For a system, that contains battery and generator requires having dispatch strategy. Dispatch strategies are two types, load following and cycle charging strategies. *Optimization:* In this process, it simulates each different system configurations in search of the lowest NPC and lists each power systems that meet the load demand. The purpose of optimization is to determine the optimal system based on the decision variables imposed by the designer. Decision variable is a variable that has control by the designer. HOMERs decision variables may include like; PV array size, head and water flow, generator size, size of converter, quantity of batteries, dispatch strategy.

A *dispatch strategy* is a set of rules used to control the operation of the generator(s) and the battery bank whenever there is insufficient renewable energy to supply the load. *Sensitivity analysis*: It examines the effect of external parameters and does optimization for each sensitivity variables. First defining the variables that can affect the system over its entire life is mandatory to input into the software. The optimization process is repeated after specifying the sensitive parametric variables as an input in to the software. The sensitivity variables can be climatic data variations, components and fuel cost, interest rate, capacity shortages, operating reserves and others. HOMER does multiple optimizations using various sensitive inputs to see how sensitive output of the power system. The sensitivity results are displayed from HOMER in tabular and graphical forms [64; 26].

System constraints: Is a condition that system must meet to be feasible. In the system allows you to modify system constraints, which are conditions the systems must meet feasibility. HOMER discards systems that do not satisfy the specified constraints, so they do not appear in the optimization results or sensitivity results. The considered system constraints in the system are operating reserve and annual capacity shortage. The maximum annual capacity shortage is the maximum allowable value of the capacity shortage fraction, which is the total capacity shortage divided by the total electric load. HOMER considers infeasible (or unacceptable) any system with a higher value of the capacity shortage fraction. Allowing some capacity shortage can change the results dramatically in some cases. This might happen if there were a very high peak for a very short time. If the maximum annual capacity shortage is set to zero, HOMER will size the system to meet even this very high peak load. This could mean that the system has to include large, expensive equipment that is not fully used most of the time. If you allow a small amount of capacity shortage, HOMER could choose to install smaller, less expensive equipment that would be able to supply all but that peak load.

Required operating reserve is the minimum amount of operating reserve that the system must be capable of providing. HOMER calculates the required operating reserve for each time step based on the values that you enter on the Constraints window. Whenever possible, HOMER ensures that enough dispatch able capacity is available to keep the operating reserve equal to or greater than the required operating reserve. HOMER records any shortfall as a capacity shortage. Because operating reserve guards against increases in the load or decreases in the renewable power output, the required operating reserve is a function of both the load and the renewable power output (specifically, the solar and wind power output, since the hydro power output typically experiences little short-term variability). The amount of required operating reserve therefore typically changes from one time step to the next [26].

Even though the HOMER software is very essential in the design of a mini-grid system, the choice and sizing of the components, the most adequate control and management strategy must be obtained. Numerous configurations of hybrid energy systems have been installed in a variety of countries over the last three decades. This has provided the necessary experience to identify the strengths and weaknesses of different configurations. Thus good performance models have been developed, that are able to prioritize the functionality of the power supply systems in such a way as to achieve cost reductions and improve system reliability. Hybrid power systems can be categorized according to their configurations: Series configuration, Switched Configuration and Parallel Configuration [27]. Among the above system configurations, we used parallel Configuration**.** *The parallel configuration***,** current hybrid energy system, software simulations and designs are based on this model design as shown in fig. 2.2. It allows all energy sources to supply the loads separately depending on the demand, as well as meeting an increased level of demand by combining the various energy sources. The bi-directional inverter charges the battery (acting as a rectifier) when excess energy is available from the other generators, as well as act as DC-AC converter (inverter) under normal operation. The Bi- directional arrow, from Fiug.2.2 shows the convertor converts in to two directions (AC-DC or DA-AC). The main advantage of this system is improved system efficiency and reliability through optimal operation and sizing of the generation components to meet the demand. While the main disadvantages to this system are, its complexity, and thus the need to automate the different controls; and specialized training to operate the system [27].

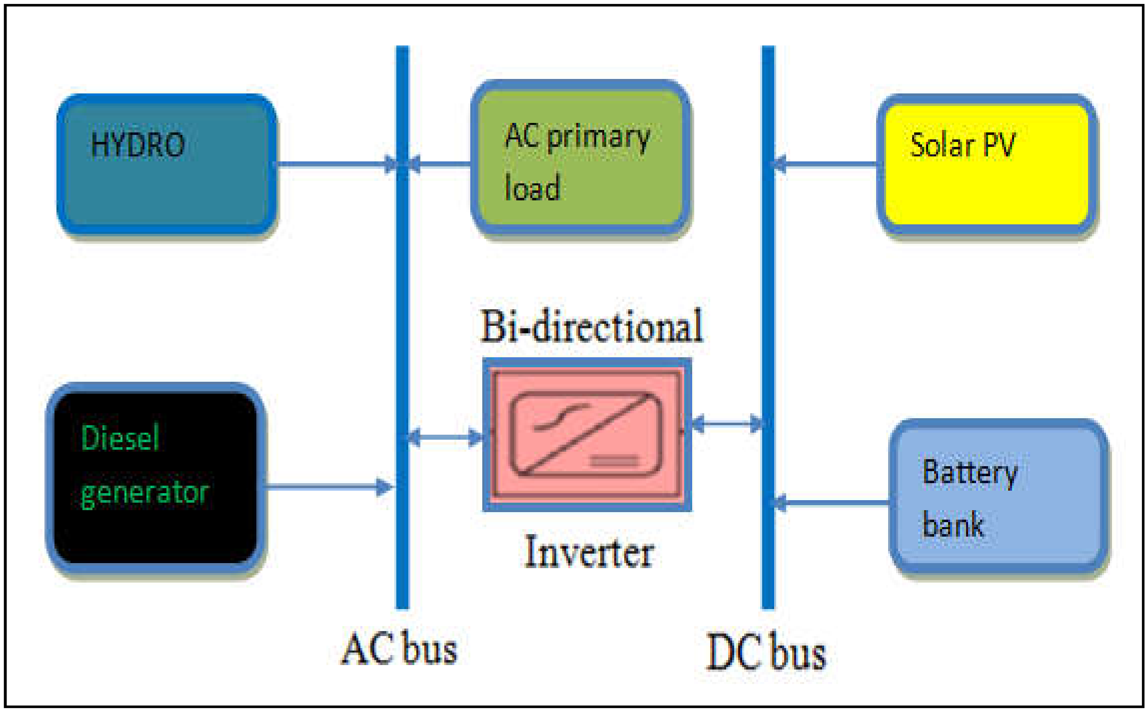

Fig.2. 2: Parallel configuration hybrid systems as simulated in Homer

CHAPTER THREE

Methodology

To design micro hydro/PV/Diesel generator/Battery hybrid power system, one has to provide some hybrid system inputs such as hourly load profile, flow data average solar radiation, the initial costs of each component (renewable energy generators, diesel generators, battery, and converter), cost of diesel fuel, annual real interest rate project lifetime, etc.

3.1. Sources of data

Sources of data for this study are classified in to two. These are primary data sources and secondary data sources. These sources of data are discussed in the following ways.

3.1.1. Primary Data Collection

Primary data are the data collected through field survey by the researcher.   Flow rate data of the site was taken from MoWIE. The gross head was measured during field survey using portable GPS. The community services and commercial loads collected from Toke Kutaye District Administration of Ethiopia, and the local people live near to the selected Indris River.

Table3.1: Primary data collection

Data collected	Value
Gross head of the river	50m
Design flow rate	140l/s
Number of primary schools	1
Number of religious houses	4
Number of health post	1
Number of flour mills	2
Current house hold number	505

3.2. Secondary Data Collection

Secondary data is a data, which is obtained from other related literatures. Some of the data was solar radiations data of study area taken from online data of NASA meteorological department.

The capital cost of equipment were taken from website and adjusted to local value by including transportation and other costs. The load profile of the village was determined using the wattage and hour of use of the proposed equipment as explained in subsequent section. To get hourly load profile of the village, Excel spreadsheet program was used.

Table3. 2: Secondary data collected from various sources

Data collected	Value/ component types
Solar data of the study area (NASA)	22 years solar data
Household number [2007 Census and Toke kutaye Wereda administration]	419
Hybrid component type and cost	Battery storage, PV module, Diesel generator and Converter

3.3. Data Analysis

In the analysis, it was established that there existed current household number is about 505 households in Melka Hera village. In this paper, the electric load demand of the village community is divided in to three major energy-consuming sectors. These are household sector, commercial sector, community load that consists of elementary school; health clinic; religious load demand.

The total electric load estimated for the listed appliances above were summed up to get the required load supplied by the system. Peak operation hours of the appliances were proposed. Electric estimation way based on the electric equipment used by each sector. The first to know in calculating the electric load is deciding which appliance has used by the rural family households accounting the current and future situation of the local community as well as the countries energy system framework. The three years load projection done by taking population growth of the community living in the village. The above energy consumption sectors called primary loads. Energy demand (kWh) = (number of appliance used × power rating of each appliance (W) × hours of operation (hr) × no of days per week)/1000).

3.3.1. Household Electric Load

Household the electricity demand is suggested to apply for low energy compact fluorescent humps (CFL), radio, TV and for Enjera baking. The conventional electric "Enjera" baking machine consumes an average power of 12kW/m^2 of pan surface area and the effective pan diameter is about 55 cm [30]. Based on data gathered by questioner and their analysis shows that the individual households were assumed to use 5 units of 11W compact fluorescent lamps: 4 units for household rooms lighting and 1 unit for external lighting. In Ethiopia, the weekends recognized as religious holidays and at these days, there are no practical activities done particularly in the agricultural fields. Based on household's economic situation, the electricity load demand of the community separated in to two levels: high and low energy income household's level. It assumed that high-income households are 25% of total population of the village and low energy income households are about 75% from total population of the village. We assumed that Cooking stove and a TV suggested for high-level households.

Table3.3: Household electric consumption features (high-income household)

Appliances	Quantity	Capacity (W)	Run-time (h/d)	period	load(kW) 25% House hold	kWh/ d
Low-energy lights	5	11	6	18:00-00:00	6.985	41.9
TV during weekday	1	70	6	18:00-00:00	8.89	53.5
Weekend TV	1	70	14	8:00- 22:00	8.89	35.6
Radio working days	1	30	6	18:00-00:00	3.81	22.8
Cooking stove (one sit stove)	1	1000	4	6:00:00-8:00 17:00- 19:00	89	356
Enjera Backing Mitad	1	2850	2	17:00-19:00	103.4	206.8
Mobile charger	1	15	3	6:00-8:00 20:00-21:00	1.905	5.7
Total						722

Table3. 4: Household Electric Consumption Features (low income HH)

Appliances	Quantity	Capacity (W)	Run-time (h/d)	Period	Peak load (kW) 75% HH	kWh/d
Low-energy lights	5	11	6	18:00-00:00	20.79	124.7
Mobile charger	3	15	3	6:00-8:00 20:00-21:00	17.01	51.00
Radio during working days	1	30	6	18:00-00:00	11.34	68.0
Radio during Weekends	1	30	12	8:00-20:00	11.34	36.0
Total						379.0

The main target for the selection of the appliances in table 3.3 and 3.4 is taking the low energy saving into consideration. The minimum facilities that could be owned by the village is estimated to 1101kWh/day.

3.3.2. Commercial Electric Load

Two flour milling machine were installed in the village community. The machine has power rating of 12.5kW [30]. They operate only for 8 hours during the working day. The total daily electricity demand by the flour-milling machine is shown below in Table 3.4.

Table3. 5: Commercial electric load

Appliances	**Quantity**	**Capacity (W)**	**Run-time (h/d)**	**Period**	**Peak load (kW)**	**kWh/day**
Flour milling	2	12500	8	08:00-12:00 13:00-17:00	25	200
Street light	40	60	11	19:00-6:00	2.4	26.4
Total						226.4

The total load for commercial electrical energy [kWh/day] = 226.4kWh/day.

3.3.3. School Electric Load Demand

The village's primary school contains 8 class rooms, 3 toilet rooms, 1 unit desktop computer, 1 unit printer. As noticed above during the daytime there is no need of electricity for the classrooms since the sunlight can brighten the classes through the windows. Each of the class rooms are assumed to be installed with 2 units of compact fluorescent lamps, Moreover, 3units of CFL for the school surroundings lighting is also proposed. During the weekends, evening classes will acquitted in the daytime from 8:00 to 12:00. The yearly break of the academic year for schools is during July and August and the semester break is in January. The total daily electricity consumed by the school except for January, July and August is shown in table 3.6. However, the load during annual school break (during July, August and the semester break in January) can be compensated by the load consumption during the weekday evening classes.

Table3. 6: School electric load demand

Appliances	Quantity	Capacity (W)	Run-time (hr/d)	period	Peak load (kW)	kWh/day
Class room light [CFL]	8	15	3	18:00-21:00	0.12	0.36
Toilet room light [CFL]	3	11	3	18:00-21:00	0.033	0.099
External light [CFL]	3	40	3	18:00-21:00	0.12	0.36
Staff room light [CFL]	2	13	3	18:00-21:00	0.026	0.078
Computer	1	150	8	8:00-12:00 13:00-17:00	0.1	0.8
Printer	1	60	1	15:00-16:00	0.06	0.06
Total						1.679

The total energy demand for school$[\frac{kWh}{day}] = 1.679\frac{kWh}{day}$ and the peak load [kW] = 0.459Kw.

3.3.4. Health post Electric Load Demand

The main possible appliances that draw electric power in this clinic are low energy light bulbs, TV, computer, printer, water heater, laboratory microscope, and vaccine freezer. The health post has 14 rooms including reception and toilet rooms lighted with 13W fluorescent lump and two units of 40W lumps for external lighting.

Table3.7: Health post electric load

Appliances	**Quantity**	**watts (W)**	**Runtime (hr/d)**	**period**	**Peak load** (kW)	Load in kWh/day
Room lighting[CFL]	10	13	8	8:00-12:00 13:00-17:00	0.13	1.04
Toilet light[CFL]	2	13	3	18:00-21:00	0.026	0.07
External light[CFL]	2	40	6	18:00-00:00	0.08	0.48
Television	1	70	12	08:00-20:00	0.07	0.84
Computer	1	150	8	8:00-12:00 13:00-17:00	0.1	0.80
Printer	1	50	1	14:00-15:00	0.05	0.05
Lab. Microscope	1	20	4	8:00-12:00	0.02	0.08
Vaccine freezer	1	60	24	24:00:00	0.06	1.44
Water Heater	1	1000	3	8:00-11:00	01	3
Total		1366			1.536	7.80

The daily energy consumption by the health center is 7.80kwh and with peak load 1.536kW.

3.3.5. The Electric Load Demands in Churches

The village has four churches (three Protestant churches and one Orthodox Church) and some electric loads are proposed for them. These loads are lighting 2 unit for each Hole with a power rating of 60W compact florescent lamp and a megaphone 4 unit (one for each church) rated for 15 W. There are two staffs rooms for each churches lighted with 13W CEL each room and two toilet rooms lighted with 11W CFL for each room.

Table3.8: Religious electric load demand

Appliances	**Quantity**	**Capacity (W)**	**Run-time (h/d)**	**period**	**Peak load () Kw**	**Kwh/d**
Megaphone	4	15	5	18:00-20:00 9:00-12:00	0.06	0.3
Hole Lighting	8	60	3	18:00-21:00	0.48	1.44
Staff lighting	8	13	3	18:00-21:00	0.104	0.312
Toilet light	8	11	3	18:00-21:00	0.088	0.264
Printer	1	60	1	11:00-12:00	0.06	0.06
Computer	1	150	3	8:00-11:00	0.1	0.3
Total		259			0.892	2.676

The total energy for the church [kWh/day] = $2 \text{ x } 0.06 + 3\text{x } 0.06 + 3 * 0.48 + 0.104 * 3 + 0.088\text{x}3 + 0.05\text{x}1 + 0.06\text{x}3 = 2.676$kWh/day and peak load [kW] = 0.892kW/day.

Adding the total energy demand of the village is given by: household load (high income level HH+ low income level HH energy consumption) +School load demand+ Health post load demand+ Church load demand+ Commercial load demand [kWh/day] ≈1341kWh/day. Yearly village energy demand can be calculated.

Annual Energy consumption of the village (Kwh) = ((number of appliance used x power rating of each appliance x hours of operation number of days)/1000)/7.

Thus E_L/year =1341kWh/day x 365≈ 489400kWh/year.

3.3.6. Power and Population Projection of the Village

To reduce load variability and future energy increase, calculating power and population projection is important in this case. Load forecast was done by taking population growth of the community living in the village. In 2007, numbers of households in the village were 419 with the total population of 2890. The current, number of households in the village is about 505 with the total population of 3591. Therefore, the Population growth rate of the village with one-year range can be calculated as: $r = \frac{78}{2890} \text{x } 100 = 2.69$ %/ yr.

To estimate number of population the coming three year, equation 3.1 can be used [31].

$$P_n = P_o (1+r)^n \quad (3.1)$$

P_n= population at time n in the feature

P_o= present population

r=annual growth rate of population

n= Year of projection

By using the equation 3.1 above, the population and energy projection can be calculated as:

$P_3 = 3591 * (1 + 2.69/100)^3 = 3889$, Where, n= 3years. Numbers of population Increased within three years = 298/3yrs ≈ 100 / year. The next step is determining energy demand of the projected population. By using the excel sheet, the projected power can be calculated as E_{LP} = 125kWh/day. Where, E_{LP} is the energy required for the projected population. Here it is known that there will not be further extensions in school, health post and commercial service loads can accommodate the coming three years load. So, significant load is expected only for domestic load. To import the load data into HOMER hourly load profile for the whole year is required. A load profile of 8,760 hours was created for a year based on hourly estimated load for different months. Therefore, after population projection, Melka Hera's daily total energy demand is 1466kWh/day. The total yearly energy demand of the village energy demand is estimated as 1466kWh x 365= 535,090kWh/year. Simulation result of hourly demand by using HOMER software was given on Fig.3.1 below. The simulated in HOMER software shown in following figure below presents total daily and hourly demand of current plus load projected which is expected after three years.

