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Master's Thesis

[APPLICATION OF MICRO-HYDRO PV/BATTERY OFF- GRID HYBRID ENERGY SYSTEM FOR ETHIOPIAN RURAL AREA]

A thesis Submitted to the Addis Ababa Institute of Technology, School of
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List of Abbreviations

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
EPCO	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% (in 2012) 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%. The village for this study, Mogno Keshenbel Village (8.57^0N, 37.45^0E) has a total population of 4526 and 874 households (CSA, 2007, Guder Wereda Health Office). The village is about 68km from Guder substation; whicht makes the extension of the grid not yet practical and off grid electrification is the best option for the village. The community in the Mogno Keshenbel village uses Kerosene for lighting, water for milling and 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.

In this study, feasibility of micro hydro/PV/battery hybrid electric supply system to the village is analyzed using HOMER software (hybrid optimization model for electrical renewable) as optimization and sensitivity analysis tool. The logic behind HOMER selection is that it is proven and worldwide used for micro power design. Hydro potential of the village is analyzed by measuring the gross head of the river with the help of GPS (Geographical Position System) and stream flow data obtained from Ministry of Water, Irrigation and Energy and also 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, 'injera Mittad", water pumps, milk processing and flour mills is estimated. One primary school and one health posts are also considered for the community. Additionally three Protestant churches and two Orthodox churches also considered. As a result, many feasible hybrid system combinations are generated, and accordingly, total net present cost (NPC) of the hybrid configuration and cost of energy (COE) for PV/ micro hydro/ battery hybrid system is $394,819 and $0.044/kWh, respectively, which is much lower than previously studied Micro hydro/wind hybrid system and PV/hydro/wind hybrid systems, and this value is less than the current grid price of Ethiopian ($0.06) [EPCO].

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

Chapter One

1. Introduction

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 [14].

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 [14].

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.

Hybrid energy systems are combinations of two or more energy conversion devices (e.g. Diesel/Wind with storage devices), or two or more Renewable energy resources (e.g. PV/Hydro), Hybrid systems provide a high level of energy security, and reliability through the integrated mix of complementary generation methods, and often will incorporate a storage system (battery, fuel cell) and backup system (Generator) to ensure consistent supply [Clean Energy Action Project, case studies].

1.1. Off Grid-PV -Micro Hydro Power System

Off grid, electricity can be generated by single-source system using solar photovoltaic panel, wind turbine generators, micro-hydro power plant or fuel-powered combustion engine generator sets, or by integrating, one or more types of these electricity-generating sources in a so-called hybrid system (see figure 1.2), hybrid system can supply power to AC or DC load or both. It may require AC, DC or both types of buses power conversion devices are used to transform power.

An off grid power system will need somewhere to store the generated electricity and this is usually stored in batteries. The battery bank provides electricity at night, and during periods of cloud cover (9).

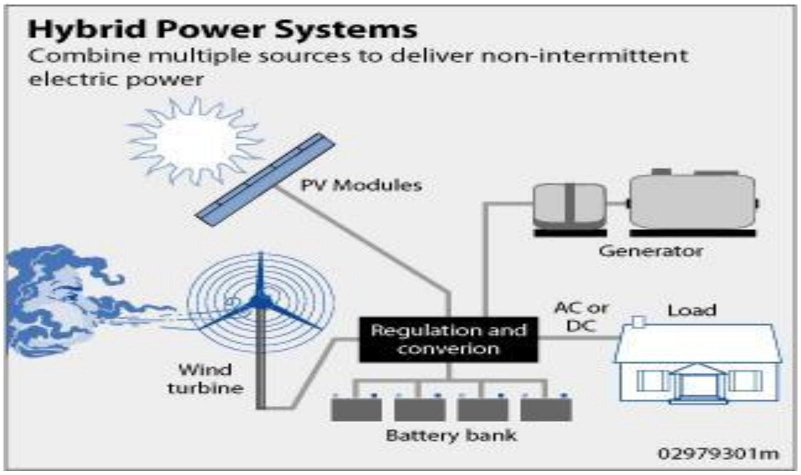


Fig 1.1 system component of typical hybrid energy system

According to Ministry of Water and Energy recent studies, Ethiopia has potential capacity of more than 1.3 million MW for wind resources and annual reserves of 2 million TWh of solar energy and 45MW exploitable hydropower potential according to the Master Plan [14].

1.2. Background and 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. [www.mowe.gov.et]. 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.

Hence Off grid electrification for remote place is nowadays become attractive and alternative option for remote villages, which are detached from the central grid. There is a huge potential for utilizing renewable energy sources, for example solar energy, wind energy, or micro-hydropower to provide a quality power supply to remote areas. The abundant energy available in nature can be harnessed and converted to electricity in a sustainable way to supply the necessary power demand and thus to elevate the living standards of the people isolated to the central grid. The Ethiopia Government is now aware the national utility alone through Continuous grid extension cannot accelerate rural access to electricity. To improve rural access to electricity, the government has recently updated its strategies and improved any obstacle and constraints to accelerated off-grid rural electrification (Scaling up renewable energy).

Where rivers have inconsistent flow characteristics (dry in summer, frozen in winter), a hybrid system applying with PV support can be attractive.

Therefore; Guder Wereda, is a small town having many rural villages far from the central grid, of which Mogno Keshebel Village is one of the village that does not have access to electricity, in spite of having year round flowing river crossing it, the name of the river is Guder River and have a good potential of Solar Radiation.

1.3. Project Description

The proposed Hybrid system is comprised of a renewable energy generator (PV), and inverter (DC/AC converter), a back-up unit generator set (Generator) and a storage system (batteries), and uses renewable energy resources of solar radiation and water resource as a main energy source.

1.4. Research question

In general, the research and analysis has been guided by addressing and answering the following questions:

1. Resource Assessment-is micro-hydro-PV-battery hybrid configuration can produce an optimal combination for rural electrification?

2. Technical and economic feasibility of the hybrid system-is hybrid system economic feasible for the rural electrification?

1.5. Objective of the study

1.5.1. The main objective

The main objective of this thesis is to study the feasibility of micro-hydro-photovoltaic system and energy storage for hybrid electrification of remote villages for Mogno Keshenbel Village to sustainably and efficiently satisfy the energy demand of remote village, where central grid electricity has not reached yet due to many geographical and economic constraints.

1.5.2. Specific objectives

i. Determine the present and near future electrical energy need of the community living in the area.
ii. Estimate the renewable energy resource of the area; micro hydro and solar radiation potential.
iii. Design a standalone hybrid system to meet the electrical energy demand of the community \
iv. Selection and assessment of the main components of the system
v. Analyze the performance of the designed system by using a tool (HOMER)
vi. Evaluate the technical and economic performance of the micro hydro-PV Hybrid System and make sensitivity analysis.
vii. Provide valuable information to the government and Non government organization (NGO) about the potential of technology in the country for a rural electrification project in Ethiopia.

1.6. Scope of the study

The scope of this study is to assess the technical and economical feasibility of a standalone PV-Micro hydro hybrid energy system to supply the rural community detached village from national grid in Ethiopia. The study will investigate different renewable energy option to satisfy the energy demand of the village.

This study shall collect and analyze relevant data and information to examine and select the most suitable systems configuration, recommend necessary action, necessary measures that configure a system to accommodate the current and near future electrical energy demand for the village. The study only focuses on solar energy and micro-hydro resource assessment of among different renewable energy resource in the village, like biogas and biomass. In so doing, we shall recommend for further production of a model by other researchers and the limitations of this research shall then clearly be told as to give a way to next coming researchers and those who are interested in the area.

Chapter Two

2. 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].

All most all of the above scholar’s paper shows the hybrid system either only PV/wind excluding hydro or PV/Wind/Hydro include wind turbine. But in this study we combine PV with Micro-Hydro. This system configuration is best of all due to the reason Ethiopia have plenty of solar resource and Huge 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.

2.1. Micro-Hydropower 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).

2.1.1. Micro- hydropower basics

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 [Mahai, 2007].

2.1.1.1. 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 (m3/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. [Micro Hydro Power Resource Assessment Handbook]. 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”.

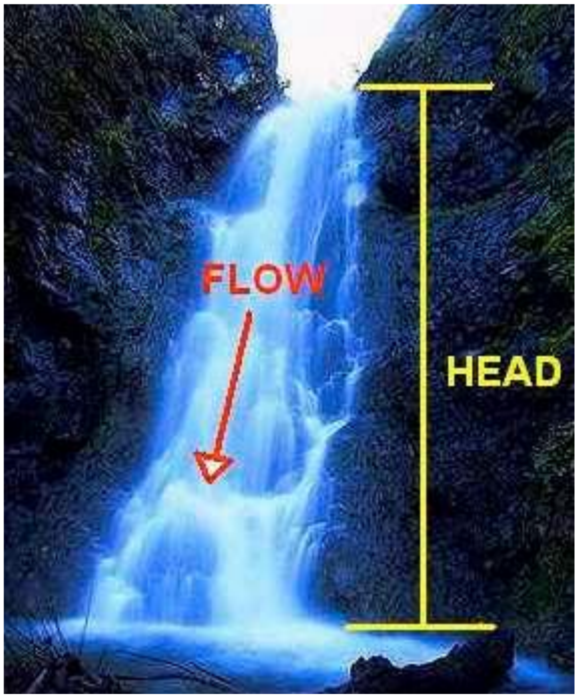


Fig 2.1 Flow and head relation in hydropower

2.1.1.2. *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 m3 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 (m3/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].

$$P = Q \times H \times \eta \times 9.81 \ (kW) \qquad eq\ 2.1$$

Where,

P= power at the generator terminal, in kilowatts (kW)

H= the gross head from the pipeline intake to the tail water in meters (m)

Q= flow in pipeline, in cubic meters per second (m^3/s)

η= The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator 9.81 is a constant and is the product of the density of water and the acceleration due to gravity (g)

This available power will be converted by the hydro turbine in mechanical power.

2.1.2. Classification of Micro-Hydropower

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.

2.1.2.1. 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 *pondage* 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].

2.1.2.2. .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 pondage of the water supply necessary [57].

2.1.2.3. Classification of hydro power by installed capacity

Classification of hydropower according to installed capacity is different from different scholars. However, here with the most common classification source hydropower engineering lecture notes in AAIT).

Table 2.1 Hydropower classification by installed capacity (source Lecture Notes)

S.No	Types of plant	Installed capacity in (KW)
1	Pico	< 5
2	Micro	< 100
3	Mini	< 1000
4	Small to medium	< 6000
5	Large	> 6000

2.1.2.4. 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].

2.1.3. Principal Components of Micro-hydropower plant

The principal components of a simplified MHS (Micro Hydropower System) is shown below in Fig 2.10

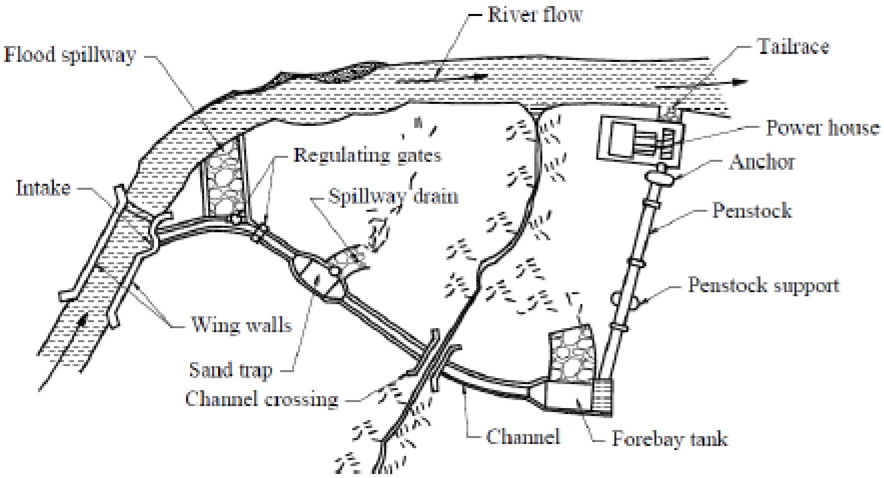


Figure 2.2 General layout of the MHP (Micro Hydro Project) and its principal components (Pandey B 2006).

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].

2.1.3.1. Civil Work Components of Micro Hydro power unit

The civil components described in this section are those major components such as the intake, headrace canal, de-Sanding basin, spillway, forebay tank, penstock pipes and tailrace (BPC Hydro consult, 2006).

- **Intake**

  Intake is the primary means of passage of water from the source of water. Intake could be of side intake type or the bottom intake type. Usually, trash racks have to be placed at the intake, which acts as the filter to prevent large water born objects to enter the waterway of MHP (Micro Hydro Project) (Harper, December 2011).

- **Headrace Canal**

  Headrace canal conveys the water to the fore bay. Sometimes, pipes can also be used in place of the canals. (Pandey V., 2011).

- **Settling Basin**

  In order to reduce the sediment density, which has negative impact to other components of the MHS (Micro Hydropower System) de-sanding basins are used to capture sediments by letting the particles settle by reducing the speed of the water and clearing them out before they enter the canal. Therefore, they are usually built at the head of the canal. They are equipped with gate valves for flushing the settled undesirable sediments. De sanding basin is capable of settling particles above 0.2-0.3 mm of size (Harvey, Micro Hydro Design Manual, 1983).

- **Spillway**

  Spillways need to be designed to remove the excess water due to floods, in order to minimize the adverse effects to the other components of the MHS (Micro Hydropower System) spillways are often constructed in de-sanding basin and the fore bay, from which the excess water is safely diverted to the water source.

- **Fore bay tank**

The fore bay tank serves the purpose of providing steady and continuous flow into the turbine through the penstocks. For bay also acts as the last settling basin and allows the last particles to settle down before the water enters the penstock. Forebay can also be a reservoir to store water-depending on it size (large dams or reservoirs in large hydropower schemes are technically forebay). A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trash rack need to be installed to prevent large particles to enter the penstock. A spillway competes the forebay tank [39].

- **Penstock**

  The penstock is the pipe, which conveys water under pressure from the forebay tan to the turbine. Penstock is a significant component of the MHP scheme and needs to be designed and selected carefully as it represents a major expense in the total budget (for some high head installations this alone could cost as much as 30% of the total costs). Here the main aspects to consider are head loss and capital cost. Head loss due to friction in the pipe decreases dramatically with increasing pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore a compromise between cost and performance is considered for design and selection of pipe diameter and material.

- **Tailrace**

  Tailrace is very similar to headrace canal described previously in this section. The only difference with that of the headrace canal is that it is situated at the end of the civil components and is used to convey the water back to the source after use in the micro hydro plant [Sanchez & Rodriguez, June 2011].

2.1.3.2. Powerhouse Components

The powerhouse components of Micro-Hydropower are used to the conversion of mechanical energy of water into electrical energy takes place. Powerhouse consists of electro-mechanical equipment such as turbines, generator and drive systems.

- **Turbine**

  In a MHS (Micro Hydropower System), hydraulic turbine is the primary component, which converts the energy of the flowing water into mechanical energy through the rotation of the runner. The choice of particular turbine depends upon technical parameters such as design head and discharge at which the turbine is to operate as well as other practical considerations such as the availability and cost of maintenance personnel. The optimum speed of the turbine is the particular speed of its rotor at which the turbine performs its best. The turbine needs to operate at this optimum speed in order to get maximum possible output at all loading conditions [Khatri & Uperty, 2002].

- **Generators**

  Although this study is not overly concerned with the selection, and uses of generators in the MHS (Micro Hydropower System) it is, however, relevant to describe the basic types of generators and how they are integrated in the MHS (Micro Hydropower System). There are two types of generators in use for hydroelectricity generation; either synchronous or induction generators. Synchronous generators are the primary types of generators, which are used extensively in large-scale power generation. When the power output levels are generally low (less than 10 MW), induction generators are extensively used. Induction generators are also the preferred type of generators in MHP (Micro Hydro Project) because they can operate at variable speeds with constant frequency, are available cheaply and requires less maintenance than the synchronous generators. Both of these generators have the possibility to be used connected to the grid or just standalone operation (Upadhayay, 2009).

- **Drive Systems**

  The main purpose of the drive systems is to transmit the power from turbine to the generators at a stable voltage and frequency at a required direction and required speed. Like any normal drive systems, in a MHS also, drive systems comprise of generator shaft, turbine shaft, bearings, couplings, gearboxes, belts, and pulleys. The different types of drive systems common in MHS (Micro Hydropower System) are direct drive, “V” or wedge belts and pulleys, timing belt and sprocket pulley and gearbox drive systems. A direct drive system is one in which the turbine shaft is connected directly to the generator shaft. In contrast, “V” or wedge belts and pulleys are the most commonly used type of drive systems in MHS (Micro Hydropower System). However, in very small systems (less than 3 kW) where efficiency is critical, timing belt and sprocket pulley are commonly used. Gearboxes are suitable in large machine where drive belts are not efficient. Due to high maintenance and alignment costs of gearboxes, they are less frequently used in MHS (Micro Hydropower System) (Upadhayay, 2009).

- **Electrical Load Controllers**

  All MHS (Micro Hydropower System) will have to have switchgear in order to separate the power flow when necessary and to control the electrical power flow. There are several different kinds of switches used in an MHS (Micro Hydropower System) such as isolators, which are manually operated, switch fuses which additionally can provide fuse for current limiting, MCCB (Molded Case Circuit Breakers) which are used for protection from over current or short circuits and also on. The choice of electronic load controller is largely dependent upon the type of generator installed in MHS. For instance, when the induction generator is used in the MHS. It is necessary to install induction generator controllers (IGC) [12].

2.1.4. 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

2.1.5. Types of 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.

2.1.5.1.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).

- **Pelton Turbine**

  Pelton turbines are impulse turbines where one or more jets impinge on a wheel carrying on its periphery a large number of buckets. Each jet issues water through a nozzle with a needle valve to control the flow (figure 6.4). they are only used for high heads from 60m to more than 1000m. The axes of the nozzles are in the plan of the runner. In case of an emergency stop of the turbine (e.g. in case of load rejection), the jet may be diverted by a deflector so that it does not impinge on the buckets and the runner cannot reach runaway speed. In this way the needle valve can be closed very slowly, so that overpressure surge in the pipeline is kept to an acceptable level (max 1.15 static pressure) [20].

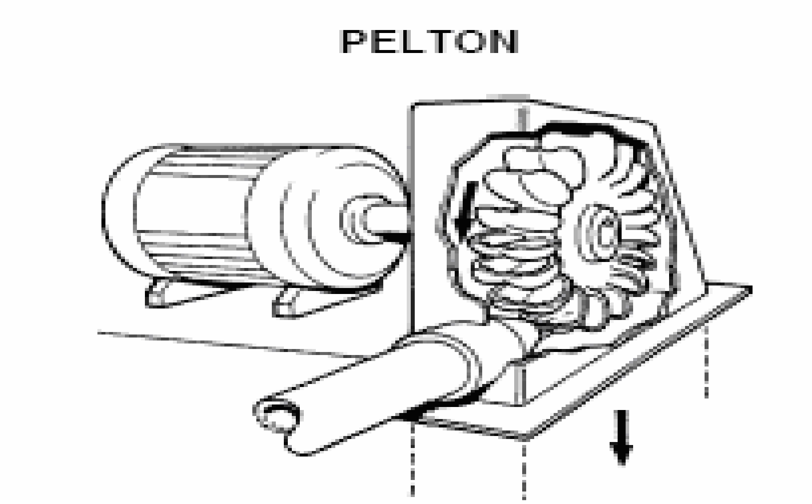


Fig 2.3 Pelton turbine [**20]**

- **Turgo turbines**

The Turgo turbine can operate under a head in the range of 30-300m. Its buckets are shaped differently from the Pelton turbine and the jet of water strikes the plane of its runner at an angle of about 20^0. Water enters the runner through one side of the runner disk and emerges from the other whereas the volume of water decreases. Pelton turbine can admit is limited because the water leaving each bucket interferes with the adjacent ones, the Turgo runner does not present this problem. The resulting higher runner speed of the Turgo makes direct coupling of turbine and generator more likely, improving overall efficiency and decreasing maintenance cot. Despite the advantages, Turgo turbines are seldom build today and are only applied in very small MHPs.

