ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

Department of Electrical and Computer Engineering

Design of Standalone (PV/Micro-Hydro/DG) Hybrid Power Supply for off Grid Rural Community – A Case Study of Maji District (Tum) in South Nation Nationality People Region (SNNPR).

A thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical and Computer Engineering (Electrical Power Engineering Stream)

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Advisor: Dr - Ing. Fekadu Shewarega

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Declaration

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

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This thesis work has been submitted for examination with my approval as a university advisor.

Dr - Ing. Fekadu Shewarega ___________________

Advisor's Name Signature

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Emebet Tolcha

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NOMENCLATURE

a	Regression coefficient
AC	Alternating Current
b	Regression coefficients
CC	Cycle Charging
CFL	Compact Fluorescent lamp
COE	Cost of Energy ($/kWh)
CSA	Central Statics Agency
DC	Direct Current
DG	Diesel Generator
EEP	Ethiopian Electric Power
EEPCO	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
ETAP	Electrical Transient Analyzer Program
g	Gravitational acceleration (9.81 m/s2)
G_0	Extraterrestrial irradiance at any angle of incidence
G_{on}	Extraterrestrial irradiance at normal incidence
GPS	Global Position Surface
Gsc	Solar constant equal to 1367 W/m^2
H	Monthly average daily solar radiation on a horizontal surface
H o	Monthly average extraterrestrial daily solar radiation on a horizontal surface
HOMER	Hybrid Optimization Model for Renewable Energy
I	The load current (A)
I_D	The diode current (A)
I_L	Current produced by the cell (A)
I_{mp}	Maximum power current (A)
I_{mpp}	Current at maximum power point
I_0	Reverse saturation current of the diode (A)
$I_{sc(G)}$	The short circuit current at radiation level G (A)
I_{sh}	Current through the shunt resistance (A)
I-V	Current versus Voltage
LCOE	Levelized Cost of Energy
LF	Load Follows dispatch strategy
MHP	Micro Hydro –Power
MPP	Maximum Power Point
MoWIE	Ministry of Water, Irrigation and Energy
N	Monthly average daily hours of bright sunshine
n	Monthly average of the maximum possible daily hours of bright sunshine
NASA	National Aeronautics and Space Administration
n_d	Number of days
NPC	Net Present Cost
NPV	Net Present Value
NREL	National Renewable Energy Laboratory

P_p	Peak power of the solar panel (W_P)
P-V	Power versus Voltage
PV	Photovoltaic
PV gis	PV Geographical Interface System
RES	Renewable Energy Sources
RET	Renewable Energy Technology
S	Solar time in hour
SHP	Small Hydropower
SNNPR	South Nation Nationalities People Region
STC	Standard Test Condition
SWERA	Solar and Wind Energy Resource Assessment
δ	Declination angle
€	Euro
ϕ	Latitude angle
ω_s	Sunset hour angle
$	United States Dollar

Abstract:

Off-grid electrification from available renewable energy resources with hybrid power supply is the best solution for rural town (village) where grid extension is found costly and infeasible. This thesis studied the feasibility of the main renewable energy resources available for the electrical production in the administrative city of Maji district (Tum) under Bench-Maji Zone in south Nation Nationality People Region (SNNPR) of Ethiopia.

Even though Tum is the capital city of Maji district, the task of electrification via grid system has been found very difficult till to date for the main reason that its location is far from the nearest substation which is about 174KM. Kerosene has been used for lighting for most of the communities in the town; diesel power generation for milling and rarely for lighting and TV's; leaving biomass for cooking and dry cells for radio. In 2008, a local private company initiated to provide electricity to the whole district which unfortunately could not be realized.

In this thesis, feasibility of renewable energy resources for electric supply system to Tum has been studied using HOMER software as optimization and sensitivity analysis tool. Meteorological data from National Meteorological Agency of Ethiopia and other sources, such as NASA and PVgis, have been used for comparison of the result obtained by analytical method to estimate the solar energy potential of the area.

Electric load for the basic needs of the community, such as lighting, radio, television, electric baker, water pumps and flour mills, have been estimated. Schools, churches, mosques and health centers are also considered as energy users of the community services. The result from Homer simulation showed that micro hydro is the first best optimized system and DG/ Micro hydro the second categorized hybrid system. PV/Micro hydro is found the third and PV/Micro hydro/DG hybrid the fourth categorized result from homer optimization result based on the NPC.