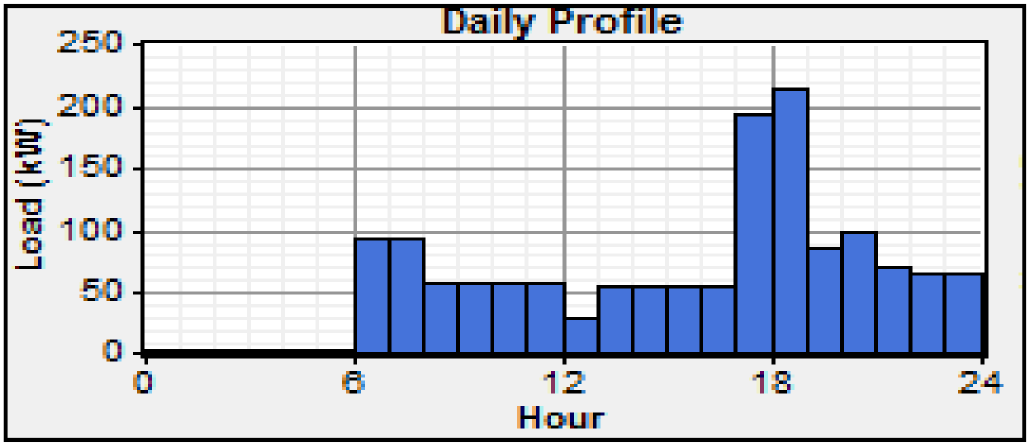

Fig.3.1: Energy demand profile of the village

The daily and hourly primary load demand is indicated in figure 3.1; the electricity load profile varies during the day. The load is almost zero from mid night till morning, between 0:00-6:00 hours, whereas the demand rises during breakfast times from 6:00-8:00 hours, especially at night starting from 18:00-00:00 hour took the maximum power demand than other hours. Therefore, Melka Hera's daily total energy demand is 1466kWh/day, with a peak load of 213kW, and daily average of about 61.1kW.

3.4. Estimating Energy Resource of the Village

The potential of solar energy resource, and hydropower resource of the village have been assessed. The average solar radiation and clearness index are obtained from the NASA surface meteorology, and average stream flow is obtained from Ministry of Water and Energy (MoWIE).

3.4.1. Micro Hydro Resource Assessment

The only resource needed for micro hydro power plant is available water flow at a gradient. Planning for any small hydro plant begins with near to accurate estimation of head and flow available at the proposed site. In the following sub section, various methods of measuring the head and discharge available have been described in detail. When a site has been identified as topographically suitable for hydropower, the first task is to investigate the availability of an adequate water supply. In order to assess adequately, the minimum continuous power output to be expected from the micro-hydropower system, the minimum quantity of water available throughout the year must be determined. The Fig.3.2 shows the topography of the micro hydro plant at the selected site.

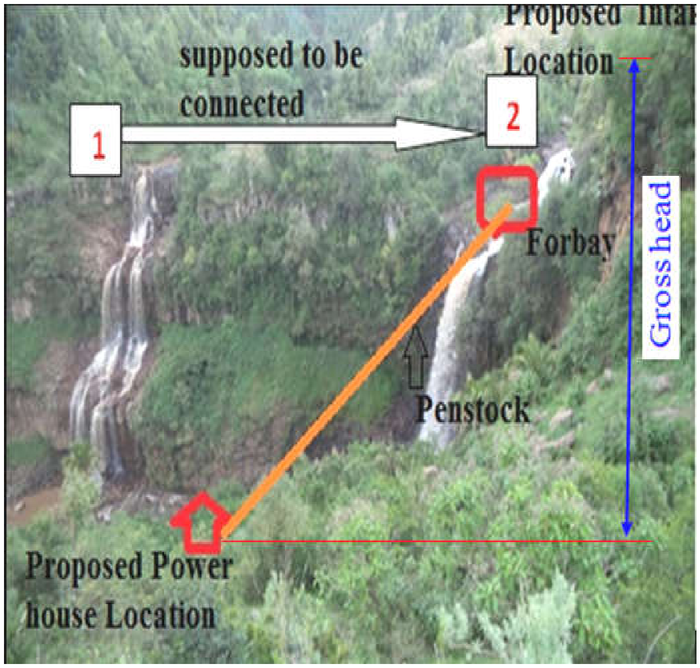

Fig.3. 2: The major components of the MHP of the site [29]

For the selected site, the gross head was measured by portal **GPS**. The principle used by this device is that for an increase in elevation of 100m, atmospheric pressure decreases by approximately 9mm of mercury. This is used to measure the change in elevation which is essentially a barometer calibrated in meters. The difference in elevation between the two points is determined by reading the altimeter at the two points and the difference of the two readings, with some atmospheric effect considered, gives gross head required. All that have done at the site is to record one reading at the proposed forebay location and one at the site of the turbine in order to determine the head. The second reading was taken as quickly as possible to prevent atmospheric changes in pressure (changing weather) from affecting the readings. The survey at a planned site proves that a gross head of 50 m and penstock length of 60m is available.

3.4.2. The Power Input to the Turbine (Pti):

$$P_{ti} = Qd \times He \times \rho \times g \quad (3.2)$$

P_{ti} = power input to the turbine, Qd = design flow-rate, He = effective head, ρ = density of water and g = gravitational constant.

Effective head (He): The effective head is the actual vertical drop minus this head loss in the penstock as shown in Fig.3.3, HOMER calculates the effective head (or net head) using the following equation:3.2

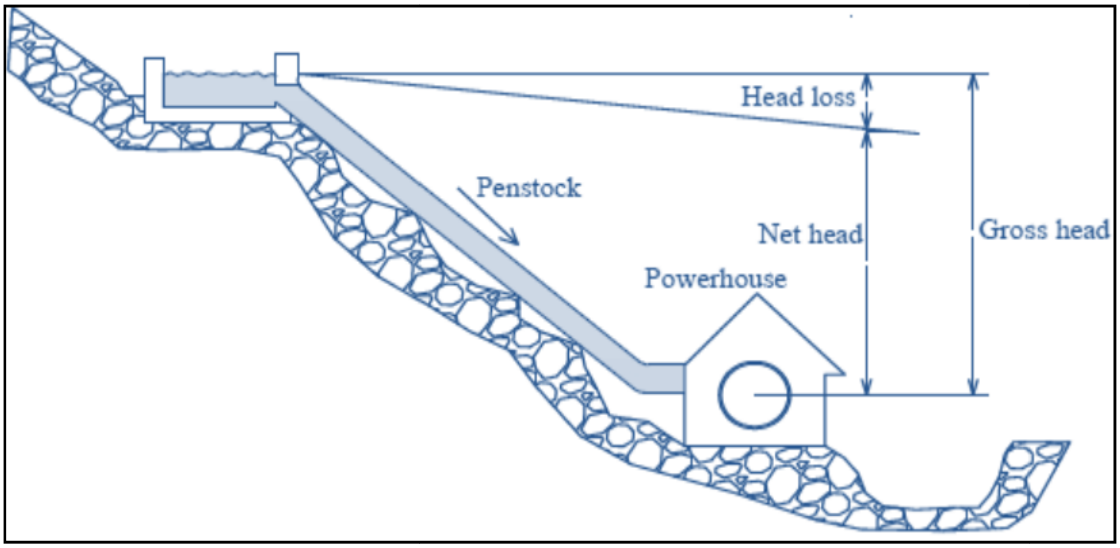

Fig.3. 3: Effective head after pipe loss [32]

He= Hg-hl (3.3)

Where, Hg is Gross Head and hl is Head loss.

Head loss calculation: To choose a turbine for the site, the net head need to be known. The next step is to calculate the net head, which is the gross head minus the total head loss. The total losses are a function of both turbulence and friction. To calculate the head loss, the first thing is selecting the proper penstock diameter corresponding to the design flow. This can be done by using developed formulas; by Sarkaria's equation for economical determination of a penstock diameter [32, 33].

The selection of pipe material and pipe wall thickness depends on the pressure that the pipe will experience. There are two types of pressure to be considered: 1) Static pressure (pressure at the bottom of the pipe when the pipe is filled and when water is not flowing), and 2) pressure waves (waves caused when water flowing is suddenly changed, as by opening or closing a valve).

Pressure waves depend on how fast, the flow changes in the penstock. To aid in determining the design pressure rating of the penstock and selecting the suitable material, the wall thickness (t_w), pressure rating(P_R), and surge allowance factor(S_A) for several sizes of commonly available pipe materials. In this case the stile pipe is appropriate than PVC pipe due to the pressure rating value (P_R) is larger than the penstock design pressure(P_R) for steel. PVC with a P_R smaller than the $P_{D,}$ cannot be used in this case. Or the weakness of PVC pipe is its limited resistance to surging pressure. Next to penstock pipe selection, head loss can be calculated. The head loss due to friction is then determined from the following "Darcy Weisbach"Formula:

$$h_l = f.\frac{Lp}{dp}\cdot\frac{Vp^2}{2.g} \tag{3.4}$$

Where, L_p = length of the penstock (60m), g = acceleration due to gravity (9.81 m/s^2), the friction factor (f) can be determined from a Moody chart [Appendix B] and Vp velocity inside the pipe. The internal diameter of the penstock is given as [61]:

$$d_{P=}2.69 * ({n_p}^2 * Q^2 * \frac{Lp}{H_g})^{\ 0.1875} \tag{3.5}$$

Where, $n_p is$ Manning factor of steel penstock $\cong 0.012$

$d_{P=}2.69 * (0.012^2 * 0.14^2 * \frac{60}{50})^{\ 0.1875}$= 0.254m

And $Vp = \frac{Qp}{Ap} = \frac{4Qp}{\pi dp2}, where\ Ap = \frac{\pi dp2}{4}$

g = 9.81 m / s^2, dp - diameter of penstock pipe (m), Qp - penstock discharge (m^3/s) and

A_p - Cross sectional area of penstock pipe. (m^2)

A_p = 3.14× (0.254)^2/4.0 =0.0467m^{2,} and Vp= 0.14/0.0467=3m/s

We have the diameter of the penstock to be 0.254m (9.9 in), so we can select the available 10-inch penstock diameter. Both the friction coefficient and the Reynolds number (Re) must be determined to calculate the head loss. The friction coefficient depends on the height of the surface bumps in the pipe (∈) relative to the diameter of the pipe (*D*). Once $\in/D$ (relative roughness) is determined, the friction coefficient can be obtained from the "Moody Diagram" as shown in Appendix B.

The Reynolds number "*Re*" is defined as:

$$Re = V * \frac{D}{v} \tag{3.6}$$

D = A nominated characteristic length of the system (in the case of a hydropower penstock, the diameter), V= velocity of water in pipe, and *v* = the kinematic viscosity of water= 1.004x 10−6 (m²/s). Instead, water flow is most likely to be turbulent and this occurs for values of Reynolds number in excess of 3000. For turbulent flows, the Moody diagram is a good reference [13].

Reynolds number of 7.6×10^5 and calculated relative roughness is ∈/D =0.046/254 = 0.00015 and a friction coefficient (f) is determined by following the curved line from the relative roughness value to the intersection of the Reynolds number line and from this point, a line is projected to the left to read the friction (resistance) coefficient. We read off the corresponding friction factor, which is 0.013. Therefore, head loss (h_l) is about 1.39m. This determines the net head available at the end of penstock. Thus, the effective head is determined as He= Hg-hl= 50m-1.39= 48.61m. To calculate power output, the next step is selecting hydro turbine.

3.4.3. Turbine Selection Method

The type and size of a turbine of one hydropower system is differs from the other one project from. Therefore, using these factors as criteria, the type and size of turbine for a particular hydropower system can be determined. The selection of type, geometry and dimensions of the turbine for a particular micro hydro site depends on the site characteristics; the dominant factors being the head available, flow rate and the power required. Some turbines like the cross-flow and the Kaplan work efficiently with a large range of flow variation while others like the propeller turbines work only for a narrow range of flow variation with their efficiency falling rapidly with a little variation in flow. Therefore, this criterion may help for selection of the turbine type to be used especially in standalone MHP systems [39].

Hydro turbines can be categorized mainly in to two types: Impulse turbine and Reaction turbine. *Impulse turbines:* are a hydro turbine more widely used for micro-hydro applications as compared to reaction turbines because they have several advantages such as simple design (no pressure seals around the shaft and better access to working parts - easier to fabricate and maintain), greater tolerance towards sand and other particles in the water, and better part-flow efficiencies. The Pelton turbine, Turgo turbine, Cross-Flow turbine are types of Impulse turbine. *A Reaction turbine*: is one of the hydro turbines develops power from the combined action of pressure and velocity of water. The runner placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines. Francis Turbines, Kaplan and Propeller turbines are the reaction hydro turbine types [8]. Based on the following turbine selection chart (Fig. 3.4), the turbine type can be determined.

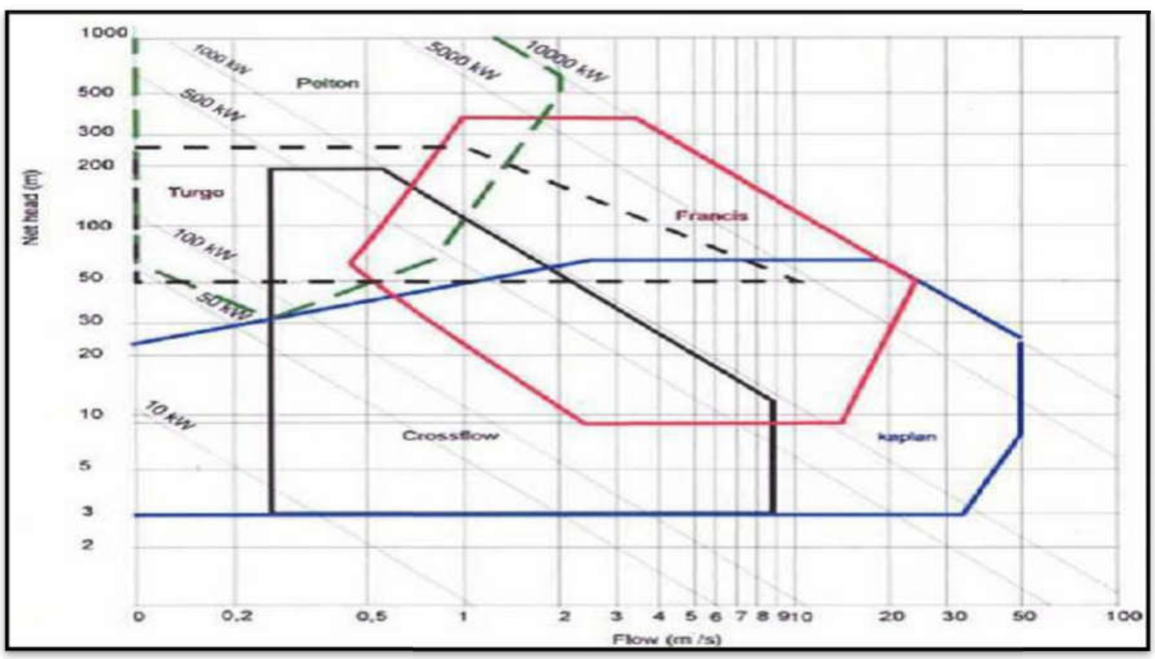

Fig.3. 4: Turbine selection chart [40]

Based on measured water head and flow rate, the turbine type can be determined. Thus using turbine selection chart (Fig.3.5), a pelton turbine is appropriate for the measured flow rate and gross head of this case study. Pelton wheel is most efficient, when the available water source has relatively high hydraulic head at low flow rates. Thus, more power can be extracted from a water source with high-pressure and low-flow than from a source with low-pressure and high-flow, even when the two flows theoretically contain the same power. The smallest Pelton wheels are only a few inches across, and can be used to tap power from mountain streams having flows of a few gallons per minute. Some of these systems use household plumbing fixtures. For water delivery, Pelton turbines can reach up to 95% efficiency, and even on 'micro' scale systems 90% peak efficiency is achievable [63].

3.4.4. Power output from micro hydro power plant (MHPP)

The mechanical power output can be calculated from MHPP from the gross head ,and flow rate with turbine efficiency values of (η_t). From Fig.3.2, there are two waterfalls, which are only about 15 meters apart each other and the flow rate is 70L/s for each water fall at the driest season of the year. Therefore, to increase the power output from the river, It was proposed to combine the first water falls to the second using channel so that we can increase the flow rate of the site to $0.14m^3/s$ and the gross head remain the same. The flow of water in the selected river is adequately high year round so that the theoretical limit of power production does not limit the proposed project and we assumed the design flow rate to be $0.14m^3/s$ for the driest season of the year [29]. Homer calculates the actual nominal power from turbine is estimated as equation 3.7 below:

$$P_n=H_g*\rho_{water}*g*Q_d*\eta_t \quad (3.7)$$

Pn= nominal power, ρ_{water}= density of water, η_{t}= hydro turbine efficiency, Hg = gross head and g= acceleration due to gravity. Therefore, by taking turbine efficiency 85%, nominal power can calculated as below. The nominal power would be the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine [26]. The nominal power output is then,

Nominal power [kW] = $[50m\times1000kg/m^3\times9.81m/s^2\times140l/s\times0.85]$ /1000 = 58.4KW.Village's load observed is greater than the available supply capacity of 58.4kW from the design supply of Micro Hydro power plant. Thus to meet the electric load demand of the village, the other supply configuration has to be investigated. Therefore, electricity supply for the village is based on available resource of hydro and solar potential. As included in the design, battery storage and diesel generator are also used for back up option. The capital cost of wind turbine is higher than that of PV system. Therefore, at our design system, PV is reliable and incurs lower costs relative to wind system [38].