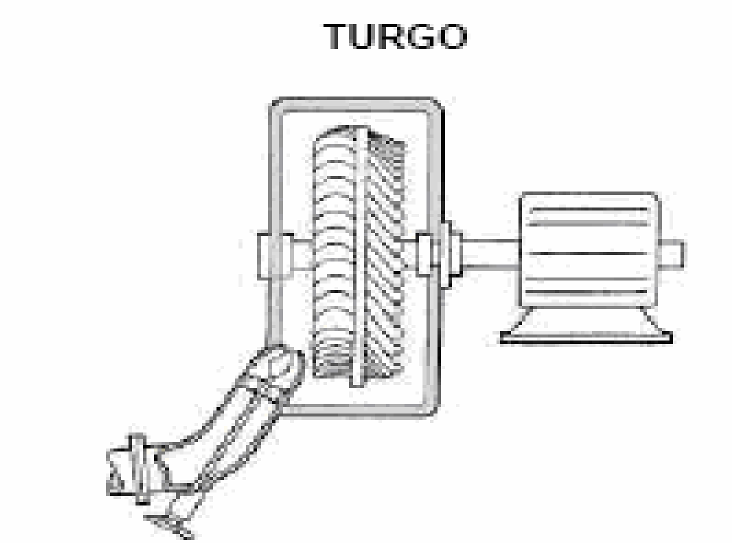


Figure 2.4: Turgo turbines.

Source [LAY 99] p.158

- **Cross-Flow Turbine**

  A cross flow turbine gets its name from the way the water flows through, or more correctly ‘across’ the rotor as shown in Figure 2.4 below (hence across flow or cross flow). The water flows over and under the inlet guide-vane which directs flow to ensure that the water hits the rotor at the correct angle for maximum efficiency. The water then flows over the upper rotor blades, producing a torque on the rotor, then through the centre of the rotor and back across the low rotor blades producing more torque on the rotor. Most of the power is extracted by the upper blades (roughly 75%) and the remaining 25% by the lower blades. Obviously the rotor is rotating, so what are the upper blades one moment will be the lower blades the next [20].

  The cross flow turbine is also named as Banki turbine. Its structure is simple, but the efficiency is low, used for small power stations with

  - Water head of 10m-150m

- Output power could be up to 300 KW

The advantage of cross-flow turbines is they can be easily manufactured, cheap compare to other turbine type, easy to repair. It can generate power even during low flow rate period

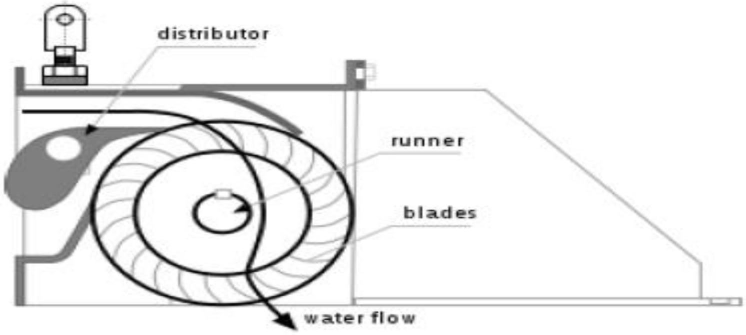


Fig 2.5 Cross –flow turbine [20]

2.1.5.2. *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].

- **Kaplan and Propeller turbines**

  Kaplan and propeller turbines are axial-flow reaction turbines; generally used for low heads from 2m to 40m. The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide-vanes. If both blades and guide-vanes are adjustable, it is described as “double-regulated”. If the guide –vanes are fixed it is “single-regulated”. Fixed runner blade Kaplan turbines are called propeller turbines. They are used when both flow and head remain practically constant, which is a characteristic that makes them unusual in small hydropower schemes [20].

Fig 2.6Propeller hydropower turbines[www.hydroquebec.com/]

- **Francis turbines**

  The Francis turbine is a reaction turbine where water changes pressure as it moves through the turbine, transferring its energy. A watertight casement is needed to contain the water flow. Generally, such turbines are suitable for sites such as dams where they are located between the high-pressure water source and the low-pressure water exit.

  Francis turbines can be designed for a wide range of heads and flows and along with their high efficiency makes them one of the most widely used turbines in the world. Large Francis turbines are usually designed specifically for each site so as to gain highest levels of efficiencies (these are typically in the range of over 90%). Francis turbines cover a wide range of head- from 20 meters to 700 meters, and can be designed for outputs power ranging from just a few kilowatts to one Gig watt.

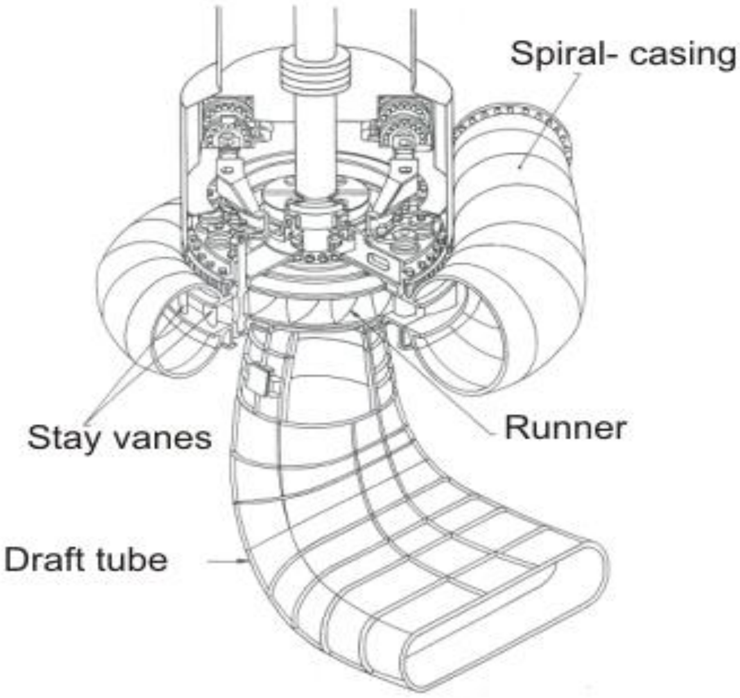


Fig 2.7 Francis turbine [www.hydroquebec.com/]

2.1.6. 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 2.8 shows an example of a real site development without efficiency guarantees laboratory work [20].

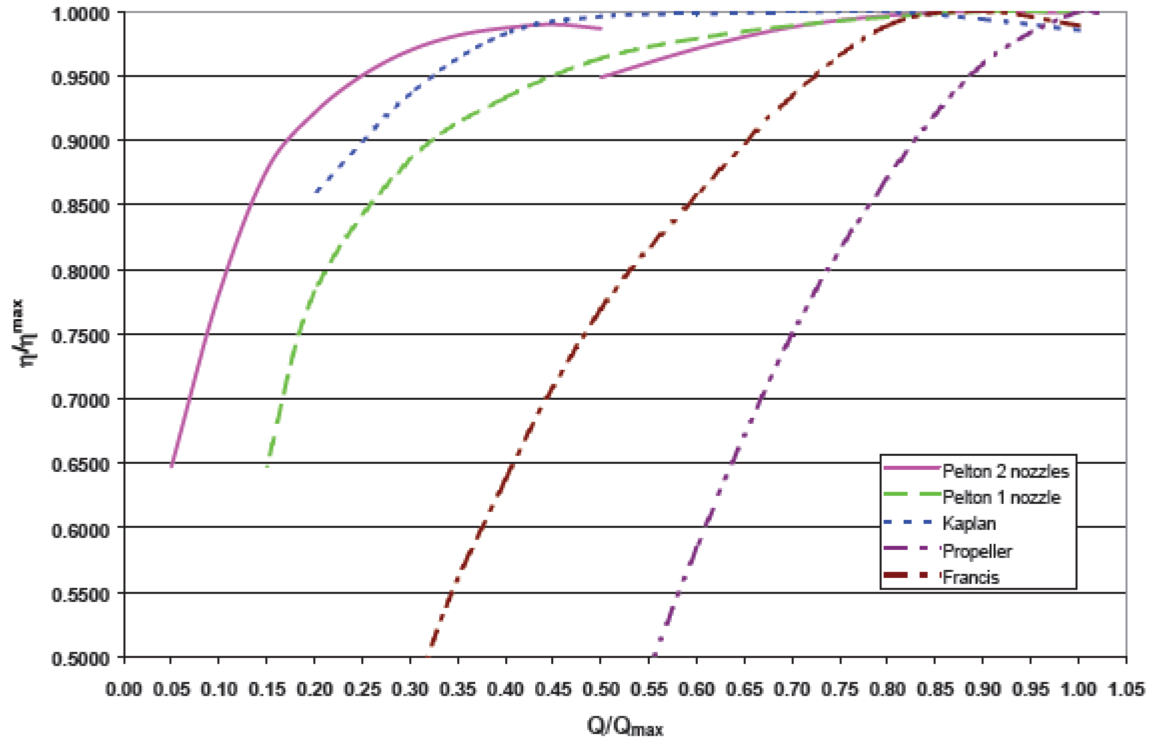


Fig 2.8: Typical small hydro turbines efficiencies [20]

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

Table 2.2 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

2.1.7. 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. The correlation between specific speed and net head are given for the following turbines.

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. Mathematical description of specific speed of cross flow turbine is given:

$cross\ flow$:

$$\eta_s = \frac{513.25}{H^{0.505}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \ eq3.1$$

Flow based metric system for specific speed (Ns) used in Europe is given by equitation below

$$N_s \quad = \frac{Nr\sqrt{Pr}}{Hr^{(5/4)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \ eq\ 3.2$$

Where Nr= revolutions per minute

Pr= power in metric horse power at full gate opening –(1 KW=0.86 metric hp)

Hr= rated head in m.

The specific speed value defines the approximate head range application for each turbine type and size low head units tend to have a high specific speed, and high –head units to have a low specific speed [13].

The determination of head is very important steps in the design of MHS (Micro Hydropower System). The gross head was measured to be 20 meters during field survey by the use of GPS (Global Position Service).

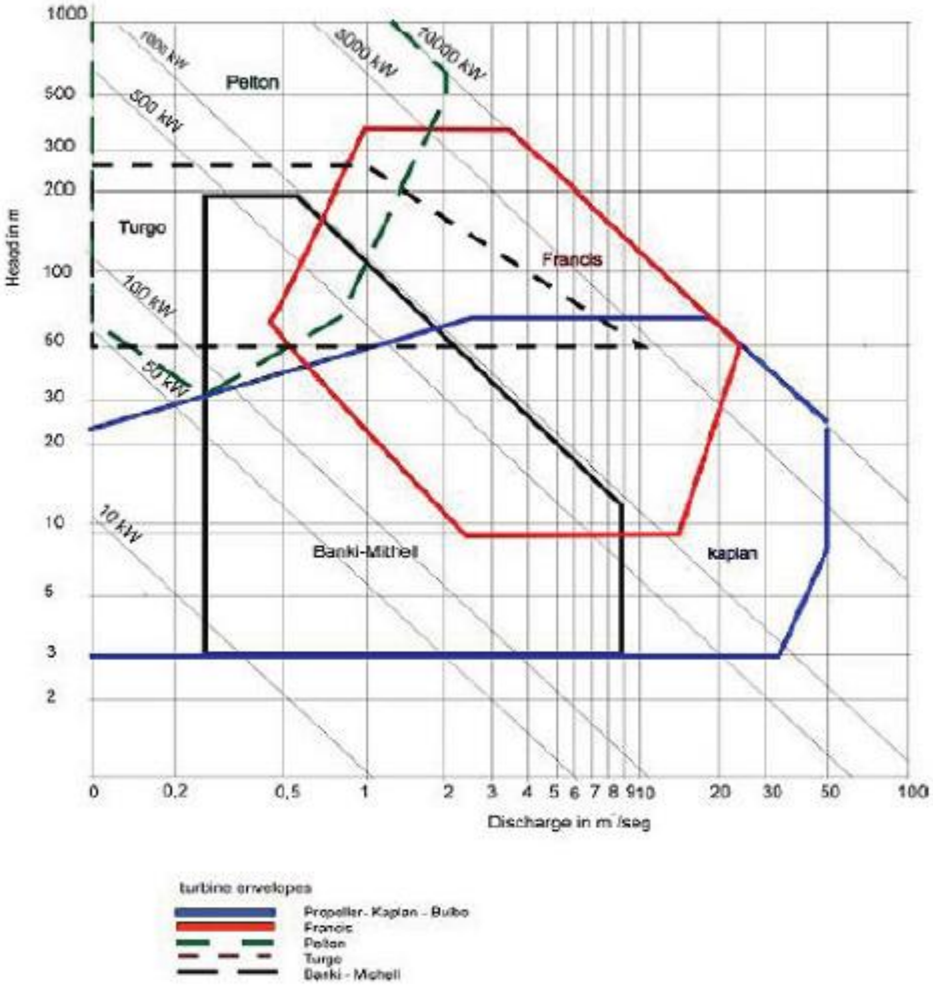


Fig 2.9 Turbine application chart [source: st.onge environmental engineering, PLCC used with permission and as a courtesy from the owner [H13]

Selection of a hydroelectric turbine should take into account applicable head pressures and flow rates. For the village under study, which has a gross head of approximately 20 m and a design flow of 0.6m3/s. from Figure 2.8. Turbine selection chart, Cross flow turbines are appropriate for the above measured head. The cross flow turbine offers a simple design with lower peak efficiency and a much broader efficiency curve due to the sequential deployment of high velocity water onto varying areas of the turbine. This turbine can have a wide range of flows that produce power, but the efficiency drops at low flows.

2.2. Photovoltaic Technology and Solar Energy Resources

2.2.1. Introduction

The energy source of all-live on the 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].

2.2.2. 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 [6].

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) [6].

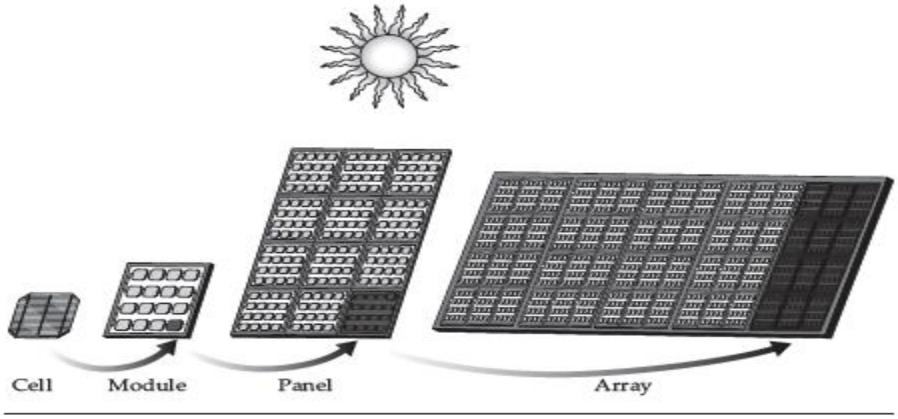


Fig 2.10 PV system component [63]

2.2.2.1. *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.

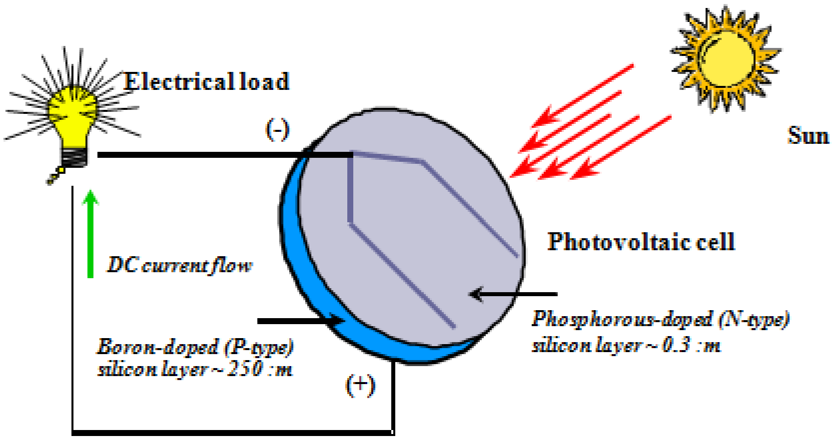


Fig 2.11 Solar cell working principle. [15]

2.2.2.2. *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/m2. 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 2.15 shows the relationship between solar irradiance and insolation [15].

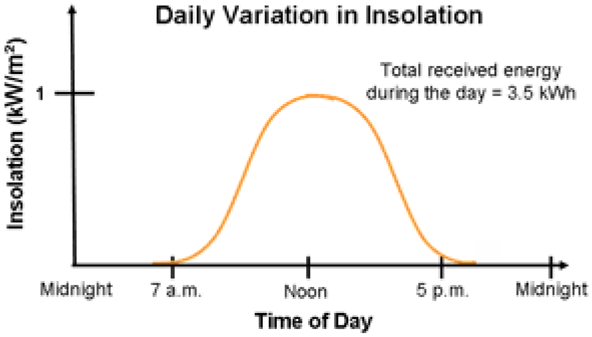


Fig 2.12 Relation between solar Irradiance and Solar Radiation [15]

2.2.3. Main Components of Photovoltaic System

i. 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 [6].

ii. 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 [6].

In this study, Surrette6CS25PS 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 Surrette6CS25PS battery is rated for 3300 cycles at a 40% depth of discharge.

iii. 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 [6].

iv. 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 [6].

v. Loads

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

2.2.4. Photovoltaic Rating

Photovoltaic's 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°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 filed with performance of 85 to 90 percent of the STC rating.

2.2.4.1. Solar Module Rating and Price at STC.

Table 2.3 Solar module power rating and price at STC[www.Alibaba.com]

Solar Panel Brand	**Peak power Watts**	**Cost USD per solar Panel**	**P=poly M= mono T=Thin film**	**Efficiency (%)**	**Price Per Watt($)**	**Country of Manufacturer**	**Vendor**
Canadian Solar Cs6X-300P	300	288.00	P	15.63	0.98	China	Affordable solar
Canadian Solar Cs6P-245P	245	227.0	P	14.61	0.93	China	Affordable solar
Canadian Solar Cs6P-250P	250	222.50	P	15.54	0.89	China	Affordable solar
Hyundai His-255MG	255	244.80	M	15.80	0.96	Canada	Affordable solar
Sharp ND-250Qcs	250	275.00	P	15.30	1.10	USA	Affordable solar
Canadian Solar Cs6P-235P	235	225.0	P	14.61	0.98	China	Affordable solar
Canadian Solar Cs6X-280P	280	255	P	16.16	0.91	China	Alternate Energy
Sun tech PLUTO 240-WDE	240	200.00	P	14.80	0.83	China	Alternate Energy
Solar world SUN Module SW250Mono V 2.0 Frame	250	225.0	M	14.90	0.90	USA	Alternate Energy

2.2.5. 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 2.17. 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.

