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Study and Design of Solar and Micro-Hydro Hybrid System for Rural Area of Debre Berhan, Ethiopia

A thesis submitted to the School of Graduate Studies in partial fulfilment of the requirement for the degree of Master of Science in Electrical and Computer Engineering

By

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Certificate

I hereby certify that the work which is being presented in the Thesis entitled "Study and Design of Solar and Micro-Hydro Hybrid System for Rural Area of Debre Berhan, Ethiopia", in partial fulfillment of the award of degree of Master of Engineering in Industrial Control submitted to Electrical and Computer Engineering Department of Addis Ababa Institute of Technology, Addis Ababa, Ethiopia, is an authentic record of my own work carried out under the supervision of **Dr. Mengesha M**. The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

Fekade Yehualawork **.....**

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

Dr. Mengesha M. **.....**

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Acronyms

PV:	Photovoltaic
MHP:	Micro Hydro -power
HOMER:	Hybrid optimization model for Renewable Energy
GPS:	Global Position surface
NASA:	National Aeronautics and Space Administration
NPC:	Net present cost
COE:	Cost of energy
MoWIE:	Ministry of Water, Irrigation and Energy
EEPCO:	Ethiopian Electric Power Corporation
AC:	Alternating current
DC:	Direct Current
MHS:	Micro hydropower system
I-V:	Current versus Voltage
P-V:	Power versus voltage
STC:	Standard test condition
SHP:	Small hydropower
FDRE:	Federal Democratic Republic of Ethiopia

Abstract

Ethiopia is a developing country with a total access to electricity not exceeding 41% and the number of household connected to this access is 17%. About 85% of the population lives in places where access to electricity is less than 2%. Basonawrna, a small woreda in north shoa zone, has a total population of 250. The village is about 7km from Debre Berhan substation; which makes the extension of the grid not yet practical, and off grid electrification is the best option for the village. The community in this woreda uses Kerosene for lighting, biomass for cooking and dry cells for radios. Nothing has been done so far in developing the renewable energy resources, such as small-scale hydro, solar and wind energy in the village.

The main essence of this thesis is to design and analyze feasibility of PV-Micro hydro hybrid electric supply system to the Basonawrna woreda. HOMER software (hybrid optimization model for electrical renewable) as optimization analysis tool is used to verify the result. The reason behind the selection of HOMER is that it simplifies the task of evaluating design of off-grid power system for variety of application. Hydro potential of the village, the gross head of the river and stream flow, data is obtained from Ministry of Water, Irrigation and Energy. Meteorological data of the village is collected from National Meteorological Agency of Ethiopia and NASA. Surface Metrology is used for the estimation of solar energy potentials. Electric load for the basic needs of the community, such as, for lighting, radio, television, water pumps, milk processing, and flour mills is estimated. The system proposed and analyzed is a micro hydropower plant and battery. In this configuration, a micro hydro power plant of 20 kW and the battery bank of 55.5 kWh is used. The micro hydro power plant generates approximately 122.6 MWh/year. The total net present cost of the hybrid system is $108,631 and the cost of energy for the hybrid system is 0.096$/kWh.

Keywords: Hybrid energy systems, Photovoltaic, Micro - hydro, off - grid system, HOMER

Chapter One - Introduction

1.1 Background

Now, life without energy is unimaginable. The access to electricity has proven to be a key factor necessary for socioeconomic development, both for the peoples and infrastructure of a country. It is a basis for urbanization and industrialization in the current modern times. With electricity, lines being confined to large cities and towns, developing countries lag far behind in many sectors when compared to industrialized countries. Ethiopia, despite being the one of Eastern African country, has a very poor electricity penetration rate. Electricity is available for 41% of the population and only 17% of the households are connected to the central grid; even the above coverage is confined to major towns and cities [11].

Since the Ethiopian Government advocates Green Economy Renewable energy sources (solar, wind, hydropower etc.) are attracting and got more attention as an alternative energy sources than conventional biomass based energy system it accounts 88 % of the total primary energy consumption in the country [11].

This is not only due to the diminishing fuel sources, but also due to environmental pollution and global warming problems. Among these sources is the solar and hydropower energy, which is the most promising, as the fabrication of less costly photovoltaic (PV) devices becomes a reality and Attractive exploitable capacity of Hydropower. However, using only one type of energy source may result shortage of reliable and sustainable energy supply for the country. Such kinds of problems arise due to large variances of PV output power under different insolation levels and reduction of stream flow during drought seasons. Hence an alternative option to overcome is by integrating Hydropower with Photovoltaic panel which alleviates this problem [14].

PV-Hybrid Systems

Hybrid systems generally refers to the combination of any two input sources, here solar PV can be integrated with Diesel Generator, Wind Turbines, Bio-mass or any other renewable on non-renewable energy sources. Solar PV systems will generally use battery bank to store energy output from the panels to accommodate a pre-defined period of insufficient sunshine, there may still be exceptional periods of poor weather when an alternative source is required to guarantee power production.

PV-hybrid systems combine a PV module with another power sources - typically a diesel generator, but occasionally another renewable supply such as a wing turbine. The PV generator would usually be sized to meet the base load demand, with the alternate supply being called into action only when essential.

Hybrid systems can also be sensible approach in situations where occasional demand peaks are significantly higher than the base load demand. It makes little sense to size a system to be able to

meet demand entirely with PV if, for example, the normal load is only 10 % of the peak demand. By the same token, a diesel generator-set sized to meet the peak demand would be operating at inefficient part-load for most of the time. In such a situation a PV-diesel hybrid would be a good compromise.

1.2 Problem Statement

According to EEPCO, current data with only 17% of households connected and 41% of the he population is estimated to have access to electricity and the per capital energy consumption is 100kWh, which is the lowest in the sub-Sahara average, that is 510kWh [72]. Most of the non-electrified regions are found in rural part of the countries. These regions can be electrified either by extending the grids of the existing power systems or by constructing isolated (standalone) power systems. In general, it is preferred to go for the extension of the existing grids but they are not always affordable the fact that most of the non-electrified parts are located in remote and difficult areas, like hilly regions, forests, and they are scattered, which demand enormous investment for grid. Currently, in rural areas communities uses Kerosene for lighting, water for milling and biomass for cooking and dry cells for radios. This thesis work on the solution of this problem, to fulfill the electricity demand in reliable, affordable, and sustainable manner with a cost-effective way.

The main concern is the cost effective and applicable, since the people in rural areas cannot afford the money for implementation and also cannot afford the maintenance cost. So the thesis will investigate a solution for this cost problem and applicable of hybrid power system.

1.3 Objective of the study

General Objective

The general objective of this thesis is to design of an applicable solar-micro hydro hybrid system in local area of Ethiopia.

Specific Objectives

- Determine the electrical energy need of the community living in the area.
- Estimate the renewable energy resource of the area;
- Design a standalone hybrid system to meet the electrical energy demand of the community
- Selection and assessment of the main components of the system
- Evaluate the technical and economic performance of the micro hydro-PV Hybrid System and make sensitivity analysis.

1.4 Relevance of the study

The purpose of this thesis is the development of solar-micro hydro hybrid system that harnesses the renewable energies in the sun and water to generate electricity. The research mainly focuses on the design and analyze of electricity using renewable energy source for Ethiopian rural area.

Most of the schools, health centers, administration posts and residents will use the generated electricity after implementing this thesis.

1.5 Scope of the study

The scope of this study is limited to determining the best techno-economic combination of RE resources in a hybrid configuration for electrification of one community selected in Ethiopia and the evaluation for performance of the system is included but this will not deal with the complete configuration of the electricity by this hybrid system. The analysis of this hybrid system will be done by considering the following assumptions.

- Meteorology and solar energy data and wind data from NASA Surface Meteorology and Solar Energy website represented by RET Screen International are considered to accurate for computing solar PV systems for off-grid electrification systems[12].
- The same annual variations of solar radiation occur all over the project lifetime.
- The consumers live conforming to a daily routine coming from the same load cycles every day, since there is no summer or winter for the selected location because the temperatures seems to constant in the year.
- Rate of inflation will be considered the same for all types of costs (operation cost, maintenance cost, and labor cost .etc.) occurs [4].
- The hybrid configuration is not location specific and will be the optimal configuration for other locations where the renewable energy potential is the same as the selected region. This is a good example for other location in Ethiopia, depending with the load profile and availability of the renewable energy resources.

Chapter Two - Literature Review

2.1 Hybrid Energy System

Hybrid energy systems are becoming popular as an efficient way of handling the intermittence of solar and wind resources. The use of hybrid energy systems can optimize the power supply especially for remote community applications where extension of grid supply is expensive, e.g. in rural areas. A hybrid energy system consists of two or more energy sources and storage components combined to provide increased system efficiency and a more balanced energy supply. Most frequently used hybrid renewable energy systems for rural electrification are PV-wind-diesel, PV-wind, PV diesel, PV-wind-diesel. The energy source combinations mentioned above are frequently occurring as stand-alone systems for energy production [58].

Renewable energy systems (RESs) are one of the most suitable and environmentally friendly solutions to provide electricity within urban and rural areas. On-grid and off-grid electrification based on the generation of power through the installation of renewable energy power systems in urban and rural households have been proven to be capable of delivering the reliable electricity for heating, lighting, and demands alike. Using RESs have many advantages over conventional sources including the following [2]:

- High accessibility to reliable electricity at any time
- Reduce the dependency on fossil fuels and from oil price fluctuations
- Increase economic productivity and create local employment opportunities
- Fight climate change
- Allow for a better use of local natural resources

Wind-solar hybrid systems can provide a steady community-level electricity service, such as residential electrification, also offering the possibility to rural areas to be upgraded through grid connection in the future. Furthermore, in case of installation and use in rural areas, due to their high levels of efficiency, reliability and long term performance, these systems can also be used as an effective backup solution to the public grid in case of natural disasters, emergencies, sudden blackouts or weak grids.

Another significant point is to store the energy generated by wind turbines and PV-systems for future use when no wind and/or no irradiation is available but the user demand exists. For this, an energy storage bank can be incorporated in such a way that the battery stores energy whenever there is excess supply and discharges when there is more demand than supply. The hybrid power system, described here, basically includes the following main elements:

- Renewable energy sources: PV-array and wind turbine generator
- DC-DC converters, controllers and an inverter
- Energy storage system: Battery bank
- AC and DC loads

2.2 Photovoltaic Technology and Solar Energy Resources

The main energy source of the living things on planet earth is the sun. In addition, the sun is the ultimate source of most of renewable energy sources. Solar energy can be used to generate electricity in a direct way with the use of photovoltaic modules. PV technology is now spreading into terrestrial applications ranging from powering remotes sites to feeding utility grids around the worlds. Photovoltaic is the field of technology related to the devices, which directly convert sunlight into electricity where the term photovoltaic is a compound word and comes from the Greek word for light, photo, with, volt, which is the unit of electromotive power. The technology of photovoltaic cells was developed rapidly over the past few decades [15].

Photovoltaic Cells

The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice [6].

There are several types of solar cells. However, more than 90% of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Wafer-based silicon solar cells are approximately 200 μm thick. Another important family of solar cells is based on thin-films, which are approximately 12 μm 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 [7].

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a ‘photovoltaic module’. Modules are designed to supply electricity at a certain voltage, such as a common 12-volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

There are two main types of photovoltaic system. Grid connected systems (on-grid system) are connected to the grid and inject the electricity into the grid. For this reason, the direct current produced by the solar modules is converted into a grid-compatible alternating current. However, solar power plants can also be operated without the grid and are then called autonomous system (off-grid systems) [8].

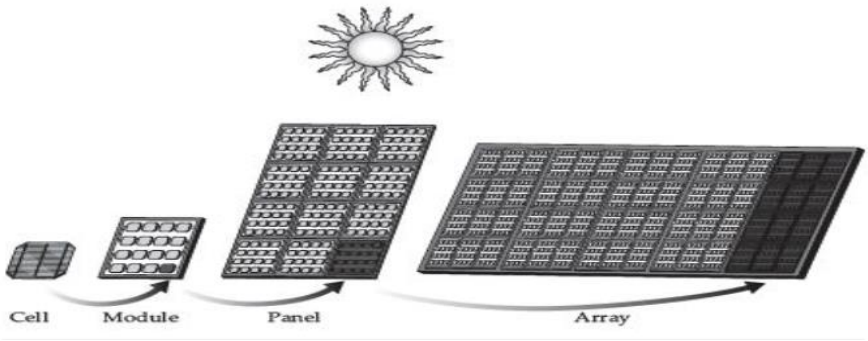


Figure 2.1 - PV system component [63]

Principle of operation of Solar Cell

When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric filed across the junction separates photo- generated positive charge carriers (holes) from their negative counterpart (electrons). In this way, an electrical current is extracted once the circuit is closed on an external load.

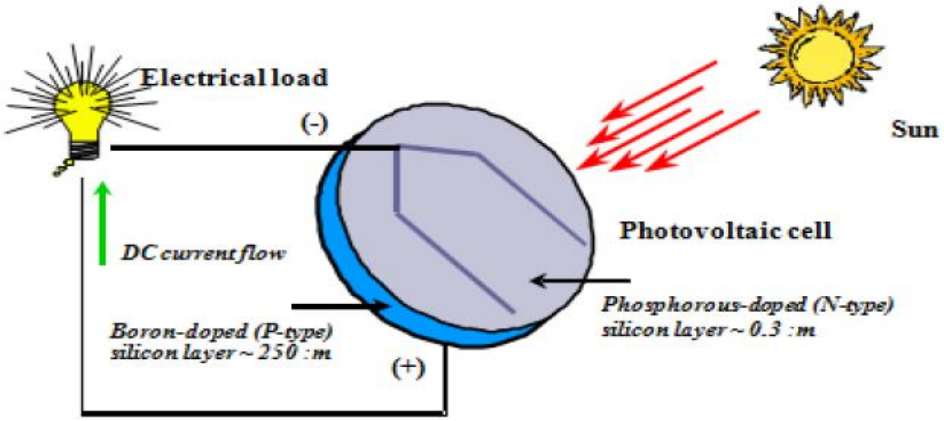


Figure 2.2 - Solar cell working principle [15]

Common Terminologies of Photovoltaic Cells

- **Solar irradiance**: is an instantaneous quantity describing the rate, or flux of solar radiation (power) incident on a surface, commonly expressed in units of kilowatts per square meter (kW/m^2). Outside the earth's atmosphere, the solar irradiance on a surface oriented normal (perpendicular) to the sun's rays is essentially constant at $1.36kW/m^2$. Due to atmospheric effects, the peak solar irradiance incident on a terrestrial surface oriented normal to the sun, at noon on a clear day is about $1\ kW/m^2$. A solar irradiance level of $1kW/m^2$ is often called peak sun and is the reference condition commonly used to rate the peak electrical output of photovoltaic modules and arrays.
- **Solar insolation**: is an amount of solar energy received on a surface commonly expressed in units of kilowatt-hours per square meter (kWh/m^2). Solar insolation (energy) is

essentially the average solar irradiance (power,) integrated with respect to time. When solar insolation data is represented on an average daily basis, the value is often called peak sun hours (PSH), and can be thought of as the number of equivalent hours per day that solar irradiance is at its peak level of 1 kW/m^2. The worldwide average daily value of solar insolation on optimally oriented surfaces is approximately 5 kWh/m^2. Figure 2.3 shows the relationship between solar irradiance and insolation [15].

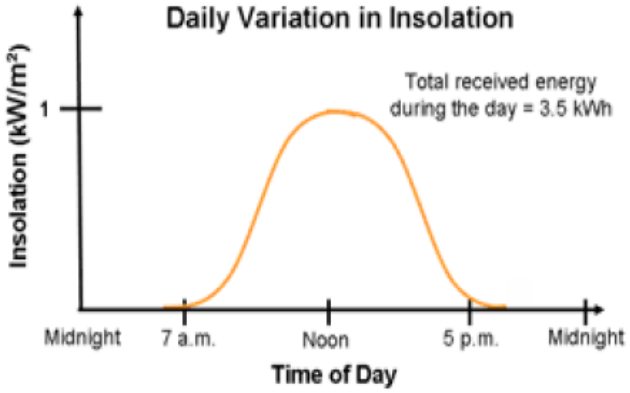


Figure 2.3 - Relation between solar Irradiance and Solar Radiation [15]

Main Components of Photovoltaic System

- **PV modules**

A PV module is composed of interconnected photovoltaic cells encapsulated between a weatherproof covering (usually glass) and back plate (usually a plastic laminate). It will also have one or more protective by-pass diodes. The output terminals, either in a junction box or in a form of output cables, will be on the back. Most have frames. Those without frames are called laminates. In some, the back plate is also glass, which gives a higher fire rating, but almost doubles the weight [16].