3.5. Solar resource assessment of the village

To meet electrical load demand, the next step is investigating solar resource potential of the village. HOMER runs based on directly imported solar resources from the NASA surfaces Methodology and Solar Energy database by entering the **GPS** coordinates.

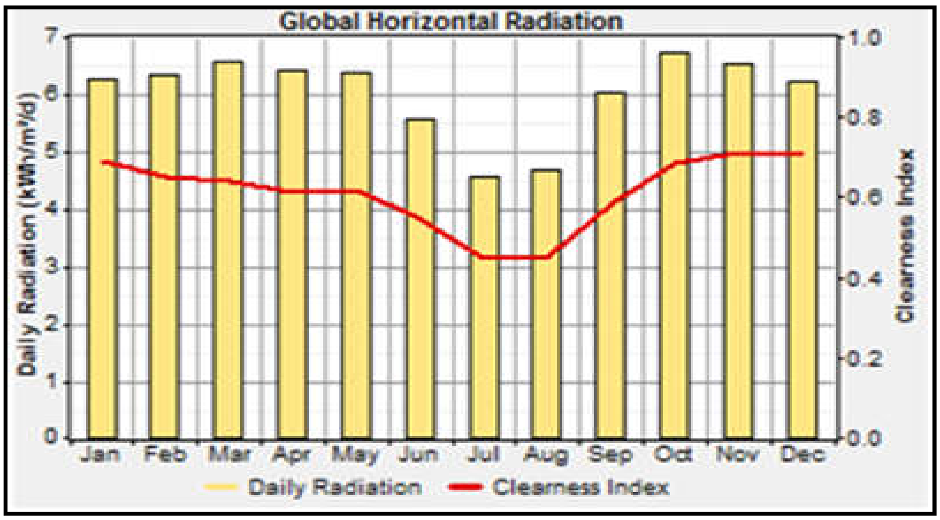

Fig.3. 5 : Village monthly solar resource [NASA]

The village's average solar radiation used to estimate solar energy potential of the site. The 22 years monthly average solar resource of the village varies from 6.716kWh/m^2/d in October and 4.563kWh/m^2/d in July, which the summer of Ethiopia, and clearance index obtained from NASA. From the analysis, the average solar radiation for the village is 6.02 kWh/m^2/ day. See Table 3.9 below. The clearness index shown on Table 3.9 is a measure of the clearness of the atmosphere and the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. In addition, it is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions [64].

Table3. 9: Village average solar radiation [NASA]

Month	Clearness Index	Average Radiation kWh/m^2/day
Jan	0.693	6.263
Feb	0.654	6.331
Mar	0.641	6.583
Apr	6.412	6.412
May	6.375	6.375
Jun	5.569	5.569
Jul	4.563	4.563
Aug	0.452	4.692
Sep	0.585	6.019
Oct	0.685	6.716
Nov	0.713	6.519
Dec	0.709	6.233
Selected annual average		6.02kWh/m^2/day

3.5.1. Radiation Incident on the PV Array

The solar resource window allows you to specify the global horizontal radiation incidence (GHI) for each time step in the Homer simulation. The GHI is the total amount of solar radiation streaking the horizontal surface on the earth. But the power output of the PV array depends on the amount of radiation striking the PV array, which is necessarilynot horizontal. Therefore, in each time step, HOMER must calculates global solar radiation incident on the surface of the PV array [27]. It can be described that the orientation of the PV array using two parameters: a slope, and an azimuth. The slope is the angle formed between the surface of the panel and the horizontal surface, so a slope of zero indicates a horizontal orientation, whereas a 90° slope indicates a vertical orientation. HOMER uses the convention whereby zero azimuths correspond to due south, and positive values refer to west-facing orientations. Irradiation values on the horizontal plane will be sufficient for countries with latitudes between zero (0^o) and +/- 10^o (near the equator). In such cases, the module will be installed at a very small degree of inclination (10^o from the horizontal).In countries where the latitude is greater than 10^o, the module will often be inclined to an angle equal to the latitude of the site in order to receive the maximum irradiation throughout the year [40]. *The azimuth (γ)*is the orientation, which is supposed to be followed by placement of panels in terms of slope. Sites in North hemisphere orient the PV towards South, while in South hemisphere it is oriented north facing. Therefore, the azimuth (γ)orientations with0° for south, -90° for east, 90° for west and 180° for north [40, 27]. Thus in this case study, the panels have no tracking system and are modeled as fixed tilted due south atazimuth0° with the slope of 8.85^0.

3.5.2. Determining of PV Power Output

The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. To calculate the global radiation incident on the PV array HOMER uses the following equation [26].

$$P_{PV} = \gamma_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)[1 + \alpha_P(T_C - T_{C,STC})] \quad (3.8)$$

Where, α_P = the temperature coefficient of power [%/°C]

$\gamma_{pv} =$ is the rated capacity of the PV array, meaning its power output under STC [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]

(Average solar radiation in peak sun hour's incident for specified tilt angle =6.02kwh/m^2)

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

T_c= is the PV cell temperature [°C]

T_{STC} = is the cell temperature under standard test conditions [25°C]

3.5.3. Determining Number of PV Modules of the System

After knowing PV power output, number of the PV module can be determined. *Number of modules in series (Nms):* The number of modules in series can be determined by equation 3.9 below. It is determined by dividing the designed system voltage V_{syst} (usually determined by the battery bank or the inverter). Where, V_{nom} is nominal module voltage at STC [42].

$$N_{ms} = V\frac{sys}{Vmod} \quad (3.9)$$

*Number of modules in parallel (Nmp)***:** The number of modules in parallel can be calculated by equation 3.10 below. In other words, it is determined by dividing the designed array output by the selected module output and the number of modules in series. $N_{mp} = \frac{P_{pv,arry}}{V_{ms*P_{module}}}$. (3.10)

Where, $P_{pv,arry} - tot\ power\ for\ PV\ array\ and\ P_{module} - power\ of\ the\ PV\ module$

Total number of modules of the system (N_{mt}) is given from equation 3.11.

$$N_{mt=} N_{ms} * N_{mp} \tag{3.11}$$

At the end, HOMER calculates the PV array outputs by using the above mathematical Formulas.

3.6. Hybrid System Component's Characteristics and Costs

This section discusses the characteristics, operation, maintenance and relevant costs of the hybrid system components. It starts with discussing the basic technological configurations of hybrid systems. Then, it proceeds with explaining the characteristics of the components; PV panel, Micro hydropower system, diesel generator, battery bank and the convertors in this chapter.

3.6.1. Micro Hydro Power plant Unit Cost

Since the cost of micro hydro power plant differs according to various items, in which it is very difficult to know the cost of every one items. Because, most of the items require detail understanding, in this project it is preferred to estimate the cost of micro hydro power plant using other researches that have been conducted on cost per watt of the output power produced and the literature review on Micro hydro installation in Ethiopia.

Micro hydro power plant installation in Ethiopia costs about US$1,200 per kW, and this is about half of the installation cost of other power plants built in eastern Africa [44]. In addition, the information from [7], the investment cost for a micro hydro per plant can be estimated as $1136per kW, replacement cost is 50% of capital cost and O & M cost is 10% of capital cost. Moreover, internationally, an initial capital cost estimated for micro hydropower plants with is estimated to be between US$1500 to $2500/kW. The 75% of this development cost is decided by the location conditions, and the remaining 25% is the cost of purchasing engineering components (the turbine, generator, electronic load control, manual shunt-off value, and other components). Thus in this development, the cost is taken as an average at $1200/kW by considering the remote area, and thus complicated position of the village and neighboring areas. The capital cost, replacement cost and O & M cost of the Micro Hydropower system estimated to be $46,200, 23100 and $462 respectively.

3.6.2. Solar PV Module Types and Cost

PV module selection depends on the performance characteristics given by manufactures. The selection is actually based on efficiency and maximum power output of the module. World's most efficient currently commercially available crystalline silicon PV module produces are given on appendix E. For this study, a PV module producer by Sun Power with model X21-345 is selected. Universities and independent research laboratories around the world compared the performance of solar panels from Sup Power against other technologies. The selection is based on technical performance of the module and prices of PV. The specification of the selected PV module is given in table 3.10 below.

Table3.10: Specification for PV module of model X21-345 at STC [43]

Electrical data (at STC)	**Value**	**Unit**
Maximum power Pmax	345	Wp
Open circuit voltage Voc:	68.2	V
Short circuit current Isc	6.39	A
Maximum power point voltage Vmpp:	57.3	V
Maximum power point current Impp:	6.02	A
Module Efficiency	21.5	%
Temperature coefficient of power	-0.30	$\%/^0c$
Nominal operating cell temperature	47	^0c
STC = Standard Test Conditions: irradiance 1,000 W/m², AM 1.5 and Tc 25°C.		

Therefore, the PV type determined in this case is Sun of Power with model X21-345 with efficiency 21.5% is $2/Watt [43]. In addition, other costs such as labor, installation, structure costs, civil work also have significant portion of the capital costs. Other cost account for 22%of total module cost [45]. Generally, PV capital cost is given as: PV capital cost (kW) = PVsyst + other cost = 2000$/kW + 429$/kW = 2429$/kW. According to Department's National Renewable Energy Laboratory (NREL), the modeled costs to install solar photovoltaic (PV) systems continued to decline. The continuing, total cost decline of solar PV systems demonstrates the sustained economic competitiveness of solar PV. The global weighted average cost of off-grid PV year-to-year nominal cost decline. Therefore, the PV cost cold decline by 43% from 2009 to 2016[45.46]. Thus based on interview done to the MoWIE of Ethiopian, we assumed the project could be implemented after three years. Due this, PV cost could decline by 18% from 2017 levels by 2020 [45]. By 2020, the PV cost is estimated at $1991/kW. In the study the replacement cost is taken as 60% of the PV price and the operation and maintenance cost would assumed zero [47]. The replacement cost and O & M cost are 119$/kW and $0/kW respectively. There are various investment incentives in Ethiopia: Tax-free importation of capital goods [48]. Thus, considering transport cost of 20%[49], the total cost for 1kW comes to $2500and replacement cost is about $1500.

3.1.1. Converter Size and Cost Estimation

The power conditioning units are electronic devices and grouped into DC-DC/AC, AC/DC/ the DC/DC converters are electronic devices used to change DC voltage or current in to needed voltage and frequency outputs. The DC/AC converter uses to switch the DC voltage or current produced by the hybrid system to the AC type voltage output. This type of power converter is called power inverter. The AC/DC power converter functions as an inverse of the inverter and it is called rectifier. Inverters for solar electric system are also divided into four types depending on their application: Stand alone, Grid connected inverter, hybrid power Grid interactive inverter. With this project, we will use the Hybrid power inverters, which are good for the combination solar and hydropower or diesel generator or any other RE source. The incorporation of the bi-directional converter is used to switch the DC voltage that comes from battery & PV, moreover to change the AC voltage from the micro hydro or diesel generator into direct current when it is needed to charge the batter. In order to determine the size of an inverter, the determination of all the demanding loads from all consumers, which are likely to function at the same time, is an important step. However, in this paper case since power provided from both diesel generator and micro hydro directly to the consumers so inverter size can be smaller than the load to supplied at one time or equal to PV system load [50].

In this case, the Sunny Island 6048, which is a bidirectional inverter for stand-alone systems, was selected. The comfortable support of AC and DC coupling, as well as the expandability of the systems formed with the Sunny Island guarantee highest flexibility. In addition, innovative technology allows the Sunny Island to achieve efficiency 96% is costs about $1.19/Watt [40]. Optimized for the partial load operation, it impresses with low open-circuit and standby consumption. Due to the high overload capabilities and the integrated output management, there is no need to oversize the Sunny Island. It can control connected diesel generators in a particularly gently and fuel saving manner. The Sunny Island can also deactivate loads automatically if the batter does not provide sufficient electrical energy. The lifetime of converter is 20 years in both the directions. The global weighted average cost of off- grid converter year-to-year nominal cost declines to 18% by 2020. By estimating the transportation cost 20%, the capital cost is about $1214. In this project, the approximation of replacement cost taken as $1214.

3.1.2. Cost and Size of Battery Storage

The method of electricity storage is to use the electric rechargeable batteries, especially when PV modules produce the DC current required for charging the batteries. Most of batteries used in PV systems are lead-acid batteries. In some applications, for example when used in location with extreme climate conditions; or where high reliability is essential nickel-cadmium batteries are used. The major difficulty with this form of storage is the relative high cost of the batteries and a large amount required for large-scale application [50].

The following factors should be considered while choosing a battery for a PV application. Battery capacity: Batteries used in all solar systems ware sized in ampere-hours under standard test condition of 25^0C. Battery manufacturers usually specify the maximum allowable depth of discharge for their batteries. The depth of the discharge is a measure of how much of the total battery capacity has been consumed. A day of autonomy is the minimum number of days that should be considered for even the sunniest locations on earth. The number of days of autonomy that should be considered for on earth is 2-5 days [51]. The battery bank capacity required (C_x) is given by: $$Cx = \frac{(A_{batt} * E_L)}{DOD_{max} * V_{sys} t * \eta_{batt}} \quad (3.12)$$

Where, C_x= Required battery capacity

E_L= Estimated load energy in [kWh], DOD= Maximum depth of discharge, η_{batt}= Battery efficiency, V_{syst}= system voltage and A_{batt}= Number of days of battery autonomy.

The battery bank autonomy is the ratio of the battery bank size to the electric load. HOMER calculates the battery bank autonomy using the following equation: [64, 52].

$$A_{batt} = \frac{\left[N_{batt} \times V_{nom} \times Q_{nom} \times \left(1 - \frac{q_{min}}{100}\right) \times \left(\frac{24h}{day}\right)\right]}{(E_{L,avg} \times 1000kWh/day)} \quad (3.13)$$

Where, N_{batt}= number of batteries in the battery bank, V_{nom}= nominal voltage of single battery [V], Q_{nom}= nominal capacity of single battery [Ah], q_{min}= minimum state of charge of battery bank [%] and E_L=average primary load [kWh/d].

The storage battery chosen is Surrette 6CS25P from the manufacturer Rolls/Surrette. This battery has a very high capacity compared to other battery storages in the HOMER tool library [52]. Dual case replaceable cells small footprint and an expect life of over 10 years (depending on maintenance and application). The selected battery has the following characteristics obtained from HOMER modeling tool. The nominal capacity of this battery is 1156Ah (6.94kWh), maximum charge current is 41S, lifetime throughput of 9645 kWh was considered, minimum state of charge is accounted for 40%, round-trip battery efficiency is taken as 80%. Capital cost of $1170/Battery, replacement cost of $1170/Battery and assuming maintenance cost of $30/hr [53, 54]. For the same approach with module cost, the capital cost comes to $1212. In this project, the approximation of replacement and O & M cost has been taken as $1212.

3.1.3. Charge Controller

The charge controller regulates the electric current that is following into and out of the battery bank. By controlling the rate of electric current, charge controllers prevent overcharging and can protect against over-voltage, which could damage the battery or motor. A charge controller can also prevent totally draining/deep discharging a battery, or perform controlled discharges, depending on the battery technology, to protect battery life [13]. The solar charge controller is about 3 to 5% of the whole solar system cost. However, investing in a quality controller ensures good battery management, which extends battery life and reduces associated costs. 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 [55].

3.6.3. Costs and Types of Diesel Generators

Backup generator is part of the hybrid system contemplated in this thesis. Although this paper concentrates the renewable resources but to get continuous supply of electricity mostly to meet the peak load demand, diesel generator can be used. Backup generator is used to optimize renewable power output, to improve frequent shortfall of energy when power interruption is happened from renewable sources and the battery is unable to provide the required energy. Backup generators allow designing power systems with minimum or without storage batteries. Based on the explanation given in generator operates efficiently at full load, and thus it is better to run only after the energy storage (batteries) have fallen 20% of their full charge. The cost of generation is mainly depend on the diesel price. Therefore, to make economically profitable and reduce the generation cost it would be a wise decision to run the diesel at peak load time [49]. According to their rated power and manufacturer, price of each one, and the cost in ($/kW) for each, there are different types of diesel generators. It is obvious that cost ($/kW) depends on the design (method of cooling) and rated power and for the same design it decreases as rated power increase. The thesis done on solar PV and diesel generator hydride system on Jimma ,Ethiopia has demonstrated that the cost DG/kW is about 500$/kW. This ensures that during local market assessment, the cost of DG is about 550$/kW. As there is a variety of generator available from various manufacturers and distributors, it is difficult to compare all the different information. Here Perkin diesel generator was selected because it is completely maintenance free and automatic voltage regulated. The replacement cost is considered to be 80% of capital cost and operation and maintenance cost of $0.015/hr. The lifetime of diesel generator is taken as 15,000hr [57]. This cost includes costs of installation, logistics and dealer mark-ups. The minimum load ratio taken to be 30% of the capacity; moreover, HOMER requires the partial load efficiency to simulate this component. HOMER calculates the total operating cost of the generator based on the amount of time it has to be used in a year [45].

CHAPTER FOUR

Hybrid System Designing

The chapter presents the modeling of hybrid system using the optimization software called HOMER. The chapter starts with describing the important inputs that demonstrate the technical specifications, resources data, and the costs relevant for modeling the system in HOMER. Finally, a hybrid power system designed or the village by combining micro-hydro with photovoltaic array, convertor, battery storage, and diesel generator as a backup unit will be presented.