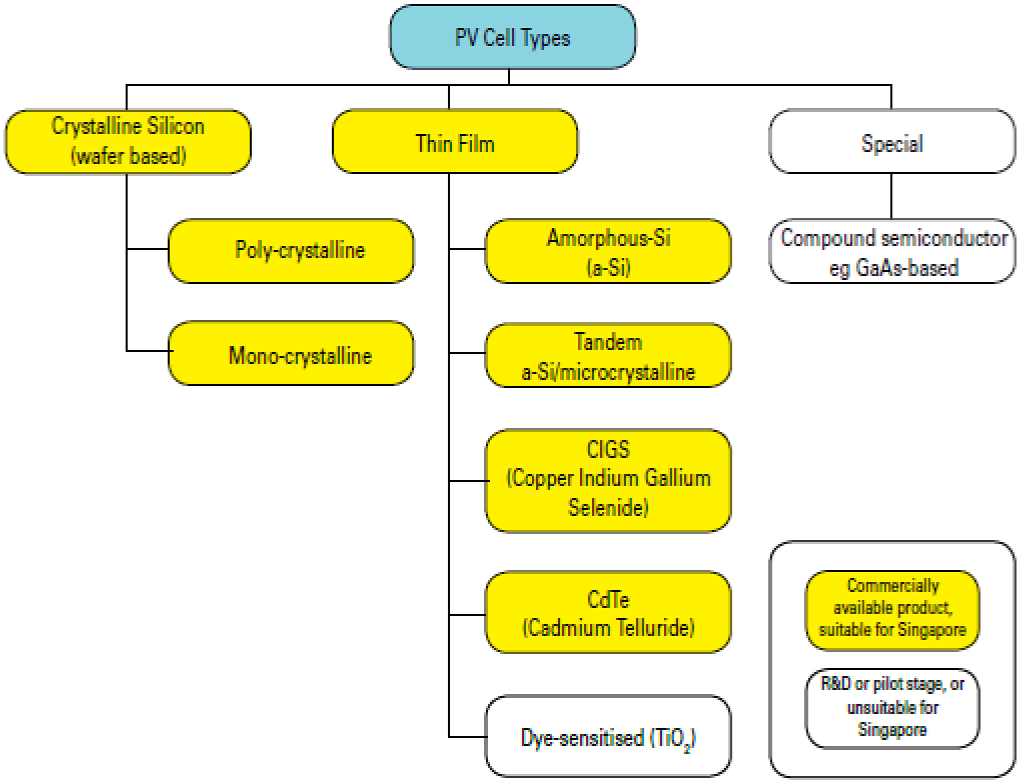


Figure 2.13 PV technology family trees

2.2.5.1. *Different Module Technologies*

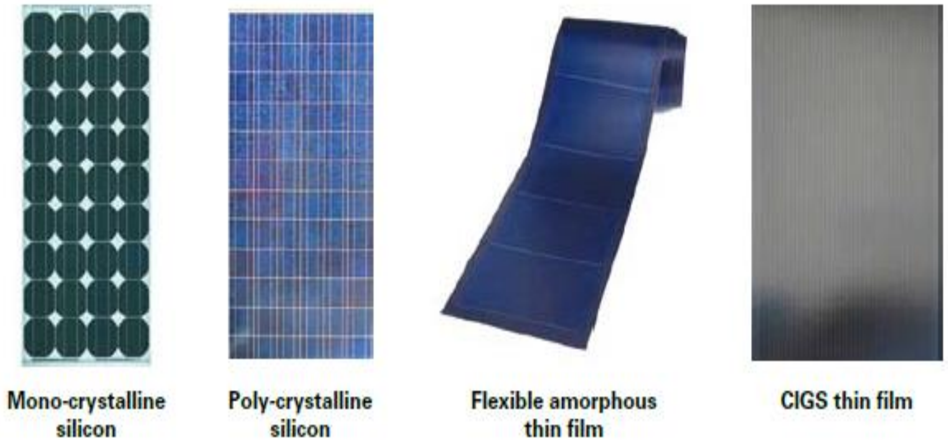


Figure 2.14 Common PV module technologies

2.2.5.2. *Crystalline Silicon and Thin Film Technologies*

Crystalline cells are made from ultra-pure silicon raw material such as those used in semiconductor chips. They use silicon wafer that are typically 150-200 microns (one fifth of a millimeter) thick. Thin film made by depositing layers of semiconductor material barely 0.3 to 2 micrometers thick onto glass or stainless steel substrates. As the semiconductor layers are so thin, the costs of raw material are much lower than the capital equipment and processing costs.

Table 2.4 Technology and Module Efficiency of PV [22]

Technology	Module Efficiency
Mono-crystalline silicon	12.5-15%
Poly-crystalline silicon	11-14%
Copper indium Gallium Selenide(GIGS)	10-13%
Cadmium Telluride(CdTe)	9-12%
Amorphous Silicon(a-Si)	5-7%

A part from aesthetic differences, the most obvious difference amongst PV cell technologies is in its conversion efficiency, as summarized in table 2.4. For example, a thin film amorphous silicon PV array will need to close twice the space of a crystalline silicon PV array because its module efficiency is halved, for the same nominal capacity under Standard Test Conditions (STC) rating.

For crystalline silicon PV modules, the module efficiency is lowered compared to the sum of the component cell efficiency due to the presence of gaps between the cells and the border around the circuit i.e., wasted space that does not generate any power hence lower total efficiency [22].

2.2.6. Electrical characteristics of the solar cell

2.2.6.1. Electrical Equivalent Circuit of PV cell

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in figure 3.2 below. The following parameters cal for consideration. The current/at the output terminals is equal to the light-generated current $_L$/less the diode It$_D$/ and the shunt-leakage current$_{sh}$/. The series resistance R_s represent the internal resistance to the current flow, and depends on the p-n junction depth, impurities and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to the ground. In an ideal PV cell R_s=0 and R_{sh}= the PV conversion efficiency is sensitive to small variations in R_s. But insensitive to variations in R_{sh}. A small increase in R_s can decrease the PV output significantly.

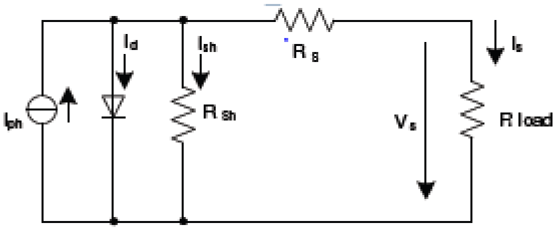


Figure 2.15 Equivalent circuits for a PV cell [Duffy and Beckman, 2006]

The open –circuit voltage Voc of the cell is obtained when the load current is zero and is given by the following

$$V_{oc} = (I_L - I_D)R_{sh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq2.1$$

The diode current is given by the classical diode current expression

$$I_D = I_o\left[exp\left(\frac{qV_{oc}}{AKT}\right) - 1\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq2.2$$

Where Io is the saturation, current of the diode (A), q is electron charge ($1.6x10^{-19}$C), A is curve-fitting constant, K is Boltzmann constant ($1.38x10^{-23}$ J/^{o}K), T is temperature on absolute scale ^{o}K.

Thus, the load current is given by the expression

$$I = I_L - I_D - I_{sh}$$

$$I = I_L - I_o\left[exp\left(\frac{qV_{oc}}{AKT}\right) - 1\right] - \frac{V_{oc}}{R_{sh}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . eq2.3$$

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

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

The maximum photo voltage is produced under the open-circuit voltage. Again by ignoring the ground leakage current, equation 2.4 with I give the open-circuit voltage as follows:

$$V_{oc} = \frac{AKT}{q} In\left(\frac{I_L}{I_o} + 1\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . eq2.4$$

2.2.6.2. I-V and P-V Curves of Photovoltaic Cells

Current-voltage relationships are used to measure the electrical characteristics of PV devices and are depicted by curves. The current-voltage, or I-V, curve plots current versus voltage from short-circuit current I_{sc} through loading to open circuit voltage Voc. The curves are used to obtain performance levels of PV systems (cells, modules, arrays) [Solar energy, renewable energy & the environment].

I-V curve is obtained experimentally by exposing the PV cell or module to a constant level of irradiance while maintaining a constant cell temperature, varying the load resistance, and measuring the current produced. The horizontal and vertical axes measure voltage and current, respectively. I-V curve typically passes through the two ends: the short-circuit current, Isc, and the open-circuit voltage, Voc. The Isc is the current produced with the positive and negative terminals of the cell shorted; the voltage between the terminals is zero, corresponding to zero load resistance [24].

The Voc is the voltage across the positive and negative terminals under open-circuit conditions with no current, corresponding to infinite load resistance. I-V curves can show the peak power point located on the farthest upper right corner of where the rectangular area is greatest under the curve [24].

The PV cell may be operated over a wide range of voltages and currents. By simply varying the load resistance from zero (a short circuit) to infinity (an open circuit), it is possible to determine the highest efficiency as the point where the cell delivers maximum power. Because power is the product of voltage times current, the maximum-power point (pm) occurs on eh I-V curve where the product of current (Imp) times voltage (Vmp) is a maximum. No power is produced at the short-circuit current with no voltage or at open-circuit voltage with no current, so maximum power generation can be expected to be somewhere between these points. Note that maximum power is generated at only one point on the power curve; this occurs at the knee of the curve. This point represents the maximum efficiency of the device in converting sunlight into electricity [21,24].

Each I-V curve has a set of distinctive operation points that should be understood in order to appropriately install and troubleshoot PV power systems:

- **Short-circuit current** (Isc) is the maximum current generated by a cell or module and is measured when an external circuit with no resistance is connected (i.e., the cell is shorted). Its value depends on the cell’s surface area and the amount of solar radiation incident upon the surface. It is specified in Amperes and, because it is the maximum current generated by a cell, Isc is normally used for all electrical capacity design calculations. Nameplate current production is given for a PV cell or module at standard reporting condition (SRC) as specified by ASTM. The SRC commonly used by the PV industry is for a solar irradiance of 1,000 w/m^2, a PV cell temperature of 25^0C, and a standardized solar spectrum referred to as an air mass 1.5 spectrum (AM=1.5). This condition is also more commonly referred to as standard test condition (STC). However, in reality, unless one is using PV in a relatively cold climate, the cells operate at a much hotter temperature (often 50^0C or more), which reduces their power performance. The temperature effect is much greater for crystalline cells ad compared to amorphous cells.

- **Maximum power operating current** (Imp) is the maximum current specified in Amperes and generated by a cell or module corresponding to the maximum power point on the array's current-voltage (I-V) curve.
- **Open-circuit voltage** (Voc): is the maximum voltage generated by the cell. This voltage is measured when no external circuit is connected to the cell.
- **Rated maximum power voltage** (VMP): corresponds to the maximum power point on the array's current-voltage (I-V) curve.
- **Maximum power** (PMP): is the maximum power available from a PV cell or module and occurs at the maximum power point on the I-V curve. It is the product of the PV current (Imp) and voltage (VMP). This is referred to as the maximum power point. If a module operates outside its maximum power value, the amount of power delivered is reduced and represents needless energy losses. Thus, this is the desired point of operation for any PV module.

The peak voltage (Vp) of the majority of nominal 12v modules varies from 15 v (30 cells in series) to 17.5v (36 cells in series) each module has on its back side a decal placed by the manufacturer that shows the electrical specifications. For example, the decals on the back of a BP poly crystalline VLX-53 module whose characteristics are mentioned are provided in table 2.5.

The power produced by a crystalline PV module is affected by two key factors: Solar irradiance and module temperature. Figure 2.5 shows how the I-V curve is affected at different irradiance levels and module temperature. The lower the solar irradiance is, the lower is the current output and thus the lower is the peak power point. Voltage essentially remains constant. The amount of current produced is directly proportional to increases in solar radiation intensity. Voc does not change; its behavior is essentially constant even as solar-radiation intensity is changing. Figure 2.17 shows the effect that temperature has on the power production capabilities of a module [24].

Table 2.5Typical manufacturer’s specifications for a 53-wp PV module [24]

Operating point	Model BP VLX-53
P_{mp}	53 Wp (peak Watts)
V_{mp}	17.2 V
I_{mp}	3.08 A
V_{oc}	21.5 V
I_{sc}	3.5A
Standard test conditions (STCs)	1,000 W/m2, 25°C,AM 1.5

At the ‘knee’ of a normal I-V curve is the maximum power point (Imp, Vmp), the point at which the array generates maximum electrical power. At voltages well below Vmp, the flow of solar-generated electrical charge to the external load is relatively independent of output voltage. Near the knee of the curve, this behavior starts to change. As the voltage increases further, an increasing percentage of the charges recombine within the solar cells rather than flowing out through the load. At Voc, all of the charges recombine internally. The maximum power point, located at the knee of the curve, is the (I-V) point at which the product of current and voltage reaches its maximum value. [21,24].

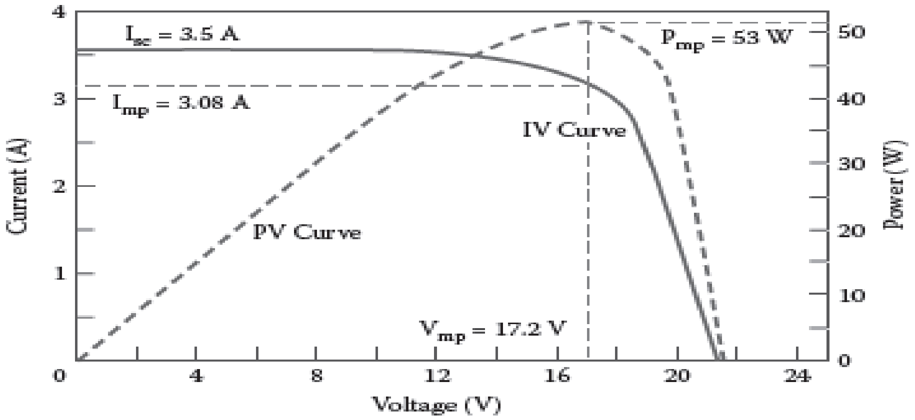


Figure 2.16 Typical I-V and power curves for a crystalline PV module operating at 1,000W/m^2 (STC) [24]

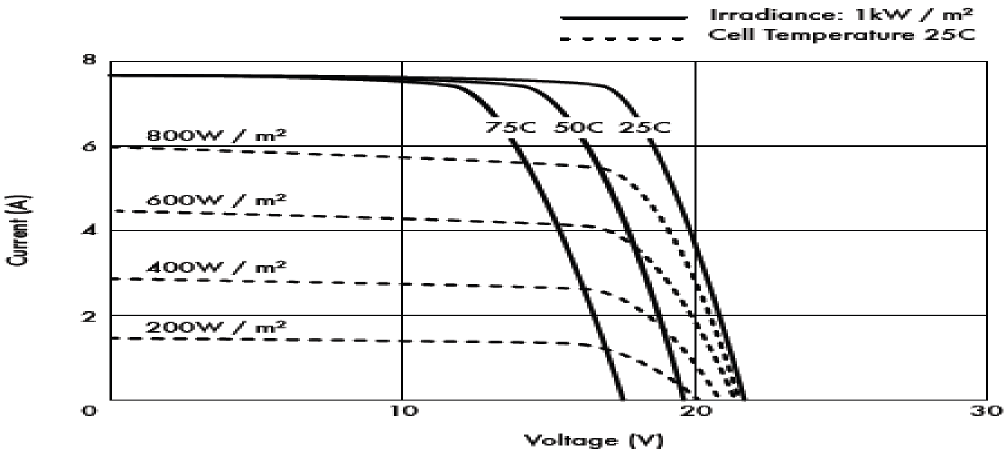


Figure 2.17: Different IV curves.

The current (A) changes with the irradiance, and the voltage (V) changes with the temperature.

2.2.7. The fill factor (FF) of a PV module or string is an important performance indicator.

It represents the squareness (or 'rectangularity') of the I-V curve, and is the ratio of two areas defined by the I-V curve, as illustrated in Figure 2.18. Although physically unrealizable, an ideal PV module technology would produce a perfectly rectangular I-V curve in which the maximum power point coincided with (I_{sc}, Voc), for a fill factor of 1 [21].

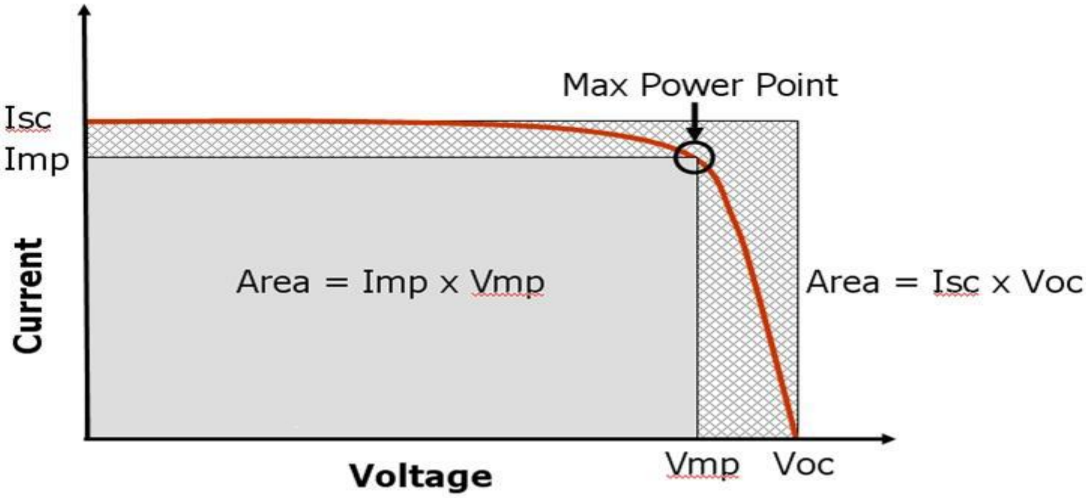


Figure 2.18 Fill Factor, (Imp x Vmp)/(Isc x Voc), represents the squareness of the I-V curve.

Chapter Three

3. Energy Demand of the Study village

3.1. Profile of the Village under study

The selected off-grid remote rural village for this thesis is Mogno Keshenbel. It is a small village in the Guder Wereda in the Oromia Regional State of Ethiopia. Figure3.1 shows the location of the village on the map. It is located at latitude 8.57^{0}N and longitude 37.45^{0}E and has an average elevation of 2101 meters above sea level. Currently Mogno Keshenbel has a total population 4,526, out of which 2,292 male and 2,234 female. [Guder Wereda Health Office]. According to 2007 census and data collected by Guder Wereda Health Office, the population of the village has increased by 1.6 per year The nearest town is Guder, which is about 65 to 68 km away, the Wereda is 12 km away from Ambo city.