- **Battery bank**

For systems that require energy storage, like any system that needs to operate without the utility grid. A battery bank, multiple batteries wired together to achieve the specific voltage and energy capacity desired. The battery bank is typically housed in a container to keep the batteries safe. The PV array connects to it in order to provide charging a charge controller. The battery bank is also connected to the inverter to provide power for the AC loads. If the system also uses DC loads, the battery bank is wired to a DC load center. Common batteries used for typical PV system.

- **Sealed batteries**: these come in a sealed container that requires a reduced amount of maintenance by the end user.
- **Flooded batteries**: these come in an open (or flooded) container that requires a higher level of user interaction.

All batteries give off gas when they are charging, releasing hydrogen. Sealed batteries release minuscule levels of hydrogen; flooded batteries can give off substantial levels of it. A wise choice (actually a requirement in most locations) is to keep all batteries inside a protective container that vents to the outside to avoid the possibility of hydrogen buildup and an explosion hazard [26].

In this study, Surrette 6CS25PS battery selected. (6CS25PS) is a modular construction 6-volt, dual container battery based on the high capacity CS plate. This unique battery design has each cell self-contained in a high temperature-retardant, durable polypropylene case. The outer container is made of high-density unbreakable polyethylene, providing double protection against breakage and leakage. Cell replacement is easy and quick using bolt-on connectors-allowing the battery to be assembled or repaired on location. The Rolls Surrette 6CS25PS battery is rated for 3300 cycles at a 40% depth of discharge.

- **Charge Controller**

A charge controller is a piece of electronics that is placed between the PV array and the battery bank. Its primary function is to control the charge coming into the battery bank from the PV array. Charge controllers can vary from a small unit intended to connect a single PV module to a single battery all the way to a controller designed to connect a multiple-kilowatt PV array to a large battery bank [31].

- **Inverter**

Inverters turn the DC power produced by PV arrays or stored by battery banks into the AC power used in hones and community services.

- **Loads**

Loads are all the pieces of electrical equipment people want to use in their homes and offices.

Photovoltaic Rating

Photovoltaics' modules are available in a range of sizes. Those used in grid tied or stand-alone systems range from 80W to 300W. The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under the Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25^{o}C (77 F), an incident solar irradiant level of 1000 W/m^2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always present PV modules and arrays operate in the filled with performance of 85 to 90 percent of the STC rating.

Solar Module Rating and Price at STC

Table 2.1 - Solar module power rating and price at STC [59].

Solar pane brand	Peak power watts	Total wattage	Cost US$ per solar panel	Total cost	P=poly M=mono T=Thin film	%=module efficiency	Price per watt	Vendor
Canadian solar CS6P-230P	230	4600	$161.00	$3,220.00	P	-	$0.70	Green solar com
Stion STO145 BAA 145W CIGS	145	3625	$105.82	$2645.50	T	12.00%	$0.73	Civil solar
Sun tech STP245-20/Wde	245	245	$183.30	$183.30	P	15.00%	$0.75	Solar syz
Canadian solar CS6P-245P	245	5880	$191.1	$4586.40	P	15.230%	$0.78	GoGreen solar com
DM solar	158	316	$134.00	$268.00	M	-	$0.85	DM solar
Hyundai	230	5750	$195.50	$4887.50	P	14.20%	$0.85	DM solar
Conergy CGY-51115 PH	250	6250	$212.50	$5312.50	P	15.20%	$0.85	GoGreen solar com
Eco Solargy	240	7200	$209.00	$6270.00	P	14.00%	$0.87	Solar panel online

PV Technology

Many crystalline or thin film PV modules power a solar PV system. Individual PV cells are interconnected to form a PV module. This takes the form of a panel for easy installation. PV cells are made of light-sensitive semiconductor materials that use photons to dislodge electrons to drive and electric current.

There are two broad categories of technology used for PV cells, namely, crystalline silicon, as shown in figure 2.6. This accounts for the majority of PV cell production and thin film, which is

newer and growing in popularity. The "family tree" in figure 2.16 gives an overview of these technologies available today and figure 6 illustrates some of these technologies.

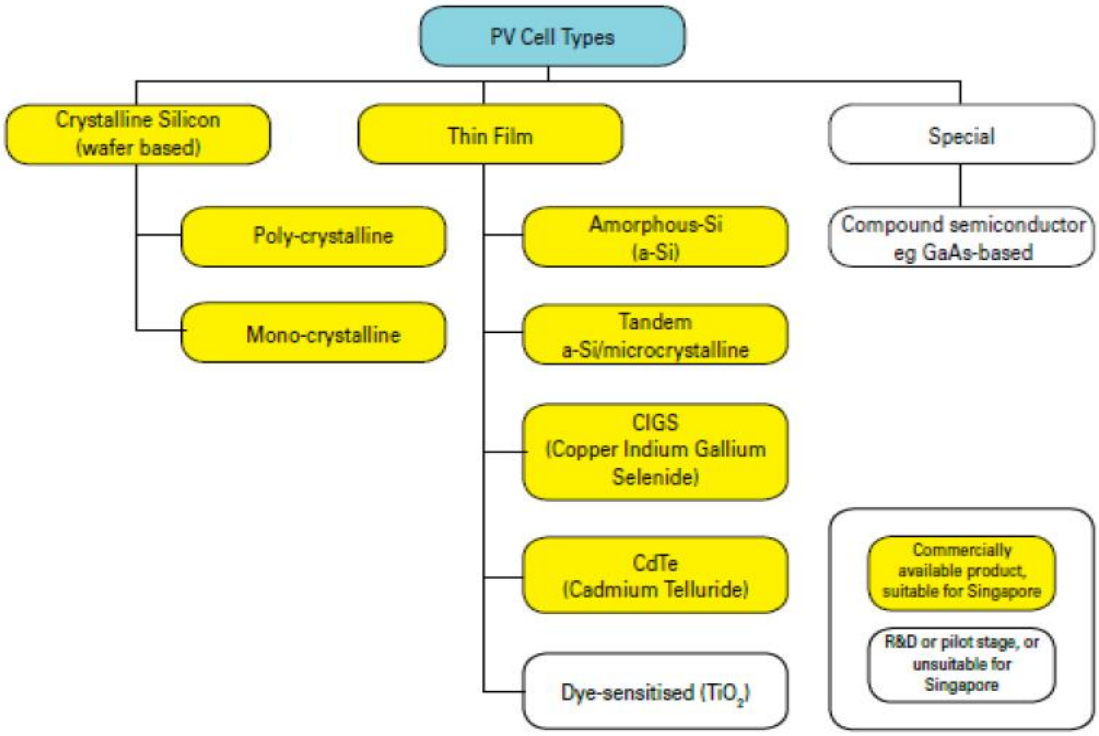


Figure 2.4 - PV technology family trees

2.3 Wind Energy System

Wind turbine systems can be divided into two main groups based on the shaft orientation. These groups can be further subdivided by looking at rotor blade configuration or the number of blades and the way the turbine system is connected to the grid. The two main groups of turbines consist of those with horizontal shaft configuration and those with vertical shaft configuration.

As the names state, in the case of the horizontal shaft configuration the shaft is in a horizontal position with the blade(s) connected to the one end of the shaft, as shown in Figure 2.5 (left side) The vertical shaft wind turbine has a much longer shaft in a vertical position with the blades connected to the shaft at more than one point, as shown in Figure 2.5(right side).

The vertical shaft configuration turbines are further sub-categorized into groups by looking at the positioning and form of the blades. The most well-known vertical shaft wind turbine is Darrieus's phi-configuration, also known as the eggbeater configuration. Other well-known groups are the Musgrove, Diamond, Savonius, Giromill and Phi types [31, 32].

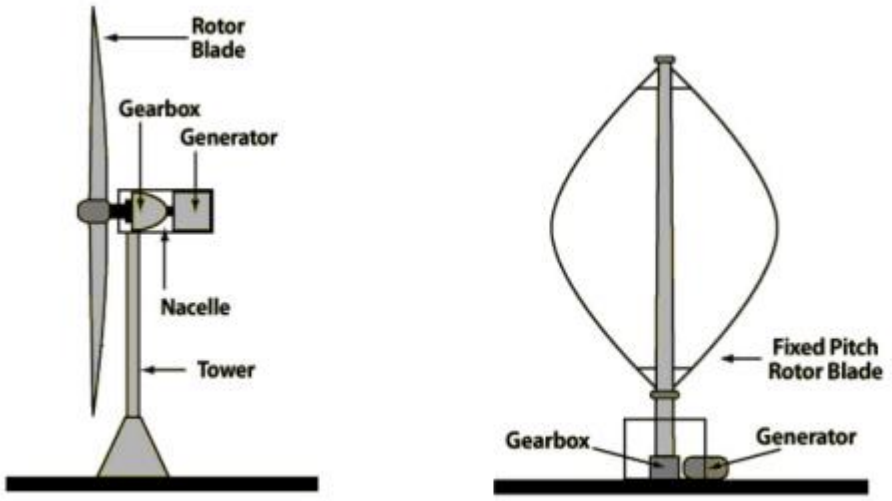


Figure 2.5 – turbine configuration

Most modern wind turbine systems make use of the horizontal shaft configuration. This type of turbine configuration can be further sub categorized by looking at the number of turbine blades, which include single-blade, two-blade, three-blade, and multi-blade configurations. The advantages of having only a single blade are minimum drag losses and high ideal operation speed. High operation speed leads to a low-ratio gearbox which is cheaper. The disadvantages that stem from high operating speed are more wear and tear on the system and high noise emissions.

Another disadvantage is that the blade needs to be balanced with a counter-weight. This weight does not contribute to the energy extracted but adds to drag losses. The single-blade configuration is unpopular because of problems with the balance, visual acceptability and high noise emission due to high aerodynamic loading and high speed [19,35]. As with the single-blade turbine, the two-blade turbine's ideal operating speed is high and, therefore, still quite noisy.

The biggest disadvantage that turbines with an even number of blades have is that the uppermost blade gets maximum power from the wind at the exact time that the lowermost blade gets minimum power from the wind due to the influence of the tower. This results in stability problems in a machine or gearbox with a stiff structure. Consequently, turbines with an even number of blades are not used that often [19,34]. Since traditional manufacturers of two-blade turbines have switched to three-blade configurations, the three-blade upwind configuration is currently the most widely used commercial wind turbine [19, 32 & 34]. The three-blade turbine is also known as the classical Danish concept.

This turbine provides greater dynamic stability than single- or two-blade turbines as they have an optically smoother operation, hence, visually integrating better into the landscape. All major manufacturers have three-blade turbine models available ranging from tens of kilowatt to as big as 6 MW [35]. After years of research by all the major turbine manufacturers, it seems that most have opted for the horizontal shaft configuration with three blades and situated upwind and this is the configuration which will be used in this thesis.

2.4 Micro-Hydro power Generation System

Water is the most common source of energy in Ethiopia. It accounts 97.65 percent of the total energy mix [14]. Hydropower engineering refers to the technology involved in converting the pressure and kinetic energy of water in to more easily used electrical energy. The prime mover in the cost of hydropower is a water wheel or hydraulic turbines, which transform the energy of the water in to mechanical energy [10].

A micro-hydropower system is a small system in the range of 5-100 KW. The simplest micro-hydropower plant is based on a run-of-river design, which means it does not have water storage capability. It will produce power only when water is running or it might have relatively small water storage capability. Micro-hydropower is an interesting prospect for providing electricity for rural communities [14].

General Principles of MHP

Power generation from water depends upon a combination of head and flow. Both must be available to produce electricity. Water is diverted from a stream into a pipeline, where it is directed downhill and through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. The turbine in turn drives the generator where electrical power is produced. More flow or more head produces more electricity. Electrical power output will always be slightly less than waterpower input due to turbine and system inefficiencies.

Water pressure or Head created by the difference in elevation between the water intake and the turbine. Head can be expressed as vertical distance (feet or meters), or as pressure, such as pounds per square inch (psi). Net head is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water flow is turned off (static head), due to the friction between the water and the pipe. Pipeline diameter also has an effect on net head.

Flow is quantity of water available, and is expressed as ‘volume per unit of time’, such as gallons per minute (gpm), cubic meters per second (m^3/s), or liters per second (L/S). Design flow is the maximum flow for which the hydro system is designed. It will likely be less than the maximum flow of the stream (especially during the rainy season), more than the minimum flow, and a compromise between potential electrical output and system cost. Sites where the gross head is less than 15m would normally be classed as “low head”. From 10-50m would typically be called “medium head”. Above 50m would be classed as “high head”.

Power from a MHP

To determine the power potential of water in a stream it is necessary to know the flow quantity of water available from the stream and the available head. The quantity of water available for power generation is the amount of water (in m^3 or liters) which can be diverted through an intake into the pipeline (penstock) in a certain amount of time. This is normally expressed in cubic meters per second (m^3/s) or in liters per second (l/s)

Head is the vertical difference in level (in meters) through which the water falls down. The theoretical power (p) available from a given head of water is in exact proportion to the head and the quantity of water available [39].

The Micro-Hydropower Plants can be classified based on type of Operational feature, by demand of Electrical power, by installed capacity, available head at the inlet, discharge through the vanes and specific speed.

Classification of Hydropower by Operational Feature

In studying the subject of hydropower engineering, it is important to understand the different types of Hydro power plant development. The flowing classification system is used in this text:

- **Run-of-river developments**. A dam with a short penstock (supply pipe) directs the water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment of the water.
- **Diversion and canal developments**. The water is diverted from the natural channel into s canal or a leg penstock, thus changing the flow of the water in the stream for a considerable distance.
- **Storage regulation developments**. An extensive impoundment at the power plant or at reservoirs upstream of the power plant permits changing the flow of the river by storing water during high –flow periods to augment the water available during the low-flow periods, the supplying the demand for energy in a more efficient manner. The word storage is used for long-time impounding of water to meet the seasonal fluctuation in water, availability and the fluctuations in energy demand. While the word poundage refers to short-time (daily) impounding of water to meet the short-time changes of energy demand [57].
- **Pumped Storage Developments**. Water is pumped from a lower reservoir to a higher reservoir using inexpensive dump power during periods of low energy demand. The water is then run down through the turbines to produce power to meet peak demand [57].

Classification of hydro power based on the demand for electrical power.

- **Based-load developments**. When the energy from a hydropower plant is used to meet all or part of the sustained and essentially constant portion of the electrical load or firm power requirements, it is called a base-load plant. Energy available essentially at all times is referred to firm power.
- **Peak-load developments**. Peak demands for electric power occur daily, weekly, and seasonally, plants in which the electrical production capacity is relatively high and the volume of water discharged through the units can be changed readily are used to meet peak demands. Storage or poundage of the water supply necessary [57].

Classification of hydro power by installed capacity

Classification of hydropower according to installed capacity is different from different scholars. Hydro systems can be regarded as a renewable energy source resulting from the natural hydrological cycle, it is by some considered sustainable due to the lack of impoundment of water and assumed negligible environmental impact [57]. The technology was initially used in Himalayan villages in the form of water wheels to provide motive power to run devices like grinders [57]. Table 2.2 shows the classification of the hydropower system based on the generated power output.

Table 2.2: Classification of hydropower by size [57].

S/N	Classification	Rated Power	Consumer
1	Large- hydro	>100 MW	usually feeding into a large electricity grid
2	Medium-hydro	15 - 100 MW	usually feeding a grid
3	Small-hydro	1 - 15 MW	usually feeding into a grid
4	Mini-hydro	100 kW - 1MW	either stand-alone schemes or more often feeding into the grid
5	Micro-hydro	5kW -100 kW	usually provided power for a small community or rural industry in remote areas away from the grid
6	Pico-hydro	< 5kW	

Classification of hydro power by head

Hydraulic head is a key site-specific factor affecting the turbines type selection, equipment, and construction costs of an SHP. Hence, a set of representative reference models should developed for different head ranges and corresponding turbine types:

- Low head (2-25m): axial flow (AF) Kaplan/propeller, cross-flow, Francis
- Medium head (25-70m): conventional Kaplan/propeller, Francis
- High head (>70 m): Francis, Turgo, Pelton

It is noted that the suggested water head ranges are not rigid but are merely a means of categorizing sites, and the turbine selection also depends on flow ranges and other factors at the individual sites [20].

Principal Components of Micro-hydropower plant

The principal components of a simplified MHS (Micro Hydropower System) are shown below in Fig 2.6.