4.1.System Inputs

To analyze the system, HOMER requires information like energy resources, economic constraints, control methods, include village load demand renewable resources, component technical details, costs, and type of dispatch strategy. Thus, the HES modeled in this system are Hydro+ Solar+ battery storage +Diesel configuration. See Fig. 4.1 below.

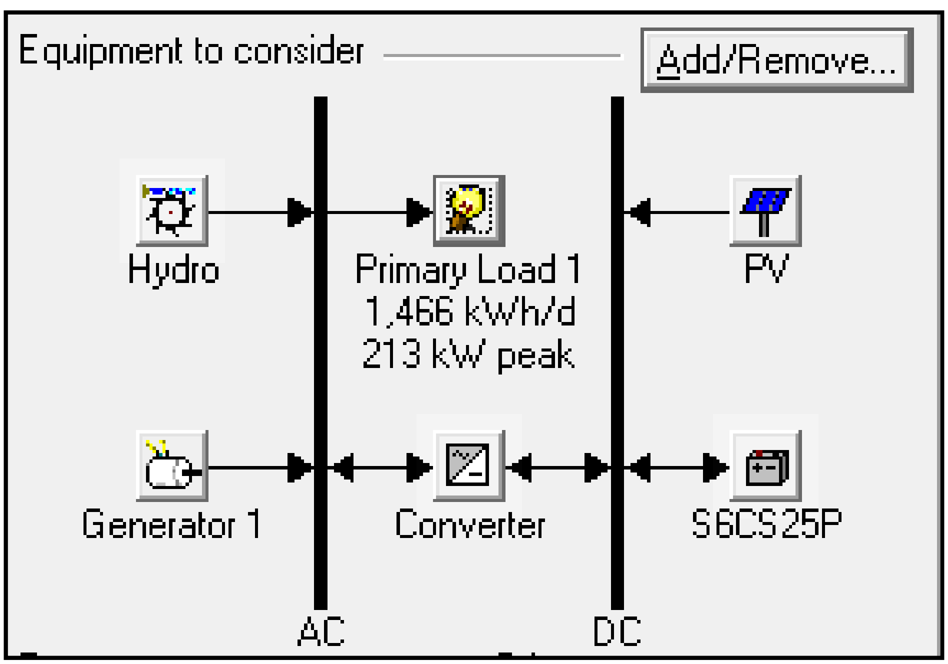

Fig.4.1: Hybrid system design topology for the village, from homer

4.1.1. Load Demand Input to the HOMER Software

Different profiles for different months and profiles for weekdays are specified. The load during yearly school break in July, August and January will be compensated by load consumption during weekday evening class at school. The daily and hourly noise (load variability) inputs allows to add randomness to the load data to make it more realistic. Therefore, in this study, 0% hourly and 0% daily load noise is assumed; because the load demand is calculated by considering variability of load demand. Each hour, Homer calculates the power produced by the elements of the system to serve the total primary load. To import the load data into Homer hourly load profile for the whole year is required from appendix A. A load demand of 8,760 hours was thus created for a year based on hourly estimated load for different months.

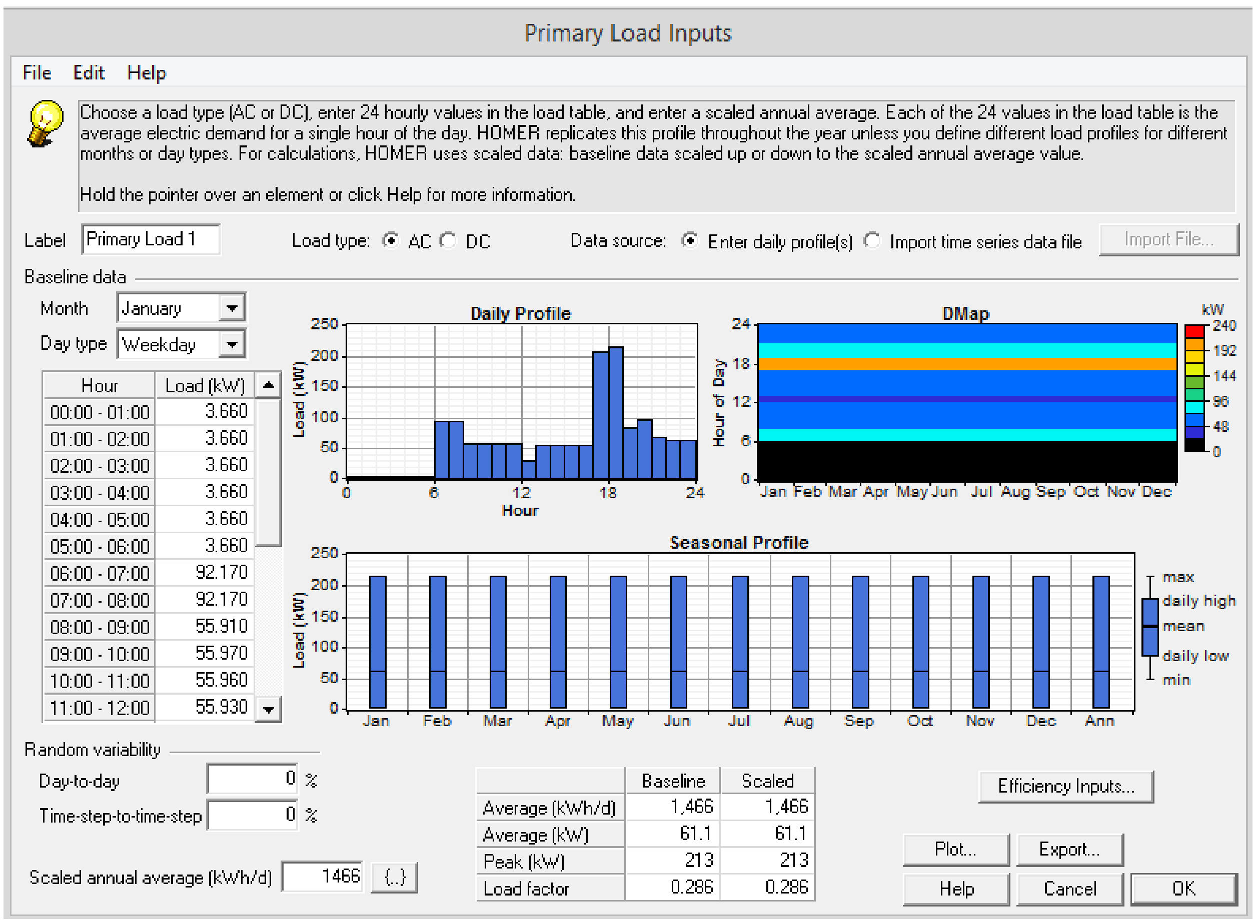

Fig.4. 2: HOMER primary load input window, from HOMER

The load type served is AC and it varies during summer and winter months. The load demand is approximately 1466kWh/day and 213kW peak and a load factor of 0.286. Low load factor customers would benefit from a battery energy storage system to distribute electrical usage out over longer intervals of time and smooth the peaks. The daily hourly pattern and the seasonal profile can also be seen in the graphs inside Fig. 4.2 above.

4.1.2. Hydro Inputs

In order to calculate the output power of the hydropower turbine, HOMER uses effective head, design flow rate (Qd), efficiency of turbine and length of the pipe. The hydropower is connected alternating current (Ac) bus and has a lifetime of twenty-five years [43, 49]. The capital cost for plant is taken as $46200 while the replacement cost and O&M cost are considered$23100 and $4,620 respectively. The nominal power of the hydro system would be the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine. The calculation of the nominal hydropower includes the hydro turbine efficiency of 85% [26].

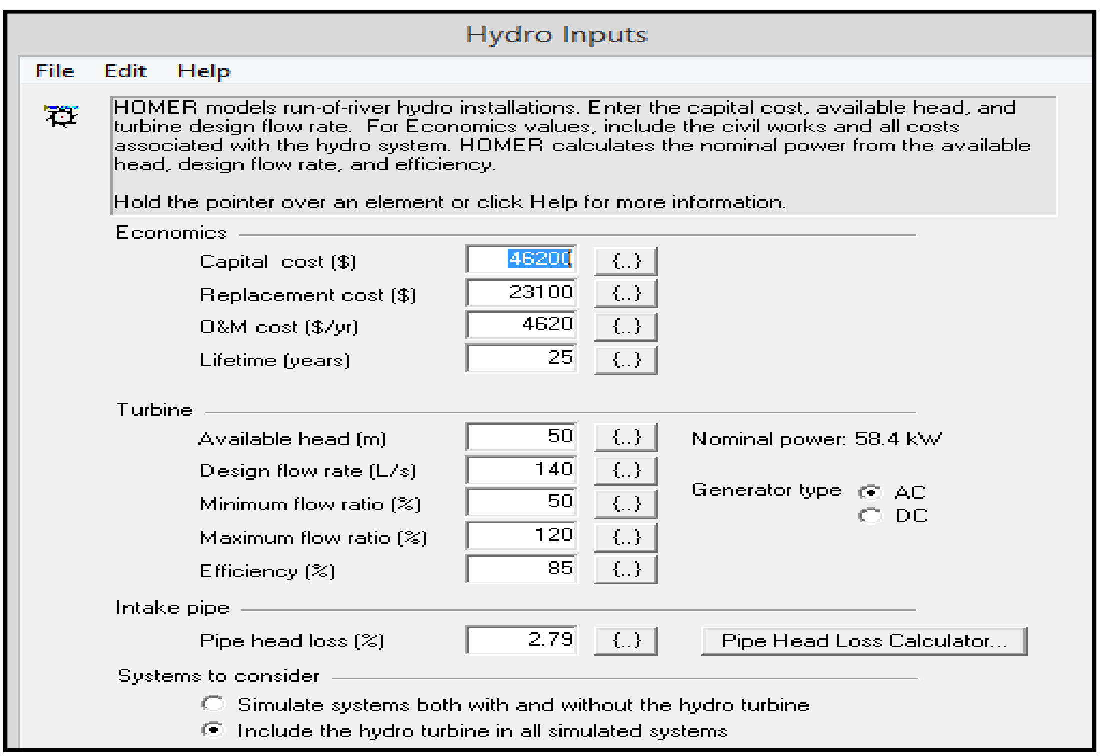

Fig.4. 3: Hydro input window, from HOMER

4.1.3. Solar PV Inputs

This section is used to characterize the cost of PV panels, select the sizes that HOMER will calculate for the optimal system, and specify the placement of the array. In the cost table as shown in the table 4.1, the PV cost depends with size of the system. In this thesis, the capital price of PV panels for a 1kW photovoltaics system has been specified and taken at $2500 and the cost for replacement is assumed $1500. The O&M cost is specified as $0. Fig.4.6 below summarizes the parameters required by homer for the PV input. We can take PV array is 25 years with a derating factor of 85%, this factor reduces the PV production by 15% to approximate the varying effects of temperature wiring loss and dust on the panels [42]. In case of Ethiopia by taking latitude greater than 10^{o} and the system as fixed-slope systems, an approximation of slope equal to latitude of the location. Thus the panels have no tracking system and are modeled as fixed tilted due south at 0° with the slope of 8.85^{0}.

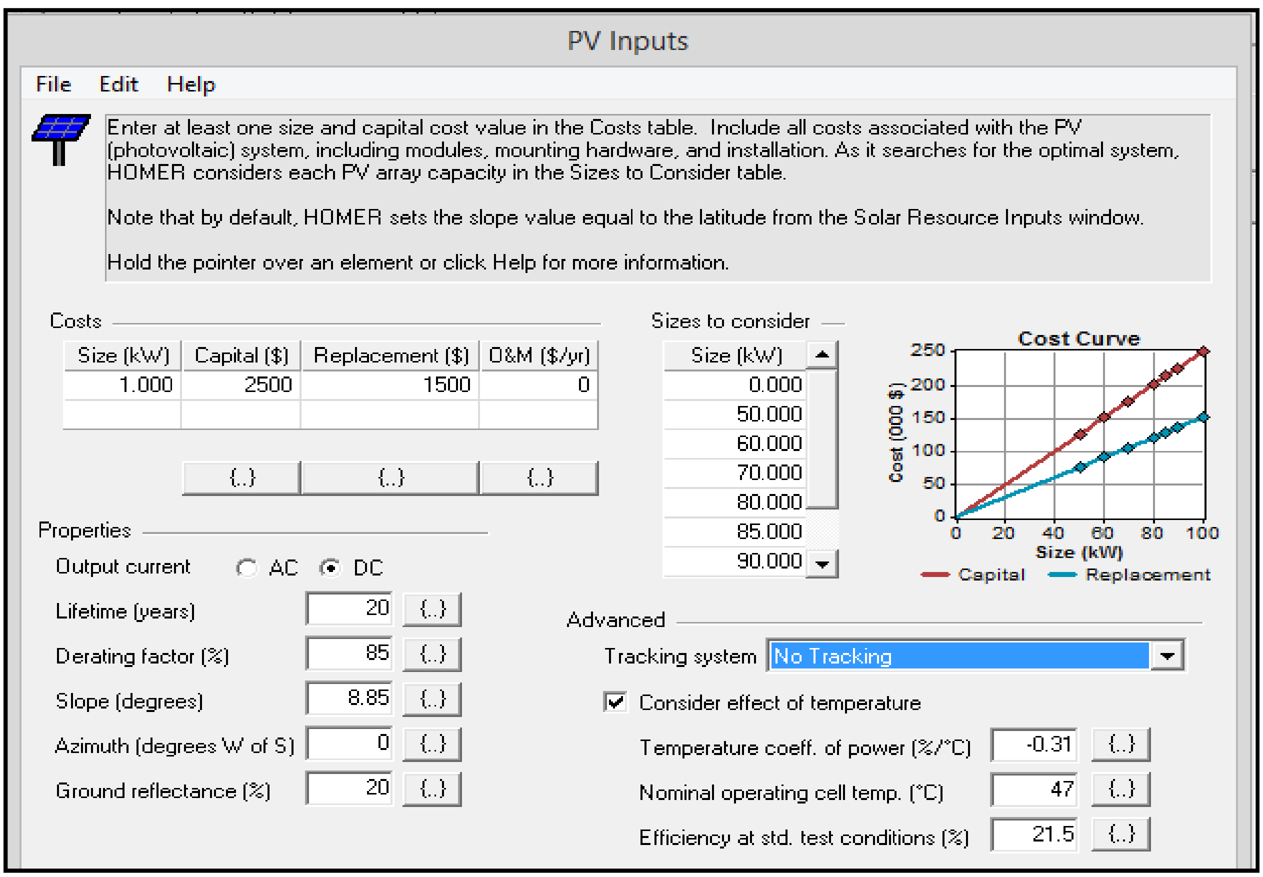

Fig.4. 4: PV input window, from HOMER

4.1.4. Diesel Generator Inputs

In this section, homer allows user to enter the cost, characteristics and performance of a diesel generator. Generator Minimum Load, the minimum percentage of rated capacity for the generator for good functioning. The existence of this parameter is required because some manufacturers recommend that their machines not to be operated under a certain load. Lifetime, the number of hours that can be considered by the generator during its life and the manufacturers of diesel generators usually provide this number of working hours in their product brochures or data sheet. The lifetime of the selected generator is 15,000 hours. In HOMER, the lifetime of generators is specified in terms of operating hours. The lifetime that a generator will last is therefore an output variable, which Homer computes according to the following equation:

$$R_{gen}=\frac{R_{gen,h}}{N_{gen}} \quad (4.1)$$

Where, R_{gen} is generator operational life [hr]

$R_{gen,h}$ is the number of hours the generator operates during one year [hr/yr]

N_{gen} is generator lifetime [hr]

In this project, a machine of 1 kW costs $550 capital cost, $440 for replacement and $ 0.0150/hr for O&M. The current diesel price in is Ethiopia is estimated as $ 0.72/l [57].