The cost of energy for the first, second, third and fourth optimization results of categorized display are \$0.058/kWh, \$0.058/kWh, \$0.060/kWh and \$0.061/kWh respectively, which is of course extremely incomparable with what the communities are paying now for diesel generator owner that is estimated at 1.46/KWh for the usage of one lighting bulb only but higher than a grid selling price of Ethiopian Electric Utility (EEU) for domestic load which is about \$0.027/KWh.

Moreover, load flow analysis is studied using ETAP software to know power flow of the designed power system. A one line diagram is presented as the outcome of the design and after the simulation; the power flow is indicated on it. It includes mainly 33KV and 400V voltage levels. The result shows generation supplies the load plus losses on the system, bus voltages are maintained to near nominal value, the system is not over loaded

Key words: Solar radiation, Hybrid, HOMER, Micro Hydro, DG, Load Flow.

CHAPTER ONE

1.1. INTRODUCTION

Energy is a central to achieve the interdependent economic, environmental and social aims of sustainable human development. Like in many other Sub-Saharan countries, Ethiopia's energy sector depends highly on biomass. The link between energy and the economy has never been more evident than now when energy-related events tend to impact on a country's economic performance. Electricity is a basic requirement to sustain our industrial, commercial and to a certain extent, agricultural activities. There is no doubt that energy is a fundamental tool in any country's development and a priori in the improvement of the people's quality of life. Specially access to reliable and affordable electrical energy is vital for sustainable development in rural communities. It can play significant role in reducing poverty, deforestation, improve healthcare and living standards. Being aware of this fact, the Ethiopian Government has therefore adopted a three-track strategy comprising a grid-extension by Ethiopian Electric Power/ Utility (EEP/EEU)**,** off-grid electrification and promotion of new energy sources.

One of the strategies developed to ensure access to modern electricity was through universal electricity access program which focused on supplying electricity to rural town/villages from national grid since **2007**. But now a days, this sector found difficult to reach all of off-grid villages through grid extension due to the mountainous landscape of the country, expensive to connect all households to the main grid and tends to find other options to electrify this remote communities through micro grid or min-grid options either from single supply or hybrid options from available renewable energy resources in the specified sites.

Thus, this thesis has devoted in investigating the renewable energy resources available in Maji district whose administration center is called Tum town, design, optimize hybrid system through Homer and do load flow by using one of power system analyzer software to encourage government, private investors and local communities to take the advantage of these technologies.

1.3. PROBLEM STATEMENT AND MOTIVATION OF THE STUDY

Despite of the abundant renewable energy resources, many communities still live without access to electricity either from the utility grid or independent renewable energy generated electricity. Supply of electricity to the population from grid system to each village is challenging due to their geographical locations and economic constraints. But electricity is a basic requirement to sustain water supply, communication, and transportation, industrial, commercial and to a certain extent, agricultural activities, Health care and education are some mandatory needs for any community to escalate out of poverty. Thus supply of reliable electricity is prerequisite to cater these services. The demand as well as the energy exploitation is rising in Ethiopia from single source mainly hydro. Now a day's the government of Ethiopia has shown an interest towards other renewable energy sources.

Thus, the abundant renewable resource available in nature can be harnessed and converted to electricity in a sustainable way to supply the necessary power demand and then to elevate the living standards of the people isolated from central grid. The Ethiopian Government is now aware that 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).

Among other off grid rural villages in Ethiopia, Maji district is one of the districts of Bench Maji Zone in south Nation Nationality People Region (SNNPR) whose rural villages have no access to electricity yet. Tum town, a Maji district administrative center, is the focus of this thesis work.

1.3. OBJECTIVES

1.3.1 GENERAL OBJECTIVES

The objective of this thesis is to study the feasibility of hybrid micro-hydro/photovoltaic system/ Diesel generator as backup and find the best combination of renewable energy technology(RET) from the available resources in selected town that can meet the electricity demand in a reliable and sustainable manner using HOMER. Load flow analysis has been done to study the power flow of the designed system using Electric transient Analyzer Program (ETAP) software.