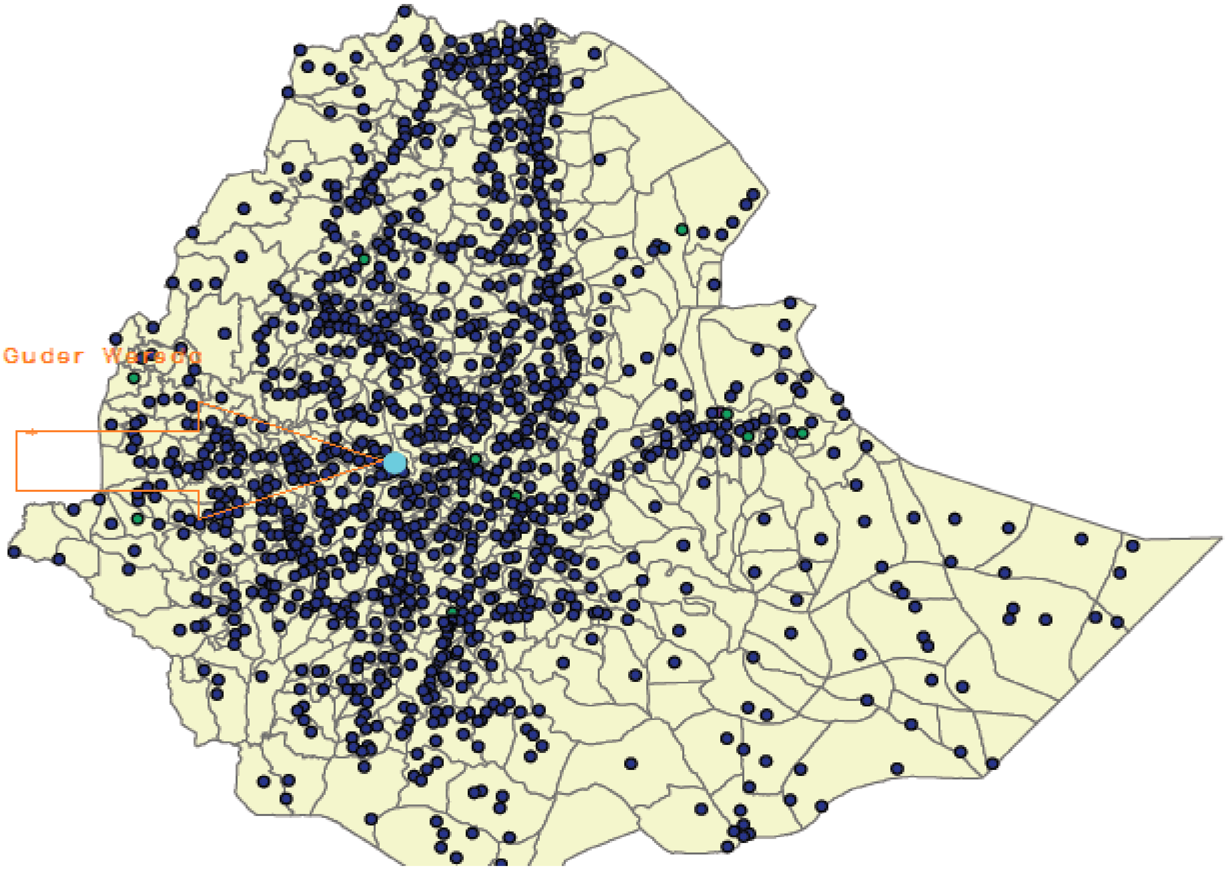


Figure 3.1 Location of the Village

The area around the village is partially hilly; the rest of it is flat plains. The village has drinking water facilities from river. There is no transport access from the village tit is town Guder. There is only one primary school in the village and for high schools and colleges; students have to go to neighboring Guder and Ambo cities. The medical unit present is just a primary health post at Keble level, for hospitals the inhabitants have to travel 80km. the village has no access to grid electricity (58).

3.2. Primary and Secondary Data Collection

3.2.1. Primary data

Primary dates are those data that are collected by the researcher his/herself by conducting field survey. During the field survey, the primary 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 measured by 72HGPS, with an accuracy of 3.4m, where as the number of churches, community services are collected from Guder Wereda Administration, Guder Wereda health office, Guder Wereda Education office and the local people live near to the selected River. Accordingly the primary data collected are listed below in Table 3.1

Table 3.1 Primary data collected

Data Collected	Value	Data Source
Gross Head of the river	20m	Field survey direct Measurement with GPS
Number of Primary school	1	Guder Wereda Education Offices
Number of Health Post	1	Guder Wereda Health Offices
Number of Churches • Protestant Churches • Orthodox Churches	 3 2	Guder Wereda Administration Office

3.2.2. Secondary data

Is a data that is not collected by the researcher for his purpose; others collect it for other purpose. Secondary data more appropriate for this 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] & Guder Wereda Administration respectively. The following table show secondary data collected for the village under study:

Table 3.2 Secondary data collected

Secondary Data Collected	**Value**	**Data Source**
Stream flow (From 1980-2009)	29 years average	Ministry of water and energy
Solar Resource	22 years average	NASA
Number of Population		2007 Census and Guder Wereda Administration
I. 2007 Census	2,816	
II. Current Population	4,526	
Renewable Energy Equipments costs	--	Websites (solarbuz,Alibaba.com etc)

Figure 3.2Site survey and gross head measurement for Guder River

3.3. Energy Demand Assessment and Load Scheduling of the Village

Energy is the oxygen of the economy & the blood live of the growth. 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 equipments, 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 two categories i.e. small/medium and large houses based on their income and living standard information obtained from Guder Wereda Administration. The estimated energy consumed by each of the categories is shown in load Table 3.3. 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.

According to Guder Wereda Administration, the population living in the selected village is divided in to two classes based on their income and living standard as small/medium and large households. Based on their living standards the Wereda Administration selected 200 families as large households out of 874 households; the rest of the community is categorized as small/medium houses. For load planning, the current population size described in the above paragraph is considered[8].

3.4. Scheduling of Electrical load

The estimated electrical load for small households include, three 11W CFL (Compact Fluorescent Lamp) 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 CFL 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 CFLs. Beside class rooms' indoor, four CFL and three CFL 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 3.3 Summary of energy demand of the village

Large House Loads(200)							
No	End Use Device	Unit end use Power [W]	Qty	[Load for 200 Houses [kW]	Operating hours		Daily Energy Demand [kWh/d]
					Period	hr/d	
1	Lighting	11	4	8.8	18:00hr-23:00hr	6	52.8
2	TV(21' inch)	100	1	20	18:00hr-20:00hr	4	80
3	Radio at Working days	30	1	6	09:00hr-12:00hr 18:00hr-23:00hr	4	24
4	Radio at Weekend	30	1	6	09:00hr-17:00hr	9	54
5	Cooking stoves	1000	1	200	08:00hr-11:00hr	2	600
6	'Injera Mittad'	3500	1	7	05:00hr-07:00hr	2	420
7	Miscellaneous	20	1	0.02	00:00hr-23:00hr	24	0.48
	Sub total			247.82			1231.28
Small House Loads(674)							
No	End Use Device	Unit end use	Qty	[Load for 200	Operating hours		Daily Energy Demand
					Period	Hr/d	

		Power [W]		House [kW]			[kWh/d]
1	Lighting	11	3	20.242	18:00hr-23:00hr	5	101.24
2	TV(214’ inch)	100	1	50.500	18:00hr-23:00hr	5	252.5
3	Radio at Working days	30	1	20.220	09:00hr-12:00hr 18:00hr-23:00hr	4	80.8
4	Radio at Weekend	30	1	20.220	09:00hr-17:00hr	9	181.8
5	Miscellaneous	20	1	0.02	00:00hr-23:00hr	24	0.48
	Sub total			90.82			3.94
Public Loads							
Health Post							
No	End Use Device	Unit end use power [W]	Qty	Load for 200 House [kW]	Operating hours		Daily Energy Demand [kWh/d]
					Period	Hr/d	
1	Vaccine Refrigerator	60	1	0.06	18:00hr-23:00hr	24	1.44
2	Small Refrigerator	200	1	0.2	18:00hr-20:00hr	24	4.8
3	Microscope	15	1	0.15	09:00hr-12:00hr 18:00hr-23:00hr	6	0.09
4	Lighting	11	5	0.165	09:00hr-17:00hr	8	1.32
5	Water Heater	1000	1	1	08:00hr-11:00hr	8	8
6	3 Rooms for health post		1	-------	05:00hr-07:00hr		0.48
7	Miscellaneous	20	1	0.02	00:00hr-23:00hr	24	
	Sub total			1.46			16.13
Schools							
No	End Use Device	Unit end use power [W]	Qty	Load for 200 House [kW]	Operating hours		Daily Energy Demand [kWh/d]
					Period	Hr/d	
1	Lighting	15	32	0.540	18:00hr-20:00hr	3	1.620
2	Computer	100	4	0.400	08:00hr-12:00hr	4	1.60
3	Different office lighting	15	6	0.06	18:00hr-20:00hr	4	0.24
4	Miscellaneous	20	1	0.02	00:00hr-23:00hr	24	0.48
	Sub total			1.020			3.94
Church							
No	End Use Device	Unit end use power [W]	Qty	Load for 200 House [kW]	Operating hours		Daily Energy Demand [kWh/d]
					Period	Hr/d	
1	Lighting	11	25	0.275	18:00hr-20:00hr	3	1.620
2	Megaphone	15	10	0.150	06:00hr-08:00hr	3	1.60

3	Miscellaneous	20	1	0.02	00:00hr-23:00hr	24	0.48
	Sub total			.215			1.75
Others							
No	End Use Device	Unit end use power [W]	Qty	Load for 200 House [kW]	Operating hours		Daily Energy Demand [kWh/d]
					Period	Hr/d	
1	Pump	2000	3	0.275	09:00hr-12:00hr	8	1.620
2	Milk Processing	4000	2	0.150	08:00hr-11:00hr	4	1.60
3	Flour Mill	7500	1		08:00hr-11:00hr 14:00-17:00hr	8	
	Sub total	---------	------------	.215			1.75
	System daily total energy Demand						1925.35

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 under study the current energy Demand is 1940kWh/d, peak energy demand is 238kW and 703,570kWh/year. However, From Simulation Result 34.8% of the Energy is Excess energy, for the time being this excess energy will be damped by damping resistor, when the demand increases the excess energy can be utilized. Hence, the Village future Energy Demand Growth will be satisfied by this excess energy Generated by the designed hybrid system.

The assumed daily load for working days and summer are given in Figure3.3 and Figure3.4, respectively.

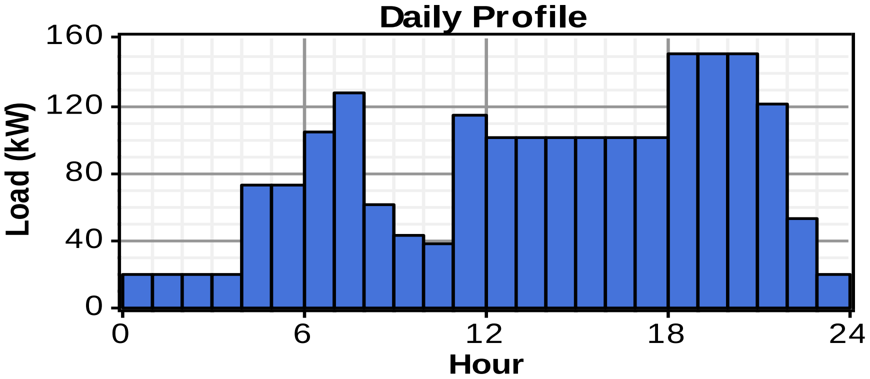


Figure3.3. Working days daily energy demand of the village

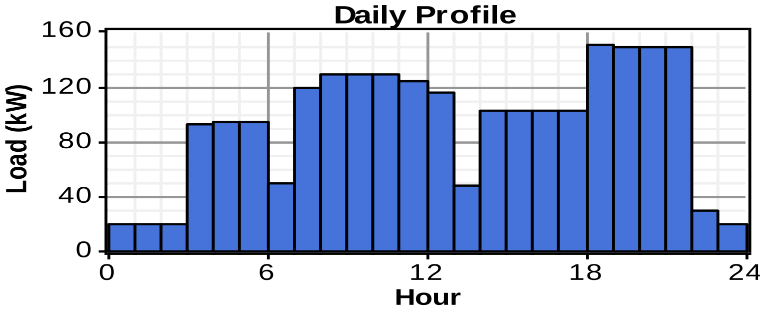


Figure3.4. Summer daily energy demand of the village

The total estimated peak load shown in Figure 3.3 is not the actual peak load that will be seen by the system, because not all the loads allocated for a certain period might be operated on at the same time. Therefore, a demand factor is applied to the load data. Based on experience on electrical engineering and engineering judgment, the demand factor is assumed 0.8. Additionally a 10% spinning reserve is assumed in the system as well. To import the load data into HOMER hourly load profile for the whole year is required. A load profile of 8,760 hours was thus created for a year based on hourly estimated load for different months.

The average daily energy demand of the village after assuming demand factor of 0.8 and becomes 1552kWh, hence the yearly energy demand is estimated as:

$$Annual\ Average\ Energy = 1540 * 365\ days = 562.202MWh/year$$

Chapter Four

4. Micro-hydro 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 Ethiopia

For Ethiopia as a whole, the yearly average daily radiation is 5.26 kWh/m^2. This varies significantly during the year, ranging from a minimum of 4.55 kWh/m^2 in July to a maximum of 5.55kWh/m^2 in February and March. On a regional basis, the yearly average radiation ranges from values as low as 4.25kWh/m^2 in the areas of Itang in th Gambella Regional State (Western Ethiopia), to as high as 6.25kWh/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 3.5Mw, 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 huge 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 insolated every year (Patel, 2006).

4.2.1. Solar resource assessment of the village

The 22 years monthly average solar resource of the village varies from 6.69kwh/m^2/d in February and 4.79kwh/m^2/d in July, which is the summer of Ethiopia, is and clearance index are obtained from NASA. An average solar radiation for the village is 6.01 kWh/m^2/d. the clearance index and daily radiation the village is obtained from NASA surface metrology at latitude 8.57N and longitude of 37.45 E. for a photovoltaic system to supply sustainable power, the daily radiation should be greater than 4 kWh/m^2/d. Figure 4.1 shows the solar resource profile for Mugno Keshenbel village and is tabulated in Table 4.1

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

Month	Clearance Index	Daily Radiation in kWh/m2/d
January	0.725	6.540
February	0.692	6.690
March	0.624	6.410
April	0.592	6.220
May	0.588	6.090
Jun	0.541	5.510
July	0.469	4.790
August	0.468	4.860
September	0.549	5.650
October	0.640	6.270
November	0.720	6.580
December	0.749	6.570

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.

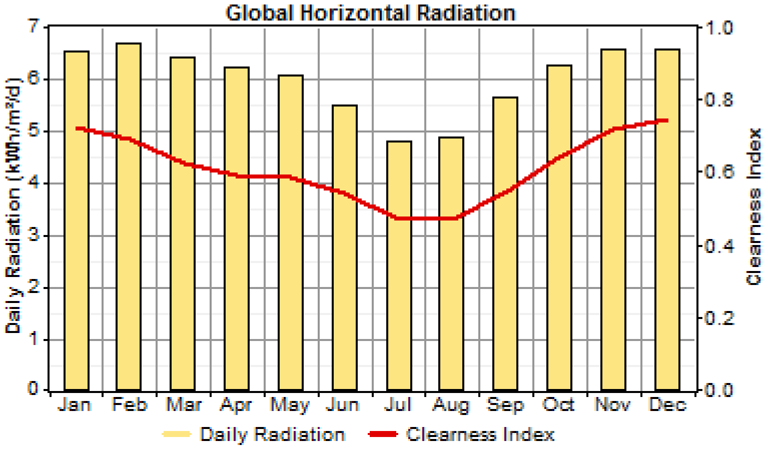


Figure 4.1 Village solar resources (NASA)

4.2.2. Solar radiation variation

February is the sunniest month of the year, at which time solar energy resource is 6.69kWh/m^2/day, while in July it drops to 4.79 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 decreases with differences from month to month as (0.72), (0.692), (0.624), (0.592) and 0.588) respectively. In these months, the micro-hydro can compensate.

Where as in the months of October, Novembers and December, the clearance index increases from month to month as (0.640), (0.720), and (0.749) respectively.

4.2.3. Estimation of PV output of the village

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

1. Determine the radiation at the horizontal surface based on the day of the year and the site latitude and then establish a clearness index.
2. The clearness index is then used to calculate the direct, diffuse and random components of the radiation on a horizontal surface.
3. The total radiation is then calculated from the direct, diffuse and random values obtained.
4. 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 (NREL, 2008):

$$\delta = 23.45 sin\left(360^0 \frac{284+n}{365}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq\ 4.1$$

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 (NREL, 2008).

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 (NREL, 2008):

$$E = 3.85(0.000075 + 0.00868.\cos B - 0.032077 * sinB - 0.014615 * \cos 2B - 0.004089 * \sin 2B) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq\ 4.2$$

where: B is given by

$$360^0 \frac{(n-1)}{365} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq\ 4.3$$

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 (NREL, 2008):

$$\begin{aligned} cos\theta = sin\ \delta\ sin\emptyset\ cos\beta - sin\delta\ cos\emptyset\ cos\beta\ cos\omega + cos\delta\ cos\emptyset\ cos\ \beta\ cos\omega \\ + cos\delta\ sin\emptyset\ sin\beta\ cos\gamma\ cos\omega + cos\delta\ sin\beta\ sin\gamma\ sin\omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ eq\ 4.4 \end{aligned}$$

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 90^0 when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find a equation for the zenith angle by setting $=0^0$ in the above equation, which yields (NREL, 2008):

$$cos\theta Z = cos\delta\ cos\emptyset\ cos\omega + sin\emptyset\ sin\delta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ eq\ 4.5$$

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 (NREL, HOMER user manual, 2008):

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

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 (NREL, 2008):

$$\bar{G_o} = \frac{12}{\pi} G_{on}\left[cos\emptyset\ cos\delta\ (sin\omega 1 - sin\omega 2) + \frac{\big(II(\omega 2 - \omega 1)\big)sin\emptyset\ sin\delta}{180^0}\right]$$

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 (NREL, HOMER user manual, 2008):

$$K_T = \frac{\bar{G}}{\bar{G}_o} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq\ 4.7$$

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 fro 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 (Beckman, 1980). 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 (NERL, 2008):

$$\bar{G} = \bar{G}_a + \bar{G}_b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq\ 4.9$$

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 (NREL, 2008).

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 (NREL, 2008):

$$\frac{G_b}{G} = \{0.9511 - 0.1604 * K_T + 4.388 * K_T^3 + 12.336\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq4.10}$$

$$\frac{G_b}{G} = \left\{0.9511 - 0.1604.K_T + 4.388.K_{T_{0.165}}^{2^{1.0-0.09.K_T}} - 16.638.K_T^3 + 12.336.\frac{K_T^4}{for}\right\} \ldots \text{eq4.11}$$

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 (NREL, HOMER user manual, 2007).

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

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

The anisotropy index, with symbol Ai, 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 (NREL, 2008)

$$A_i = \frac{\bar{G}_b}{\bar{G}_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq4.13$$

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 (NREL, 2008):

$$f = \sqrt{\frac{\bar{G}_b}{\bar{G}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . eq4.14$$

Therefore, to calculate the global radiation incident on the PV array HOMER uses the following equation by ignoring the effect of temperature, [HOMER, ver., 2.68 beta].

If the effect of temperature on the PV array ignored, HOMER assumes that the temperature coefficient of power is zero.

$$P_{PV} = Y_{pv} f_{pv} \left(\frac{G_T}{G_T}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq4.15$$

where:

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

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

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 Guder 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 chanced in to monthly average. The site gross head is 20 meter. The monthly average stream flow and its pictorial representation is given in Table4.2 below.