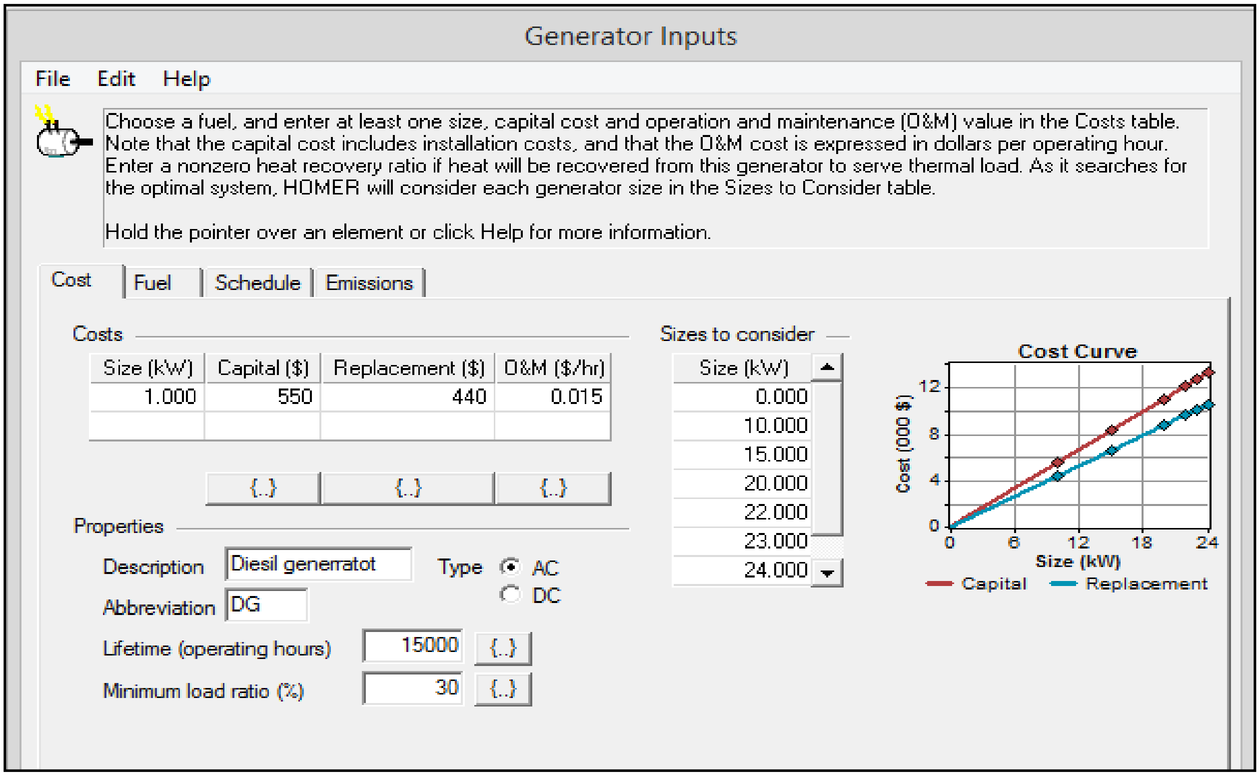

Fig.4. 5: Diesel generator inputs, from HOMER

4.1.5. Battery inputs

The Fig. 4.6 allows the Homer user to select the type and size of battery, tell the software how many batteries to be considered for the optimal configuration [52]. The HOMER drop-dawn box contains all the batteries stored in homer component library. It helps to choose an appropriate battery model from this list. To determine number of batteries in the system, PV System voltage must be known. Therefore, the PV system voltages are considered 12, 24 or 48 Volts. For small daily loads, a 12V system voltage can be used. For intermediate daily loads (1kWh-5KWh), 24V is used and for larger loads (>5kWh), 48V is used [45]. Thus In this study a Surrette 6CS25P of 6V has been selected and 48V system voltage, which require 8 batteries in string. In the figure below, this window helps to indicate the cost of battery. I have entered an amount of one battery for capital, replacement and O& M costs. In this study as shown on Fig. 4.6, the costs of one unit battery cost is about $ 1,212 initially, $ 1,212 replacement, and $ 30 annually for O&M. The battery cost details are explained in section 3.6.4.

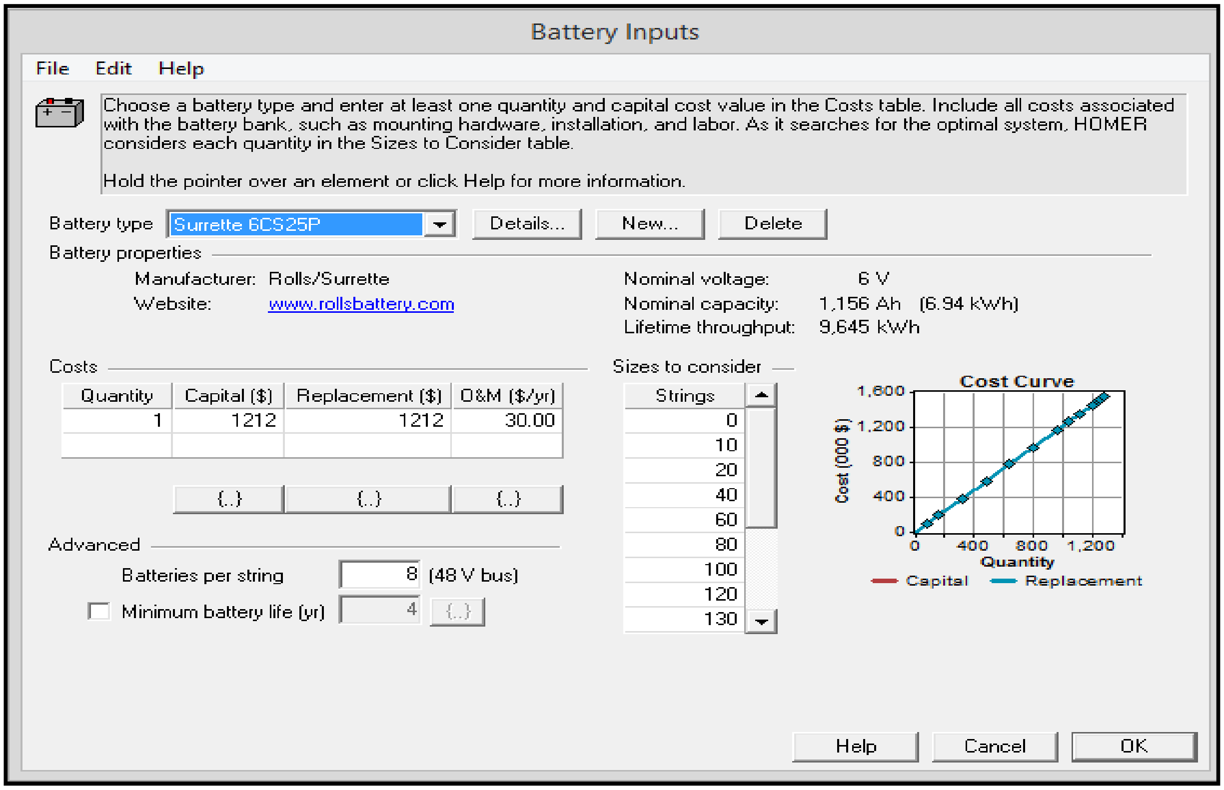

Fig.4. 6: Storage battery input window, from HOMER

4.1.6. Converter Inputs

Homer uses in the calculations the convertor efficiencies, which entered in the input table. Accordingly this study, the efficiency from the manufacturer of the inverter has been taken as 96%. The efficiency of rectifier to convert AC form to DC form, in percentage is taken as 96 [40]. *Lifetime* is about 20years has been assumed. *Economics,* in the cost table as shown in the Fig. 4.7, the cost of converter depends on the size. In this project, the capital and replacement price for 1 kW converter is assumed as $ 1214. We can see converter cost detail from section 3.6.3 above.

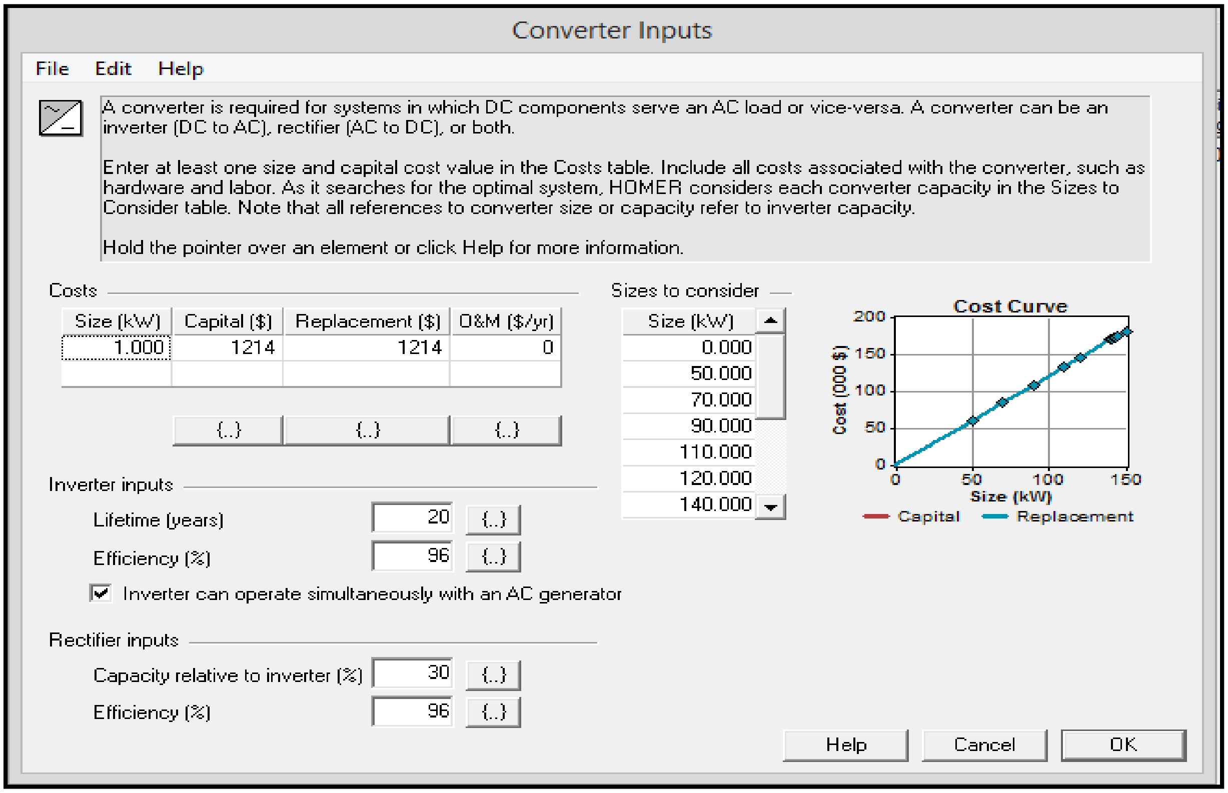

Fig.4. 7: converter input window, from HOMER

4.1.7. Economic Inputs

Homer considers the economic input to each system it simulates to calculate systems net present cost. The life-time of the project has been studied here is about 25 years. Homer suppose the rate of inflation to be the same for all types of costs like fuel cost, maintenance cost, labor cost, etc. The real interest rate (percentage) in Ethiopia is about 5.0% [48, 59].

4.1.8. System Control Inputs

Diesel generator is the only none renewable and dispatch able energy source used in this hybrid energy system. Since the output power from renewable sources is highly intermittent and cannot be controlled by the user. It has to be used when it is available for supplying the load. The optimal system depends on factor like the power size of the generator. Therefore, dispatch strategy should also be developed when optimizing the hybrid system. Two dispatch strategies; 1) Cycle charging (CC),batteries are to be charged to the set point state of charge when the system starts to charge with no interruption until it will reach the set point state of charge.

It helps to reduce the generator number of start cycles, charge and discharge cycles of the battery bank and the time the battery waste at minimum state of charge. 2**)** Load following (LF),this means batteries do not charged by the diesel generator, it gets maximum charging time when renewable sources gets higher, meaning when generated power is greater than the load demand. In this study, as shown in Fig. 4.8, both the strategies have been selected to see which is more suitable in the given constraints of the system. The set point charge for the batteries is kept at 100% [26].

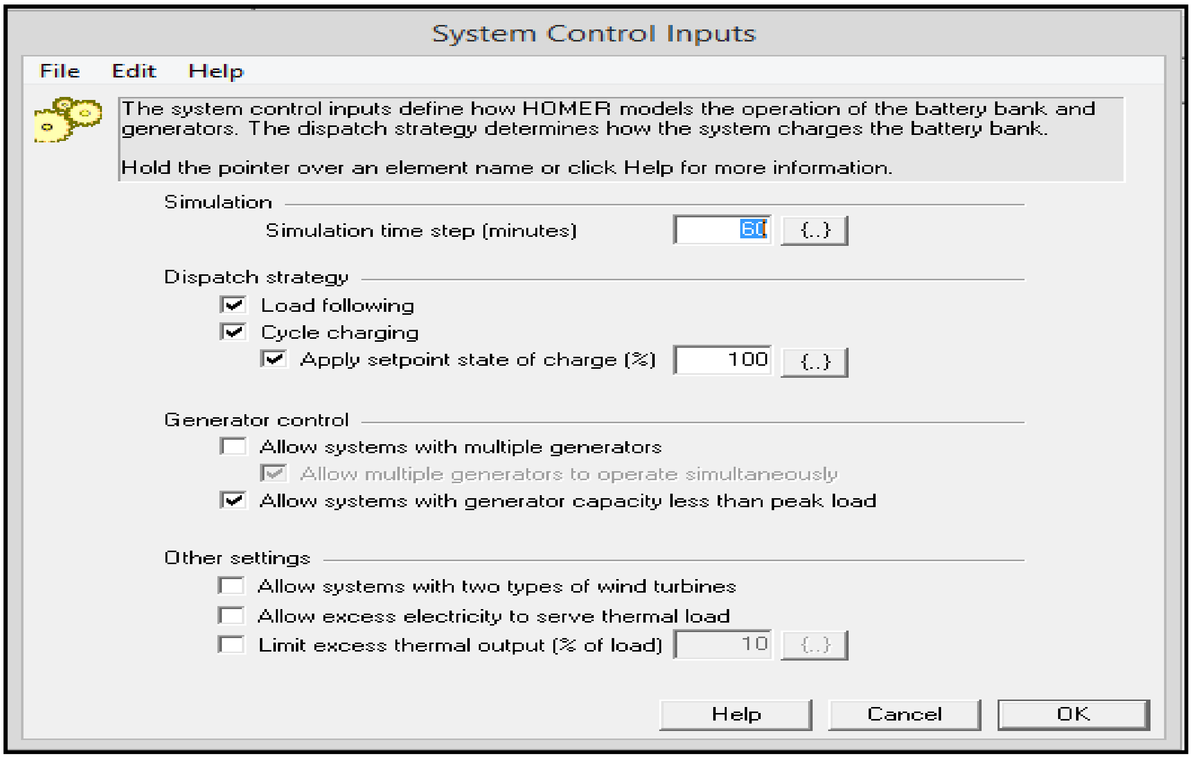

Fig.4. 8: System control input window, from HOMER

4.1.9. System Constraint Inputs

Constraints are a circumstance that system must fulfils to be feasible. If a small amount of load is allowed to go unserved, this can significantly enhance the economic performance of the hybrid RE system. If the system can be designed to be down for a short period in a year or if some load can be shed, this can help in reducing the battery bank and hence significantly reduce the capital cost of the hybrid system. It is shown in Fig.4.10 that the maximum annual *capacity shortage* is considered1% and operating reserve of 1%. The minimum renewable fraction is about 60%.Fig. 4.10 shows us the different system constraints, which are taken care of during optimization.

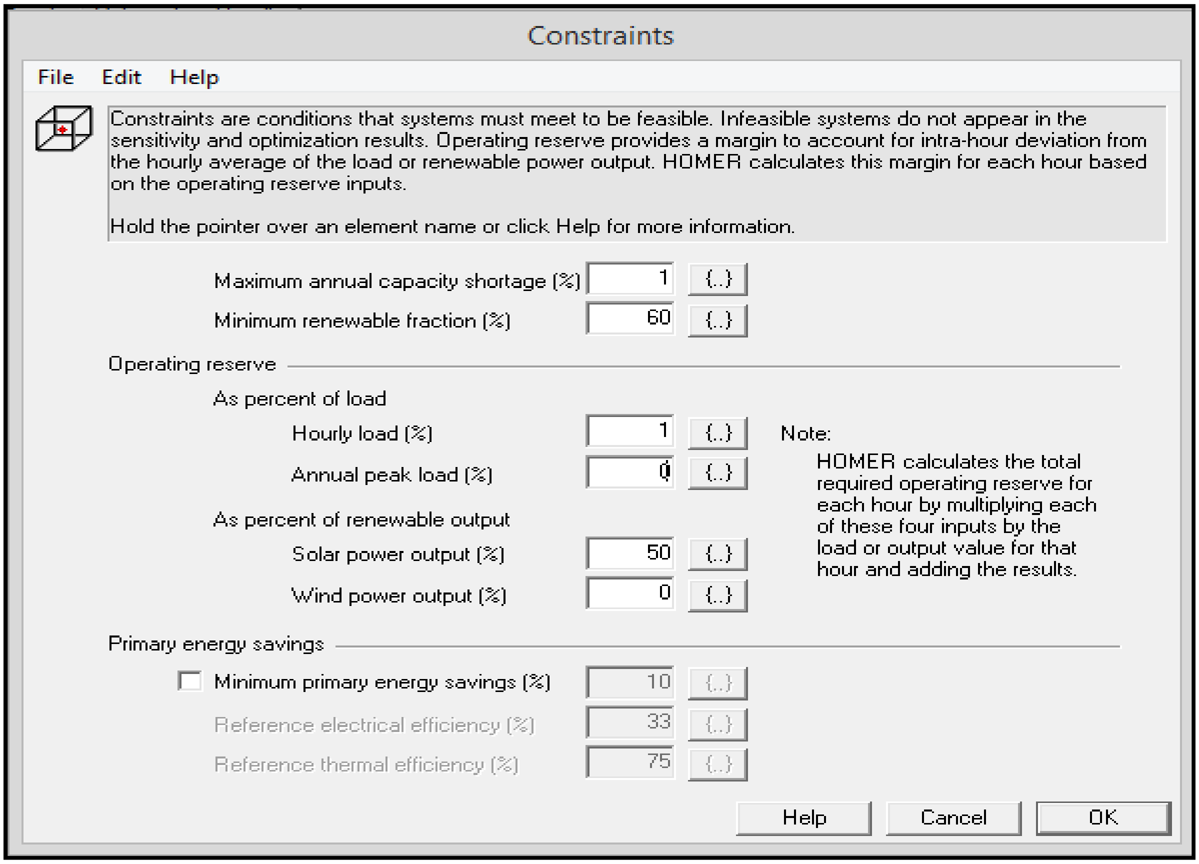

Fig.4. 9: System constraints input window, from homer

CHAPTER FIVE

Result and Discussion

This chapter deals with optimization results for the selected combined power system of a typical 505 households and discussed thoroughly. After carefully inputting all of the considered input variables in to the software, it runs to get feasible results. In the results, Optimization displayed in the overall and categorized forms showing the most feasible power systems architecture, which meets the load and the input constraints made by the modeler, and the most feasible solutions presented in an increasing order of the NPC, COE etc. The categorized table presented the least cost effective combination among all components setup whereas, the overall optimization results shown all of the affordable system combinations. Power systems are selected after simulation based on primarily minimum net present cost.