1.3.2. SPECIFIC OBJECTIVES

The specific objectives include:

i. Estimate the renewable energy resource of the area; micro hydro and solar radiation potential.

ii. Determine the present and near future electrical energy need of the community living in the area.

iii. Asses the main components of the system and back up depending on the energy demand for the households and the institutions.

iv. Design a standalone hybrid system to meet the electrical energy demand of the community.

v. Evaluate the technical and economic performance of the micro hydro-PV Hybrid System and make sensitivity analysis using a tool (HOMER).

vi. Compare the cost of designed hybrid system with grid extension.

vii. Perform load flow analysis of the designed system to study whether; the generation supplies the load plus losses on the system, bus voltages are maintained to near nominal value and the system is not over loaded.

1.4. Methodology

The main focus of this thesis is to develop a design procedure for standalone rural power supply system. The preliminary steps in this process are to identify load and resource profiles. The general methodology used in this thesis work involves the following steps:

i. DEVELOPING LOAD PROFILE

Collect list of appliances used commonly in the rural area:

- Identifying the number of homes, health center, schools, cottage industry, etc.
- Size and number of appliances in homes number of television sets, radio, light bulbs, etc.
- Light bulbs, refrigerators, television sets, communication equipment, autoclave to sterilize instruments in health centers and schools.
- Light bulbs and other equipment required by the cottage industry.

- Obtaining the load profile of the village by aggregating the energy usage pattern of the individual components (homes, public loads (schools, health center, churches) and industry during every hour.
- Identifying the number of peaks and the peak hours.
- Demand projection for twenty five years after getting a good picture of load demand by the village.

ii. RESOURCE ASSESSMENT

- Collecting data on isolation levels, micro hydro and other resources
- Characterizing the resource profile (primary resource) for the power supply need and the load requirements of the consumer.
- Evaluating the suitability of the resource for the time-of-day needs and assessment of any storage or back-up needs.

iii. LITERATURE REVIEW

Literatures on the experience and models on standalone/hybrid electrification are studied. Works on PV / micro hydro and DG systems in off grid rural electrification are more focused. Theoretical description of hybrid system and its components details are reviewed. Different websites and papers especially related to cost of PV modules, hydro turbines, diesel generator and converter also visited and reviewed. These helps in getting relevant data's and adopting different concepts and methodologies as required.

iv. SITE VISIT AND DATA COLLECTION

Data are also collected from National Meteorological Agency, Energy office/administration office of Maji district. Population data, Sunshine hour, micro hydro resource and brief history of the district are collected from these offices and agency. Site visit was performed as it is important to get information on geographical layout, population distribution, surrounding environment in relation to the system design and geological characteristics. Onsite information about rural household energy demand and supply was also crucial to evaluate the sustainability and economics of designed system.

v. MODELING FOR THE SYSTEM USING HOMER SOFTWARE

Based on the information from literature review and data collected, model was prepared for the systems using Homer for techno- economic analysis. Finally the result from the analysis is discussed and conclusion is drawn from the simulation result of the software.

1.6. ORGANIZATION OF THE THESIS

Chapter one gives the introduction, the motivation and problem statement, the objective and methodology are also covered here. Chapter two reviews literatures:-country over view, hybrid power systems, description of hybrid energy systems components like, solar PV types, radiation incident to the PV surface, PV module and array, PV modeling methods, micro hydro power, its classification based on different categories. Chapter three gives brief note on the description of the study area, detail of electricity load estimation of the community which includes primary and deferrable loads, solar & hydro potential assessment. Chapter four deals with HOMER tool, the climatic input data, cost values of all components, economic inputs, constraint inputs, and sensitivity values, Optimization analysis, sensitivity analysis its result and discussions. Chapter five is about load flow analysis using ETAP software, its result also discussed and lastly Chapter six is dealt through conclusions and recommendations.

CHAPTER TWO

2.1 THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.2. ETHIOPIA: AN OVER VIEW

2.2.1 BASIC INFORMATION

Ethiopia is one of the eastern African countries, having a population size of around 94 Millions. Its total area is 1,104, 300km^2 with climatic condition of tropical monsoon with wide topographic-induced variation. It has topography of high plateau with central mountain range divided by Great Rift Valley. The rain pattern of the country is with mean annual rain fall from 2000mm over some pocket area highlands in southwest and less than 250mm in low lands. In general, annual precipitation ranges from 800 to 2200mm in highlands (altitude>1500m and varies from less than 200-800mm in lowlands (altitude<1500m) [53].