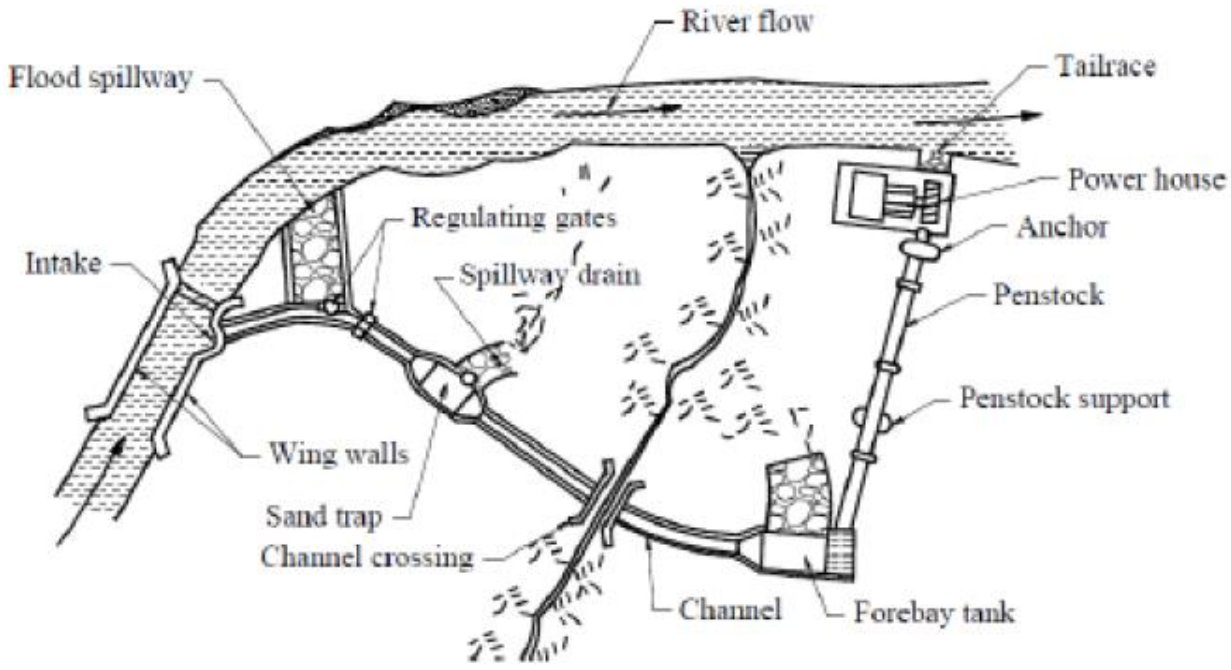


Figure 2.6 - General layout of the MHP and its principal components [4].

The principal components that are used in the MHS (Micro Hydropower System) could be further classified into civil components, powerhouse components and transmission and distribution networks. The first two components are again elaborated in the following sections.

The constructional building of a hydropower plant is strongly reliant on the characteristics of the particular locations. Each construction has different basic conditions. Generally, small hydropower

plants are established as either medium-or high-pressure plants. That is to say, a comparatively small amount of water produces electricity using a penstock and a high head [4].

- **Hydraulic Turbines**

The device, which converts hydraulic energy into mechanical energy or vice versa, is known as Hydraulic Machines. The hydraulic machines, which convert hydraulic energy into mechanical energy, are known as hydraulic turbines. Turbines can be categorized mainly in two types: Impulse turbine and Reaction turbine. Turbine is the heart of hydro system, as they transform the hydraulic energy in the mechanical one, which is a more easily usable form of energy.

- **Impulse Turbines**

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications.
There are three basic types of impulse turbines, which distinguished and which have different physical principles and characteristics. These are the Pelton turbines, the Turgo-turbine and the Cross flow-turbine (also known as Banki-Mitchell or Ossberger-turbine).

- **Reaction Turbine**

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines tare generally used for sites with lower head and higher flows than compared with the impulse turbines [20].

Hydro Turbine Efficiency

It is important to remember that the efficiency characterizes not only the ability of a turbine to exploit a site in an optimal manner but also its hydrodynamic behavior. Average efficiency means that the hydraulic design is not optimum and that some important problems may occur (as for instance cavitations, vibration, etc). That can strongly reduce the yearly production and damage the turbine. Each power plant operator should ask the manufacturer for an efficiency guarantee (not output guarantees) based on laboratory developments. It is the only way to get insurance that the turbine will work properly. The origin of the guarantees should be known, even for very small hydro turbines.

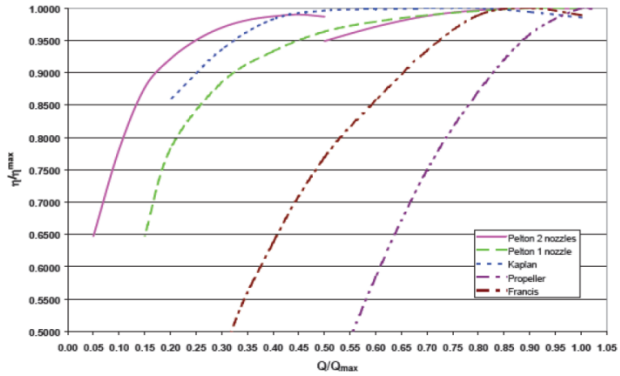


Figure 2.7 - Typical small hydro turbines efficiencies [20]

The plant performance, as annual energy production is directly connected with the unit expected efficiency, which could be a choice parameter.

Table 2.3 - Efficiency of different turbines [61]

Turbine type	Best efficiency
Kaplan single regulated	0.91
Kaplan double regulated	0.93
Francis	0.94
Pelton multi-jet	0.90
Pelton 1 jet	0.89
Turgo	0.85
Cross-flow	0.80

Hydro Turbine Selection

Main turbine selection criteria are, mainly on available water head and less so on the available flow rate. In general, impulse turbines are used for high head sites, and reaction turbines are used for low head sites. Kaplan turbines with adjustable blade pitch are well-adapted to wide ranges of flow or head conditions, since their peak efficiency can be achieved over a wide range of flow conditions [58].

Specific speed of the turbine is another selection criterion to be considered. The specific speed is a determining factor for appropriate turbine speed. This is important to derive the correct gear ratio needed in producing the required generator speed for either charging the battery or providing directly to load. This term is specified as the speed in revolutions per minute at which the given turbine would rotate, if reduced homologically in size, so that it would develop one metric horse power at full gate opening under one meter head. Low specific speeds are associated with high heads and high specific speeds are associated with low heads. Moreover, there is a wide range of specific speeds, which may be suitable for a given head.

2.5 Literature Review

Several researches have been conducted in hybrid off-grid power generation all over the world and in Ethiopia. Different scholars used different Technology option and approaches to evaluate the various configurations of renewable energy resources, such as solar energy, wind energy, small hydropower and their hybrid configurations. A number of studies results have been published some of the thesis paper are reviewed and evaluated in the following paragraph.

Berihun G. (2013) presented a case study of rural area in Ethiopia entitled "Modeling and Simulating of a Micro Hydro-Wind hybrid power generation system for rural area of Ethiopia" by using HOMER software. His objective was to develop 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 by comparing the cost of energy to identify cost competitive for the remote village compared to extending the existing grid to the area since the break-even grid extension is 23.6km which is less an the extension of the grid, so grid extension can be an option. 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 in the hybrid configuration, his hybrid system may be cost effective regarding to his title [8].

Getachew, B and Palm [17] studied the alternative of supplying electricity from solar-wind hybrid system to a remotely located community of 200 families isolated from the national grid in Ethiopia through HOMER software. The results were compared from the list of feasible renewable power sources sorted based on net present cot and found that hybrid solar and wind system is only the promising technology for power generation to these communities.

A research conducted by Leak. E Woldemaria 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 [38].

Gelma Boyena developed Design of a Photovoltaic/ Wind hybrid Power generation system for Ethiopian remote area. His aim was to design and model a stand-alone PV-Wind hybrid power

generation system, for Balley and Surrounding areas of 100 households and community services. He discussed that for those community isolated from the central grid, life style of the target community could be improved by promoting a cost effective PV-wind hybrid system. He simulates the proposed hybrid system and the result obtained affected by the renewable energy access. The cost of energy for the proposed hybrid set up configuration feasible in range between 30 cents to40 cents per kilowatt hour. He pointed out that this tariff is higher than the current tariff of the country. However; from social point of view and improvement of the life of the people not connected from the central grid the cost is not such significant and cannot be rejected [19].

ArashAsrari, AbolfazlGhasemi, and Mohammad Hossein Javidi [7] in their research aims, firstly, was to explore how to expand the contribution of RES by combining the diesel power sources and renewable energy sources so that the system can supply electricity to the rural centers in economical way. On their second stage, they have tried to connect RESs to the national utility grid in order to realize a more cost effective and techno-optimum system. The software called HOMER has been used to see the practicability of possible combination of hybrid configuration using diesel-RES and distributed power system with RES. The results demonstrate that the RES integration is a key for cost effective for the system which is certainly cleaner and more climate-friendly [1]. This paper has been selected because, it deal with some techniques used for distributed power system and the combination of renewable energy technology of socio-economic optimization.

Tshering Dorji, Tania Urmee and Philip Jennings [8] in their study the aims was to identify the least-cost and optimum technologies be used in the rural environment [1]. Their study focuses on the energy needed by rural communities, resources available to the selected rural area, and policies and programs that should be fulfilled for the electrification of rural areas. The software HOMER has been used in hybrid optimization model for the design of distributed generation (DG) systems. This paper has been selected due to its comparison between the costs obtained from the RETs systems and the grid extension cost.

S.M. Shaahid and I. El-Amin [11] the aim of their study was to examine solar system in order to evaluate the best techno-economic of hybrid RES composed with PV–diesel–battery to answer to the load required by the selected remote village with the demand of 15,900 MWh.
Several other literatures have used the Homer software for techno-economic optimum sizing of hybrid systems. Homer algorithms help in the evaluation of techno-economic feasibility of RET options and to see the technology with cost effective. It has also integrated with a product database with different products from a variety of manufactures. Hence this software is widely used for hybrid system optimization.

Almost all of the researches which are studied earlier used PV/wind excluding hydro or Wind/Hydro excluding PV. But in this study we combine PV with Micro-Hydro. This system

configuration is advantageous because Ethiopia have plenty of solar resource and enough amount of Hydro potential in almost many parts of the country.

In addition from the above literature reviews, it is observed that no researcher use RET Screen or other simulation software for the design of hybrid micro power and almost all of them dedicated to feasibility studies. Hence, HOMER is widely used for most of the RES based systems. Thus, based on the above literature reviews, HOMER software is taken for the purposes of this study to carry the feasibility assessment.

Chapter Three - Electric Load of Debre Berhan

3.1 Profile of the Village under Study

One of the villages from Debre Birhan located in the semien shewa zone of amhara region, Basonawrna woreda is selected for analysis of option of applicable solar- hydro hybrid energy system for supplying electricity. The map of the Basonawrna worda is given in the figure below. Basonawrna woreda consists with area of 300 km² and density of 522.2 inh. /km² from the woreda administration result shows that the total population of Basonawrna is approximately 250 [64].

The selected off-grid remote rural village for this thesis is Basonawrna woreda, Debre Berhan 7km far from the grid. It is a small village in the Amhara Regional State of Ethiopia and the total population of the village is approximately 250 people lives in the woreda. Figure below shows the location of the village on the map. It is located at latitude and longitude of 9°41′N 39°32′E and an elevation of 2,840 meters. The village is about 7km from Debre Berhan grid substation.



Figure 3.1 Location of the Village

3.2 Data Collection

A survey in the village will be required to conduct for collecting all these data. But real surveyed data is not available for the selected community, the load profile of the village has been derived based on the knowledge that I have on the selected area and assumptions by using the results obtained from the interviews with the households which have been conducted on the new community area where the power extension have been reached. Those data that are collected in conducting field survey. During the field survey, the data necessary for this study are the available head of the river, the number of religious institutes and type of community services, such as, school, health post and small-scale industries. The gross head is 14.1m, whereas the number of churches, community services are collected from Wereda Administration, Wereda health office, Wereda Education office and the local people live near to the selected River.

After conducting field survey, the more appropriate data for study are, stream flow of the river, solar radiation. Population size & number of households, energy equipment cost related to the proposed hybrid configuration & technologies. Steam flow and solar radiation data are collected from ministry of water & energy, Ethiopian Metrology Agencies & NASA Surface metrology respectively; whereas the population size & number of households and token from Central Statics Agency. [CSA, 2007] & Wereda Administration respectively. The following table shows data collected for the village under study:

Table 3.1 data collected

Data Collected	Value	Data Source
Hydro Resource	14.m (head of water) 0.193 m^3(flow rate)	Minister of water and energy
Solar Resource	22 years average	NASA
Renewable Energy Equipment's costs	----------	Websites (SolarBuz,Alibaba.com)
Number of population	250	Census and Basonawrna Wereda Administration



Figure 3.2 Site survey and gross head measurement for Beresa River

3.3 Energy Demand Assessment and Load Scheduling of the Village

Electricity is the backbone and imperative condition for a country to be developed in terms of economy and the good quality in terms of lifestyle for the citizens. To improve the life of the society energy is very important and crucial. Due to the low income of the society, scattered placement, the house hold energy demand of the village is lower than that of in the urban area.

The electrical energy produced from the proposed hybrid system is supplied to home appliances, community service, and religious institute and for agricultural activities. Home appliances includes lighting, TV, radio receiver, community services energy requirement includes lighting, power for office equipment's, water pumping and agricultural service includes lighting & pumps for irrigation activities and small milk processing.

The primary load is residential with some load for health post, religious institute and schools. We also include small-scale industrial loads, like milk processing. The load of the village is composed of the household devices such as lights, stoves, TVs and radios and that of refrigerators; water heater devices are included in the calculation for health post. It is assumed that the houses are divided into four categories i.e. high, upper-middle, lower-middle, low based on their income and living standard information obtained from Administration. The estimated energy consumed by each of the categories is shown in load Table 3.2. The table shows estimation of each appliance's rated power, its quantity and the hours of use by each house. Health post, churches, agricultural and school in a single day. The miscellaneous load is for unknown loads in each.

3.4 Load Forecast of Electrical load

The estimated electrical load for small households include, three 11W lamps, out of which two for indoor lighting, and one for outdoor lighting running from 18:00-23:00, a 15W radio receiver operated for 4 hours per day, on working days and 9 hours on weekends, a 70w rated color TV working for 4 hours per day on working days, and 11 hours per day on weekends. In the same manner for large houses, four lamps for each household, 30W radio receiver, 100W TV and injera baking stove also considered. The primary school has eight classrooms and each class room will obtain light from four 15W. Beside class rooms' indoor, four and three lamps are assumed for offices and outdoor lighting, respectively.

Likewise, for the health post for three rooms each 15W lamps are considered 60W rated vaccine refrigerator, 200W normal refrigerator and 1000W water heater for sterilizing medical equipment and 15W microscope is included.

Two milk processing machine rated capacity of 4kW, one flour mills with rated capacity of 7.5kW with milling capacity and three water pumps of rated capacity of 2kW assumed. The energy demand of the village is not constant it varies from time to time, day to day and season to season and working days to weekend. According to Ethiopian Calendar, the schools are closed in weekend and in summer due to semester and annual break respectively. Likewise milk processing and floor

mils are not used in weekend due to religious reason. The Summary of the village is as shown in Table 3.3 along their hours of operation.

Table 3.2 Summary of energy demand of the village

Large House Loads(50)						
No.	End Use Device	Unit end use Power [W]	Qty	Load large Houses[kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Lighting	11	4	5	5	25
2	TV(21' inch)	100	1	2	4	8
3	Radio at Working days	30	1	1	3	3
4	Radio at Weekend	30	1	2	6	12
5	Cooking stoves	1000	1	8	2	16
6	'Injera Mittad'	3500	1	7	2	14
7	Miscellaneous	20	1	0.2	10	2
Sub total						80
Small House Loads(200)						
No.	End Use Device	Unit end use Power [W]	Qty	Load Small Houses[kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Lighting 11W	11	3	6.6	5	33
2	TV(14' inch)	100	1	5	5	25
3	Radio at Working days	30	1	6	2	12
4	Radio at Weekend	30	1	3	8	18

5	Miscellaneous	20	1	0.2	10	2
Sub total						90
Public Loads						
Medical Center						
No.	End Use Device	Unit end use Power [W]	Qty	Load Medical Center [kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Vaccine Refrigerator	60	1	0.06	24	1.44
2	Small Refrigerator	200	1	0.2	24	4.8
3	Microscope	15	1	0.15	6	0.09
4	Lighting	18	5	0.165	8	1.32
5	Water Heater	1000	1	1	8	8
6	Miscellaneous	20	1	0.02	24	0.48
Sub total						16.13
Schools						
No.	End Use Device	Unit end use Power [W]	Qty	Load School [kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Lighting	15	32	0.54	4	2.16
2	Computer	20	4	0.40	8	3.2
3	Miscellaneous	40	5	0.2	10	2
Sub total						7.36
Church						

No.	End Use Device	Unit end use Power [W]	Qty	Load Church [kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Lighting	11	25	0.275	10	2.75
2	Megaphone	20	10	0.2	4	0.8
3	Miscellaneous	20	10	0.2	24	4.8
Sub total						8.35
Others						
No.	End Use Device	Unit end use Power [W]	Qty	Load Other [kW]	Operating hours(hr/d)	Daily Energy Demand [kWh/d]
1	Pump	2000	1	2	2	4
2	Milk Processing	4000	1	4	2	8
3	Flour Mill	5000	1	5	6	30
Sub total						42
System daily total energy Demand						243

3.5 Load projection for the village

Predictions of future events and conditions are called forecasts, and the act of making such predictions is called forecasting. Forecasting is a key element of decision-making. . Its purpose is to reduce the risk in decision making and reduce unexpected cost [57].