5.1.Simulation Result

The simulation output is a list of feasible combinations of Micro hydro/ PV/Diesel Generator/ Converter, and Battery hybrid system set up. Table 5.1 shows categorized simulation result, which represents optimization result. The tables generated based on a particular set of inputs and the solar and micro hydro resource data for sit. The best energy system were selected with less net present coast (NPC), minimum cost of energy (COE), high renewable fraction, less excess electricity and less fuel consumption. The maximum annual capacity shortage and minimum renewable fraction are the worst constraints case.

Table5.1: Categorized simulation result, from HOMER

PV (kW)	Hydro (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
70	58.4	12	160	140	LF	$ 591,680	28,782	$ 997,334	0.133	0.99	0.01	3,063	888
70	58.4		320	150	CC	$ 791,140	32,635	$ 1,251,091	0.167	1.00	0.01		
	58.4	20	160	130	CC	$ 408,940	83,395	$ 1,584,308	0.211	0.80	0.01	45,423	8,743

5.2. Selection of the optimized systems

Homer simulated different combinations of energy system components; but it only displays the feasible power schemes scenarios for extra detailed analysis. As shown in Table 5.1, three different configurations are displayed for further analysis, and to increase the chance of finding most optimize system. Power systems with less NPC, less COE, higher renewable fraction, less capacity shortage, smaller excess electricity and minimum fuel consumption would be suggested as optimum system configuration. From the simulation result of Table5.1, the considered systems based on the same input values are to compare using the same variable cases in terms of techno- economic aspects from among the least coast results.

- ✓ Micro Hydro/Solar PV/Diesel Generator/Battery bank (system A)
- ✓ Micro Hydro/ Solar PV/ Battery Bank (system B)
- ✓ Micro Hydro / Diesel Generator / Battery bank(system C)

In the section of optimization, the different configuration of power schemes with less NPC and minimum cost of energy was supposed to be sleeted with the idea of coast effective system, but Homer calculates the feasible system in such way that the one with low NPC ranked in the simulation result in Table 5.1. The comparison of the systems performed based on the above stated technical measuring parameters.

5.2.1 Caparison of Scenarios for Economic Power Systems

Based on total net present cost, the result indicates that the load demand of 1466kwh/d, diesel price of $0.72/l, a maximum capacity shortage of 1% and minimum renewable fraction of 60 %. The considered comparison parameters are discussed as follows in order to select techno-economic feasible power system. As shown on table 5.1, the configuration of the system (scenario A), and the net present cost is less than all other systems, which is about $997,334. System B is the next configuration with less NPC and system C was ranked in the order of increasing net present cost neat to system B. Hence, system A was the winner.

Based on cost of energy, to get detail information of the COE for each power system refer in Table 5.1, the systems (system A and system B) have almost equal cost of energy with small difference. However, system A registered the least valued from among all system. For system A the COE is around $0.133/KWh, for system B, which is about $0.167/KWh, system C: it is $0.211/KWh. Taking this parameter as comparison benchmark into account, system A is the winner from all three combination set-ups.

Based on diesel fuel consumption, the third comparison criterion is the lower diesel fuel consumption. The lower the consumption of diesel and the higher energy generation from renewable sources is recommended as god choice. Because the burning of diesel oil is the main source of environmental polluting elements and its availability in far rural areas is restricted due to different reasons. From the listed situation, system A has consumed the lower diesel fuel, which is about 3063 liters than system C, which has consumed about 45,423 liters of fuel. In the case of system B, no diesel consumed. This is just due to the absence of generator in the scheme. Thus, based on this measuring parameters and give due merit for environmental protection system B is the best choices from the categorized systems. But incorporating diesel generator with renewable energy system, diesel generator is able to increase the electricity supply during sudden increase in energy demand of the village. Therefore, we have to ignore system B. By comparing system A and C, the system A consumed less fuel. Hence, scenario A is the winner.

Based on renewable fraction, based on RF, system B has 100% renewable fractions, which are higher than all other system. Despite of the higher RF of B, in this case there is fraction of capacity shortage 1%, which is again higher than the other system. System displayed fraction of capacity shortage of zero which is good choice in this case: however, renewable fraction are less than system (A and B). This has renewable fraction of 80%. In comparing power system, with such parameters, a system with higher RF and less capacity shortage is considered as a good choice. Although system B has higher RF since architecture is designed only from renewable sources however it required high investment, large quantity of batteries, consequently high cost of energy. In such cases, a wisely selection approach is important that means compromising cost and environmental conditions should be give an intention. Thus, system A is the next lager RF with lower net present cost and lowest cost of energy. Thus from simulation result, system A is the most technically feasible.

Based on excess electricity production; in this comparison parameter, electricity production considered; the lowest excess electricity production is the optimal system, which is first selected to implement. System (B& C) have produced the lower excess electricity of 6.75% and 8.13% respectively and selected as winners of this comparison; following these two system, system A has generated 8.68%. Excess electricity generation should be account for all the constraints set by the designer. Even though excess electricity production can be used in the future, expansion of energy load demand incurs extra cost. Looking in to the amount of excess electricity only, system B is good option but as explained above considering all the constraints' like 1% hourly operating reserve, solar variation and capacity shortages, system A selected for this case study. Based on the above comparison made, the system A is most preferable system among the other three systems.

5.2.2. Optimized System Outputs

Hydro system output: the hydro nominal capacity generated from the system is 58.4kW, the capacity factor 97.2%, total amount electric production is 497,075 kWh/yr and the levelized cost to be 0.0159$/kWh. The determination of the nominal hydropower includes the efficiency of the hydro turbine. Thus, the actual electrical power output of the hydro turbine is 56.7kW. This Micro Hydropower plant generates annual energy production is 497,075 kWh/year which is the highest percentage (79%) from the overall energy generated. This system can meet the load demand with an availability of around 100% resulting in only around 0 hours of power outage during a year.

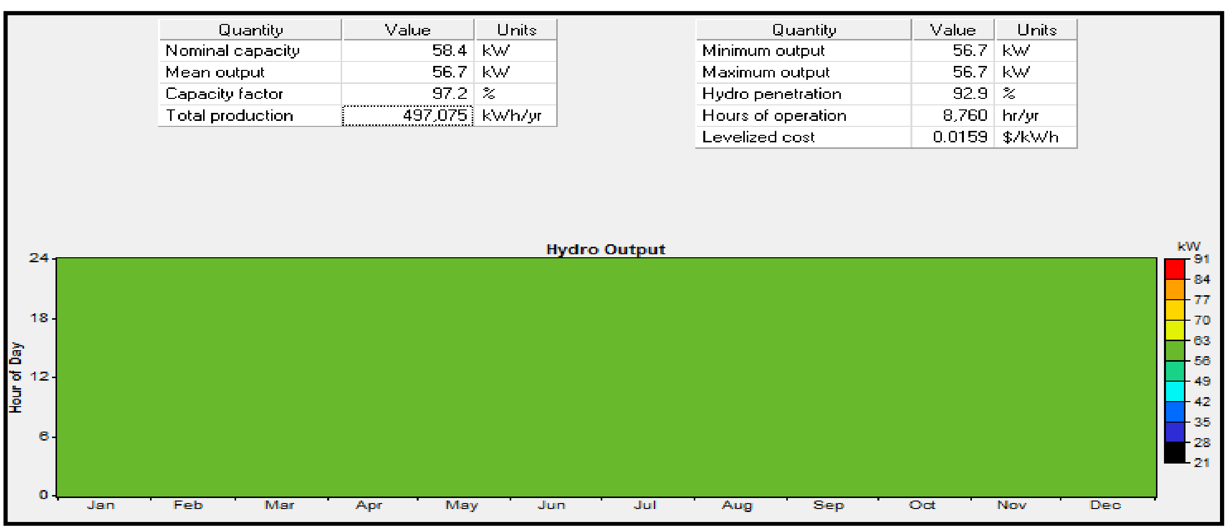

Fig.5. 1: Hydropower output of the system

PV output : The rated capacity of PV array is 70.0 kW , mean output 14.49 kW, the capacity factor is about 20.7%, total electric production 127,016 kW h/yr, hour of operation 4,473 and levelized cost 0.09785$ kW h.

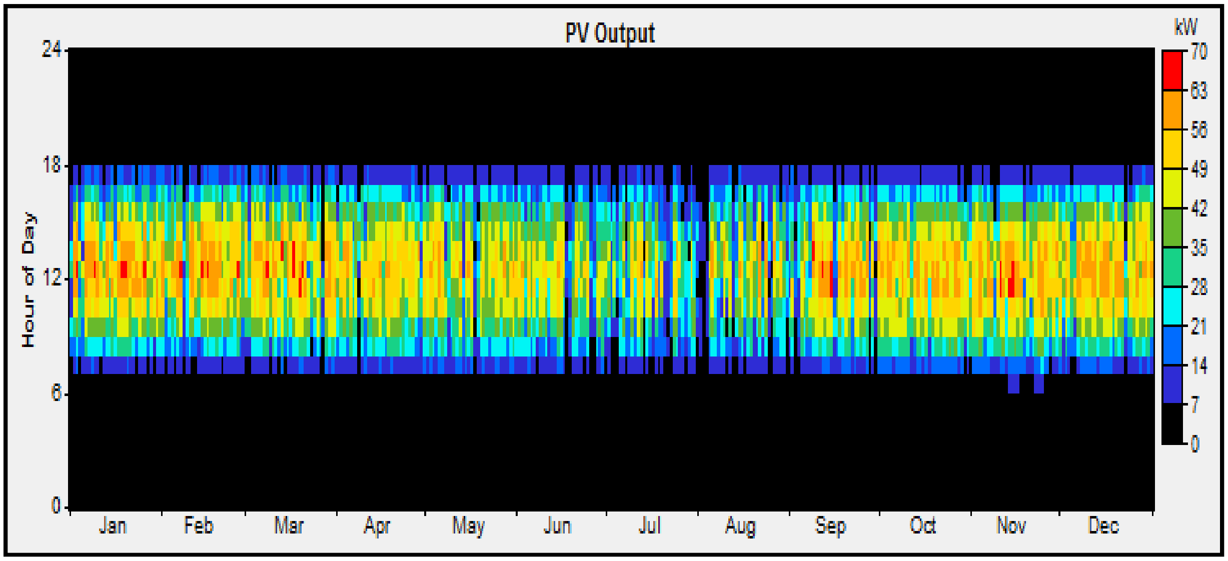

Fig.5. 2: Hourly and monthly Solar power output of the system

As displayed on the Fig. 5.2, electricity generation is higher at the times of high solar radiation striking the earth's surface. October is the month that gets the largest amount of irradiation. Starting from May until end of September, PV power energy production is lower than the other month. Thus, less power output is 0KW (during 0:00hr to 6:00hr and 18:00hr to 23:00hr). This result indicates that almost more than 10hour per day solar PV is generating the power.

Diesel Generator output: The following Fig 5.4 shows power output and diesel generator power of the system.

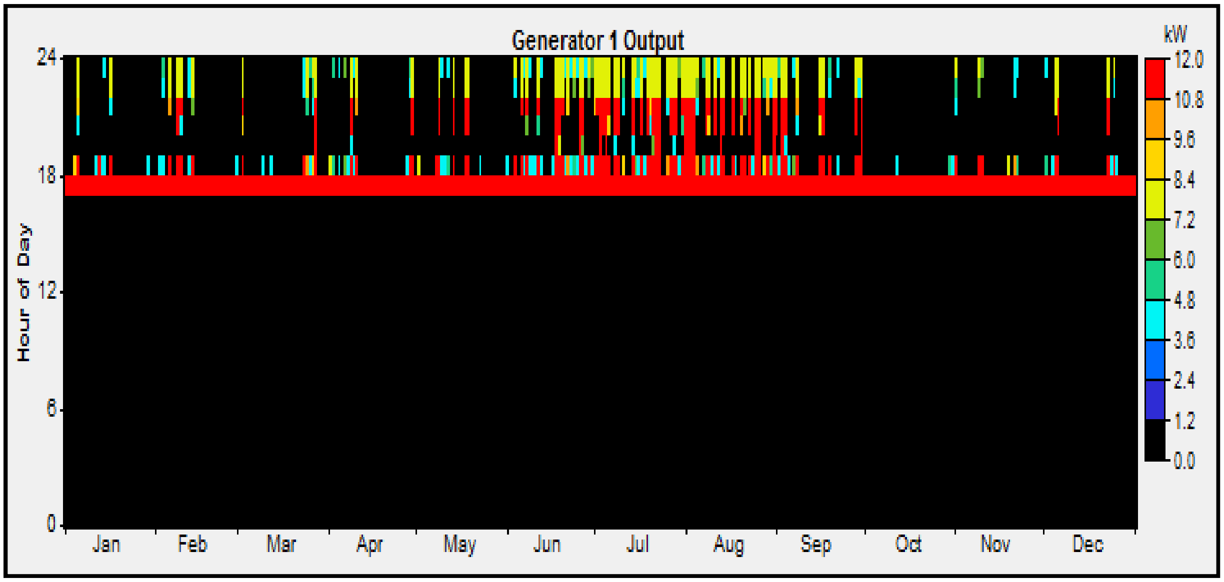

Fig.5. 3: Diesel Generator output of the system, from HOMER

The power generation from diesel generation is relatively high during summer season of June to September because PV power production is minimum during this period. Particularly, diesel power production is in the evening time (18:00-00:00). Generator participating in this hybrid power system generates average power output of 9.96KW, minimum electrical output of 3.6KW. The optimal dispatch strategy of the diesel generation has been found to be `` load following`` and the generator should be operated only for direct supply of the load in case of unavailability of the renewable generation and depleted battery bank. According to the simulation displayed on Fig. 5.1, diesel generator’s operating hours during one year is 888 hours (2.4hr/day). This is equal to 22,200 hours in 25years of project, which is the least operating hour per day. The amount of diesels fuel consumed is around 3,036 liter per annum. The electrical production per year is 7581.68 KWh/years. Therefore, to obtain continuous generation of energy incorporating diesel generator with renewable energy system, it is able to increases the electricity supply during sudden increase in energy demand or when the batteries capacity decreases and thus, it solves the supply interruption.

5.3. Optimization Analysis

Based on the simulation result and comparison of the systems, annual electrical energy production, initial capital cost, excess electricity, renewable fraction, capacity shortage, annual fuel consumption, and operation hours of generator are the criteria selected to select the systems. In table 5.1 is the displayed overall optimization result of all the promising configurations of feasible power scheme based on total NPC of the system. There was no any requirement for pre-selection of the displayed power systems listed in the table but only the ones from top ranked cost effective scheme architectures are displayed. The result is for the selected system A based on current diesel price of $0.72/liter, primary load demand of 1466kWh/year, maximum annual capacity shortage of 1%, and minimum renewable fraction of 60%. The system configuration in the 1st row of table 5.1 is the cost efficient system and technically composed of Micro hydro power with 58.4kW, 70kW photovoltaic panel, 12kW diesel generator, 160 unit batteries, and 140kW converter. From the result, the diesel generator runs in load following (LF) strategy and runs regularly the whole year due to during nighttime load sought because renewable energy sources stored in the battery is not enough to meet the load.

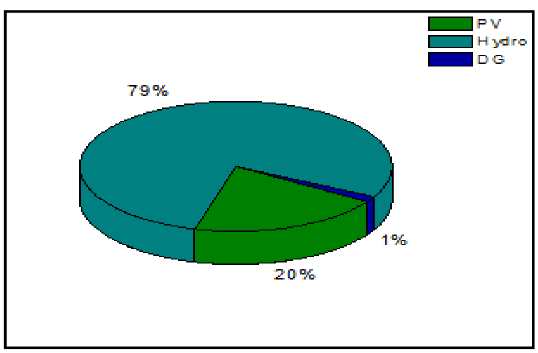

Fig.5. 4: Fraction of power generation system

The electricity generation by individual power units of the hybrid system and consumptions by primary AC are given in figure 5.4. PV array power generation is about 20% whereas Hydro is about 79%, and diesel generator accounts for 1% of total electricity produced by the hybrid scheme. As generation of electricity from Hydro sources is higher than any other scheme incorporating in the hybrid structure, hence it is considered as the base load of the hybrid assembly.