Table 4.2 Monthly average Stream flow

Month	Stream flow (I /s)
January	780.0
February	640.0
March	860.0
April	1,010.0
May	1,670.0
June	11,230.0
July	34,260.0
August	45,910.0
September	35,630.0
October	11,190.0
November	2,520.0
December	1,040.0
Average	12,228

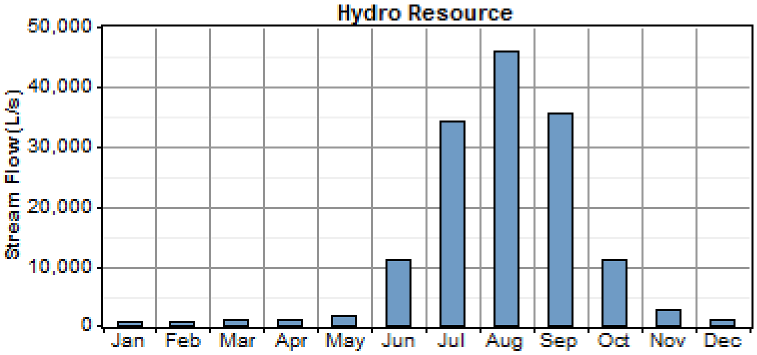


Figure 4.2 Average Stream Flows (14)

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:

$$P_{theo} = \gamma Q h_g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. eq4.16$$

where, $\gamma=\rho g$, 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: [HOMER ver. 2.68 beta]

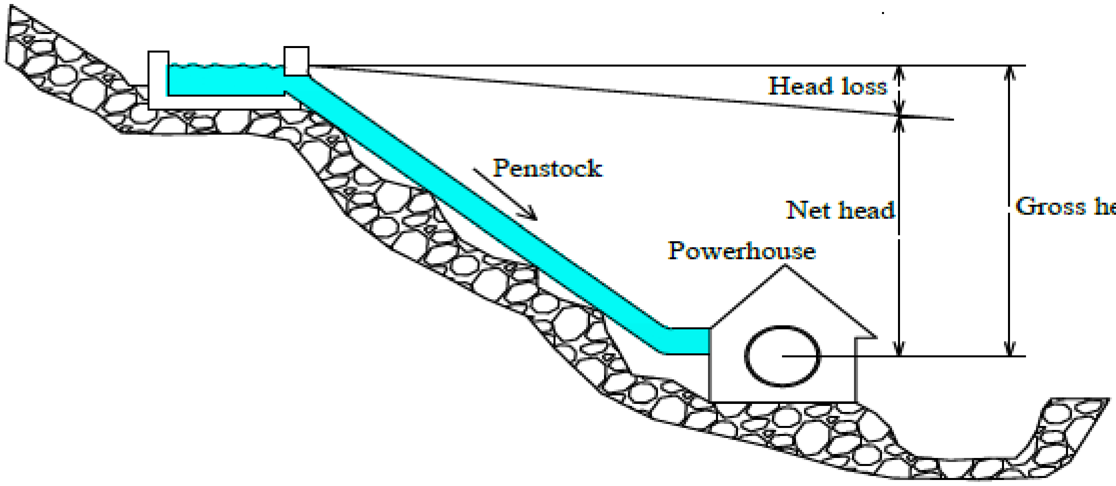


Figure 4.3 Net head after pipe loss

$$h_{net} = h - (1 - f_h) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. eq4.17$$

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 ηt and generator efficiency ηg

$$\eta = \eta_t * \eta_g \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq4.18$$

The practical power output is estimated as follows:

$$P = \eta\gamma Q_{es} h_{net} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq4.19$$

where Q des is the design flow rate of the micro-hydro power, which is 0.6 m3/s assumed, hence the annual energy of the hydropower is calculated as follows:

$$Annual\ energy\ production \left(\frac{kWh}{year}\right) = power * \frac{365days}{year} * \frac{24days}{1000} \dots\dots\dots\dots\dots. eq4.19$$

Based on the above mathematical analysis the total energy produced by the micro –hydropower without considering the efficiency of hydro turbine is 1,041,637kWh/year. Assuming 80% turbine efficiency and pipe head loss of 10%, the annual energy production becomes 825,192 kWh/year. The primary load of the village is 703,570kWh/year. From this discussion, the hybrid system totally meets the energy demand of the village.

Chapter Five

5. 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 and diesel generator. 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, [Ali B. et al, 2012].

The hybrid system studied in this thesis is one combining solar PV and micro hydro with bank of batteries and diesel generator during on demand scan for critical loads, like clinic and water pumping, which are included from backup purposes and emergency purpose respectively. 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, [Patel, 2006].

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 [Patel, 2006].

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, [Getachew, 2009].

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 with including a diesel generator as a standby system.

The charge controller will charge the batteries with energy from PV modules and hydropower. The main objective of PV/ micro hydro hybrid system is to provide clean, efficient and sustainable power to from freely available renewable energy. The diesel generator operates only when the system totally blackout and provide power for critical loads only. The diesel generator does not considered as major part of the hybrid system rather as a standby source.

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 [HOMER, ver. 2.68 beta]. 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 874 households currently living in village, with an average five members per family were considered based on the data obtained from Guder Wereda 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 and diesel generator 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 power conditioning units are dc-dc and ac-dc converters, with the sole purpose of matching the PV and batteries voltages to that of the bus voltage at the dc bus. The primary load is an electric demand that must be served according to a particular schedule discussed earlier.

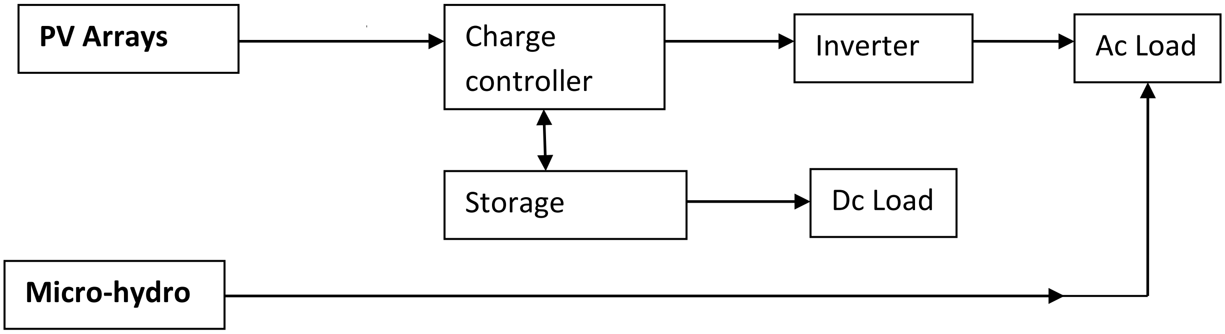


Figure 5. 1 Block Diagram of PV-micro hydro hybrid system proposed

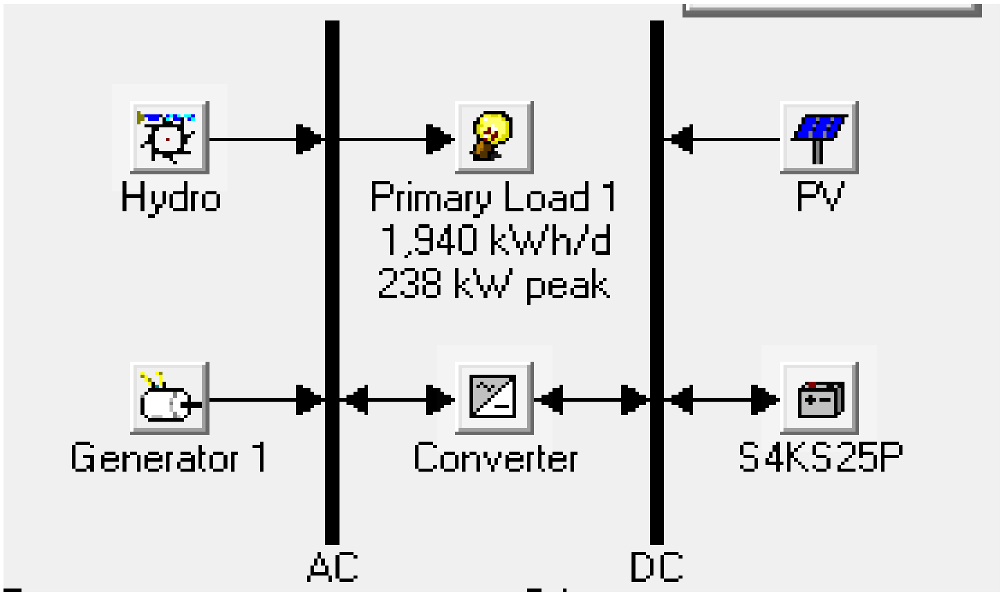


Figure 5.2 Equipment considered and system configuration for HOMER

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 [HOMER user manual].

- **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 size of each generator
- The number of batteries
- The size of the dc-ac converter
- The dispatch strategy

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, [HOMER user manual].

- **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 fuel 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 or price of the diesel 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, [HOMER, user manual].

5.2. Design of Standalone PV/micro-hydro/battery hybrid system

A hybrid power system for Mogno Keshenbel village is designed where photovoltaic module has been combined with micro- hydro, battery, and diesel generator as a backup unit. 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 generator 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.

Primary load: primary 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 [HOMER user manual].

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. [Getachew, 2009]. 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 874 households with an average five members per family. Out of 874 households, 200 households are large class and the rest are small/medium classes based on the data obtained from Guder Wereda Administration.

The system is autonomous (off-grid) and can serve ac and dc electric loads, [HOMER user manual].

System that contains a battery bank and one or more generators required a dispatch strategy, which is a set of rules governing how the system charges the battery bank. The simulation process serves two purposes. First, it determines whether the system is feasible. The feasible system is one, which can adequately serve the electric demanded and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The lifecycle cost is a convenient metric for comparing the economics of various system configurations.

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, such as the annual fuel consumption, annual generator operating hours, 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, the cost of maintenance and fuel [HOMER user manual].

- **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 **536.02 kWh/day.**

The total energy daily energy demand for school is **3.94 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 **140 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). Thus, the daily electrical energy schedule pattern is that given in appendix E

Fuel: HOMER provides a library of several predefined fuels, and users can add to the library if necessary. The physical properties of a fuel include its density, lower heating value, carbon content and sulfur content. The user can also choose the most appropriate measurement units, L, m^3 or kg. The two remaining properties of the fuel are the price and the annual consumption limit.

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, and Diesel generators are examples of components. Other auxiliary are things considered like converters, battery bank [HOMER user manual].

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. The power output of the PV array is calculated using the following equation [HOMER, Ver., and 2.68 Beta].

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \left[1 + \alpha_p \left(T_c - T_{c,STC} \right) \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. eq\ 5.1$$

Where Y_{pv} is the rated capacity of PV array (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), p a is the temperature coefficient of power (% ^{o}C), T_c is the PV cell temperature in the current time step (^{0}C), and T_C STC, is the PV cell temperature under standard test conditions (25^{o}C)

If the effect of temperature on the PV array is not considered, the above equation simplified:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; eq\ 5.2$$

The rated capacity (sometimes called the peak capacity) of a PV array is the amount of power it would produce under standard test conditions of 1 kW/m^2 irradiance and a panel temperature of 25^{o}C, the derating factor is a scaling factor meant to account for effects of dust on the panel, wire losses, elevated temperature, or anything else that would cause the output of the PV array to deviate from that expected under ideal conditions. The key selection criterion for the PV system is the cost and rating at standard test condition.

To calculate the PV output of a Photovoltaic Module, HOMER uses eq5.1 if effect of PV temperature is considered; however, if temperature effect is ignored HOMER uses eq5.2. For this study, the effect of PV cell temperature is ignored.

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 20m and design flow of 600 liter/second (0.6m^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 (www.alibab.com)

Diesel Generator as a backup unit on demand scan

The diesel generator in this hybrid system acts as the secondary power source. It is set to support the PV when they are not producing enough electricity to meet the load. Diesel generators are cheaper to install but have higher operational costs than the wind turbines and batteries therefore; they are run for as few hours as possible.

One diesel generator was chosen and different sizes were considered for simulation, from 0-35 kW. This allows the software to select the most economical generator capacity for the system. The capital cost for the generator was set at 500 USD / kW, cost of replacement at 400 USD per kW and 0.05 USD per hour is the operation and maintenance cost excluding fuel cost [33].

The diesel generator fuel consumption depends on the output power. A generator consumes fuel to produce electricity, and possibly heat as a byproduct. In this study, generators are used as a standby purpose whenever the renewable energy source does not meet the demand. The principal physical properties of the generator are it maximum and minimum electrical power output, its expected lifetime in operating hours, the type of fuel it consumes, and its fuel curve, which relates the quantity of fuel consumed to the electrical power produced. The fuel curve is a straight line with a y-intercept and uses the following equation for the generator's fuel consumption [HOMER, ver.2.68 Beta].

$$F = F_o Y_{gen} + F_1 P_{gen} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; eq\ 5.3$$

where: F is fuel consumption in liters (L), F_0 is generator fuel curve intercept coefficient (L/hr/kW rated), F_1 is generator fuel curve slope (L/hr/kw), Ygen is rated capacity of generator (kW), and Pgen is output of the generator in this hour (kW).

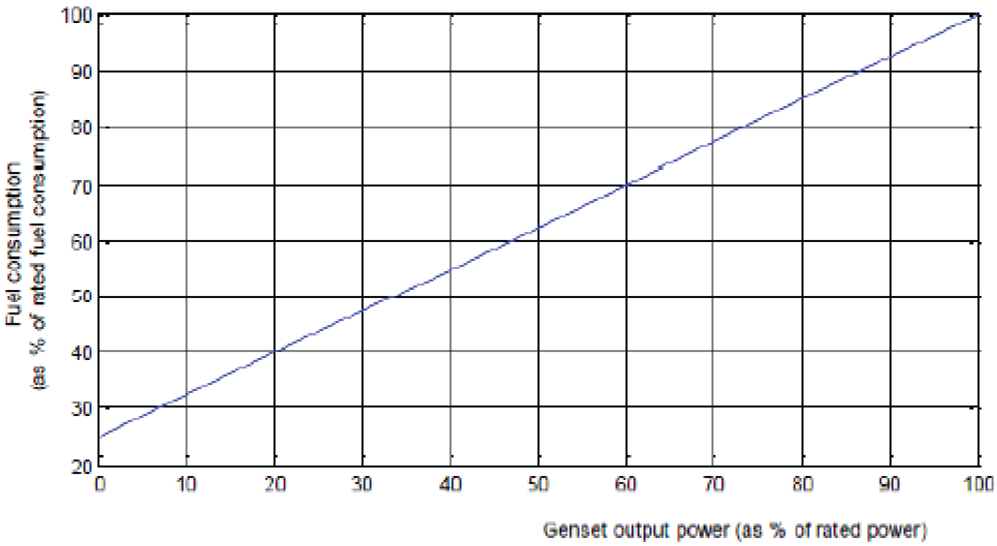


Figure 5.3: The typical fuel curve of Diesel generator [Leake, 2010]

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. The technical specification of the battery has been given in Appendix B.

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.

- **Dispatch strategy**

In addition to modeling the behavior of each individual component, how those components work together as a system has been simulated. That requires hour-by-hour decisions as to which generators should operate and at what power level, whether to charge or discharge the batteries. In this section, the logic used to make such decisions is described briefly. A discussion of operating reserve comes first because the concept of operating reserve significantly affects dispatch decisions.

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% o 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 dispatchable sources that can serve the loads equally well, the one that does so at the lowest cost is chosen.

Dispatch strategy: the economic dispatch logic described in the previous section governs the production of energy to serve loads and hence applies to all systems. But for systems comprising both a battery bank and a generator, an additional aspect of system operation arises, which is how the generator should charge the battery bank. This battery-charging logic cannot be based on simple economic principles, because there is no deterministic way to calculate the value of charging the battery bank.

HOMER provides two simple strategies and lets the user model them both to see which is better in any particular situation. These dispatch strategies are called load following and cycle charging. Under the load-following strategy, a generator produces only enough power to serve the load and does not charge the battery bank. Under the cycle-charging strategy, whenever a generator operates, it runs at its maximum rated capacity and charges the battery bank with the excess. Both cycle-charging (CC) and load-following (LF) dispatch strategies are analyzed to determine which is optimal in a given situation.

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. Resource inputs are summarized in Table 5.2.These inputs are the principal guidelines for selecting the size of the power components. 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

No	PV	Hydro turbine	Diesel Generator	Battery(Surrette6CS25P)	Converter
Size of Energy equipment	1kW	1kW	1kW	1156Ah,6V	1kW
Capital cost($)	2,750	682	500	1250	900
Replacement Cost($)	2500	545	400	1100	900
O$&M cost($/yr)	5$/yr	27	0.05$/hr	15$/yr	18
Size considered(kW)	0,25,30,35,40			16,24,32,40, 48,56,64,72, 80,130	0,30,35,40,45,50
Quantities considered	-	-	-	48	-
Life times	25 yrs	25yrs	12000 hrs	9,645kWh(lifetime thought)	15 yrs

For this analysis, Diesel is considered as the generator fuels with price of 1.0 USD to 1.5 USD per liter. The current Diesel price is about 1.0 USD per liter and considered in the analysis. The efficiencies of inverter and rectifier are assumed as 90%. The project lifetime is 25 years, and the interest rate is assumed the present rate, 5-6%.

Other important inputs 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:

$$D_{grid} = \frac{C_{NPC}.CRF\left(i, R_{proj}\right) - C_{power}.L_{tot}}{C_{cap}.CRF\left(i, R_{proj}\right) + C_{om}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..eq\ 5.4$$

where: C_{N}pc, 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_{com} operation and maintenance cost is interest rate.

In order to compare standalone system with grid extension we can use the exciting grid as standard bench mark reference and the capital, replacement and operation and maintenance costs are $125,000, $2500 and 0.06$/kWh respectively [EEPCO].

Table 5.2 Resource inputs to HOMER

Resources	Average value	Data Source
Solar radiation	6.01kW/m2/d@8.57lat and 37.45 E long	NASA
Stream flow	12320 liter/second	Ministry of water &Energy
Diesel	1.0,1.5 $/liter	From local market
Head	20m	GPS site measurement
Primary load	1940kWh/day,80.8 kW average,238 peak	Homer

Design flow	600 liter/second	After trial of several simulation

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, a battery bank and a diesel generator for backing up the system. State of charge (SOC) of batteries is used as a measure for the performance of the system. The running time of the diesel generator is determined by the SOC of the batteries. In this method it is shown that the usage of micro hydro electricity is maximized, the size of the components is optimized and the size of PV module and the amount of fuel used for the diesel generator is minimized.

Micro hydro power is the largest supplier of energy to this system and the fluctuation of the household demand fluctuation, are the only external variables influencing the system the steam flow is very low during January and February. The base load is covered by firmly available micro hydro plant that is 80.8kw base load easily met by micro hydropower of 94.2kw.

The PV systems share only 6% of the hybrid system. Hence Micro hydro only satisfy the Energy demand of the village ,However ,PV with battery banks share some of the loads during low flow period of January and February. We assumed diesel generator and battery banks are 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 diesel fuel price, 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 effect is discussed in sensitivity analysis. 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 1940kwh/d, that is 80.8kW average power and the peak of the village is 238kW 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 of 34.8%. 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

6. 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 equipments and installation them), and other costs are incurred at later times (includes costs of fuel if exists, operation and maintenance). The later costs may occur t 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) [source Rai, G.D. (2005), Solar Energy Utilization. (5th edition), Delhi: Khanna publishers.

$$PWV = PWF * C_0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots eq\ 6.1$$

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

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 or fuel cost.

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

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, fuel and/or operation costs, and salvage costs or salvage revenues. Initial costs include purchasing the following equipments required by the hybrid system: hydro turbine, PV modules, batteries, diesel generator, 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.

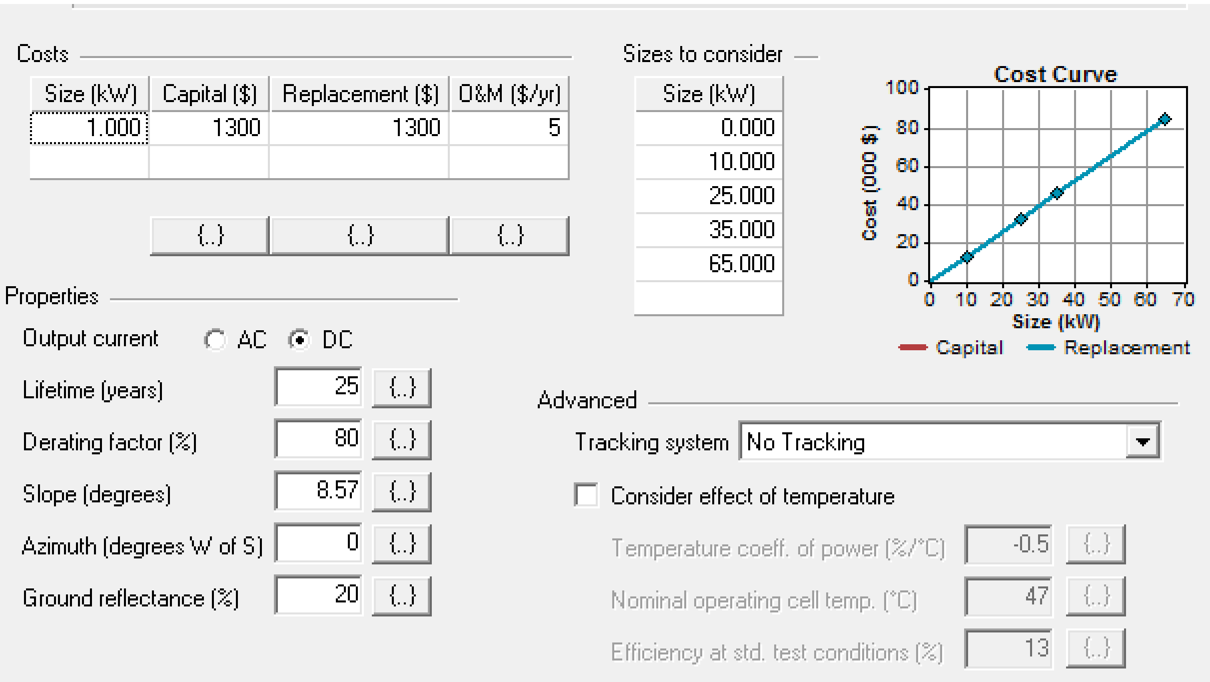
$$capital\ cost\ (1kW) = PVs + installation\ (labour + civil\ work\ and\ material) cost$$

$$capital\ cost\ (1kW) = \frac{\$700}{kW} + \frac{\$600}{kW} = \$1300$$

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 [www.affordable-solar.com].