Energy Consumption in the Future across the residential, commercial and industrial sectors in the Village will be strongly influenced by economic growth. Increasing personal income, capital investment and housing starts are major contributors in continued growth in electricity demand.
For this study, Load, projection for the village is considered from the country average. The electricity demand forecast considers both the peak demand for electricity and average demand throughout the year. Peak demand refers to the highest level of electricity consumption that the utility can supply at any one time. According to EEPCO the Target Scenario electricity, demand will be expected to grow by 32% for the period 2011-2015 [EEPCO].

From this Forecasting Estimation we assume the village Energy Demand also will increases by 25% because village Energy Demand is lower than urban Demand. Therefore, for the village is under study the current energy Demand is 243kW/day, peak energy demand is 39kW. However, the assumed daily load of working days and seasonal load profile are given in Figure3.3 and Figure3.4, respectively.

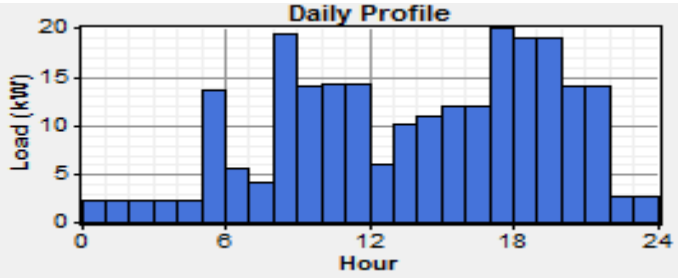


Figure 3.3 Daily load profile of the village

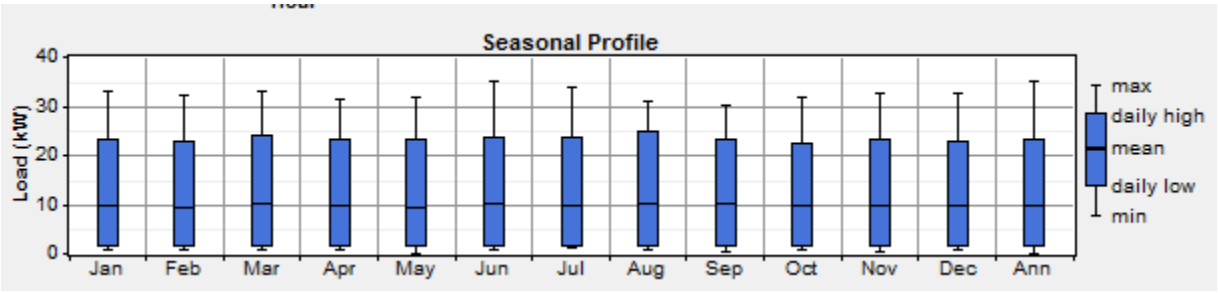


Figure3.4. Seasonal load profile of the village

Based on these, a typical daily load curve with hourly resolution has been derived for this village and it is given in Figure 3.3. With respect to the derived load profile, the maximum demand of the village is around 29 kW but with the random variability of 10 % (standard deviation: daily and hourly noise to make the load data more realistic) for both day to day and time step to time step, this maximum demand can become 39 kW with the energy consumption of around 243 kW/day. The average daily energy demand of the village is 243kW/day, hence the yearly energy demand is estimated as:

Annual Average Energy = 243kW/day X 365 days/year = 88.7MWh/year

Chapter Four - Micro-hydro, Wind and Solar Resource Assessments of the Village

4.1 Introduction

The potential of solar resource, and hydropower resource for the village was assessed. The, solar radiation and clearness index for 22 years average was obtained from the NASA surface meteorology, solar map of Ethiopia was obtained from SWERA, and 29 years daily basis stream flow is obtained from Ministry of Water and Energy.

4.2 Solar Resource Assessment of Basonawrna Wereda, Debre Berhan

For Basonawrna Wereda, Debre Berhan the yearly average daily radiation is 6.03 kWh/m^2. This varies significantly during the year, ranging from a minimum of 5.3 kWh/m^2. In July to a maximum of 6.65 kWh/m^2. On a regional basis, the yearly average radiation ranges from values as low as 4.25 kWh/m^2.In the areas of Itang in th Gambella Regional State (Western Ethiopia), to as high as 6.25 kWh/m^2. Around Adigrat in the Tigray Regional State (Northern Ethiopia).

Current uses of solar energy are for Off-grid rural applications in homes, rural telecoms and in the social sectors (water pumping, health services, schools). Solar energy is also becoming an important alternative to water heating in the major cities. The current total installed photovoltaic power in Ethiopia is about 3.5 MW, three-quarters installed in telecom stations (mostly in mobile towers but also in other stations). Solar water-heating installations are in a thousand or so units in Addis Ababa and the major cities [59].

Solar radiation that reaches the earth's surface in a in a straight line is called direct, while sunlight scattered by could, dust, humidity and pollution is called diffused. The sum of the direct and diffuse sunlight is called global-horizontal insolation. 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 not only use the direct component of the light, but also produce electricity when the sky is overcast to the average total solar energy received over the year, rather than to refer to instantaneous irradiance.

Solar radiation provides a large amount of energy to the earth. The total amount of energy, which is irradiated from the sun to the earth's surface, equals approximately 10,000 times the annual global energy consumption. On average, 1,700 kWh/m^2. Is insulated every year [44].

4.2.1 Solar Resource Assessment of the Village

The 22 years monthly average solar resource of the village varies from 5.74 kWh/m^2/day in February and 5.9 kWh/m^2/day in July, which is the summer of Ethiopia, is and clearance index are obtained from NASA. An average solar radiation for the village is 6.03 kWh/m^2/day the clearance index and daily radiation the village is obtained from NASA surface metrology. For a photovoltaic system to supply sustainable power, the daily radiation should be greater than 4

KWh/m^2/day. Figure 4.1 shows the solar resource profile for Debre Berhan village and is tabulated in Table 4.1.

Table 4.1 Clearance index and daily radiation of the village (Source: NASA)

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.596	5.320
February	0.598	5.740
March	0.600	6.150
April	0.607	6.380
May	0.639	6.650
June	0.620	6.350
July	0.574	5.900
August	0.565	5.880
September	0.595	6.110
October	0.646	6.290
November	0.666	6.020
December	0.637	5.530
Average:	0.611	6.027

In order to capture as much solar energy as possible, the photovoltaic panel must be oriented towards the sun. If the photovoltaic cells have a fixed position, their orientation with respect to the south (northern hemisphere), and tilt angle, with respect to the horizontal plane, should be optimized. For regions nearer to the equator, this tilt angle will be smaller, for regions nearer to the poles it will be larger. A deviation of the tilt angle from the optimum angle, will lead to less power to be capture by the photovoltaic system.

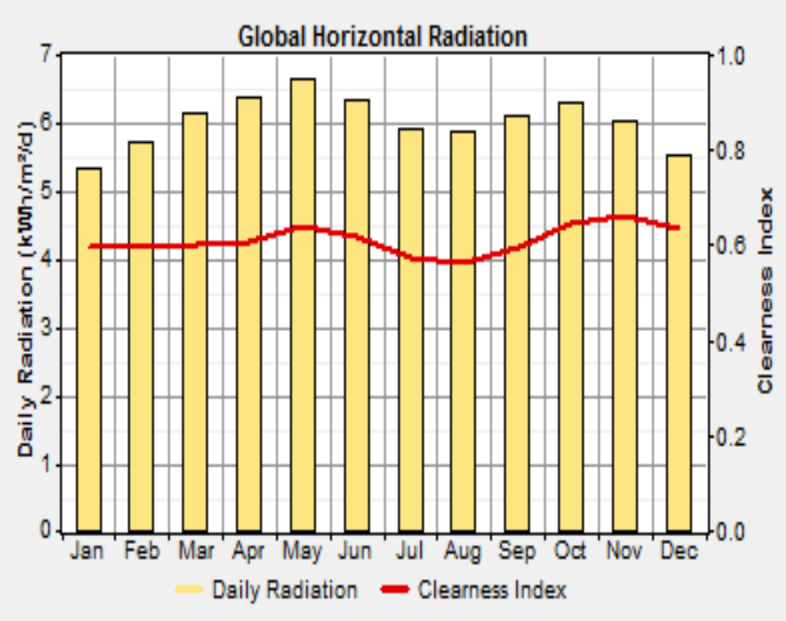


Figure 4.1 Village solar resources (NASA)

4.2.2 Solar Radiation Variation

May is the sunniest month of the year, at which time solar energy resource is 6.65 kWh/m^2/day, while in January it drops to 5.53 kWh/m^2/day as shown in Figure 4.1 and Table 4.1. In the months of, January, February, March, April, May the clearance index increases with differences from month to month respectively. Where as in the months of October, Novembers and December, the clearance index decreases from month to month as respectively.

4.2.3 Estimation of PV Output of the Village

The steps to calculate approximately the output power of PV are as follows:-

- Determine the radiation at the horizontal surface based on the day of the year and the site latitude and then establish a clearness index.
- The clearness index is then used to calculate the direct, diffuse and random components of the radiation on a horizontal surface.
- The total radiation is then calculated from the direct, diffuse and random values obtained.
- Finally, the radiation on the surface of the panel is determined. It requires monthly average meteorological data at a specific site location as its input for the simulation of the solar radiation process at that site. The necessary data is the monthly average values of solar radiation on the horizontal surface, it temperature effect ignored.

Declination angle

The declination is the angular position of the sun at solar noon, with respect to the plane of the equator. Its value in degrees is given by Cooper's equation [58].

$$\delta = 23.45\sin\left(360^\circ \frac{284+n}{365}\right) \quad \text{.....eq 4.1}$$

Where: n is the day of the year

The time of year affects the solar declination, which is the latitude at which the sun's rays are perpendicular to the earth's surface at solar noon [58]. The equation of time accounts for the effects of obliquity (the tilt of the earth's axis of rotation relative to the plane of the ecliptic) and the eccentricity of the earth's orbit. HOMER calculates the equation of time as follows:-

$$E = 3.85(0.000075 + 0.00868.\cos B - 0.032077 * \sin B - 0.014615 * \cos 2B - 0.004089 * \sin 2B) \quad \text{.....eq 4.2}$$

Where: B is given by

$$360^\circ \frac{(n-1)}{365} \quad \text{.....eq 4.3}$$

Where n is the day of the year, starting with 1 for January 1st and 365 for December 31st, for a surface with any orientation, we can define the angle of incidence meaning the angle between the sun's beam radiation and the normal to the surface, using the following equation [58].

$$\text{Cos}\Theta = \sin\boldsymbol{\delta}\sin\emptyset\cos\beta - \sin\boldsymbol{\delta}\cos\emptyset\cos\beta\cos\omega + \cos\boldsymbol{\delta}\cos\emptyset\cos\beta\cos\omega + \cos\boldsymbol{\delta}\sin\emptyset\sin\beta\cos\gamma\cos\omega + \cos\boldsymbol{\delta}\sin\beta\sin\gamma\sin\omega \quad \text{.....eq 4.4}$$

An incidence angle of particular importance, which we will need shortly, is the zenith angle, meaning the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead and 900 when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find an equation for the zenith angle by setting =00 in the above equation, which yield [58].

$$cos\boldsymbol{\Theta}Z = cos\boldsymbol{\delta}\,cos\emptyset\,cos\omega + sin\emptyset\,sin\boldsymbol{\delta} \quad \text{.....eq 4.5}$$

Extraterrestrial Normal Radiation and Cleanness index

It states that the amount of solar radiation arriving at the top of the atmosphere over a particular point on the earth's surface. It assumes that the output of the sun is constant in time. But the amount of sunlight striking the top of the earth's atmosphere varies over the year because the distance between the sun and the earth varies over the year due to the eccentricity of earth's orbit. To calculate the extraterrestrial normal radiation, defined as the amount of solar radiation striking a surface normal (perpendicular) to the sun's rays at the top of the earth's atmosphere, it uses the following equation [58].

$$G_{on} = G_{sc}\left(1 + 0.033 * cos\ \frac{360n}{365}\right) \quad \text{.....eq 4.6}$$

Since HOMER simulates on a time step by time step basis, we integrate the above equation over one time step to find the average extraterrestrial horizontal radiation over the time step [58].

$$G_o = \frac{12}{\pi}\,G_{on}\left[cos\emptyset\,cos\delta\,(sin\omega 1 - sin\omega 2) + \frac{(II(\omega 2 - \omega 1))sin\emptyset\,sin\delta}{180°}\right] \quad \text{.....eq 4.7}$$

The above equation gives the average amount of solar radiation striking a horizontal surface at the top of the atmosphere in any time step. The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. The ratio of the surface radiation to the extraterrestrial radiation is called the clearness index. The following equation defines the clearness index [58].

$$K_T = \frac{G}{G_o} \quad \text{.....eq 4.8}$$

Beam and Diffuse Radiation

The correct prediction of the power generated by PV arrays requires the determination of the intensity of the global solar radiation on the surface of the arrays at a specific site location. The total global radiation is normally composed of two components namely the direct and the diffuse radiation. The direct component is the radiation received from the sun without having been scattered by the atmosphere, while the diffused component is the radiation received from the sun after its direction has been changed due to scattering. The contribution of the direct and diffuse components to the total radiation mainly depends on the cloud cover [46]. Now let us look more closely at the solar radiation on the earth's surface.

Some of that radiation is beam radiation, defined as solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere. Beam radiation (sometimes called direct radiation) casts a shadow. The rest of the radiation is diffuse radiation, defined as solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast a shadow. The sum of beam and diffuse radiation is called global solar radiation, a relation expressed by the following equation [58].

$$G = G_a + G_b \quad \text{.....eq 4.9}$$

The distinction between beam and diffuse radiation is important when calculating the amount radiation incident on an inclined surface. The orientation of the surface has a stronger effect on the beam radiation, which comes from only one part of the sky, than it does on the diffuse radiation, which comes from all parts of the sky [58].

However, in most often cases only monthly the global horizontal radiation, not its beam and diffuse components are available. The only necessary data to fill missing hourly solar is global horizontal radiation for that reason, HOMER requires the global horizontal radiation to be entered in HOMER's Solar Resource Inputs window. That means in every time step, HOMER must resolve the global horizontal radiation into its beam and diffuse components to find the radiation incident on the PV array. The well-known correlation of Erbs et al. (1982) is used, which gives the diffuse fraction as a function of the clearness index as follows [58].

$$\frac{G_b}{G} = \{0.9511 - 0.1604 * K_T + 4.388 * K_T^3 + 12.336\} \quad \text{.....eq 4.10}$$

$$\frac{G_b}{G} = \left\{0.9511 - 0.1604.K_T + 4.388.K_{T_{0.165}}^{2^{1.0-0.09K_T}} - 16.638.K_T^3 + 12.336.\frac{K_T}{for}\right\} \quad \text{.....eq 4.11}$$

4.3 Estimating the Global Radiation Incident on the PV Array

Now the final step is to calculate the global radiation striking the tilted surface of the PV array. This parameter is very important since the predication of solar array output which supplies electric demand of the two towns. The HDKR model is the well know model to calculates the global radiation incident on the PV array, which assumes that there are three components to the diffuse

solar radiation; an isotropic component which comes all parts of the sky equally, a circumsolar component which emanates from the direction of the sun, and a horizon brightening component which emanates from the horizon. Before applying that model we must first define three more factors [58].

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

$$R_b = \frac{cos\theta}{cos\theta_z} \quad \text{.....eq 4.12}$$

The anisotropy index, with symbol A_i, is a measure of the atmospheric transmittance of beam radiation. This factor is used to estimate the amount of circumsolar diffuse radiation, also called forward scattered radiation. The anisotropy index is given by the following [58].

$$A_i = \frac{G_b}{G_o} \quad \text{.....eq4.13}$$

The final factor we need to define is a factor used to account for 'horizon brightening', or the fact that more diffuse radiation comes from the horizon than from the rest of the sky. This term is related to the cloudiness and is given by the following equation [58].

$$f = \sqrt{\frac{G_b}{G}} \quad \text{.....eq 4.14}$$

Therefore, to calculate the global radiation incident on the PV array HOMER uses the following equation by ignoring the effect of temperature [58].
If the effect of temperature on the PV array ignored, HOMER assumes that the temperature coefficient of power is zero.

$$P_{pv} = \gamma_{pv} f_{pv} \left(\frac{G_T}{G_T}\right) \quad \text{.....eq4.15}$$

Where;

- γ_{pv} is the rated capacity of the PV array, meaning its power output under standard test condition [kW]
- f_{pv} is the PV derating factor [%]
- G_T Is the solar radiation incident on the PV array in the current time step [KW/m^2].
- G_T, STC is the incident radiation at standard test conditions [1 KW/m^2].