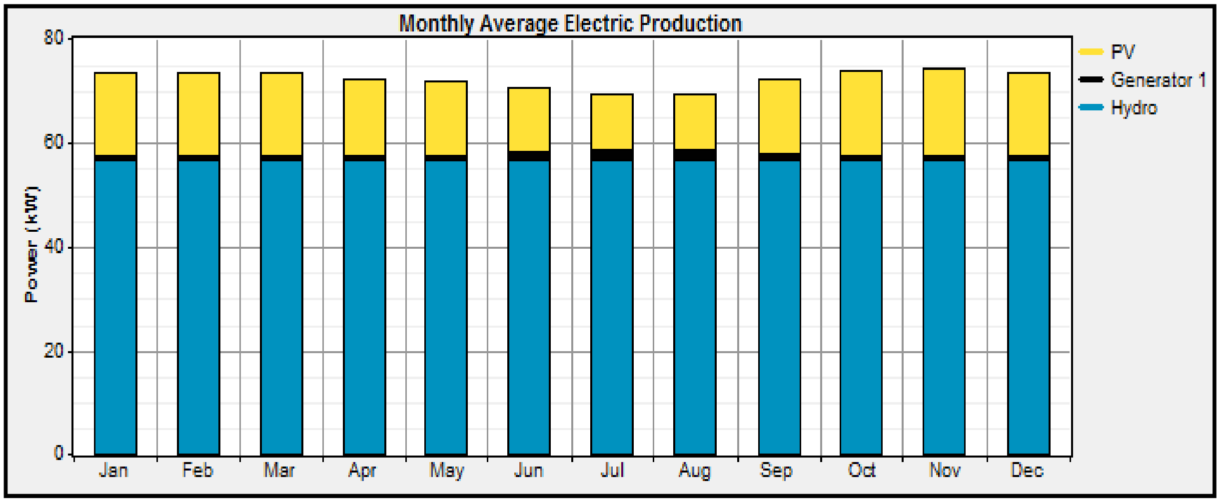

Fig.5. 5: Hydro-PV-diesel system electrical supply properties

ccording to the above observations (Fig. 5.4), we can see that PV array system produced more power than Micro Hydro system with less power output (20%) Which indicates the PV array generates more power than being consumed, the energy is used to charge the battery bank if the battery is in a low state of charge; otherwise it increases the bus frequency and automatically reduces the power feed from a photovoltaic array to the bus. On the other hand, if the photovoltaic array generates less energy than being used, the batteries provide the needed margin. Moreover, the solar PV is available only during daytime and most load profile indicate peak load in the evening time. Even though the micro-hydro produced rated power is less than PV, this system can meet the load with an availability of around 100 % resulting in only around 0 hours of power outage during a year. Thus, the hybrid system, which uses both renewable sources and diesel generator, is more economical than the system with only renewable energy sources.

Even though wisely comparing system parameters are very essential, the important matter is the sizing of the hybrid components in a right way to reduce the energy cost or net present cost of the project. If sizing is not done properly, then it may end up with a system having larger NPC than the base system was in concern.

5.4. Sensitivity Analysis

Two sensitivity variables are considered in this case. Those variables are amount of solar radiation of the site and the price of diesel fuel. It considered that these two variables affect the cost of the system. The output of sensitivity analysis is shown in Fig.5.6.The PV array/ Micro Hydro/DG/battery system is optimal until the solar radiation will reach 6.02kWh/m^2/day and less sensitive as the price of the fuel change. The current diesel fuel price in Ethiopia is around 0.72$/liter. When the diesel price increases up to 1.2 $/l, Micro Hydro/PV/DG/Battery hybrid system is economical. Therefore, incorporating diesel generator into the system is more economical.

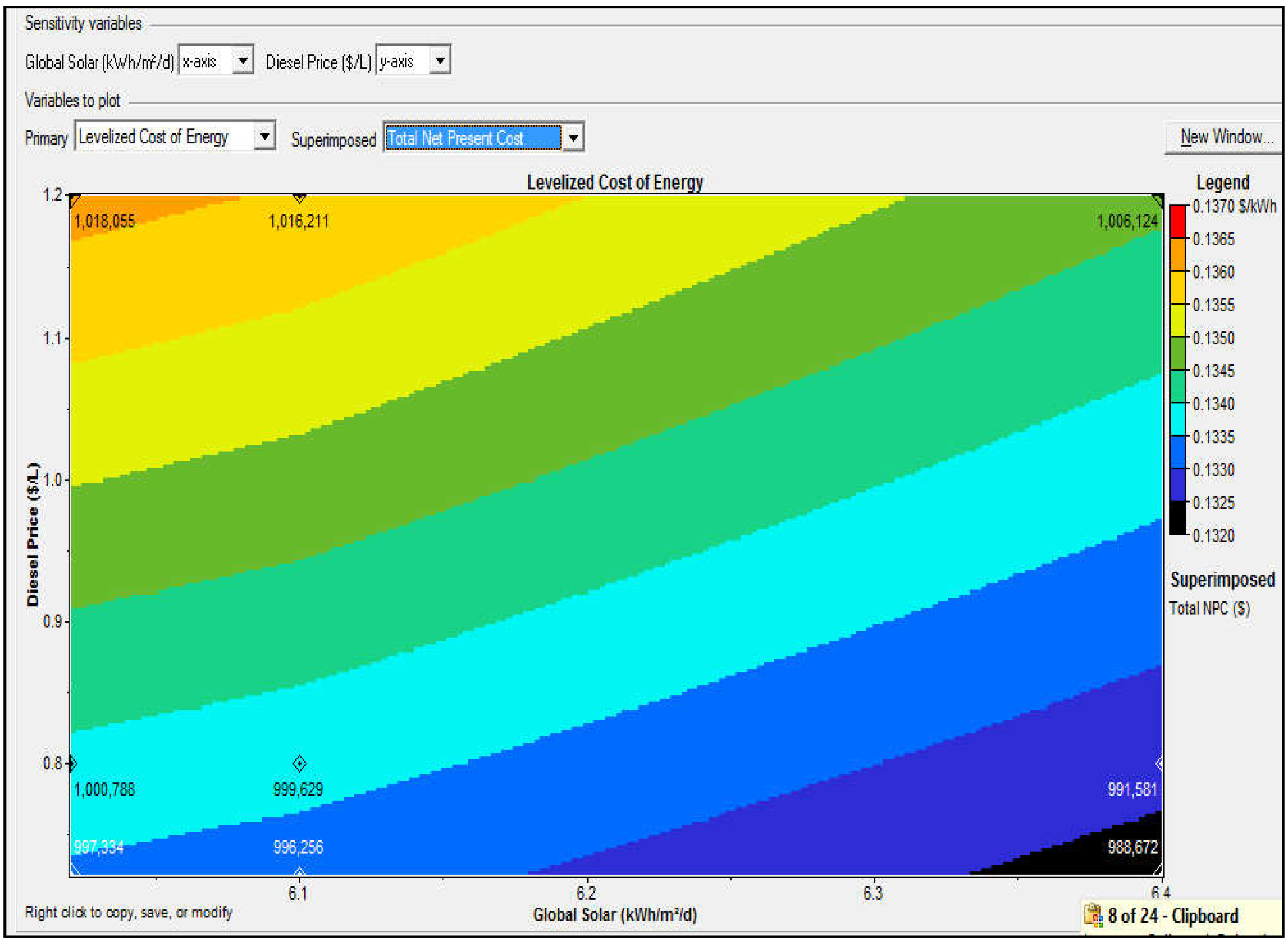

Fig.5. 6: Sensitivity Result

5.5. Engineering Economical Analysis

Once the technical requirements of a hybrid system application have been sated and a Hybrid system design completed, the economic analysis can be carried out. The economic assessment includes both cost and benefits of the system. The replacement and O&M costs are further shown in Fig.5.7 as a nominal cash flow of the system throughout 25years. From the result, it can be seen that battery replacement occurs after 9 and 18 years, and the converters will be replaced after 19 years. Yearly, the O&M cost for hydro, DG and battery will be occurred. Due to PV lifetime is equals to the project lifetime, it has t no replacement and by nature it has no O&M cost.

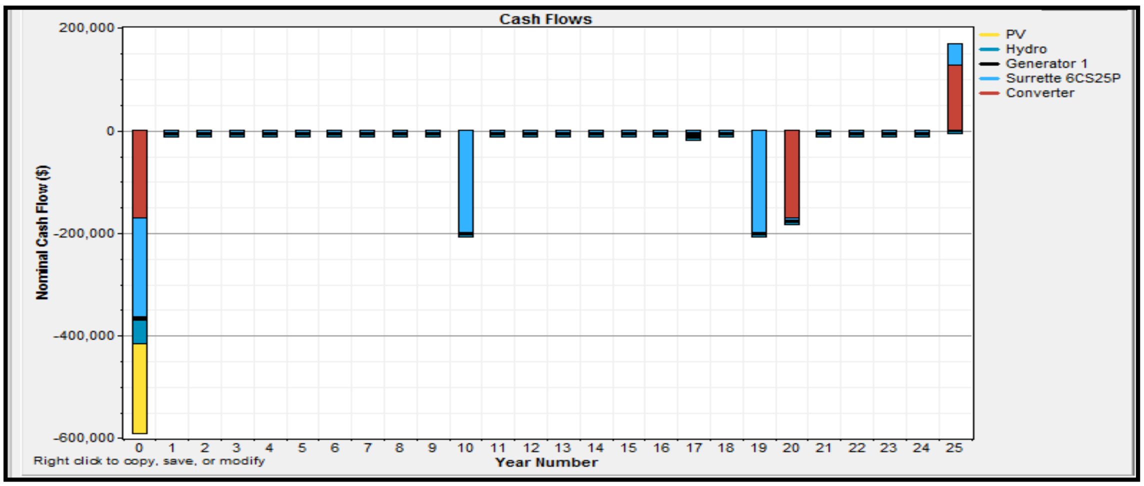

Fig.5. 7: Nominal cash flow of the project throughout 25 years

Net present cost (NPC): The present value of the cost of installing and operating the system over the lifetime of the project. Project lifetime in this study can be considered as 25years. The total net present cost is HOMER's main economic output. All systems are ranked according to net present cost, and all other economic outputs are calculated for finding the net present cost. The net present cost is calculated according to the following equation [49].

$$NPC_{tot}= C_{cap, tot} + C_{O\&M,,tot} + C_{R,tot} + C_{fuel} – \text{Total revenue of the project} \quad (5.1)$$

Where, $C_{cap, tot}$ is total capital cost, $C_{O\&M,,tot}$ is total operation and maintenance cost, $C_{R,tot}$ is total replacement cost, C_{fuel} is fuel cost and Total revenue is total salvage value plus energy sale.

$$C_{ann,tot} = \text{CRF (i, Rproj)} * \text{NPC}_{\text{tot}} \quad (5.2)$$

Where, $C_{ann,\,tot}$ is total annualized cost [$/year], which the multiplication of annualized value of the total net present cost and capital recovery factor.

The value of the capital recovery factor, $(\mathrm{CRF}\ (\mathrm{i}, \mathrm{Rproj})) = \left[\frac{i*(i+1)^n}{(1+i)^n-1}\right]$ (5.3)

Where, i= real interest rate and n= project lifetime. Therefore, the capital recovery factor can be calculated. CRF (i, Rproj) = $\left[\frac{i*(i+1)^n}{(1+i)^n-1}\right] = \left[\frac{0.05*(0.05+1)^{25}}{(1+0.05)^{26}-1}\right] = 0.0709$

$$C_{ann,tot} = NPC_{tot} * \left[\frac{i*(i+1)^n}{(1+i)^n-1}\right] = \$997{,}334 * [0.0709] = \$70{,}763/yr$$

*Levelized cost of energy (LCOE)***:** HOMER defines the levelized cost of energy (COE) as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production [49].

$$LCOE = \frac{C_{ann,tot}}{E_{prim,AC}} \quad (5.4)$$

$E_{prim,\,AC}$ is AC primary load served [kWh/year] and $PC_{ann,\,tot}$ is annualized present cost

$$COE = \frac{70763}{530{,}381} = \$0.133/kWh$$

*Simple Payback period***:** The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The number of years required for the investment to be recovered is called as payback period [60].

$$Simple\ payback\ period = \frac{\text{Initial Investment}}{\text{Annual, Cash Inflow}} \quad (5.5)$$

$payback\ period\ (P_B)$, Calculated for a proposal is to be compared with some predetermined target period (system B and C). By this method, HOMER compares P_B of system A with (system B and C). By comparing system A with system B and C, the P_B of scenario A is 3.42$\approx 4yrs$ which is the lowest payback period and the project is profitable.

Table5. 2: Present cost summary of the project based on the used components

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Solar PV	175,000	0	0	0	0	175,000
Hydro	46,200	0	65,114	0	0	111,314
Generator	6,600	2,316	22,528	31,082	-811	61,715
Battery	193,920	204,920	67,651	0	-13,559	452,931
Converter	169,960	64,056	0	0	-37,642	196,374
System	591,680	271,292	155,293	31,082	-52,012	997,334

By using equation 5.1 to 5.3, the total initial capital cost of the system is about $591,680, the replacement cost is $271,292, operation and maintenance cost is $155,293 and salvage value ($-52,012) which includes the cost of solar array, hydro power, battery bank, converter, and diesel generator. Total NPC of the system is $997,334. Based on NPC, the cash flow summary of the project by cost type can be summarized on the Fig.5.8 below.

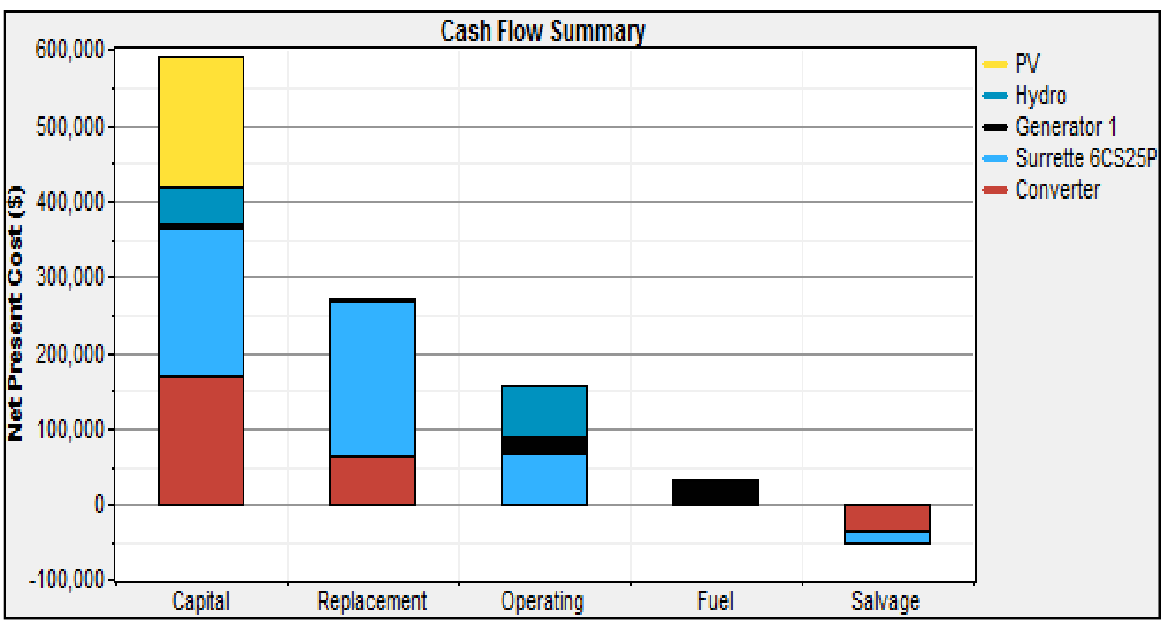

Fig.5. 8: Cash flow summary of the optimal system

One of the important points revealed by this analysis is that developing this power production scheme in Ethiopia requires government subsidies to make the service affordable to the customer. The present national grid electricity price for the domestic user is about 0.06$/kWh which consumed during one month. When compared with the current Ethiopian energy price, the price from this case study (0.133 $/kWh) is somehow affordable. However, in addition to subsidies, the active involvement of the local people to maintain the system by training on the project maintenance is very important for reducing the operating and maintenance costs.

CHAPTER SIX

Conclusion and Recommendation

6.1. Conclusion

This study deals with feasibility of Micro Hydro/PV /DG/ Battery hybrid stand-alone energy system to answer the question technically feasible and cost effective system configuration system for Melka Hera village of Western Ethiopia. The hybrid system designed to supply energy to the village solves energy needed in the village and improve the life of the community living in that area. The study of renewable energy potentials of the site based on the recently recorded data of twenty-two years average solar radiation optioned from surface metrology [NASA] and in case of Hydro, and the flow data obtained from MoWIE. The average monthly profile and hourly data for both sources were analyzed using Homer software.

The result optioned from the software gave numerous alternatives of feasible hybrid systems with different levels of renewable resource penetration in which their choice sorted by changing the net present cost of each system. From technical point of view, micro hydro/PV /GD /Battery hybrid system was selected in this study. From simulation result, the majority of energy optioned from hydropower, which accounts 79%, the PV module covers about 20%, and DG is only 1% of total load consumption. From economic point of view, it is found that for the village under study, which is characterized by average stream flow140l/s and solar radiation 6.02kwh/m^2/day. The hybrid system cost competitive with $0.133/kwh, is somehow affordable. However, it is more than the current grid energy price of Ethiopia $0.06/kwh because the main energy source of the country is Hydropower. However, Hydropower potential not generated fully to cover the electricity demand of the country. If attention given to the energy, it is very important in the improvement of life quality of the country living in rural areas. From environmental standpoint, the renewable energy fraction of the project is 99%, which implies the total energy almost obtained from renewable energy sources. Due to this study, generating clean energy and its contribution to reduction of pollutant emission released to the environment.

Generally, this study contributes minimizing environmental pollution, deforestation, and soil degradation due this, people use firewood, caw dung, other traditional biomass resources and kerosene, which is difficult to afford. This study also helps that off-grid energy system is somehow cost effective and environmentally friendly in delivering power to the village. Moreover, provide valuable information about the energy potential resources in the country to the government and nongovernmental organization (NGO). Furthermore, this study will use as a base to conduct similar study activities for other sites. Finally, it can be concluded that this hybrid power system is an excellent option solution due to technically and economically feasible and Environmentally Friendly Configuration.

6.2. Recommendation for future work

Energy is very crucial to accomplish various activities in human being .Thus, to improve energy crises at the country level, Off-grid renewable energy system Contributed using deferent mechanisms including subsidy. Giving due- merit of environmental pollution, land degradation, poor life quality of the rural community, generating renewable resource should be implemented. However, the current electrification in Ethiopia is by building large hydro dams. This constructing hydro dam could not fully cover the energy requirement of the country.