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. As there is very little maintenance required for PV, only $5/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^o with the slope of 8^o57^0



Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	1300	1300	5

Sizes to consider

Size (kW)
0.000
10.000
25.000
35.000
65.000

Properties

Output current ○ AC ● DC
Lifetime (years) 25
Derating factor (%) 80
Slope (degrees) 8.57
Azimuth (degrees W of S) 0
Ground reflectance (%) 20

Advanced

Tracking system No Tracking
☐ Consider effect of temperature
Temperature coeff. of power (%/°C) -0.5
Nominal operating cell temp. (°C) 47
Efficiency at std. test conditions (%) 13

Figure 6.1. PV panel cost inputs

Table 6.1 Price list of PV module for different brands generator price list (in USD): source [solar energy price list retrieve on [http://www.ecobusinesslinks.com/surverys/free-solar-panel-price-survery/].

Solar panel brand	**Peak power watts**	**Total wattage**	**Cost US$ per solar panel**	**Total cost**	**P=poly M=mono T=Thinfilm**	**%=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	$2,645.50	T	12.00%	$0.73	Civil solar
Sun tech STP245-20/Wde	245	245	$183.30	$183.30	P	15.10%	$0.75	Solar syz
Canadian solar CS6P-245P	245	5880	$191.10	$4586.40	P	15.23%	$0.78	GoGreen solar com
REC solar	235	9400	$183.30	$7,332.00	P	14.20%	$0.78	The Solar Buzz
Canadian	245	5880	$191.97	$4607.28	P	15.20%	$0.78	The Solar Buz

solar CS6P-245P								
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	$2,645.50	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
Canadian solar CS6P-250P	250	250	$222.50	$222.50	p	15.54%	$0.89	Affordable solar
Canadian solar CS6X-280P	280	280	$250.46	$250.46	p	16.16%	$0.89	AltE
SUNIVA MVX245 BAA 245W poly BLK	245	980	$218.79	$875.16	p	15.06%	$0.89	Civil solar
Solar world SUNMODULE SW250 MONO	250	250	$225.00	$225.00	M	14.90%	$0.90	AltE
Canadian solar CS6P-250P	250	250	$225.00	$225.00	p	15.54%	$0.90	Beyond oil solar

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
Sharp ND-240QCJ	240	2400	$226.00	$2260.00	p	14.40%	$0.94	Solar wholesale products
Canadian solar CS6P-240P	240	5760	$227.28	$5454.72	p	14.92%	$0.95	Civil solar
Canadian solar CS6P-240P	240	1440	$228.00	$1368.00	p	14.90%	$0.95	Solar wholesale products
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
Canadian solar CS6P-235PX	235	235	$225.00	$225.00	p	14.61%	$0.96	AltE
Conergy	240	6000	$230.00	$5750.00	p	14.40%	$0.96	Solar panel online
	245	245	240.00	$240.00	P	15.23%	$0.98	Beyond oil solar

A maintenance person often collects PV maintenance costs in monthly payments that cover system inspection. For this service we assumed $5/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

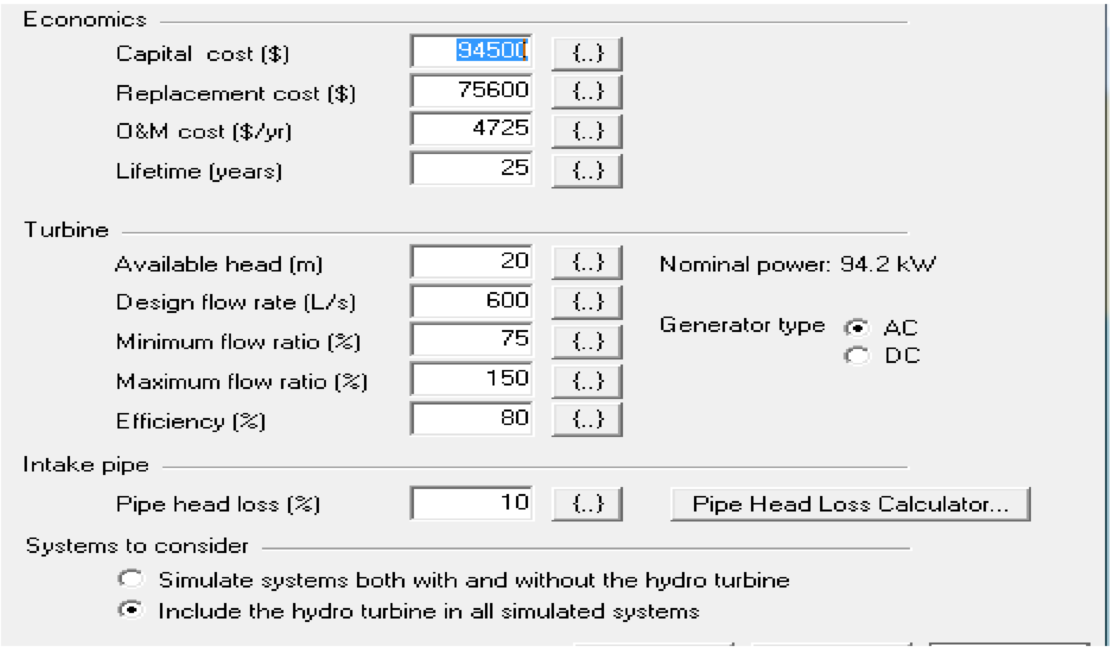
The detailed cost of micro-hydroelectric varies from place to place depending on the project location. For this study, we assume from $400 to $600 per KW of installed capacity. The transportation and civil work add another $600 to $1,000 per kW. In general, expenses are determined by the condition and cost of transportation, civil work, and technology offered in the topographic area. For this project, different micro-hydroelectric generators and civil work costs were investigate and finally capital, replacement, operation and maintenance costs estimated to be $94,500, $75,600, and $4725/year respectively [Alibab.com].

The hydropower is designed for a power output of 94.2kw 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 20m and has a design flow of 600 L/s. the turbine efficiency is 80% and has a pipe head loss of 10%.

Table 6.2 Cost specification and characteristics of hydropower

[http://www.alibaba.com/product-gs/918947497/Cross_Flow_turbine.html]

Type	**Value**	**Properties of hydro turbine chosen**	**Value**
Size established	94.5 kW	Water head (m)	20-100
Capital ($)	95,000	Design flow rate	600l/s
Replacement ($)	76000	Minimum flow ratio %	75
O&M ($/year)	4725	Max flow ratio 9%	150
Life time (year)	25	Efficiency (%)	80
Turbine type	Cross flow	Pipe head loss (%)	20
Life(years)	20-30	Frequency	50hz or 60hz
		Power out puts	5 kW-100 kW



Economics

Capital cost ($) 94500

Replacement cost ($) 75600

O&M cost ($/yr) 4725

Lifetime (years) 25

Turbine

Available head (m) 20

Design flow rate (L/s) 600

Minimum flow ratio (%) 75

Maximum flow ratio (%) 150

Efficiency (%) 80

Nominal power: 94.2 kW

Generator type ● AC ○ DC

Intake pipe

Pipe head loss (%) 10

Systems to consider

○ Simulate systems both with and without the hydro turbine

● Include the hydro turbine in all simulated systems

Figure 6.2 Micro hydro cost detailed

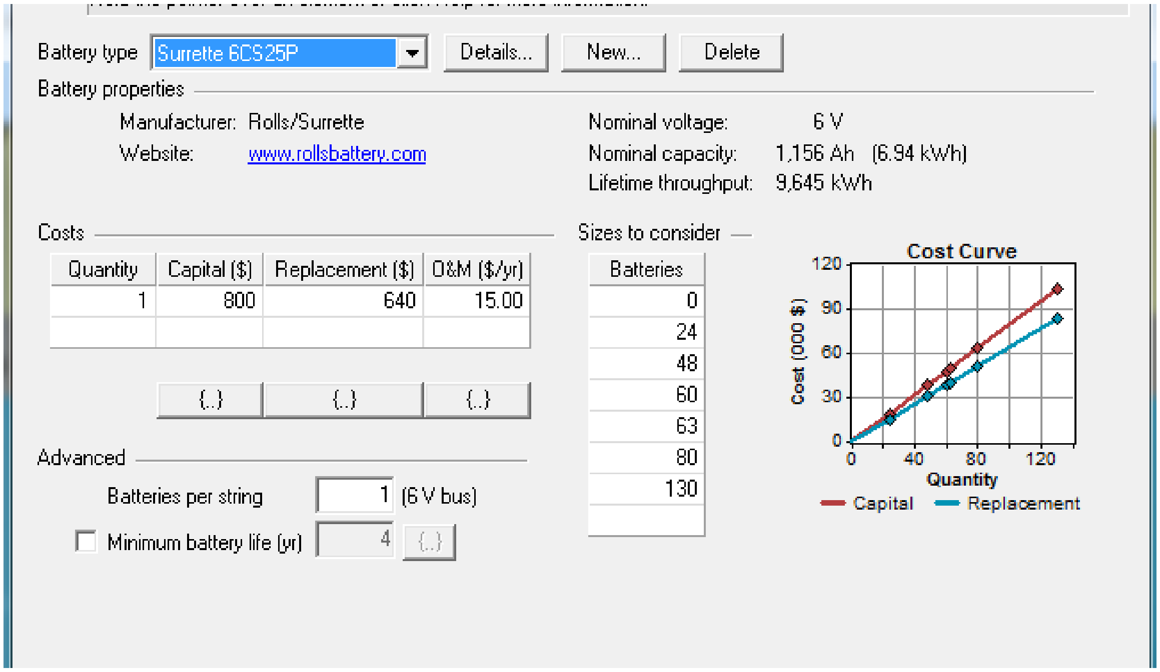
The hydropower is connected Ac Bus line and has a lifetime of 25 years. The capital cost for a 94.2kW plant is taken as $94,500 while the replacement cost and O&M cost are considered to be $75,600 and $4,725 respectively.

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.

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 [Alibab.com].



Battery type: Surrette 6CS25P

Battery properties

Manufacturer: Rolls/Surrette
Website: www.rollsbattery.com
Nominal voltage: 6 V
Nominal capacity: 1,156 Ah (6.94 kWh)
Lifetime throughput: 9,645 kWh

Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	800	640	15.00

Sizes to consider

Batteries
0
24
48
60
63
80
130

Advanced

Batteries per string: 1 (6 V bus)
☐ Minimum battery life (yr): 4

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 6.3 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].

Table6.3 cost of converter

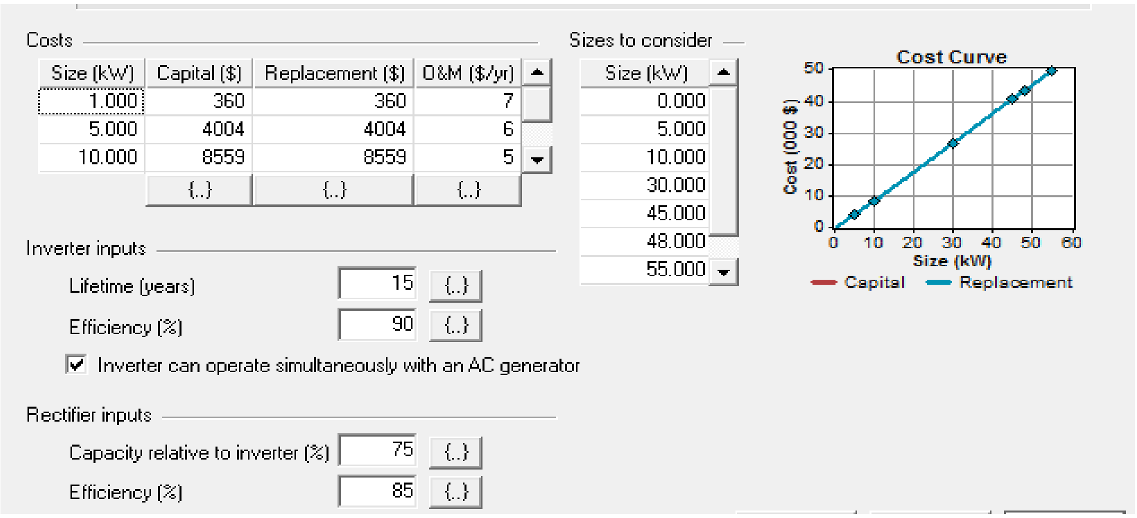
[http://www.ecobusinesslinks.com/surveys/sma-inverters-price-survey-sunnyboy-inverters/]

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 7000us	7000	7000	$2,885.61	$2,885.61	$0.41	Eco distributing
Sunny Boy SB 8000us	8000	8000	$3,250.00	$3,250.00	$0.41	GoGreen solar
Sunny Boy SB 7000us	7000	7000	$2,946.88	$2,946.88	$0.42	Affordable solar
Sunny Boy SB 8000us	8000	8000	$3,387.97	$3,387.97	$0.42	Affordable 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 6.4

Table 6.4 inverter and charge control cost characteristics [18]

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)	Life time (year)
1.000	360	360	0	15
5.000	4004	4004	6	
10.000	8559	8559	5	
50.000	45000	45000	-6	



Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	360	360	7
5.000	4004	4004	6
10.000	8559	8559	5

Sizes to consider

Size (kW)
0.000
5.000
10.000
30.000
45.000
48.000
55.000

Inverter inputs

Lifetime (years) 15

Efficiency (%) 90

☑ Inverter can operate simultaneously with an AC generator

Rectifier inputs

Capacity relative to inverter (%) 75

Efficiency (%) 85

Figure6.4: Converter technical and cost inputs

6.2.5. Costs of Diesel generators

Diesel generator initial costs vary with size, model and design. Table 6.5 shows different types of diesel generators according to their rated power and manufacturer, price of each one, and the cost in ($/kW) for each. It is obvious that cost ($/kW) depends on the design (method of cooling) and rated power and for the same design it decreases as rated power increases. For the range of power taken in this case study analysis, this cost can be considered about 500($/kW) [www.generatorjoe.net].

Table 6.5 Perkins Diesel Generator price list (in USD)

Type	Diesel engine	Rated power KW	Unit price in $ with different generator			
			Chinese	Stamford	Siemens	Marathon
7KW	403C-11G	9.4/8.5	5,074.63	NA	NA	NA
10kW	403C-15G	13.3/12	5,552.24	NA	NA	NA
15kW	404C-22G	20.4/18.5	6,567.16	NA	NA	NA
24kW	1103A-33G	30.4/27.7	7,014.93	NA	NA	NA
50 kW	1104A-44TGI	59/53	11,343.28	12,029.85	11,686.57	11,791.04
75 kW	1104C-44TAG2	98/98	13,880.60	15,074.63	14,776.12	14,686.57
120 kW	1006TAG2	143/129.5	19,253.73	20,835.82	20,626.87	20,447.76
150 kW	1106D-E66TAG4	174/156.7	23,582.09	25,268.66	24,925.37	24,820.90
200 kW	1306C-E87TAG6	239/218	33,134.33	35,000.00	34,328.36	34,626.87
250 kW	2306C-E14TAG1	304/261	35,223.88	37,611.94	36,567.16	37,059.70
300 kW	2306C-E14TAG2	344/304	36,567.16	39,253.73	37,313.43	38,686.57
320 kW	2306C-E14TAG3	387/344	40,597.01	43,134.33	41,194.03	42,552.24
350 kW	2506C-E15TAG1	435/396	49,850.75	52,238.81	51,194.03	52,089.55
400 kW	2506C-E15TAG2	478/435	52,537.31	55,671.64	54,328.36	55,537.31
500 kW	2806A-E18TAG1	556/482	73,731.34	77,358.21	74,776.12	76,895.52
520 kW	2806A-E18TAG2	611/556	80,746.27	84,776.12	82,089.55	84,328.36
800 kW	4008TAG2A	947/861	138,059.70	145,373.13	139,402.99	145,074.63
1000 kW	4012-46TWG2A	1154/1044	202,985.07	210,597.01	204,328.36	209,402.99

The generator is used as a standby application only. As there is a variety of generator available from various manufacturers and distributors, it is difficult to compare all the different information. Here we select Perkin Diesel Generator. As shown in Figure 6.5, the capital cost, replacement cost, O&M costs of a 1kw generator are taken as $500, $400 and $0.05/hr respectively [20]. The costs include the costs of installation, logistics and dealer mark-ups.

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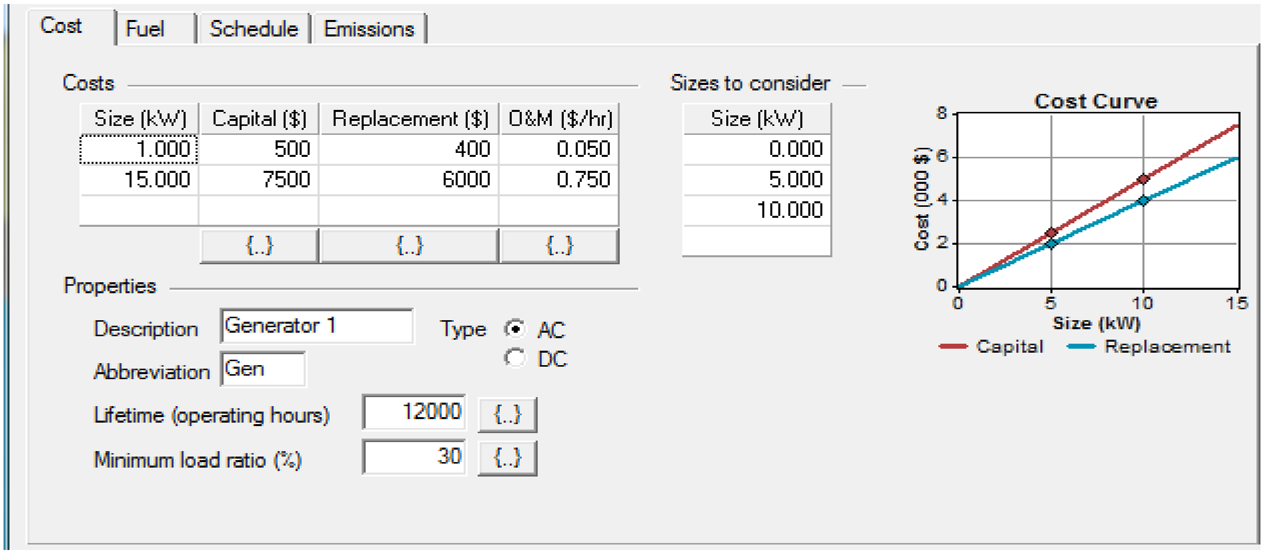


Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1.000	500	400	0.050
15.000	7500	6000	0.750

Size (kW)
0.000
5.000
10.000

Description: Generator 1
Abbreviation: Gen
Type: ● AC ○ DC
Lifetime (operating hours): 12000
Minimum load ratio (%): 30

Figure 6.5 Generator technical and cost parameter

Figure 6.5 also shows the cost curve of the generator, connected to an AC output with a lifetime of 12,000 operating hours. The minimum load ratio is taken to be 30% of the capacity; moreover, HOMER requires the partial load efficiency to simulate this component. HOMER calculates the total operating cost of the generator based on the amount of time it has to be used in a year [21].