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

4.4 Micro Hydro Resource Assessment

The daily average flow rate of Beresa River for the hydro resource data of 29 years was taken from FDRE Ethiopian Ministry of water, Irrigation and energy. However, HOMER accept monthly average stream flow so, daily average flow changed into monthly average. The site gross head is 10 meter. The monthly average stream flow and its pictorial representation is given in Table 4.2 below.

Table 4.2 Monthly average Stream flow

Month	Stream Flow (L/s)
January	800.0
February	640.0
March	860.0
April	1,010.0
May	1,670.0
June	11,230.0
July	34,000.0
August	35,000.0
September	40,000.0
October	35,000.0
November	2,520.0
December	1,040.0
Annual average:	13,753.9

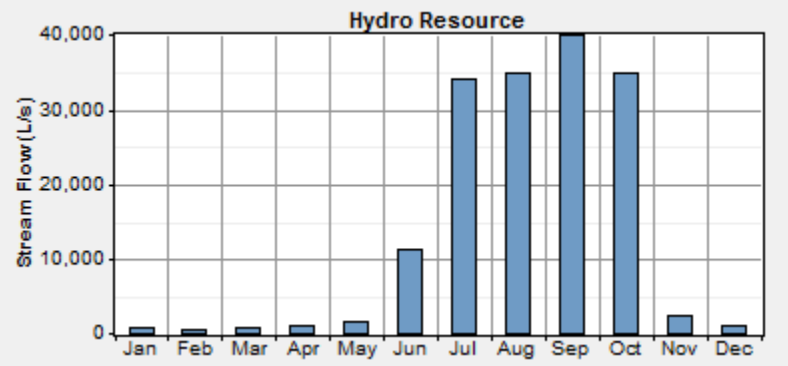


Figure 4.2 Average Stream Flows

4.4.1 Estimation of Micro Hydro Power

The potential of hydropower for the selected village estimated from the available head and flow rate of calculated as follows:

4.4.1.1 Theoretical power of hydropower

Theoretically, the power output of the micro hydro is expressed by considering head and steam flow, the magnitude of the hydropower can be expressed in equation as follows:

$$P_{theo} = \gamma Q h_g \quad \text{.....eq 4.16}$$

Where, μ = ρg, P_{theo} = theoretical power, P = density of water (kg/m^3), Q flow rate (m^3/s),

h_g = Gross head (m).

Effective head (h net)

The effective head is the actual vertical drop minus this head loss as shown in Figure 4.3, HOMER calculates the effective head (or net head) using the following equation [58].

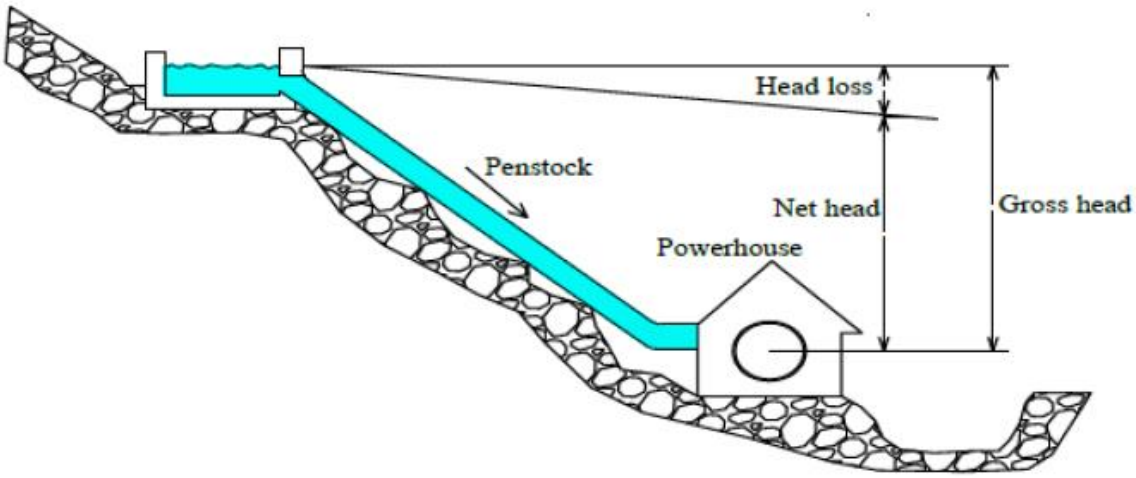


Figure 4.3 Net head after pipe loss

h_{net} = h – (1 - f_h) .....eq 4.17

Where;
h = available head[m]
f_h = pipe head loss [%]

Efficiency of the system

The overall efficiency of the micro-hydropower system is the combination of turbine efficiency and generator efficiency.

η = η_t * η_g.....eq 4.18

The practical power output is estimated as follows:

P = $\eta\gamma Q_{es} h_{net}$ .....eq 4.19

Where Q_{es} is the design flow rate of the micro-hydro power, which is 0.193 m^3/s assumed, hence the annual energy of the hydropower is calculated as follows:

Annual energy production (KWh/year) = Power X $\frac{365\ days}{year}$ X $\frac{24\ hours}{1000}$ ……..…….eq 4.20

Based on the above mathematical analysis the total energy produced by the micro –hydropower without considering the efficiency of hydro turbine is 20kW. Assuming 80% turbine efficiency and pipe head loss of 10%, the annual energy production becomes 122.6 MWh/year. The primary load of the village is 88,695 kWh/year. From this discussion, the hybrid system totally meets the energy demand of the village.

4.5 Wind Turbine

Wind turbine is to obtain energy from the wind and transform it into electrical energy. The power the wind can deliver is dependent of the wind speed as:

$$P_w = \frac{1}{2}\rho\pi R^2 V^3 \quad \text{.....eq 4.20}$$

Where ρ is the air density, R is the radius of the area covered by the wind and v is the wind speed.

Due to physical limitations the power obtained from the wind must be limited. This is with the sole purpose of avoiding the wind turbine from getting damaged. There are two ways of reducing the power given by the wind to the generator, one is reducing the pitch angle of the blades (in region 3), making the rotor reduce its angular velocity. The second one is to reduce the torque given to the generator using a breaking system in the turbine (only in region 2). It can be a magnetic break, a disc break or a clutch depending on the turbine.

The form in which the delivered energy is controlled, depending on the wind speed, determines the working region for the turbine. We can classify this working regions into 3 different areas as shown in Figure 4.4. The first one is the region lower to the minimum operational wind speed for the turbine. That is, if the wind speed is lower than a certain threshold (usually around 5m/s), then it is not worth to turn on the turbine (the energy consumed is higher than the one produced).

The second region covers from this minimum operational speed up to the speed where the maximum safe electric power can be given by the generator (around 14m/s). In this area the power delivered to the generator is controlled by adjusting the torque that is given to the generator.

The third region goes from the wind speed where the maximum safe electrical power is given up to the cut off speed, which is the speed at which it is no longer safe to run the turbine (around 25m/s). In this area the pitch angle of the blades is adjusted to keep producing the maximum power output without exceeding it.

For a wind generation system to supply sustainable power, the wind speed should be greater than 5 m/s. The wind speed is lower than a threshold (usually around 5m/s), then it is not worth to turn

on the turbine. From the investigation result Debre Berhan is not suitable to generate the wind power. So to fulfill the village load profile we need battery and inverter for daily load profile and for night load profile we use pumped storage.

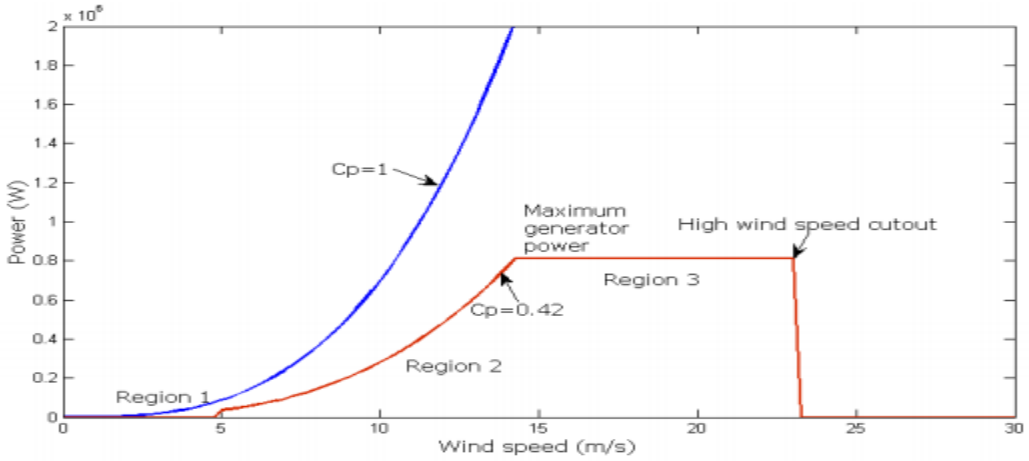


Figure 4.4 working regions depending on wind speed.

4.5.1 Wind Resource Assessment

This section discusses the wide area hourly average wind vector (speed and direction) at 50 meters above the ground. The wind experienced at any given location is highly dependent on the local topography and other factors, and instantaneous wind speed and direction vary more widely than hourly averages.

The average hourly wind speed in Basonawrna, Debre Berhan experiences significant seasonal variation over the course of the year. The average wind speed is 4.044 m/s.

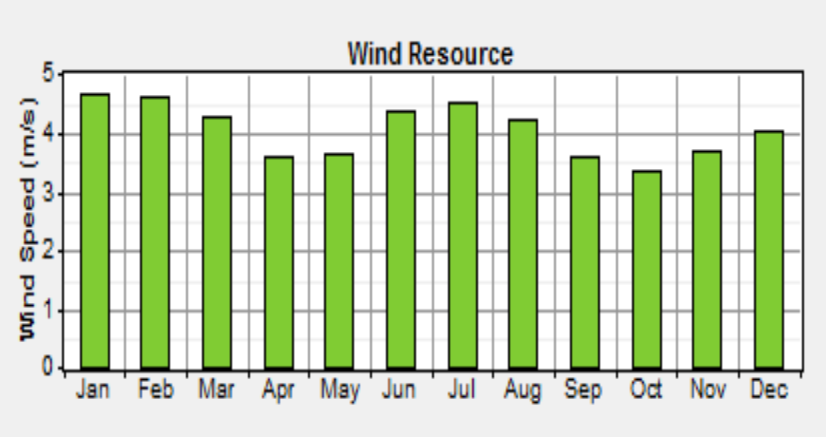


Figure 4.5 Average wind speed

Chapter Five - System Design and Performance Prediction of the Hybrid System

A hybrid system is a combination of one or more resources of renewable energy such as solar, wind, micro/mini-hydropower and biomass with other technologies such as batteries. As an off-grid hybrid power generation, the hybrid system offers clean, efficient and sustainable power that will in many cases be more cost-effective than sole energy systems. As a result, renewable energy options have increasingly become the preferred solution for off-grid power generation [4].

The hybrid system studied in this thesis is combining solar PV and micro hydro with bank of batteries. Power conditioning units, such as Converter, are also part of the supply system. Micro-Hydro-PV-Battery hybrid system, offers greater reliability than any one of them alone because the energy supply does not depend entirely on any one source. For example, during winter when hydropower generation is low there's likely enough solar energy available to make up for the loss in solar electricity and as a result the size of the battery storage and dependability can be reduced [44].

Micro-hydro and PV hybrids also permit use of smaller, less costly components than would otherwise be needed if the system depends on only one power source. This can substantially lower the cost of a remote power system. In a hybrid system the designer doesn't need to weigh the components for worst-case conditions by specifying a large PV panel size and battery bank than is necessary that make the system cost higher [44].

Other advantages of the hybrid system are the stability and immobility of the system and a lower maintenance requirement, thus reducing downtime during repairs or routine maintenance. Besides this, as well as being indigenous and free, renewable energy resources also contribute to the reduction of emissions and pollution [17].

The PV/ Micro hydro hybrid power generation system makes use of the solar PV and hydro turbine to produce electricity as the primary source to supply the load. The configuration of PV/ micro hydro hybrid system is analyzed for various PV array size and number of battery banks.

The charge controller will charge the batteries with energy from PV modules. The main objective of PV/ micro hydro hybrid system is to provide clean, efficient and sustainable power to from freely available renewable energy.

5.1 Introduction to HOMER

The hybrid optimization model for electric renewable (HOMER), which is copyrighted and developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the design of power systems and facilitate the comparison of power generation technologies across a wide range of applications [58]. HOMER is used to model a power system physical behavior and its life cycle cost, which is the total cost of installing and operating the system over its lifetime. HOMER allows the modeler to compare many different design options based on their technical and economic

merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

The design of a stand-alone PV/ micro hydro/battery hybrid power supply system to electrify a 250 households currently living in village, with an average five members per family were considered based on the data obtained from the Basonawrna woreda Administration statics office. HOMER software is used as a tool to accomplish this research. As mentioned earlier, the main objective of the study is to design PV/ micro hydro/ battery as a standby standalone power generation systems to meet the load requirements of the community mentioned earlier.

Schematic diagram and the HOMER representation diagrams of the designed hybrid system are shown in Figure 5.1 and Figure 5.2.The primary load is an electric demand that must be served according to a particular schedule discussed earlier.

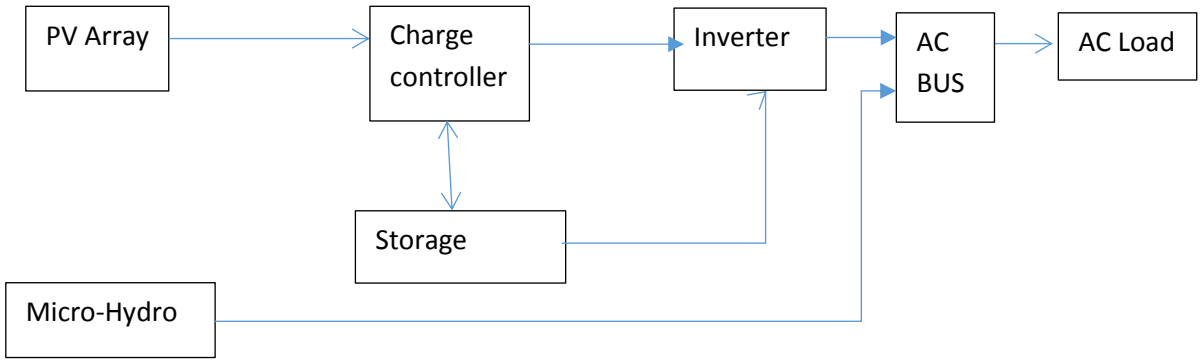


Figure 5.1 Block Diagram of PV-micro hydro hybrid system proposed

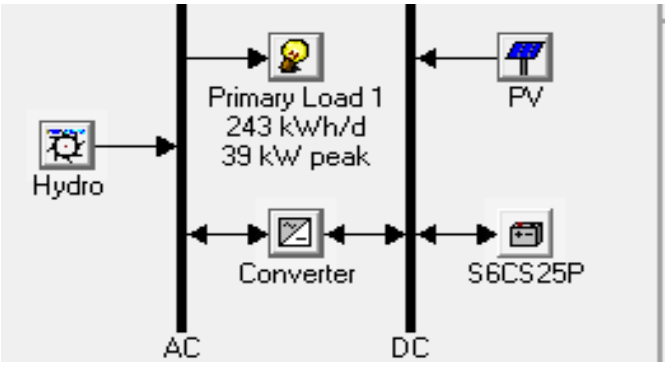


Figure 5.2 Equipment considered and system configuration for HOMER

HOMER performs three principal tasks: simulation, optimization and sensitivity analysis based on the raw of input data given by user. In the simulation process, the performance of a particular

power system configuration for each hour of the year is modeled to determine its technical feasibility and life cycle cost. In the optimization process, many different system configurations are simulated in search of the one that satisfies the technical constraints at the lowest life cycle cost. In the sensitivity analysis process, multiple optimizations are performed under a range of input assumptions to judge the effects of uncertainty or changes in the model inputs.

Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average solar radiation or the future fuel price.

- **Simulation**

The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period. HOMER can simulate a wide variety of micro- power system configurations, comprising any combination of a PV array, a run of river hydro turbine, and up to three generators, a battery bank, a dc-ac converter and other convectional or non-convectional energy source.
The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A decision variable is a variable over which the system designer has control and for which multiple possible values can be considered in the optimization process. Possible decision variables for this study include:

- The size of the PV array
- The number of batteries
- The size of the dc-ac converter

Optimization can help the modeler find the optimal system configuration out of many possibilities. Multiple values for each decision variable can be entered in search space, which is the table that contains the set of all possible system configurations over which HOMER can search for optimal system configuration. In the optimization process, every system configuration in the search space is simulated and the feasible ones are displayed sorted by total net present cost [58].