With regard to the sunshine, it is called "thirteen months sunshine country". Energy from the sun offers probably the best potential for a decentralized insertion in Ethiopia. An assessment study indicated in 2002, that the average daily solar radiation reaching the ground for Ethiopia as a whole is 5.26 kWh/m^2. This varies significantly during the year, ranging from a minimum of 4.55kWh/m^2 in July to a maximum of 6.55a kWh/m^2 in February and March) [30].

2.2.2 ELECTRICITY SECTOR OVERVIEW

In 2009, 89 per cent of Ethiopia's population lived in rural areas and rural electrification was estimated at a mere 2-per cent. [53]. The Government of Ethiopia launched its Rural Electrification Strategy in 2002 as a large governmental program for electrification, consisting of three parts: grid extension by the public utility, named universal electricity program under formerly known as Ethiopian Electric Power Corporation (EEPCo) which was separated into Ethiopian Electric Power responsible for construction and operation of voltage level above 132KV and Ethiopian Electric Utility responsible for production of maximum 66KV, operation and sales of electricity all over the country, private sector led off-grid electrification and promotion of new energy sources.

The Rural Electrification Fund (REF) with its loan programs for diesel-based and renewable energy based projects is the main implementing institution. Rural Electrification fund has been supporting 180-200 rural micro-hydropower and photovoltaic (PV) mini-grids for educational and health care facilities. The fund provides loans up to 95 per cent of investment needs with a zero interest rate for renewable energy projects. Renewable energy technologies that receive support under this program include solar PV, mini- and micro-hydro, and biomass Co-generation [53].

2.3. REVIEW OF RELATED WORKS

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 in the following paragraph.

M.S.Islam has developed a logistic type numerical optimum model of hybrid grid by using renewable and conventional fossil resources of Bangladesh. Hybrid Optimization Model of Renewable Energy (HOMER) simulation software was used to conduct a cost benefits analysis for the proposed model. Analysis was made to find out the best technically feasible renewable energy system, which will be cost effective for various households in that area. Sensitivity analysis was carried out with diesel price and wind speed to get optimum result for the proposed hybrid grid system [39].

Fulzele and Dutta had made evaluation on optimum planning of hybrid solar PV and wind renewable system with battery backup and find out the optimum solution of resources, based on economics. The approach was based on mathematical modeling of each component, and then the optimization problem was solved by HOMER in order to better manage and control the energy flow so to ensure reliable supply of demand. Economic viability should be in top priority over the technical feasibility in case of rural electrification [29].

Ahmed Helal et al. design a hybrid renewable energy system for electrification of a remote village in Egypt. Hybrid Optimization Model for Electric Renewable (HOMER) is used for simulation of the proposed system and for components sizing optimization. The total NPC (Net Present Cost) is HOMER's main economic output that proves the optimality of the designed system. The results show that the combination of photovoltaic modules, wind turbines, diesel generators, battery storage, and converter brings to the optimal configuration of hybrid renewable energy system which is used as an off grid system in that remote areas with the minimum NPC [42].

Getachew Bekele and Bjorn Palm 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 cost and found that hybrid solar and wind system is only the promising technology for power generation to these communities. Moreover, the effect of wind speeds, PV costs and diesel prices on the sensitivity analysis is also studied [21].

Himri et al. presented techno-economic assessment for off-grid hybrid generation systems of a site in south western Algeria using HOMER to evaluate the energy production, life-cycle costs and greenhouse gas emissions [27].

Islam et al presented sizing of hybrid energy system for a small community of St. Martin Island using HOMER. He also performed sensitivity analysis to see the impact of solar insolation, PV investment cost, wind speed, and diesel fuel price on the optimum result [29].

Liu et al. successfully used PV technology to investigate its performance under various circumstances and climatic conditions in Queensland of Australia. Here the aim was to optimize the size and slope of PV array in the system. Under four climatic zones, tropical, sub-tropical, hot arid and warm temperature, the performance of the PV system is studied and an optimized condition is reached using HOMER software. Finally it was concluded that PV system can effectively bring down their electric bills and to alleviate carbon dioxide emission [24].