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 6.6 Summary of initial cost of Energy Equipment

Energy Equipment	Initial Cost($)
Hydro Turbine	94,500
PV module	45,500
Battery Bank(surrette6CS25p)	64,00
Converter	25,200
Diesel Generator	12,500
Total	241,700

6.3.2. Present worth of fuel, 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 6.7 Summary of Operation and Maintenance cost and Replacement costs

Energy Equipment	Replacement cost($)	Operation and maintenance cost($/yr)
Hydro Turbine	75,600	4,725
PV module	1300	5
Battery Bank	640	15
Converter	360	7
Generator	400	0.05$/hr

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

7. Result, Conclusion and Recommendation

7.1. Result and Discussion

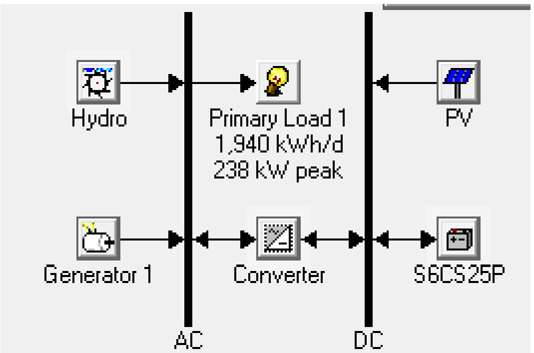


Figure 7.1: Diagram of the project with HOMER

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, converter and Generator 1) 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 Mogno Keshenbel village with latitude and longitude of 8.57 and 37.45 fed into HOMER. Figure 7.2shows 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 0.467 in July to 0.749 a very sunny month that is December.

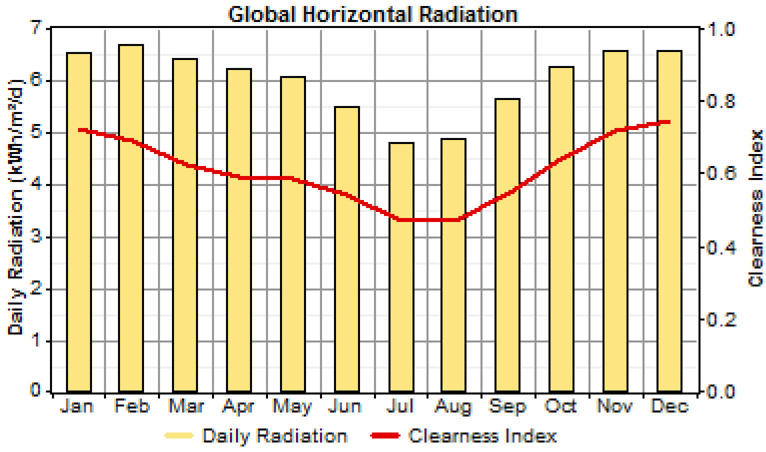


Figure 7.2: Monthly Global Horizontal radiation

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

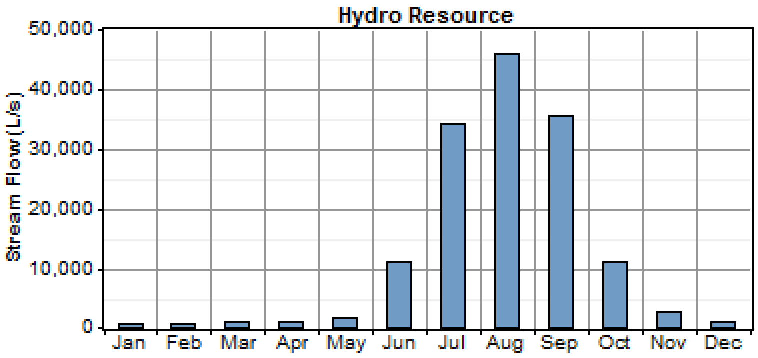


Figure 7.3: Hydro resource of Guder River [MoWIE]

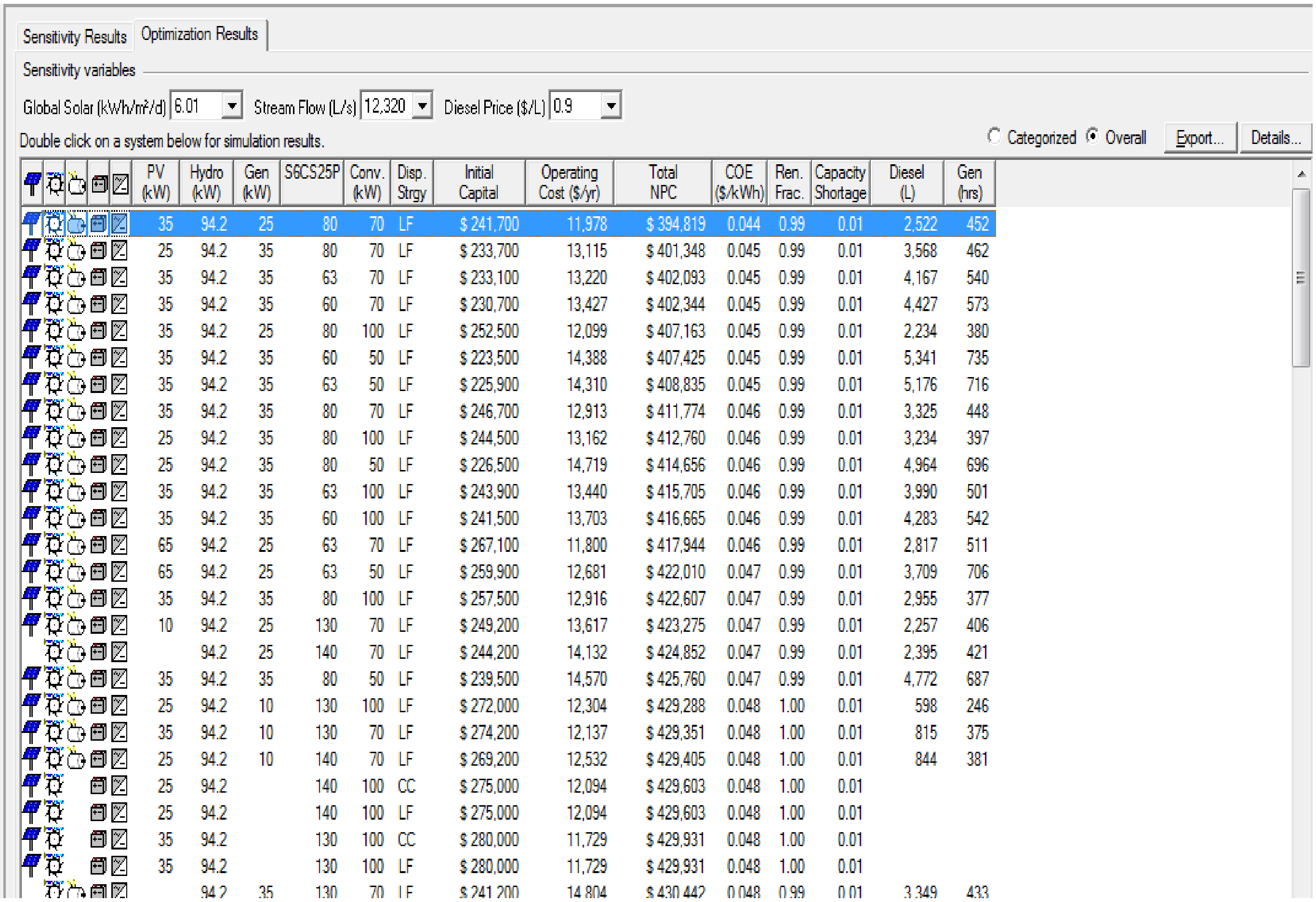
After entering the hydro and solar resource data into software, to determine the optimum solutions from different system configurations, HOMER is run several times by varying decision variables that have effect on the output. The decision variables that affect the output are the size of PV panel, the number of battery bank, the size of converter and the dispatch strategy given in table 6.1. 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 6.6& 6.7) and the solar and hydro resource data for site.

The diesel price is 1.0$/L and the PV capital cost is 1300$/kW. 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, 2013], [Solar panel price, 2013]. 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 diesel price is the current price of diesel in the country and the price of PV is also the current price of PV panels in global market obtained from different websites. The overall simulation table is too long to so only a selected part is shown in Table 7.4 and categorized table in the Table 7.5

7.2. Optimization result

For the off-grid electrification of Mogno Keshenbel village, various combinations have been obtained for the hybrid systems with PV, hydro turbines, MHP, batteries convertors and generators from the HOMER optimization simulation. This is shown in Figure 7.4.

Table 7.4: Overall optimization Result



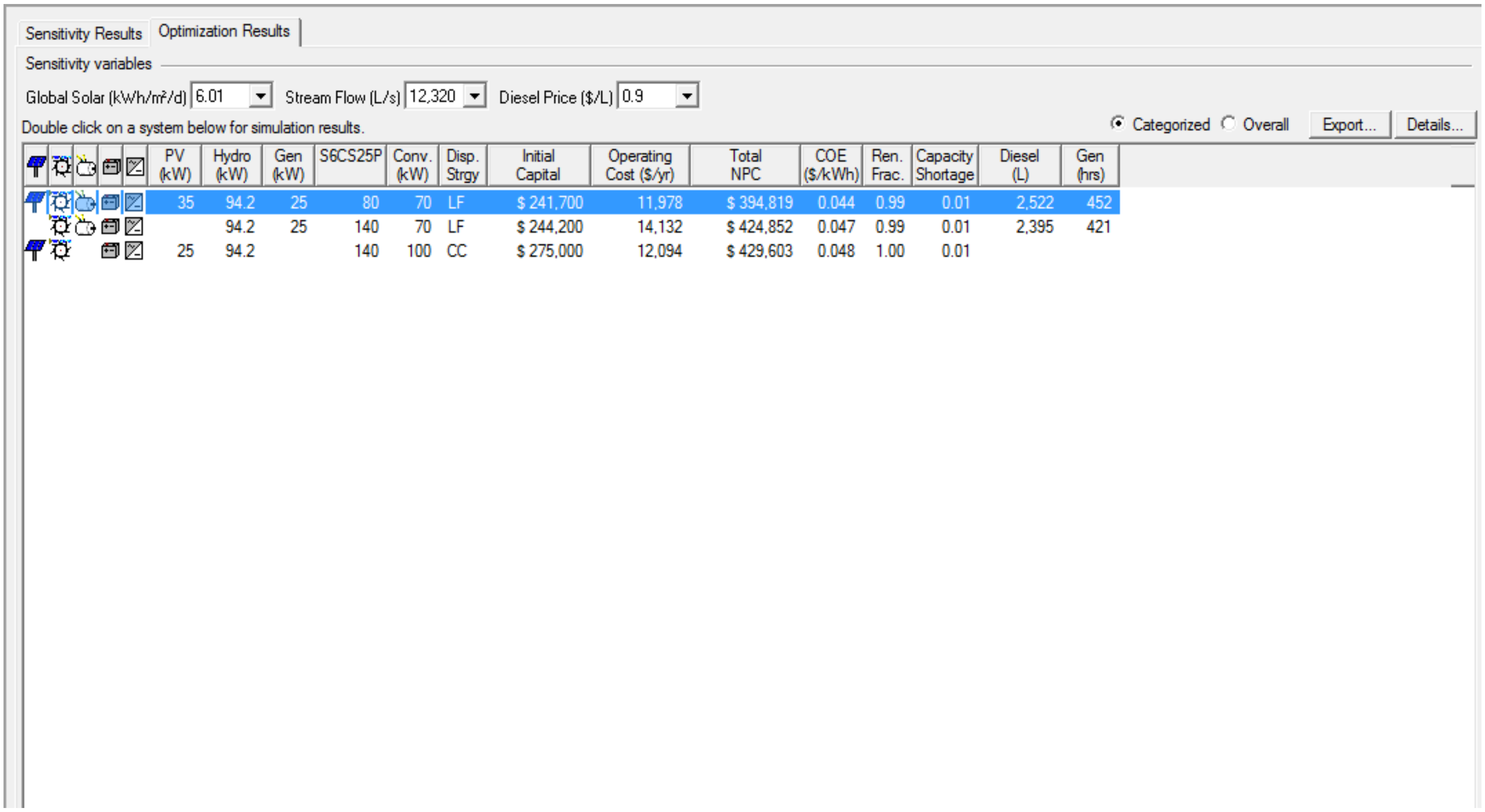
Sensitivity variables

Global Solar (kWh/m²/d) 6.01 Stream Flow (L/s) 12,320 Diesel Price ($/L) 0.9

Double click on a system below for simulation results.

PV (kW)	Hydro (kW)	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen (hrs)
35	94.2	25	80	70	LF	$ 241,700	11,978	$ 394,819	0.044	0.99	0.01	2,522	452
25	94.2	35	80	70	LF	$ 233,700	13,115	$ 401,348	0.045	0.99	0.01	3,568	462
35	94.2	35	63	70	LF	$ 233,100	13,220	$ 402,093	0.045	0.99	0.01	4,167	540
35	94.2	35	60	70	LF	$ 230,700	13,427	$ 402,344	0.045	0.99	0.01	4,427	573
35	94.2	25	80	100	LF	$ 252,500	12,099	$ 407,163	0.045	0.99	0.01	2,234	380
35	94.2	35	60	50	LF	$ 223,500	14,388	$ 407,425	0.045	0.99	0.01	5,341	735
35	94.2	35	63	50	LF	$ 225,900	14,310	$ 408,835	0.045	0.99	0.01	5,176	716
35	94.2	35	80	70	LF	$ 246,700	12,913	$ 411,774	0.046	0.99	0.01	3,325	448
25	94.2	35	80	100	LF	$ 244,500	13,162	$ 412,760	0.046	0.99	0.01	3,234	397
25	94.2	35	80	50	LF	$ 226,500	14,719	$ 414,656	0.046	0.99	0.01	4,964	696
35	94.2	35	63	100	LF	$ 243,900	13,440	$ 415,705	0.046	0.99	0.01	3,990	501
35	94.2	35	60	100	LF	$ 241,500	13,703	$ 416,665	0.046	0.99	0.01	4,283	542
65	94.2	25	63	70	LF	$ 267,100	11,800	$ 417,944	0.046	0.99	0.01	2,817	511
65	94.2	25	63	50	LF	$ 259,900	12,681	$ 422,010	0.047	0.99	0.01	3,709	706
35	94.2	35	80	100	LF	$ 257,500	12,916	$ 422,607	0.047	0.99	0.01	2,955	377
10	94.2	25	130	70	LF	$ 249,200	13,617	$ 423,275	0.047	0.99	0.01	2,257	406
	94.2	25	140	70	LF	$ 244,200	14,132	$ 424,852	0.047	0.99	0.01	2,395	421
35	94.2	35	80	50	LF	$ 239,500	14,570	$ 425,760	0.047	0.99	0.01	4,772	687
25	94.2	10	130	100	LF	$ 272,000	12,304	$ 429,288	0.048	1.00	0.01	598	246
35	94.2	10	130	70	LF	$ 274,200	12,137	$ 429,351	0.048	1.00	0.01	815	375
25	94.2	10	140	70	LF	$ 269,200	12,532	$ 429,405	0.048	1.00	0.01	844	381
25	94.2		140	100	CC	$ 275,000	12,094	$ 429,603	0.048	1.00	0.01		
25	94.2		140	100	LF	$ 275,000	12,094	$ 429,603	0.048	1.00	0.01		
35	94.2		130	100	CC	$ 280,000	11,729	$ 429,931	0.048	1.00	0.01		
35	94.2		130	100	LF	$ 280,000	11,729	$ 429,931	0.048	1.00	0.01		
	94.2	35	130	70	LF	$ 241,200	14,804	$ 430,442	0.048	0.99	0.01	3,349	433

Table 7.5 Categorized simulation result



Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.01 Stream Flow (L/s) 12,320 Diesel Price ($/L) 0.9

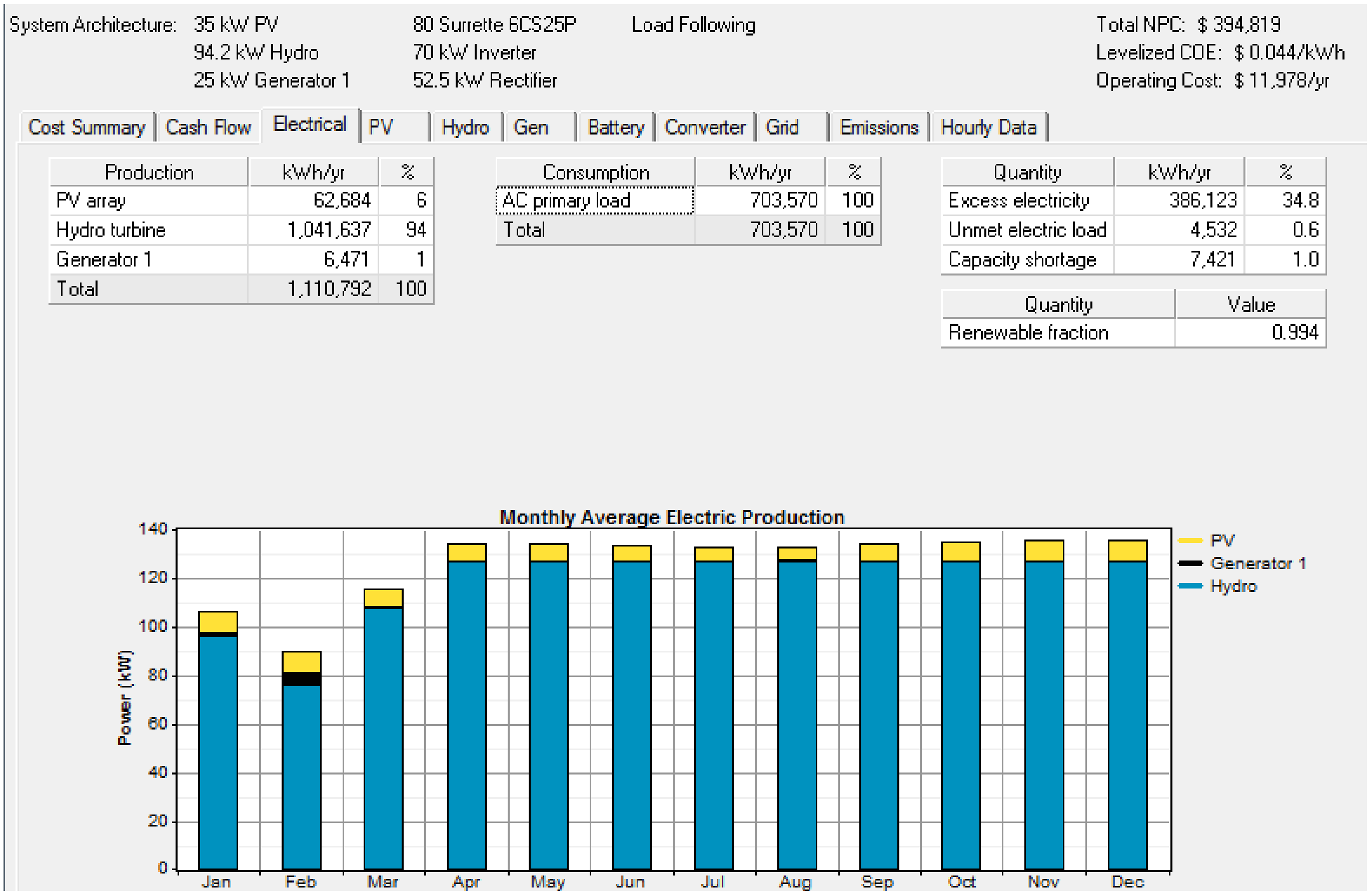
Double click on a system below for simulation results.