- **Sensitivity Analysis**

In the sensitivity analysis process multiple optimizations are performed, each using a different set of input assumptions. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs. In a sensitivity analysis, ranges of values for a single input variable are fed to HOMER. A variable for which the user has entered multiple values is called a sensitivity variable. Almost every numerical input variable that is not a decision variable can be a sensitivity variable. Examples include the PV module price, the interest rate, etc.

Sensitivity analysis eliminates all infeasible combinations and ranks the feasible combinations taking into account uncertainty parameters. HOMER allows taking into account future developments, such as increasing or decreasing load demand as well as changes regarding the resources, for example fluctuations in the river's water flow rate, solar radiation variations and changing of interest rate. Here, the various sensitive variables are considered to select the best-suited combination for the hybrid system to serve the load demand. With change in the sensitive variables, the configuration of the system changes. Even in this analysis, HOMER ranks the configurations in descending order of their total NPC [58].

5.2 Design of Standalone PV/Micro-Hydro/Battery Hybrid System

A hybrid power system for Basonawrna woreda is designed where photovoltaic module has been combined with micro - hydro, battery, and inverter. Hence, HOMER models and design the physical operation of a system is provided in detail. A power system must comprises a solar Panel, micro-hydro, battery and the estimated load for the village is Residential, public and Small-scale industry for the village. It may also comprise conversion devices such as a bidirectional converter, and energy storage devices such as a battery bank. The following section dedicated to how to design the loads that the system must met, the system architecture and their respective resources, and how system configuration components work together to meet the loads.

Input load: input load is electrical demand that the power system must meet; the system electrical demand associated with lights, radio, TV, household appliances, computers, and industrial processes is typically modeled as primary load. If electrical demand exceeds supply, a deficit is recorded as unmet load [58].

The user specifies an amount of primary load in kW for each hour of the year, either by importing and file containing hourly data or by allowing HOMER to synthesize hourly data from average daily load profiles. When synthesizing load data, HOMER creates hourly load values based on user specified daily load profiles. Different profiles for different months and different profiles for weekdays and weekends are specified. A specified amount of randomness can be added to synthesize load data so that every day's load pattern is unique. In this thesis 15% hurly and 10% daily load, noise is assumed to account for variability of load demand.

According to Getachew, Electric load in the rural villages of Ethiopia can be assumed to be composed of lighting, radio receiver, television set, water pumps, health post, and primary schools load. [17]. In this study, flourmills, milk processing and 'injera Mittad' is added to the load together with previously mentioned loads. As introduced earlier, the community understudy, which equipped with one primary school and a health post, has 250 households. Out of 250 households, 50 households are large class and the rest are small/medium classes based on the data obtained from Barosonma Wereda Administration. The system is autonomous (off-grid) and can serve ac electric loads [58].

A particular system configuration modeled by performing an hourly time series simulation of its operation over one year. Simulation steps through the year one hour at a time, calculating the available renewable power, comparing it to the electric load, and deciding what to do with surplus renewable power in times of excess, or how best to generate additional power in times of deficit. When one year's worth of calculations is complete, it is determined whether the system satisfies the constraints imposed by the user on such quantities as the fraction of the total electrical demand served, the proportion of power generated by renewable sources, the quantities required to calculate the system's life-cycle cost, expected battery life are also computed.

The quantity used to represent the life-cycle cost of the system is the total net present cost (NPC). This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The total net present cost includes the initial capital cost of the system components, the cost of any component replacements that occur within the project lifetime and the cost of maintenance [58].

- **Optimization**

The simulation process models a particular system configuration, whereas the optimization process determines the best possible system configuration. The best possible, or optimal, system configuration is the one that satisfies the user specified constraints at the lowest total net present cost. Finding the optimal system configuration may involve deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use. In the optimization process, many different system configurations are simulated; the infeasible ones are discarded.

The feasible ones are ranked according to total net present cost. The feasible one can serve the electric loads for school and community contains lighting, water pumping, a radio receiver, milk processing and flourmills. Whereas health post loads includes lighting, vaccine refrigerator, water heater, normal refrigerator electric supply necessary for some medical equipment, and other for miscellaneous use.

The daily energy consumptions of small households, large houses are calculated to be approximately 190 kWh/day. The total energy daily energy demand for school is 7.36 KWh/day. This total energy consumption of a health post calculated to be 16.13 KWh/day. The sum total of the daily energy consumption of the water pump, milk processing and flour mill is approximately 42 KWh/day.

In the weekends, it is assumed that flourmills, milk processing and schools are not working and evening adult classes are conducted at daytime. June to September is the rainy season for this area. There are no classes in July and August (annual break) and in January (semester break).

5.3 Selection of system components, simulation and optimization

For HOMER component is to any part of the system that generates, stores or transfers electric or thermal energy, and whose size or quantity is an optimization variable. Photovoltaic panels, hydro turbines examples of components. Other auxiliary are things considered like converters, battery bank [58]. For economic inputs, system optimization is the primary criterion considered when selecting the components. In this part, the components used in this thesis and discuss the physical and economic properties that the user can use to describe each are explained.

PV array: the PV array is a device that produces dc electricity in direct proportion to the global solar radiation incident upon it. In this study we select German Solar GSM6-250P.

Hydro turbine: a hydro turbine is a device that is used to convert pressure and kinetic energy of water in to mechanical energy. The primary criterion for the selection of the hydro turbine is its cost. The hydro turbines have been selected from different sources [66, 68]. To select the type of turbine used: the available head, the stream flow, are considered. For this study the available head is 14.1 m and design flow of 0.193 m^3/s.

Based on the above data mentioned above, Cross flow hydro turbines have been selected from turbine selection chart. From those hydro turbines, which were selected, for this thesis is, has been found to be the best in terms of head and flow available. This hydro turbine was obtained from hydro turbine website [72].

Battery Bank: the battery bank is a collection of one or more individual batteries. A battery is a device capable of storing a certain amount of DC electricity at fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement. The key physical properties of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. The capacity curve shows the discharge capacity of the battery in ampere-hours versus the discharge current in amperes.

Manufacturers determine each pint on this curve by measuring the ampere-hours that can be discharged at a constant current out of fully charged battery. Capacity typically decreases with increasing discharge current. The lifetime curve shows the number of discharge-charge cycles the battery can withstand versus the cycle depth. The number of cycles to failure typically decreases with increasing cycle depth. The minimum state of charge is the state of charge below which the battery must not be discharged to avoid permanent damage. The roundtrip efficiency indicates the percentage of the energy going into the battery that can draw back out.

Three parameters describe the battery: the maximum capacity of the battery, which is the combined size of the available and bound tanks; the capacity ratio, which is the ratio of the size of the available tank to the combined size of the two tanks, and the rate constant, which is analogous to

the size of the pipe between the tanks. In this study we select Surrette6CS25P, 6V, 1156Ah (6.9 KWh) and lifetime throughput is 9,645KWh.

Converter: a converter is a device that converts electric power from dc to ac in a process called inversion, and/or from ac to dc in a process called rectification. The converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The rectifier capacity, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity had been specified.

Operating reserve: operating reserve provides a safety margin that helps ensure reliable electricity supply despite variability in the electric load and the renewable power supply. Virtually every real power system must always provide some amount of operating reserve, because otherwise, the electric load would sometimes fluctuate above the operating capacity of the system, and an outage would result.

At any given moment, the amount of operating reserve that a power system provides is equal to the operating capacity minus the electrical load. The amount of operating reserve has been specified, which is 10% and HOMER simulates the system so as to provide at least that much operating reserve. Each hour, the required amount of operating reserve is calculated as a fraction of the primary load of that hour, plus a fraction of the annual peak primary load, plus a fraction of the PV power output of that hour, plus a fraction of the hydro power output of that hour. In this study we assumed an operating reserve of 10% of the hourly load 30% solar power output respectively is used.

The fundamental principle that is followed when dispatching the system is the minimization of cost. The economics of each dispatch able energy source is represented by two values: a fixed cost in dollars per hour, and a marginal cost of energy in dollars per kWh. These values represent all costs associated with producing energy with that power source that hour. Using these cost values, the combination of dispatch able sources that can serve the electrical load and the required operating reserve at the lowest cost is searched. Satisfying the loads and operating reserve without any capacity shortage paramount. But among the combinations of dispatch able sources that can serve the loads equally well, the one that does so at the lowest cost is chosen.

Economic input into HOMER is summarized in Table 5.1. The values given in this table are primarily chosen according to the size of the load for the assumed selected community. The costs are estimated according to the current local and global price of the components. Other inputs into the software, such as the range of sizes for the PV, battery, converter and lifetime of the equipment are given so as to give flexibility to the software and optimize the output results.

Table 5.1 Economic inputs to HOMER

Component	Capital($)	Replacement($)	O&M($)	Total ($)
PV module (20kW)	70,000	50,000	60	120,060
Battery (surrette6CS25p)	9,600	4,433	2,613	16,646
Inverter	11,370	4,329	22	15,721
Hydro	40,000	30,000	8,700	78,700
System	130,970	88,762	11,395	231,127

For this analysis, the efficiencies of inverter and rectifier are assumed as 90%. The project lifetime is 25 years, and the interest rate is assumed to be 5-6%.

Other important input to HOMER simulation is breakeven grid extension distance.

Breakeven grid distance is the distance from the grid, which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Farther away from the grid, the stand-alone system is optimal. Nearer to the grid, grid extension is optimal.
HOMER calculates the breakeven grid extension distance using the following equation:

$$D_{grid} = \frac{C_{NPC}\, CRF(i,R_{proj}) - c_{power}.\, L_{tot}}{C_{cap.}\, CRF(i,R_{Proj}) + C_{om}} \quad \text{.....eq 5.4}$$

where: C_{NPC}, is total net present cost of the stand-alone power system in USD, CRF is the capital recovery factor, R_{proj} is project lifetime [yrs], L_{tot} is total primary and deferrable loads [KWh/yr]. C_{power} Is cost of power from the gird [$/kWh] and $C_{cap}$is the capital cost of the grid extension [$/km] and C_{om} operation and maintenance cost is interest rate.

5.4 Performance Prediction of the Graphical Output of Power Generated Over a Year

The evaluation of energy performance of a decentralized energy system is a very important task because it will help us compare the technical capability of different energy options to meet rural energy needs. The performance of PV micro hydro battery hybrid power systems is developed in this thesis is used to predict the performance of all components integrated into a PV micro hydro battery hybrid system. The system under investigation is a hybrid power system, in which the integrated components are PV array, micro hydro and a battery bank for backing up the system. State of charge of batteries is used as a measure for the performance of the system. In this method it is shown that the usage of micro hydroelectricity is maximized, the size of the components is optimized and the size of PV.

The PV and Micro-Hydro systems of the hybrid system. We assumed the battery banks is used as a back-up source. Here a case study is given based on the practically available data with analysis using computer software. HOMER software means hybrid optimization model that simplifies the task of evaluating power system designs in a variety of applications. Both in grid tied and off grid application.

The performance of hybrid system is dependent on the environmental conditions, analysis is considered in the given study area to investigate the associated cost and component size. The interest rate, solar radiation and stream flow as a sensitivity variable are collected to determine the effect of these variables on the cost of the system and the optimal system configuration. This study have proposed a new approach to the PV/micro hydro/battery/ hybrid system excluding a wind resource, but the load of the village sufficiently supplied by micro hydro system only, that is the village has enough stream flow as well the solar resource also good enough as mentioned before in resource assessments.

The performance of the hybrid system is evaluated against the load, the primary load of the village is assumed 243kWh/d, that is 10.3kW average power and the peak of the village is 39kW respectively. Hence the hybrid system can supply the load efficiently and the demand can be met by the designed hybrid system with an excess electricity. This excess Electricity for the time being it demand damping resistor but in the future the excess electricity can cover the future energy demand of the village.

Chapter Six - Cost Analysis of the Hybrid System

The evaluation of the energy performance of a decentralized energy system is a very important task because it will help us compare the technical capability of different energy options to meet rural energy needs. In the same way important, an economic analysis of decentralized energy systems can help us evaluate the cost effectiveness of multiple energy options.

The costs of a hybrid system include purchase costs, operating costs, maintenance costs and replacement costs. At end of the life of the system, the system may have a salvage value. An economic analysis is done based on life cycle costing method, which accounts for all costs associated with the system over its life time, taking into account the value of money. Life cycle costing is used in the design of the hybrid system that will cost the least amount over its lifetime. Cot annuity (cost required to generate 1kWh of energy) is an indication on the cost of the system so that the system with the least cost annuity selected.

6.1 Life cycle cost

6.1.1 Time value of money

The life cycle cost of an item consists of the total cost of procurement and operating this item over its lifetime. Some costs involved in the procurement and operating of an item are incurred at the time of an acquisition (includes costs of purchasing equipment's and installation them), and other costs are incurred at later times (includes costs of operation and maintenance). The later costs may occur at regular basis or/and at irregular basis. In order to compare two similar items, which may have different costs at different times; it is convenient to refer all costs to the time of acquisition.

Two phenomena affect the value of money over time and shall be considered when evaluating economically the hybrid systems:

- The inflation rate (i): is a measure of decline in value of money. The inflation rate of any item need not necessarily follow the general inflation rate
- The discount rate (d) relates to the amount of interest that can be earned on the principal that is saved in a certain account.

6.1.2 Present worth analysis

A future amount of money for an item converted into its equivalent present value is called the present worth (pw) of this item. For an item to be purchased (n) years later with a value of (C0), the present worth value (PWV) [52].

$$PWV = PWF * C_O \quad \text{.....eq 6.1}$$

$$PWF = \left(\frac{1+ i^n}{1+ d^n}\right)$$ .....eq 6.2

Where i, d and n as defined before
Sometimes it is necessary to determine the present worth of a recurring expense, such as maintenance cost.

$$PWV = PWFC * C_A$$ .....eq 6.3

Where: C_A represents the summation of all annual maintenance costs

6.2 Cost Assessment of Hybrid System Component

Costs of hybrid system include, components initial costs, components replacement costs, system maintenance costs, and/or operation costs, and salvage costs or salvage revenues. Initial costs include purchasing the following equipment's required by the hybrid system: hydro turbine, PV modules, batteries, charge controllers, bidirectional inverter, cables, and other accessories used in the installation including labors.

Different set of performance and cost parameters are used by HOMER to characterize each of these different components. The components' technical and cost parameters for this study are based on data collected from different renewable energy market website, previous published literatures, information from world known manufactures, and reasonable assumptions.

6.2.1 Costs of solar photovoltaic

In general, the PV costs $0.7/W, but may be more depending on the technology used by PV arrays. The capital costs of a PV system include: the PV array cost and other costs such as labor, installation and structure costs. Different PV arrays costs were investigated and finally a 1kW PV array cost was assumed$700 [18]. Civil work also contributes a significant portion of the capital costs and based on labor wages and materials in Ethiopia, it is assumed to be $600/kW.

Capital cost (1KW) = PVs + installation (Labor + civil work and material) cost

$$\text{Capital cost (1KW)} = \frac{\$700}{kw} + \frac{\$600}{kw} = \$1300$$

The replacement cost is almost equivalent to the capital cost. Operating and maintenance costs are negligible. We can assume $10/year for simple panel cleaning and routine maintenance. The detailed summary inputs required by HOMER are shown Figure 6.1. Any PV module is characterized by its peak watt (Wp) at standard test conditions.

Price of PV module depends mainly on its rated power (peak power) and its type. Table 6.1 shows different types of PV modules according to their rated power and manufacturer, price of each module, and the cost in ($/Wp) for each module. It is obvious that as rated power of a module increases, the cost ($/Wp) decreases [59].

The PV panels are connected in series to obtain the required voltage. They are positioned due south of the equator. When the sunlight is incident on a PV panel, it produces electricity. For this study 0.7$/ watt is taken. The capital cost and replacement cost for a 1kW PV is taken as $1300 and $1300 respectively.