- The government and concerned bodies should give due attention to the combination of Micro Hydro and PV which is cost effective; provide 24-hour quality electricity.
- This study area selected randomly from the village of Toke Kutaye district in oromia region and it is not over all oromia regions. For Feature, researcher should conduct to investigate other Micro Hydro potential site and to solve energy crises in the Ethiopia rural areas.
- Most of the rivers in Ethiopia are not gauged which makes finding relevant data difficult. Therefore, I recommend the concerned governmental body to give due attention for this work.
- The essential points revealed by this analysis are that, developing this power production in the village requires government subsidies to make service affordable to the consumer. In addition to subsidies, the active involvement of local people to maintain the system is very important to reduce operating and maintenance costs.

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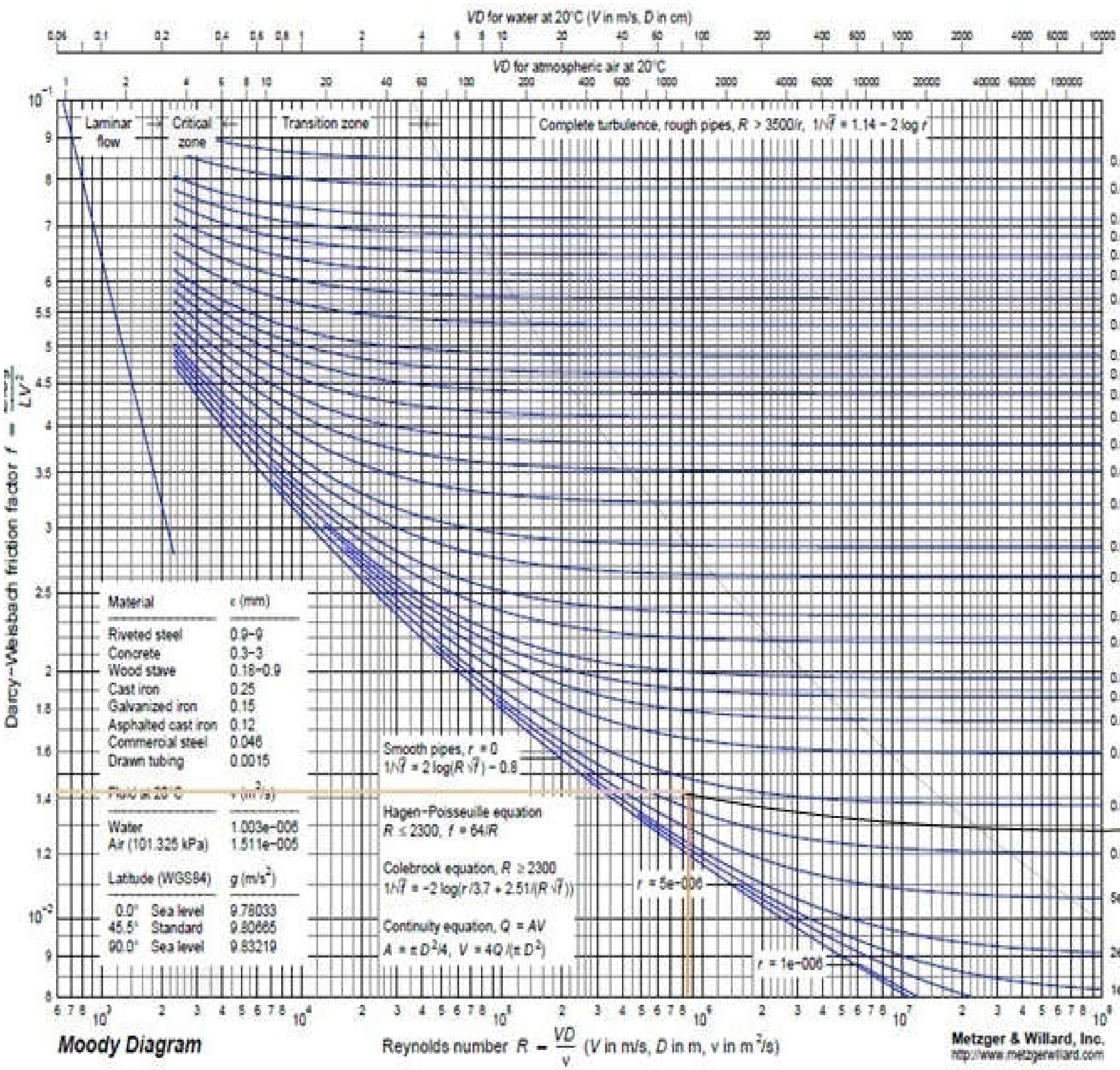
Appendixes

Appendix A: Summary for energy demanded after load projection

Period	Domestic load(kWh/d) 25%HH	Domestic load(kWh/d) 75%HH	School load (kWh/d)	Health post load (kWh/d)	Churches load (kWh/d)	Commercial (kWh/d)	Total load
00:00-1:00	0	0	0	0.06	0	3.6	3.66
1:00-2:00	0	0	0	0.06	0	3.6	3.66
2:00-3:00	0	0	0	0.06	0	3.6	3.66
3:00-4:00	0	0	0	0.06	0	3.6	3.66
4:00-5:00	0	0	0	0.06	0	3.6	3.66
5:00-6:00	0	0	0	0.06	0	3.6	3.66
6:00-7:00	73.129	18.99	0	0.06	0	0	92.17
7:00-8:00	73.129	18.99	0	0.06	0	0	92.17
8:00-9:00	16.78	12.66	0.1	1.27	0.1	25	55.91
9:00-10:00	16.78	12.66	0.1	1.27	0.16	25	55.97
10:00-11:00	16.78	12.66	0.1	1.27	0.16	25	55.97
11:00-12:00	16.78	12.66	0.1	1.27	0.12	25	55.93
12:00-13:00	16.78	12.66	0	0.06	0	0	29.5
13:00-14:00	16.78	12.66	0.1	0.25	0	25	54.79
14:00-15:00	16.78	12.66	0.1	0.25	0	25	54.79
15:00-16:00	16.78	12.66	0.16	0.27	0	25	54.87
16:00-17:00	16.78	12.66	0.16	0.25	0	25	54.85
17:00-18:00	157.245	48.53	o.25	0.27	0.73	0	207.22
18:00-19:00	200.56	12.66	0	0.06	0	0	213.28
19:00-20:00	31.41	48.53	0.25	0.27	0.73	1	82.19
20:00-21:00	37.49	54.86	0.25	0.14	0.67	1	94.61
21:00-22:00	30.325	35.87	0	0.14	0	1	67.44
22:00-23:00	24.635	35.87	0	0.14	0	1	61.65
23:00-00:00	24.635	35.87	0	0.14	0	1	61.65
total	**803.578**	**424.11**	**1.67**	**7.8**	**2.67**	**226.4**	**1466.428**

Appendix B: Moody diagram and Typical value of surface roughness



Source:https://www.google.com/search?q=moody+diagrams&tbm=isch&imgil=vUc859OQjs3d_M%253A%253B9PeYrBoG90GAHM%253Bhttp%25253A%25252F%25252Fwww.tribologyabc.com%25252Fcalculators%25252Fpipeflow_fluid.htm&source=iu&pf=m&fir=vUc859OQjs3d_M%253A%252C9PeYrBoG90GAHM%252C_&usg=AbfvWwHkLwF5Ay_FzkSd_uwrik%3D&biw=1366&bih=657#imgrc=s2O7mMOOha9P2M

Appendix C: Manning coefficient **n** for several commercial pipes

http://indmicrohydro.blogspot.com/2010/05/manning-coefficient-nfor-several.html

Types of Pipe	n
Welded steel	0.012
Polyethylene(PE)	0.009
PVC	0.009
Asbestos cement	0.011
Ductile iron	0.015
Cast iron	0.014
Wood-stave(new)	0.012
Concrete (steel forms smooth finish)	0.014

Appendix D: Head loss calculation result and calculated turbine design parameters

Pelton turbine Designing formulas and results:

$Step1$: Calculation of the turbine input power (*Pti)*

$$Pti = \rho \times g \times Hn \times Q = 1000 \times 9.81 \times 48.61 \times 0.14 = 66.76Kw$$

Step2: Calculation of the turbine speed (*N*)

$$N = Ns \times \frac{Hn^{\frac{5}{4}}}{\sqrt{Pti}}$$

$$Ns = \frac{85.49\sqrt{Z}}{Hn^{0.243}} = \frac{85.49\sqrt{2}}{48.61^{0.243}} = 47 \; and \; N = 739rpm$$

Z= Q/Qn = 0.14/0.019 =2 (number of turbine nozzles)

Vj= $Cn\sqrt{2 \times \mathrm{g} \times \mathrm{H_n}}$ = 29.85m/s (jet velocity (m/s)).

Cn Is nozzle (jet) discharge coefficient ≅ 0.98

$Qn = Vj \times An = Vj \times \pi \, d_d{}^2 = \quad 29.8 \times 0.0004 = 0.012 \; l/s$

(Qn=Water flow capacity of each nozzle, A_n= nozzle area and Q= total flow capacity=0.14m^3/s)

Step3: Calculation of the runner circle diameter (*D*) and bucket dimensions [61].

D=$38.6\sqrt{H_n}$ / N

B= 3.2 $\times d_s$ = 0.1m (Bucket width (@2 nozzles)

d_d= 1.178 $\sqrt{\left(\frac{Q}{Z}\right)\frac{1}{\sqrt{(g\times Hn)}}} \times 0.035$ (nozzle diameter)

ds = 0.54$\sqrt{\frac{Q}{H_n}}$ =0.029m (jet diameter in meters).

m =$\frac{D}{d_s}$ =0.364/0.029= 12.55 (Jet ratio)

$n_b = 0.5m + 15 = 22$ (Number of buckets) and $Bt = 3 \times ds = 0.087m$ (Bucket radial length).

Summarized turbine dimensions and pipe loss result

Head loss calculation result			
Descriptions	**Unit**	**Value**	**Source**
Flow Rate (Q)	m^3/s	0.140	MOWEI
Gross head(Hg)	m	50	Site data
Pipe Inside Diameter (d_p)	m	0.254	Determined value
Pipe Length (L)	m	60	Site data
Pipe average velocity - V	(m/s)	3	Determined value
Head Loss - Pipe	m	**1.39**	**>>**
Calculated turbine design parameters			
Design parameters	**Unit**	**value**	**Source**
Turbine input power (*Pti)*	Kw	66.76	Determined value
Turbine speed (*N*)	rpm	739	>>
Turbine specific speed (*Ns*)	rpm	47	>>
Number of turbine nozzles(Z)	N0	2	>>
Jet velocity (Vj)	m/s	29.8	>>
Runner circle diameter (*D*)	m	0.365	>>
Bucket width(B)	m	0.1	>>
Nozzle diameter(d_d)	m	0.035	>>
Jet diameter(d_s)	m	0.029	>>
Number of buckets(n_b)	N0	22	>>
D/B Ratio	-	3.6	>>

Appendix E: The most efficient solar panels offered by leading brands [43]

Manufacturer	Model	Type	Module Efficiency
Sun Power	X21-345	Monocrystalline	21.5%
Ja Solar	JAC M6PA-4	Monocrystalline	20.9%
Sanyo	HIT Double 195	Monocrystalline	20.5%
Sun Power	327-320	Monocrystalline	20.4%
Sun Power	245-235	Monocrystalline	20.1%
Sun Edison	Silvantis R-Series	Monocrystalline	17.7%
Yingli Solar	YL225C-24b	Monocrystalline	17.1%
REC	Twinpeak Series	Monocrystalline	16.7%
Ja Solar	JAM6 48-220/SI	Monocrystalline	16.6%
Sun tech	STP265/WEM	Polycrystalline	16.3%
Trina	PA05	Polycrystalline	16.2%
Jinko Solar	JKM265P	Multicrystalline	16.2%
Canadian Solar	CS6P	Polycrystalline	15.9%
Yingli Solar	YL205P-23b	Multicrystalline	15.8%
Solar World	SW 260	Monocrystalline	15.5%
Sharp	NU-U23F1	Monocrystalline	14.4%
Yingli Solar	YL 235 P-29b	Polycrystalline	14.4%

Appendix F: The overall optimization, from HOMER

Double click on a system below for simulation results. ○ Categorized ◉ Overall

PV (kW)	Hydro (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
70	58.4	12	160	140	LF	$ 591,680	28,782	$ 997,334	0.133	0.99	0.01	3,063	888
70	58.4	11	160	142	LF	$ 593,558	28,707	$ 998,155	0.134	0.99	0.01	2,955	931
70	58.4	12	160	141	LF	$ 592,894	28,888	$ 1,000,045	0.134	0.99	0.01	3,114	906
70	58.4	11	160	143	LF	$ 594,772	28,815	$ 1,000,894	0.134	0.99	0.01	3,010	952
70	58.4	10	160	145	LF	$ 596,650	28,704	$ 1,001,204	0.134	0.99	0.01	2,891	993
70	58.4	13	160	140	LF	$ 592,230	29,074	$ 1,001,995	0.134	0.99	0.01	3,274	887
70	58.4	12	160	142	LF	$ 594,108	29,012	$ 1,003,004	0.134	0.99	0.01	3,174	930
70	58.4	11	160	144	LF	$ 595,986	28,918	$ 1,003,558	0.134	0.99	0.01	3,063	971
70	58.4	14	160	135	LF	$ 586,710	29,603	$ 1,003,936	0.134	0.98	0.01	3,680	1,032
70	58.4	13	160	141	LF	$ 593,444	29,185	$ 1,004,782	0.134	0.98	0.01	3,328	905
80	58.4	10	160	140	LF	$ 615,580	27,688	$ 1,005,806	0.135	0.99	0.01	2,134	703
70	58.4	12	160	143	LF	$ 595,322	29,127	$ 1,005,835	0.134	0.99	0.01	3,233	951
70	58.4	11	160	145	LF	$ 597,200	29,021	$ 1,006,215	0.134	0.99	0.01	3,118	989
70	58.4	14	160	140	LF	$ 592,780	29,356	$ 1,006,516	0.134	0.98	0.01	3,473	886
60	58.4	15	160	140	LF	$ 568,330	31,130	$ 1,007,068	0.135	0.98	0.01	5,013	1,275
70	58.4	13	160	142	LF	$ 594,658	29,309	$ 1,007,733	0.135	0.98	0.01	3,389	927
80	58.4	10	160	141	LF	$ 616,794	27,767	$ 1,008,141	0.135	0.99	0.01	2,164	713
70	58.4	12	160	144	LF	$ 596,536	29,238	$ 1,008,612	0.135	0.99	0.01	3,290	971
70	58.4	15	160	135	LF	$ 587,260	29,913	$ 1,008,859	0.135	0.98	0.01	3,896	1,030
70	58.4	14	160	141	LF	$ 593,994	29,469	$ 1,009,324	0.135	0.98	0.01	3,528	903
80	58.4	11	160	140	LF	$ 616,130	27,929	$ 1,009,755	0.135	0.99	0.01	2,318	703
60	58.4	15	160	141	LF	$ 569,544	31,280	$ 1,010,398	0.135	0.98	0.01	5,099	1,301
80	58.4	10	160	142	LF	$ 618,008	27,844	$ 1,010,438	0.135	0.99	0.01	2,192	722
70	58.4	13	160	143	LF	$ 595,872	29,430	$ 1,010,662	0.135	0.98	0.01	3,452	948
70	58.4	12	160	145	LF	$ 597,750	29,305	$ 1,010,767	0.135	0.99	0.01	3,297	987
70	58.4	15	160	140	LF	$ 593,330	29,635	$ 1,010,998	0.135	0.98	0.01	3,667	885
60	58.4	20	160	130	LF	$ 558,940	32,099	$ 1,011,342	0.135	0.97	0.01	5,810	1,196
70	58.4	10	160	150	LF	$ 602,720	29,015	$ 1,011,649	0.135	0.99	0.01	2,866	1,113
80	58.4	11	160	141	LF	$ 617,344	28,011	$ 1,012,131	0.135	0.99	0.01	2,350	713
70	58.4	14	160	142	LF	$ 595,208	29,591	$ 1,012,264	0.135	0.98	0.01	3,588	923
80	58.4	10	160	143	LF	$ 619,222	27,921	$ 1,012,745	0.135	0.99	0.01	2,221	732

Appendix G: Questioners for Energy demand assessment of the village.

1. Questioners for household electric load assessment of the village.

Table a) house hold electric load

Appliances	Quantity	Capacity (W)	Run-time (h/d)	period
Low-energy lights ☐				
TV electric load ☐				
Radio electric load ☐				
Cooking stove ☐				
Enjera Backing machine ☐				
Mobile charger ☐				
Refrigerator ☐				
Total				

Name of Respondent: ____________________________________ signature_________

2. Questioners for community service load assessment at melka Hera village.

Table b) school electric load

Appliances	Quantity	Capacity (W)	Run-time (hr/day)	remark
Class room light ☐				
Toilet room light ☐				
External light ☐				
Computer ☐				
Printer ☐				
Class room- CFL ☐				
Total				

Table c) commercial electric load

Appliances	Quantity	Capacity (W)	Run-time (hr/day)	remark
Flour milling ☐				
Tea shop ☐				
Street light ☐				

Table d) Health Center electric Load

Appliances	Quantity	watts (W)	Run-time (hr/day)	remark
Room lighting ☐				
External light ☐				
Toilet room light ☐				
Communication radio ☐				
Television ☐				
Computer ☐				
Printer ☐				
Laboratory Microscope ☐				
Vaccine freezer ☐				
Total				

Name of Respondent: ______________________ Signature: ________________

Table e) church electric Load / mosque

Appliances	Quantity	watts (W)	Run-time (hr/day)	remark
Megaphone ☐				
Room lighting ☐				
External light ☐				
Computer ☐				
Printer ☐				
Total				

Name of Respondent: ______________________ signature: ______________