● Categorized ○ Overall

PV (kW)	Hydro (kW)	Gen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen (hrs)
35	94.2	25	80	70	LF	$ 241,700	11,978	$ 394,819	0.044	0.99	0.01	2,522	452
	94.2	25	140	70	LF	$ 244,200	14,132	$ 424,852	0.047	0.99	0.01	2,395	421
25	94.2		140	100	CC	$ 275,000	12,094	$ 429,603	0.048	1.00	0.01		

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 0.044$/kWh, and renewable resources fraction is 99% from this we can easily observe that almost the total portion of energy production is from renewable energy sources.

This setup cloud be a good choice for implementation because the system is almost from renewable energy sources. Figure 7.5 shows the monthly average electrical production of this system.



System Architecture: 35 kW PV
94.2 kW Hydro
25 kW Generator 1
80 Surrette 6CS25P
70 kW Inverter
52.5 kW Rectifier
Load Following

Total NPC: $ 394,819
Levelized COE: $ 0.044/kWh
Operating Cost: $ 11,978/yr

Production	kWh/yr	%
PV array	62,684	6
Hydro turbine	1,041,637	94
Generator 1	6,471	1
Total	1,110,792	100

Consumption	kWh/yr	%
AC primary load	703,570	100
Total	703,570	100

Quantity	kWh/yr	%
Excess electricity	386,123	34.8
Unmet electric load	4,532	0.6
Capacity shortage	7,421	1.0

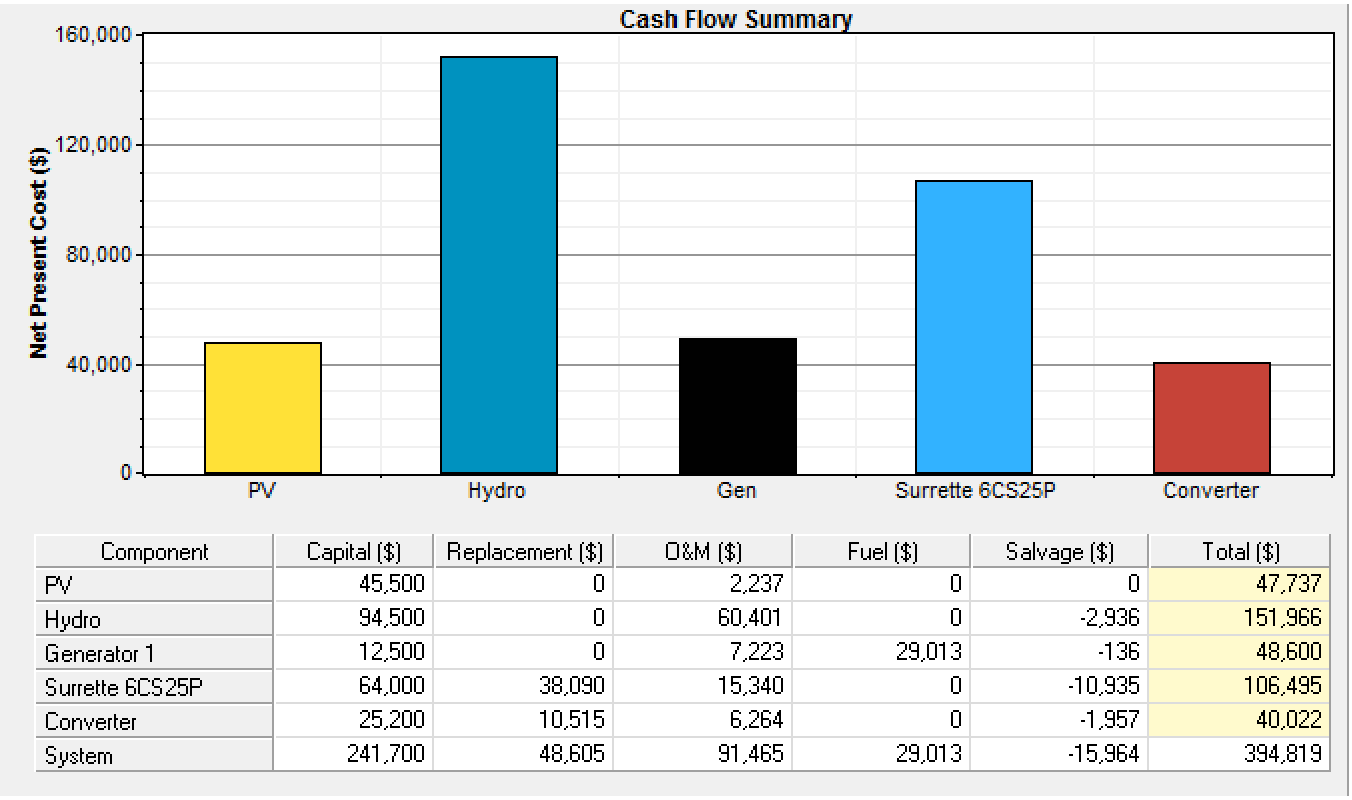
Quantity	Value
Renewable fraction	0.994

Figure 7.6: System architecture and monthly average electric production

The percentage of Energy production of the main energy sources of the hybrid system is shown in Figure 7.4. From the figure the major part of the energy comes from hydropower which is 94% and only 6% share is from PV array and 1% from Diesel generators. This situation implies even if the major part of the energy is supplied by hydro power the Photovoltaic system covers 6% of the total energy demand by the village.

Based on optimization result the most feasible hybrid configuration is 35kW PV, 94.2kW hydropower, 80 Surratt6CS25P battery and 70kW inverter and 52.5kW rectifier. The NPC of the hybrid system is $394,819 and the Levelized cost of energy for the hybrid system is 0.044$/kWh, which is little bit higher than the current electricity tariff of Ethiopia, that is $0.042/kWh [EPCO].

The cash flow summary for the winning system configuration of the village is shown below in Figure 7.5



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	45,500	0	2,237	0	0	47,737
Hydro	94,500	0	60,401	0	-2,936	151,966
Generator 1	12,500	0	7,223	29,013	-136	48,600
Surrette 6CS25P	64,000	38,090	15,340	0	-10,935	106,495
Converter	25,200	10,515	6,264	0	-1,957	40,022
System	241,700	48,605	91,465	29,013	-15,964	394,819

Figure 7.7 Cash flow summary for hybrid system and system cost break down per year for hybrid system

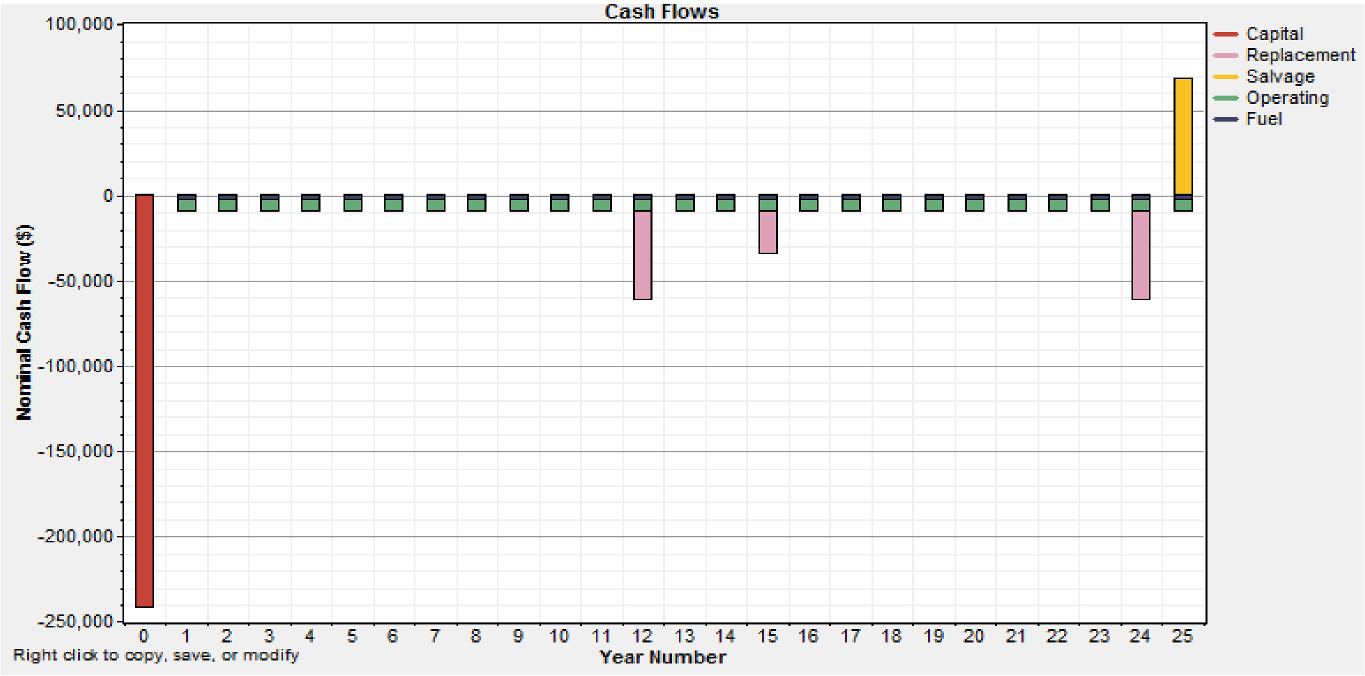


Figure 7.8 Yearly cash flow summaries by cost type

7.3. Sensitivity simulation result

This model shows how micro-hydro systems integrate with Photovoltaic system and battery in a stand-alone application.

Sensitivity analysis was carried out and Figure 7.7 shows the variation of stream flow against global solar radiation at fixed diesel price, the most cost effective set up for a particular set of hydro and battery is also included.

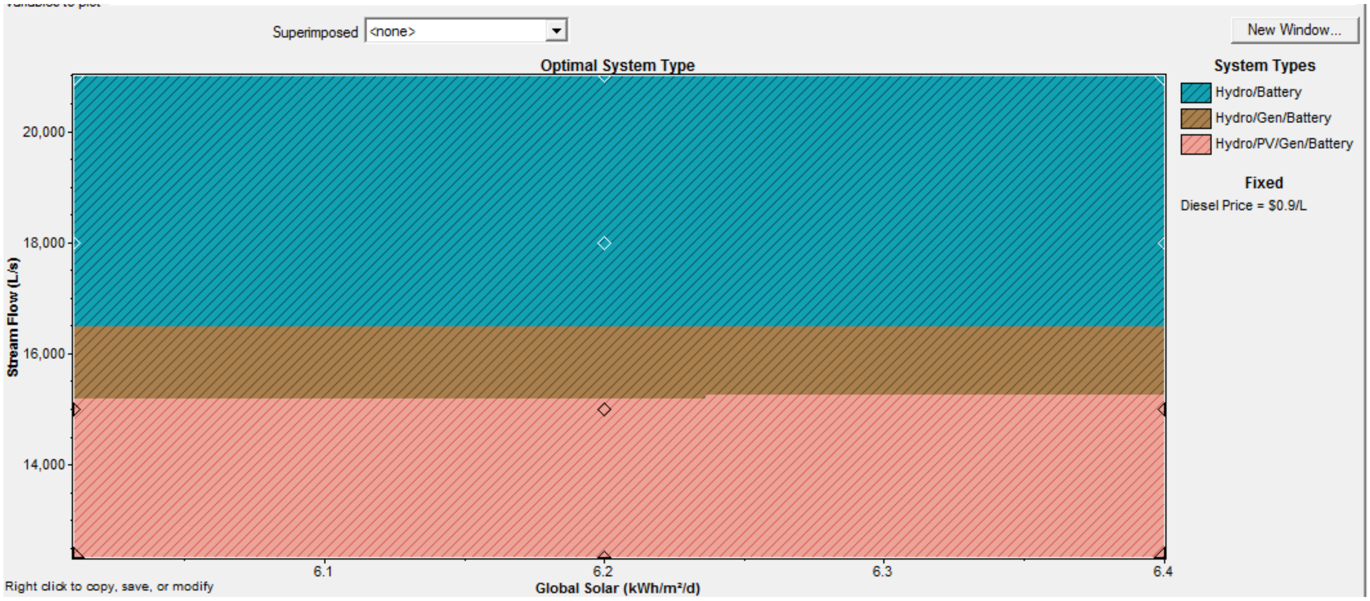


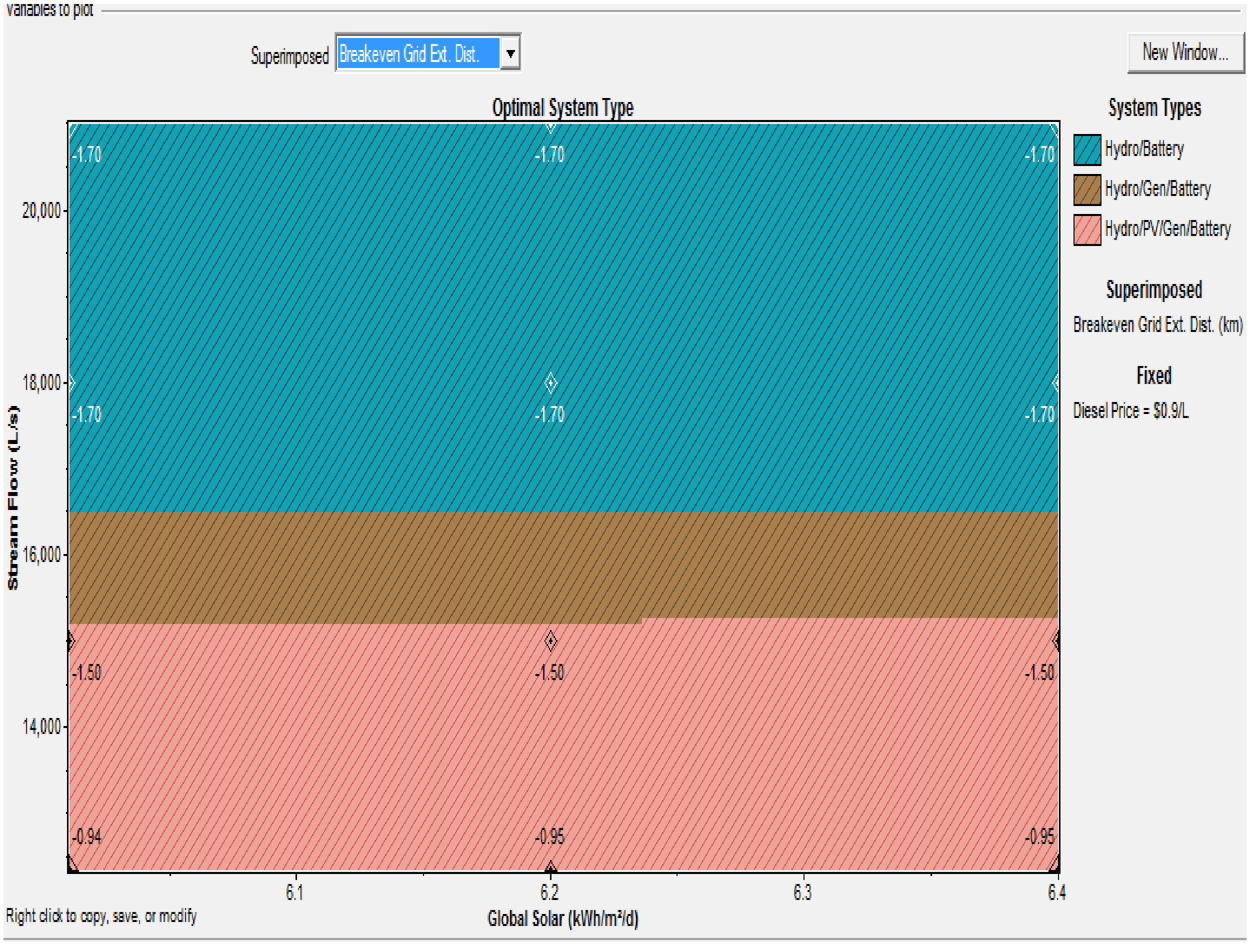
Figure 7.9: Sensitivity of stream flow and global radiation with some NPC

In this Figure, it can be seen that the hydropower plays big role in supplying energy to the community. At this point, it must be known that this is not due to less solar radiation availability; rather it is because of enough water, which can Supply the village used. From Figure 7.7, it is observed that for a stream flow lies between 16,500 liter/second Homer suggests hydro/ battery/ systems is favorable while for stream flow between 16,500 liter/second and14,500 liter/second hydro/Gene/battery is the most favorable configuration. But For a steam flow greater 14,500, liter/second and if solar radiation is ample Homer Combines Hydro/PV/Gen/Battery is an alternatives.

7.4. Comparing standalone system beside the grid extension

The distance from the gird, 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 assumes that load can be supplied either by the stand -alone system or by grid extension. The graph compares the costs of these two possibilities. The cost of the stand- alone system is independent of the grid extension distance, where as the cost of extending the grid does depend on the grid extension distance. The distance at which the cots equate is the breakeven grid extension distance.



Superimposed: Breakeven Grid Ext. Dist.

Diesel Price = $0.9/L

Figure 7.10 Superimposed Breakeven grid distance

The intercept of the grid extension cost curve corresponds to the cost of supplying power to the load. The slope corresponds to the net present cost of grid extension in $/km. The sensitivity result with superimposed breakeven grid extension is shown in figure 7.8. However, for this study the break-even grid extension is negative, which implies the off-grid is the best option.

If the Sensitivity variables of range of solar radiation is 6.01 to 6.4kwh/m^2/d and stream flow range is from 12320 to 21000 liter per second, Diesel price varies from 0.9 to 1.2$/liter, Nearer to the grid, grid extension is optimal. On the other hand, farther away from the grid standalone system is the best option. In this study, the economic distance limit is negative, which implies grid connection is not an option.

7.5. Conclusion

This thesis aimed to investigate and design a hybrid power generation system which comprises of PV arrays, Micro hydro with battery banks and power conditioning to answer the research questions raised in the begging of the thesis, is the hybrid system technically feasible and a cost effective system configuration? 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. The study of the renewable potentials of the site is based on the recently recorded data of twenty-two years average solar radiation data obtained from the NASA surface metrology [NASA, 2013], and 29 years (from 1980-2009) average stream flow obtained from Ministry of Water, Irrigation and Energy. Regarding solar energy potential there is no accurately recorded solar radiation database in the country, instead only few years solar duration for only three month measured with a very poor grade instrument data was available. Due to this reason, we used data obtained from NASA surface Metrology. HOMER does the analysis of the renewable energy resources. From the results, the 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 panel also ensure the unforeseen increase in energy demand for the society . Therefore, it is a viable option incorporated PV, and battery. The results also confirmed the availability amble solar energy at the site with an average radiation of 6.01kWh/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 is proposed in the Thesis. From the simulation result the majority of the energy is obtained from

hydropower, which accounts 94% and the PV module covers only 6% of the total load consumption. Hence the PV 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 12,320 liters/second and solar radiation potential of 6.01kWh/m^2/day, The hybrid system is cost competitive with 0.044$/kWh, this is less than the current grid price of Ethiopia 0.06$/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.

7.6. 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 huge 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 green house 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 Guder Wereda administration in Oromia region and it does not cover all around Oromia region. 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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