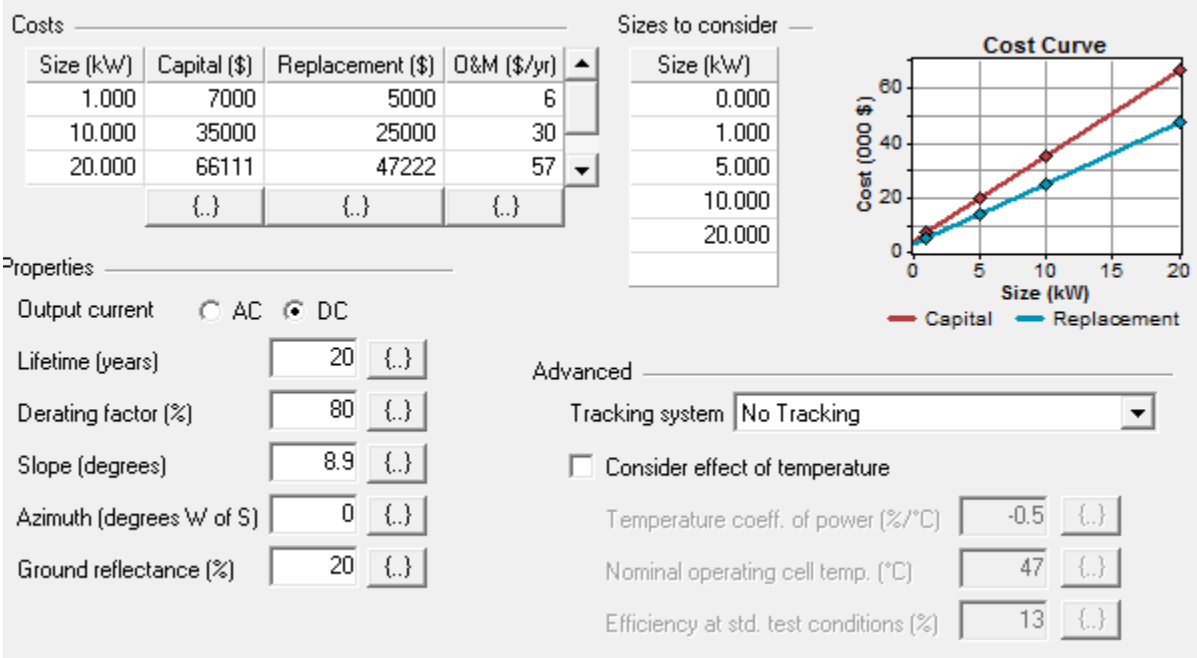


Figure 6.1. PV panel cost inputs

As there is very little maintenance required for PV, only $6/year is taken for O&M costs. The derating factor considered is 80% for each panel to approximate the varying effects of temperature and dust on the panels. The panels have no tracking system and are modeled as fixed tilted due south at 0^0 with the slope of 8.9^0

Table 6.1 Price list of PV module for different brands generator price list (in USD)[69]

Solar pane brand	**Peak power watts**	**Total watt**	**Cost US$ per solar panel**	**Total cost**	**P=poly M=mono T=Thin film**	**module efficiency (%)**	**Price per watt**	**Vendor**
Canadian solar CS6P-230P	230	4600	$161.00	$3,220.00	P	-	$0.70	Green solar com
Stion STO145	145	3625	$105.82	$2645.50	T	12.00%	$0.73	Civil solar

BAA 145W CIGS								
Sun tech STP245-20/Wde	245	245	$183.30	$183.30	P	15.00%	$0.75	Solar syz
Canadian solar CS6P-245P	245	5880	$191.1	$4586.40	P	15.230%	$0.78	GoGreen solar com
REC solar	235	9400	$183.30	$7,332.00	P	14.20%	$0.78	The Solar Buzz
Canadian solar CS6P-245P	245	5880	$191.97	$4607.28	P	15.20%	$0.78	The Solar Buz
Conergy PE 205P	250	250	$199.97	$199.97	P	15.20%	$0.80	The Solar Buz
Stion STN130 130W CIGS	130	3250	$105.82	$2,645.5	T	12.00%	$0.81	Civil solar
Suntech, STP295-24/Vd US made	295	295	$238.95	$238.95	P	15.20%	$0.81	Solar syz
Canadian solar CS6P-250P	250	6000	$202.97	$4871.28	P	15.54%	$0.81	The Solar Biz
Suntech PLUTO240-WDE	240	240	$200.00	$200.00	P	14.50%	$0.83	AltE
Sonali SS230	230	230	$190.97	$190.97	P	15.00%	$0.83	The Solar Biz

Canadian solar CS6XP-280P	280	6720	$234.36	$5624.64	P	14.59%	$0.84	Civil solar
Canadian solar CS6P-250P	250	6000	$210.00	$5040.00	P	15.54%	$0.84	GoGreen solar com
DM solar	158	316	$134.00	$268.00	M	-	$0.85	DM solar
Hyundai	230	5750	$195.50	$4887.50	P	14.20%	$0.85	DM solar
Conergy CGY-51115 PH	250	6250	$212.50	$5312.50	P	15.20%	$0.85	GoGreen solar com
Eco Solargy	240	7200	$209.00	$6270.00	P	14.00%	$0.87	Solar panel online
Hyundai	250	250	$225.00	$225.00	M	15.50%	$0.90	DM solar
Canadian solar CS6P-235PX ZEP	235	235	$217.00	$217.00	P	-	$0.92	GoGreen solar com
Canadian solar CS6P-245P	245	245	$227.85	$227.85	P	14.61%	$0.93	Affordable solar
Solar world SUNMODULE SW245 POLY V2.5 FRAME	245	245	$229.00	$229.00	P	14.61%	$0.93	AltE
Canadian solar CS6P-240P	240	1440	$228.00	$1368.00	P	14.90%	$0.95	Solar whole sale product

Canadian solar CS6X-300P	300	300	$288.00	$288.00	P	15.63%	$0.96	Affordable solar
Hyundai HiS-255MG	255	255	$244.80	$244.80	M	15.80%	$0.96	Affordable solar

A maintenance person often collects PV maintenance costs in monthly payments that cover system inspection. For this service we assumed $6/year. The PV panels are in many cases assumed to have life times of more than 25 years. During its lifetime, no PV panel replacement costs occur.

6.2.2 Cost of Hydro Power Turbine

The detailed cost of micro-hydroelectric varies from place to place depending on the project location. For this study, we assume from $400 to $600 per KW of installed capacity. The transportation and civil work add another $600 to $1,000 per kW. In general, expenses are determined by the condition and cost of transportation, civil work, and technology offered in the topographic area. In this development, the cost is taken as an average at $ 1500/kW because of the remote area, and thus complicated position of the village and neighboring areas [15]. A design flow rate of 0.193 m^3/s at 14.1 meters head, a turbine coupled to an alternator will be able to produce an electrical output power of 20kW, at an overall efficiency of 75%. The capital, renewal, and O&M worth of the micro-hydropower system were estimated at $ 40000, $ 30000 and $ 800 /year respectively.

The hydropower is designed for a power output of 20kW depending on the resources from ministry of Water, Irrigation and Energy and site survey. The figure 6.1 shows that the turbine is designed for head available of 14.1m and has a design flow of 0.193m^3/s. The turbine efficiency is 80% and has a pipe head loss of 10%.

Table 6.2 Cost specification and characteristics of hydropower [58]

Type	**Value**	**Properties of hydro turbine chosen**	**Value**
Size established	20 kW	Water head (m)	5-30 m
Capital ($)	40000	Design flow rate(m^3/s)	0.193 m^3/s
Replacement ($)	30000	Minimum flow ratio %	75%

O & M ($/year)	800	Efficiency (%)	80
Life time (year)	25	Pipe head loss (%)	10
Turbine type	Cross flow	Frequency	50Hz
Life (year)	20-30	Power outputs	5kW-25kW

The hydropower is connected Ac Bus line and has a lifetime of 25 years. The capital cost for a 20kW plant is taken as $40,000 while the replacement cost and O&M cost are considered to be $30,000 and $800 respectively.

6.2.3 Cost of Battery

Battery storage is considered in the system so that when the load demand is less than the available renewable energy, the excess energy can be stored in battery storage. Battery will supply stored energy when the load demand increases in the system. Although battery storage needs regular maintenance, it is less expensive than running a generator in the long term. However, HOMER will analyze the system with different combinations, both with diesel generator and battery storage separately and will provide the optimal solution.

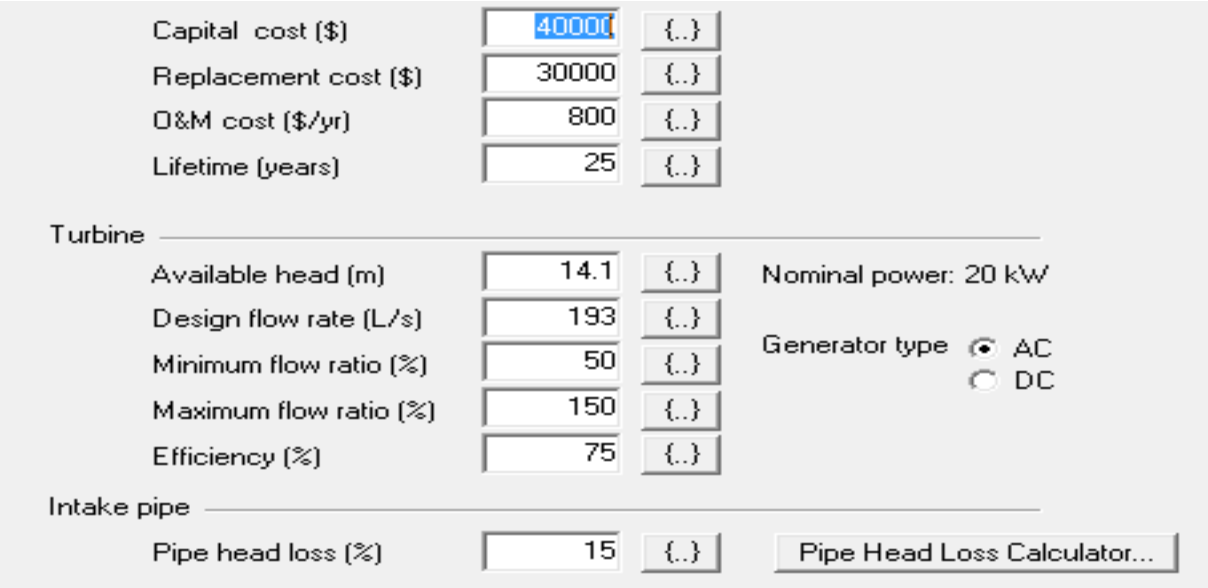


Figure 6.2 Micro hydro cost detailed

Any battery is characterized by its nominal voltage and its rated Ah capacity. The 6V cellblock batteries are the most common ones in the hybrid systems. Their prices are higher than the prices of regular batteries, but as mentioned before they are characterized by their high cycling rate and capability to stand very deep discharge. Figure 6.3 shows different types of batteries according to their capacity and manufacturer, price of each one, and cost in ($/kWh) for each. Battery operation

costs comprise expenses for maintenance and replacement. Maintenance includes checking the battery electrolyte levels. Battery maintenance costs are often included in the maintenance costs of the overall system.

Batteries are used as a backup in the system and to maintain a constant voltage during peak loads or a shortfall in generation capacity. HOMER models a number of individual batteries to create a battery bank connected in series parallel. The battery chosen for this study is Surrette6CS25P as shown in fig. Surrette6CS25P battery type was selected and the capital, replacement and operation and maintenance costs associated with it are $1250, $1100 and $25 respectively [59].

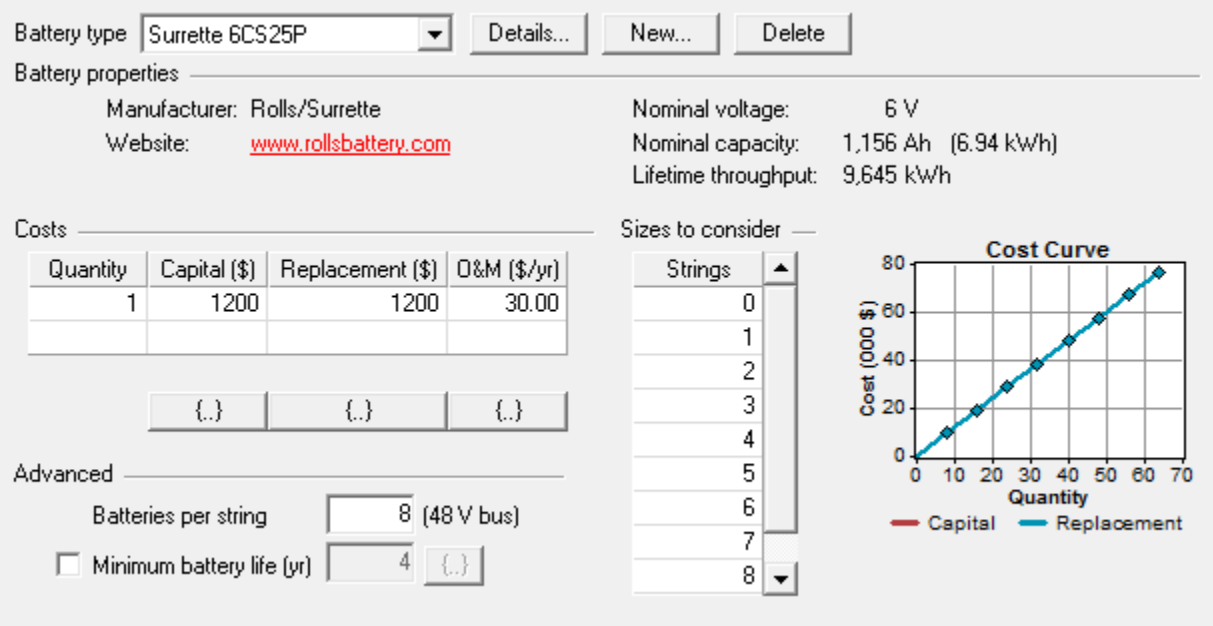


Figure 6.3: Battery technical and cost inputs

It is a 6V battery with a nominal capacity of 1,156 Ah (6.94kWh). It has a lifetime throughput of 9,645kWh. The capital cost, replacement cost and O&M costs for one unit of this battery were considered as $800, $640 and $15/year respectively [22], HOMER models the batteries on charging and discharging cycles.

6.2.4 Cost of converter

A converter is an electronic power device that is required in a hybrid system to maintain the energy flow between AC and DC electrical components. It has an inverter and a rectifier to do the conversions from DC to AC and inverter for AC to DC. The figure below shows converter technical and cost parameter. Figure 6.4 shows the capital cost, replacement cost and O& M costs for 1kW systems, which were estimated as $500 and $14/year respectively [27]. Figure 6.4 also shows the cost analysis curve, the lifetime of the converter of 15 years, inverter efficiency of 90% and rectifier efficiency of 8%.

In this hybrid system HOMER simulates the system with the inverter. HOMER also considers factors like economic inputs, economic modeling, system constraints, load priority operating reserve etc [18].

Table 6.3 cost of converter [70]

Inverter model	**Peak power watts**	**Total wattage**	**Cost US per solar panel**	**Total cost**	**Price per watt**	**Vendor**
Sunny Boy SB 8000us	8000	8000	$2,882.00	$2,882.00	$0.36	Beyond oil solar
Sunny Boy SB 8000us	8000	8000	$2,982.00	$2,982.00	$0.37	Solar wholesale products
Sunny Boy SB 7000us	7000	7000	$2,662.00	$2,662.00	$0.38	Beyond oil solar
Sunny Boy SB 6000us	6000	6000	$2,285.00	$2,285.00	$0.38	Solar wholesale products
Sunny Boy SB 8000us	8000	8000	$3,115.72	$3,115.72	$0.39	Eco distributing
Sunny Boy SB 8000us	8000	8000	$3,169.97	$3,169.97	$0.40	The solar Biz
Sunny Boy SB 6000us	6000	6000	$2,438.00	$2,438.00	$0.41	Beyond oil solar
Sunny Boy SB 8000us	8000	8000	$3,250.00	$3,250.00	$0.41	GoGreen solar

Costs of inverters and control chargers vary based on their sizes. Often they decrease per kW when the size is increased. Different sizes of inverters and control chargers were considered in order for HOMER to simulate the system with different sizes and determine the optimal size and cost. The inverters and control charger sizes and their costs are shown in Table 6.3

Table 6.4 inverter and charge control cost characteristics [18]

Size (kW)	Capital ($)	Replacement ($)	O&M($/hr)	Life time (year)
1.00	360	360	0	15
5.00	4004	4004	6	
10.00	8559	8559	6	

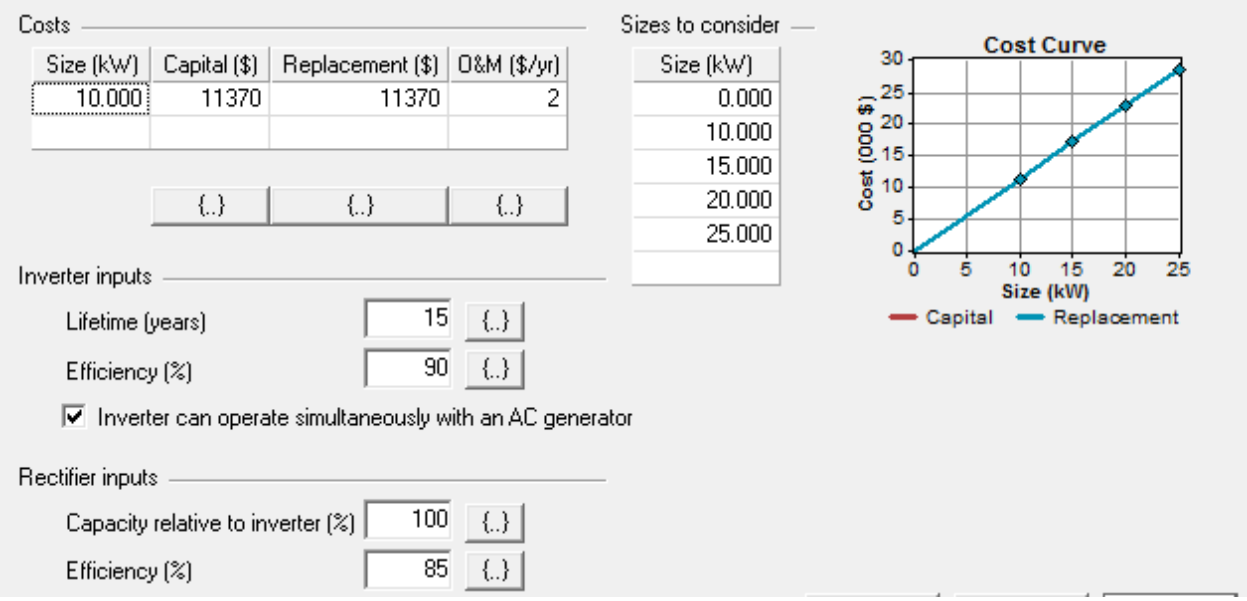


Figure 6.4: Converter technical and cost inputs

6.3 Present worth of the hybrid system costs

6.3.1 Initial costs for the design

Costs of hydro turbine, PV modules, diesel generator, battery, charging controllers, and bidirectional inverter also installation cost of hydro turbine, PV modules, diesel generator all are summed to obtain the overall initial cost.'