Ngan and Tan analyzed the potential implementation of hybrid photovoltaic (PV)/wind turbine/diesel system in southern city of Malaysia, Johor Bahru using HOMER [48].

From the above review work it can be concluded that renewable single/ hybrid system for power generation is very reliable and is very much suitable for the remote place in island or any other remote location where grid extension is too much costly and impossible due to geographical location. In addition it is observed that the researchers have used HOMER software for the design of single/hybrid micro power. 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 techno-economic analysis. However this study differs from the related studies in terms of application, load demand, climatic data, and location of the area, and vastness of the households included. More over; this study has done load flow analysis using ETAP software which can’t be done using HOMER for real time operation.

2.4. Hybrid Power Systems

Electrical energy requirements for rural communities are slightly large and it may not be cost effective or not enough renewable energy to implement a stand-alone PV system, wind turbine or any other power sources. In this case, it is recommended to combine different types of available power sources to form what is known as a “hybrid-power” system. For example, small hydro turbine, solar and wind can be combined with other power sources such as power grid or diesel generator to provide enough electrical energy for a city or rural villages. Hybrid power systems combine many different technologies to provide reliable power. Hybrid power systems are a new favorable system, especially for rural areas, to provide enough electrical energy using different available renewable energies.

Traditionally, diesel generators are used in remote communities and villages; and they will grow to be a barrier due to the operating, maintenance and gradually increasing fuel cost and other factors, such as impact on the environment and the geographical difficulties in delivering fuel to remote areas. Therefore, hybrid power systems will turn out to be a more suitable candidate solution for remote areas. Hybrid power systems can provide a steady service to remote communities.

For more reliability and responsiveness to a system's load demand, hybrid systems can be designed with a backup generator that has minimal diesel consumption. The generator would come online only when a high load is required or low renewable power is available. Hybrid systems can be designed in three different configurations according to their voltages, in order to effectively use the local available renewable energy sources. These are DC voltage bus, AC voltage bus and DC and AC voltage buses [35].

2.5. DESCRIPTIONS OF HYBRID POWER SYSTEM COMPONENTS

In this thesis micro-hydro, solar, convertors and diesel generator as back up are considered for the formation of hybrid system power supply for the town under consideration.

2.5.1 MICRO-HYDRO POWER

It is a non-polluting, environmental friendly source of energy and an interesting prospect for providing electricity for remote rural communities. Hydropower is established with simple concepts. Water movement rotates a turbine which is mechanically connected to generator, and electricity is produced. Many other components are required, but it all starts with the energy from water. The use of water falling through a height has been utilized as a source of energy a very long time [54].

2.5.1.1 MICRO- HYDROPOWER BASICS

A micro-hydropower system is a small system in the range of 10-500 KW. Site-specific conditions that include seasonal variation in water flow, determine the technological feasibility of a given micro-hydro scheme. As a result, detailed hydrological studies must be carried out at the site before a potential project proceeds. The simplest micro-hydropower plant is based on a run-of-river design, which means it does not have water storage capability. It produces power only when water is running or it might have relatively small water storage capability.

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). 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 (g p m), cubic meters per second (m^3/s), or liters per second (l/s).

2.5.1.2 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.

2.5.1.2 .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.

- **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 a canal or a leg penstock, thus changing the flow of the water in the stream for a considerable distance.
- **Storage regulation developments**. An extensive impoundment at the power plant or at reservoirs upstream of the power plant permits changing the flow of the river by storing water during high flow periods to augment the water available during the low-flow periods, the supplying the demand for energy in a more efficient manner. The word storage is used for long-time impounding of water to meet the seasonal fluctuation in water, availability and the fluctuations in energy demand. While the word poundage refers to short-time (daily) impounding of water to meet the short-time changes of energy demand [25].
- **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 [54].

2.5.1.2.2 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 poundage of the water supply necessary [54].

2.5.1.2 .3 Classification of hydro power by installed capacity

Hydropower plants can be classified as large, medium and small, depending on the capacity of energy that can potentially be generated. Plants above 500 MW are generally considered large. Plants between 500MW and 10MW are considered medium sized. Below 10 MW they are considered small sized hydro plants. Small hydro plants are further classified as mini (500 kW to 10 MW) micro (10 kW to 500 kW) and pico (less than 10 kW). Figure 2.1 below illustrates this classification.

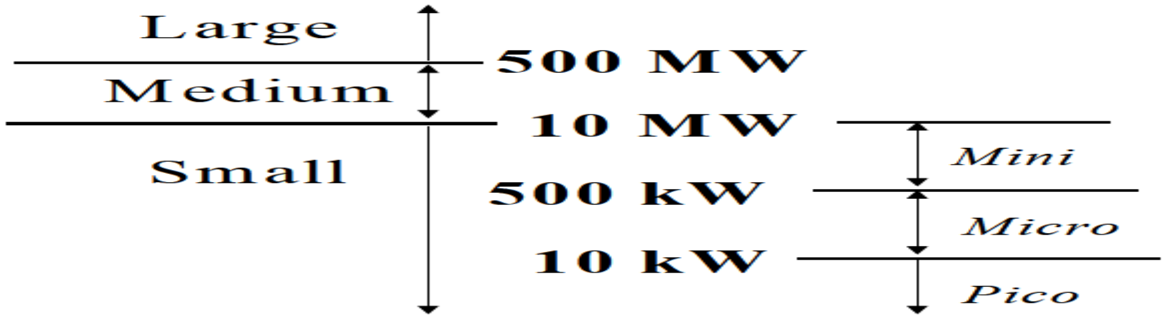


Figure 2.1. Hydropower classification based on installed capacity [26]

2.5.1.2 .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 a small hydro power. 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 [26].

The principal components of a simplified Micro Hydropower System is shown below in Fig 2.2

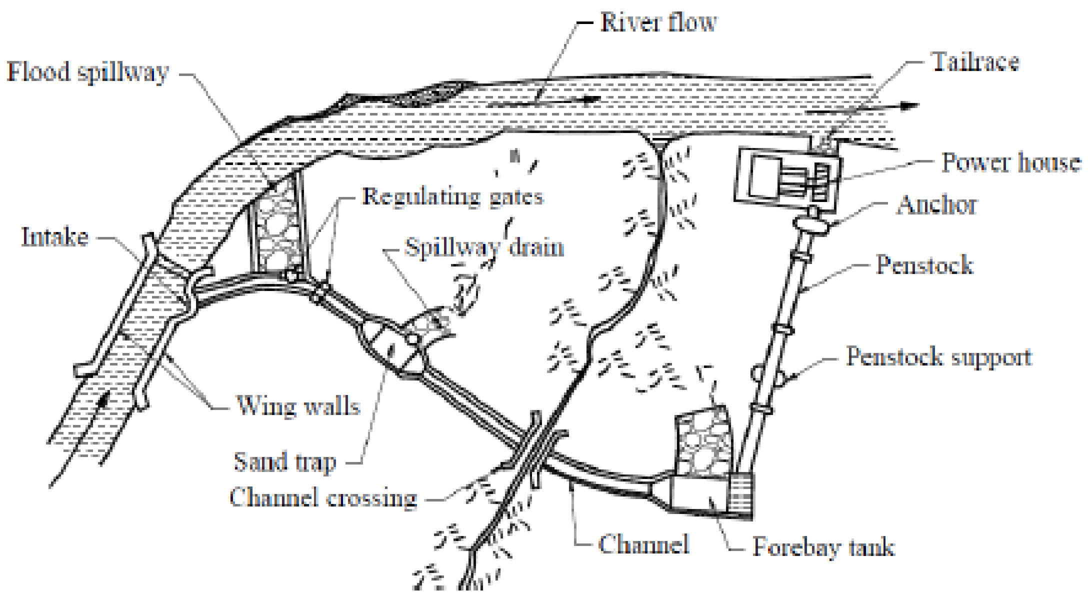


Figure 2.2 General layouts of Micro Hydro system and its principal components (20).

A technical design of the MHP consists of three different engineering aspects [20]; it consists of civil, mechanical and electrical components. The Civil Components like Intake, Weir, Settling basin, Headrace, fore bay, Penstock, Powerhouse building, Tailrace, Stop-logs and Reservoir. The Mechanical Components are Trash rack, Penstock pipe Expansion joints, Valves, Turbines, Drive system and Water governor. And finally the Electrical components are Generator, Automatic Voltage Regulator [AVR], Control and Protection System, Earthling System, Transmission Network and distribution networks. Some studies generalize mechanical and electrical components as power house components. Some components are again elaborated in the following sections.