Table 6.5 Summary of initial cost of Energy Equipment

Energy Equipment	Initial Cost($)
Hydro Turbine	40,000
Battery(surrette6CS25p)	9,600
Inverter	11,370
PV(20kW)	70,000
Total	130,970

6.3.2 Present operation, and maintenance costs

All operation and maintenance costs over the lifetime of the system, which include maintenance cost of hydro turbine, PV modules, diesel generator, and batteries, are summed and the present

worth of the sum is calculated using equation (6.3) where Ca represents the summation of all annual maintenance costs. Part of operation and maintenance costs such as inspection and monitoring test regular check for different parts of the system, cleaning and measurements are included in the labor cost of the system.

Table 6.6 Summary of Operation and Maintenance cost and Replacement costs

Energy Equipment	Replacement cost($)	O & M ($/yr)
Hydro Turbine	30,000	8,711
Battery(surrette6CS25p)	9,600	2,613
Inverter	11,370	22
PV(20kW)	50,000	2,000
Total	100,970	13,364

Operation maintenance cost from most literature ranges from 2.5% to 4% of total project capital cost. For this study operation and maintenance cost considered is 2%.

Chapter Seven – Result and Discussion

7.1 Result and Discussion

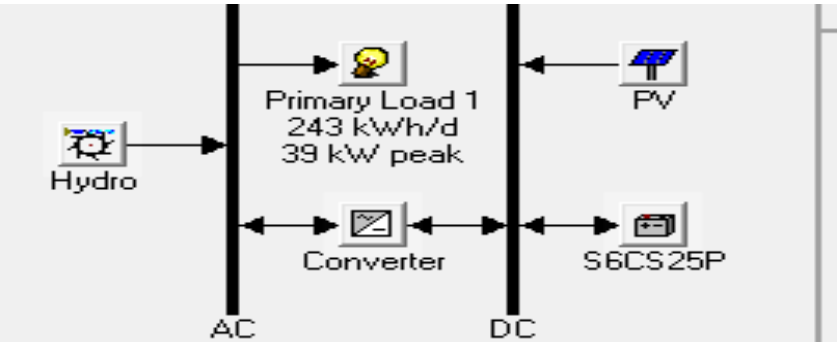


Figure 7.1: Diagram of the project with HOMER

The inputted data fed for the HOMER simulation software described the primary load, and hybrid system components and its costs (PV module, Hydro turbine, Battery bank and converter) and different sizes as mentioned in the previous sections. The system's simulations are performed by HOMER for each of the 8,760 hours in a year. The simulation output consists of several combinations of each source, with initial capital and net present cost of each of them.

The application of hybrid system, which supplies electricity to village community introduced previously. The results of the investigation will be there in the following paragraphs. The monthly average solar radiation for Debre Berhan village fed latitude and longitude into HOMER.

Figure 7.2 shows the solar radiation resource generated by HOMER software, data obtained from NASA surface metrology, this Figure also shows the clearness index, the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere, typical values for the monthly average clearness index range from 0.53 in July to 0.665 a very sunny month that is December.

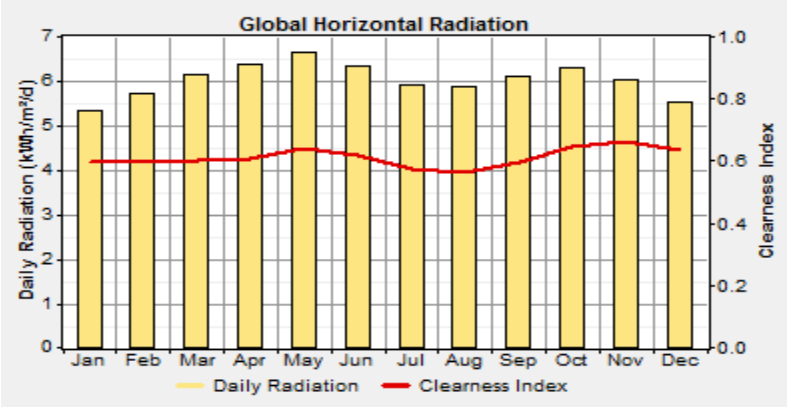


Figure 7.2: Monthly Global Horizontal radiation

In addition the hydro potential of the site is fed into HOMER and is shown in Figure 7.3

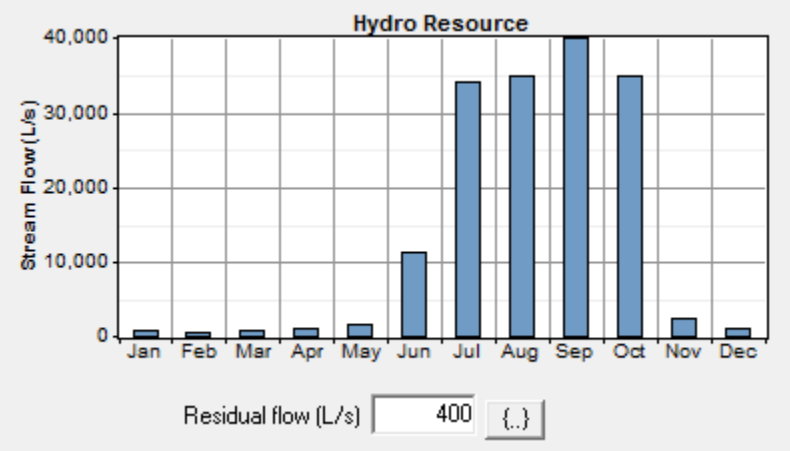


Figure 7.3: Hydro resource of Beresa River

After entering the hydro and solar resource data into software, to determine the optimum solutions from different system configurations, HOMER is run several times by varying decision variables that have effect on the output. The decision variables that affect the output are the size of PV panel, the number of battery bank, the size of converter. Other inputs parameters are multiple sizes of PV modules and have been used for sensitivity analysis. The outputs of the simulation result listed the feasible combinations of PV micro hydro, converter, and battery hybrid system and discarding the infeasible systems.

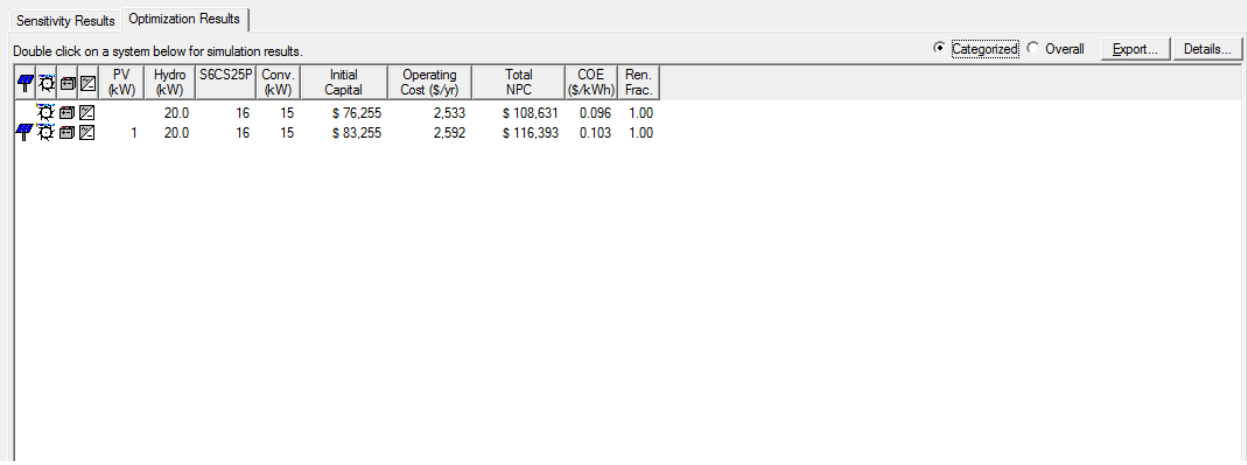
The optimization results are generated two forms; an overall form in which the top ranked system configurations are listed according to their net present cost (NPC) and in a categorized form where only the least cost system configuration is considered for each system type. Table 7.1 shows a list of the possible combinations of system components in an overall form while Table 7.2 represents optimization results in a categorized form. The tables are generated based on a particular set of inputs selected from the input summary table (Table 6.5& 6.6) and the solar and hydro resource data for site.

The price of PV has been collected from different manufacturer and different brand of PV module from different websites and the price ranged from $0.70 to $1.00 per watt [www.Ecobessinuselink.com], [Solar Buzz, 2017], [Solar panel price, 2017]. The solar and hydro data inputs are data collected from NASA and Ministry of Water, Irrigation and Energy respectively for the village under study; the price of PV is also the current price of PV panels in global market obtained from different websites.

7.2 Optimization result

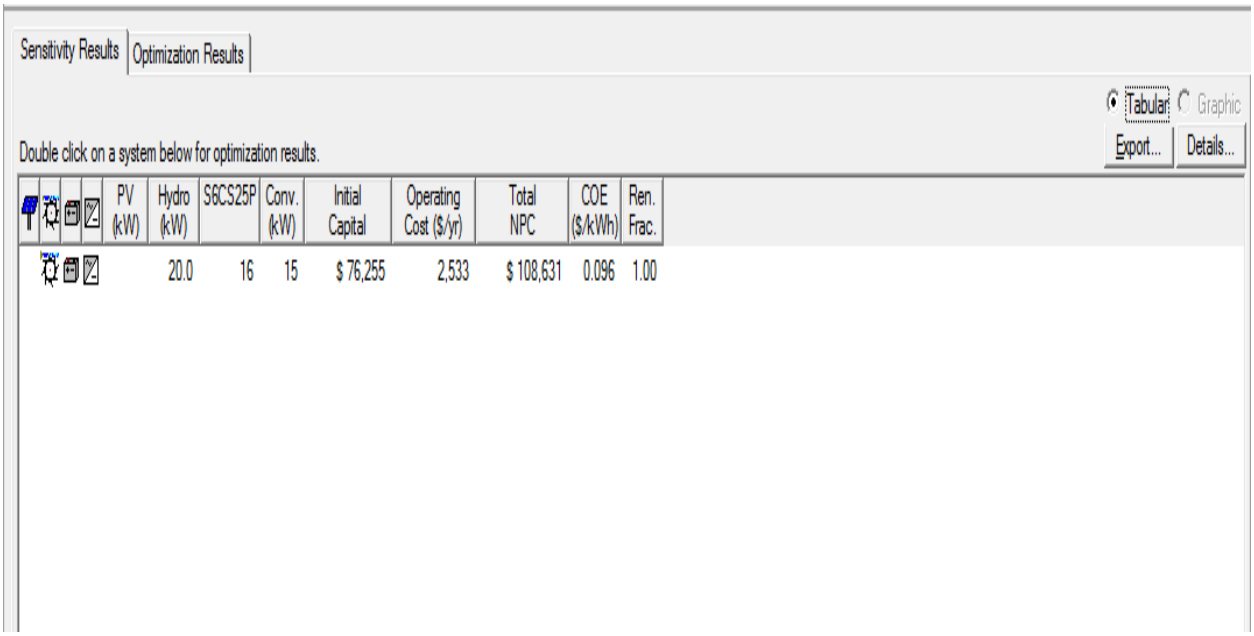
For the off-grid electrification of Basonawrna wereda, various combinations have been obtained for the hybrid systems with PV, hydro turbines, batteries and convertors from the HOMER optimization simulation. This is shown in Figure 7.1.

Table 7.1: Optimization Result



From the optimal simulation result table the most cost effective system, i.e. the system with the lowest net present cot, is the PV micro hydro battery converter configuration the cost of energy (COE) is 0.096$/kWh, and renewable resources fraction is 100% from this we can easily observe that almost the total portion of energy production is from renewable energy sources. This setup cloud be a good choice for implementation because the system is almost from renewable energy sources.

Table 7.2 Categorized simulation result



Based on optimization result the most feasible hybrid configuration is 1kW PV, 20kW hydropower, 16 Surratt6CS25P battery and 15kW inverter. The NPC of the hybrid system is $108,631 and the Levelized cost of energy for the hybrid system is 0.096$/kWh.

Chapter Eight – Conclusion and Recommendation

8.1 Conclusion

This thesis aimed to investigate and design a hybrid power generation system which comprises of PV arrays, Micro hydro with battery banks. The hybrid system Designed to supply electricity to the village, which equipped with residential loads, a health post and primary school, and some agricultural activities, to improve the life of people as well the infrastructure in the village where they are detached from the central grid.

From the results, the PV and hydro potential of the site is found to be considerably high, and sufficient for supplying the village in the current and near future energy demand of the village; However, incorporating a PV system also ensure the unforeseen increase in energy demand for the society. Therefore, it is not a viable option incorporated PV. The results also confirmed the availability amble solar energy at the site with an average radiation of 6.03kWh/m^2/d. The results obtained from the software gave numerous alternatives of feasible hybrid systems with different levels of renewable resources penetration, which their choice sorted by changing the net present cost of each set up. In General, this study relates the technical, economic and environmental impact of the off-grid system.

The Overall Conclusion of the research work reported in this thesis is summarized as follows:

1. From Technical point of view, a hybrid Micro Hydro/PV / Battery system simulation result the majority of the energy is obtained from Micro Hydro, which accounts 100% of the total load consumption. Hence the PV system should be avoided it only incurs and increase the project cost.
2. From Economic Point of View, it is found that for the village under study ,which is characterized by average stream flow potential of 0.193 m^3/second and solar radiation potential of 6.03kWh/m2/day, The hybrid system is LCOE is 0.096$/kWh.
3. From Environmental Stand point, the renewable energy fraction of the project is 99%, which implies the total energy almost obtained from Renewable Energy Resources. Due to this study promoting clean energy and its contribution to the reduction of Pollutant emission released to the environment. Finally the Author proposed that Off-grid (Micro-Hydro/PV/Battery) hybrid system is technically and economically feasible and Environmentally Friendly Configuration. Thus the government, non-governmental organizations and private sectors should make combined efforts to improve the quality of life of the communities living in rural areas.

8.2 Recommendations

The following recommendations are made out of this research; some of them are directed to other researchers while the others are directed to decision makers. Ethiopia has a enough potential of renewable energy resources, which can be used for rural electrification through the off-grid system.

There are, however, many challenges like low purchasing capacity of the rural community, unfavorable conditions towards the utilization of renewable energies, absence of awareness how to use these resources, etc.

Thus the government, non-governmental organizations and private sectors should make combined efforts to improve the low rate of rural electrification in Ethiopia.

- The implementation for this hybrid system in the village can serve as a pilot system for the whole country. This will build for more research, study and analysis.
- As far as the environmental aspects are concerned, this kind of hybrid energy systems have to be wide spread in order to cover the energy demands of rural communities, and in that support Ethiopian Government Green Economic Police as well way to help reduce the greenhouse gases emission and the deforestation of the environment in general.

- The study recommends solar radiation data measurement be taken at similar potential the actual site should be installed the whole country.
- The study done is on one randomly selected village of Debre Berhan in Amhara region, Basonawrna wereda and it does not cover all around Ethiopia. Future researchers should extend such a research work in other potential sites and make the rural people beneficial with renewable energy resource.
- In spite of the huge hydroelectric potential of Ethiopia, sever power cuts in recent years have a heavy impact on the country's economy. Standalone small hydro and standalone PV/micro hydro hybrid system recommended to be built in for the future application to crate sustainable energy supply of the country.
- Finally the software used in this study used are free trial version, However the University should purchase licensed software for more reliable analysis.

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