2.5.1.3 CIVIL WORK COMPONENTS OF MICRO HYDRO POWER UNIT

The civil components those of major components are: Intake, Headrace Canal, and Settling Basin, spillway, fore bay tank, penstock and Tailrace.

2.5.1.4 POWERHOUSE COMPONENTS

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

i. Generators

A generator is the main unit which converts mechanical energy associated with water into electrical energy. Two types of generators (synchronous and asynchronous) can be used. Depending upon the size of a machine, types of a load to be fed, other energy sources later to be integrated, a generator is to be chosen. Normally induction generators are chosen for a small MHPP due to its low cost. Synchronous generator should be chosen if reactive loads like induction motors are to be supplied and the total installed capacity is more that 10 kW. The generator general guidelines for selecting the phase and type of the generator are shown in table 2.2 [54].

Table 2.1: Generator general guidelines

Capacity	Up to 10KW	**10 to 15kw**	**Above 15 kw**
Type of generator	Synchronous induction	Synchronous or induction	Synchronous induction
Phase	Single or three- phase	Single or three- phase	three- phase only

ii. 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 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 Micro Hydropower System.

iii. ELECTRICAL LOAD CONTROLLERS

All Micro Hydropower System will 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 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 micro hydro system. For instance, when the induction generator is used in the micro hydro system, it is necessary to install induction generator controllers (IGC) [38].

iv. MICRO-HYDRO TURBINES

Energy stored in water will transfer to mechanical energy, which is needed to rotate the shaft of an electric generator. Generally there are three different types of turbines: impulse, reaction and waterwheel turbines.

The energy (kinetic and potential) associated with water is converted into mechanical energy through a water turbine. The mostly used types of a turbine in a MHP are cross-flow and Pelton turbines. The size and type of the turbine for a particular site depend upon the net head and the design flow. Pelton turbines are suitable for the site where ratio of head to flow is high. If there is more flow and low head is available the cross-flow turbine is suitable. The selection of turbine type should be based on the cost effectiveness and the technical limitations as explained below.

1. If the net head (H_{net}) exceeds 50 m, a cross-flow turbine is not a preferred option, especially for the output power below 20 kW. As a rule, a runner width should not be less than 15 to 20% of the diameter or otherwise it causes decrement in efficiency. The power available from all type of turbines can be expressed as follows [25].

$$P_e = \eta_t \eta_g {}^g H_{net} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where:

P_e	Nominal electric power	W
η_t	Efficiency of turbine	
η_g	Efficiency of generator	
Q	Design flow rate	m^3/s
g	Acceleration due to gravity	m/s^2
H_{net}	Net Head	m

2. The efficiencies at the rated output to be used in a feasibility study are as follows:

- Pelton 5-30 kW: 70-80%
- Pelton above 30 kW: 75-85%
- Cross-flow 5-30kw: 60-70%
- Cross-flow above 30 kW: 65-78%

One important parameter is that the speed up ratio should not exceed 1:3 (turbine: generator). For example, if the generator RPM is 1500, the turbine RPM should not be more than 500 RPM. For a cross-flow turbine, depending on the head and the runner diameter, the upper limit for RPM is between 100 (runner diameter 300 mm) and 1500 RPM (runner diameter 200 mm).

For Pelton turbine, RPM should be equal to the generator as far as possible so that the turbine and generator can be directly coupled and a belt drive is avoided. The suitable RPM for a Pelton is determined by the head and the runner pitch circle (pcd).

2.5.2. SOLAR ENERGY AND PHOTOVOLTAIC TECHNOLOGY

Solar energy is another promising renewable energy. The sun provides enough energy needed to sustain life in the solar system. Approximately in one hour, the sun delivers enough energy to the earth to meet its energy needs for nearly a year. Photovoltaic (PV) technology converts the energy coming from the sun to electricity.

2.5.2.1 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 [5].

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 200µm 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 [5].

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. 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.

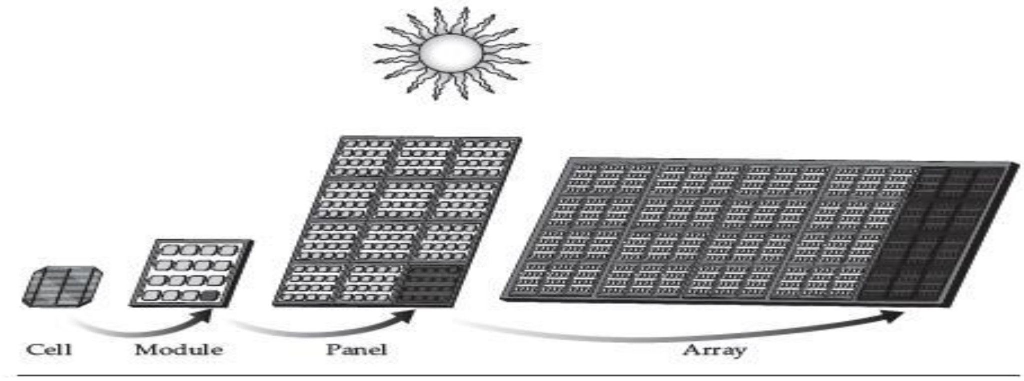


Fig 2.3 PV system component [5]

i. COMMON TERMINOLOGIES OF PHOTOVOLTAIC CELLS

- **Solar irradiance**: is an instantaneous quantity describing the rate, or flux of solar radiation (power) incident on a surface, commonly expressed in units of kilowatts per square meter (KW/m^2). Outside the earth's atmosphere, the solar irradiance on a surface oriented normal (perpendicular) to the sun's rays is essentially constant at 1.36KW/m^2. Due to atmospheric effects, the peak solar irradiance incident on a terrestrial surface oriented normal to the sun, at noon on a clear day is about 1kW/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 5kWh/m^2. Figure 2.4 shows the relationship between solar irradiance and insolation [16].

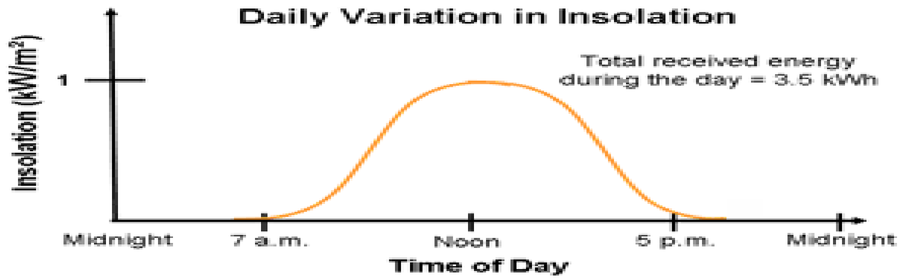


Fig 2.4 Relation between solar Irradiance and Solar Insolation [16]

ii. 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 1000W/m^2 and under Air Mass of 1.5 spectral distribution. Since these conditions are not always present PV modules and arrays operate with performance of 85 to 90 percent of the STC rating.

iii. PHOTOVOLTAIC 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 2.5. This accounts for the majority of PV cell production and thin film, which is newer and growing in popularity. The "family tree" in figure 2.5 gives an overview of these technologies available today and figure 2.6 illustrates some of these technologies.

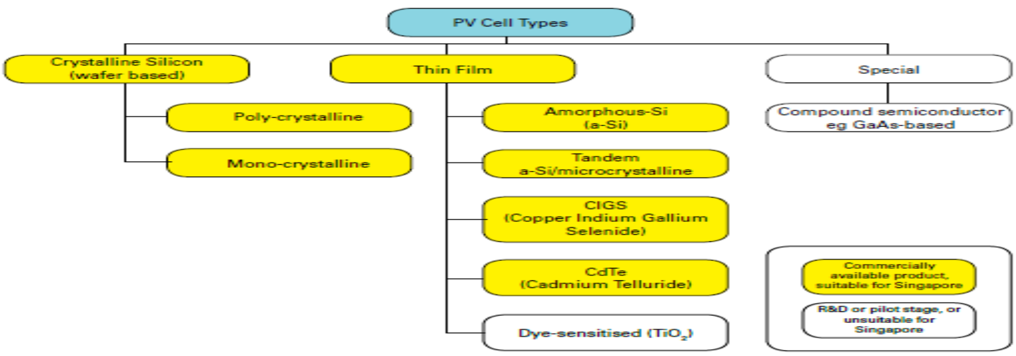


Figure 2.5 PV technology family trees (16)

• Different Module Technologies

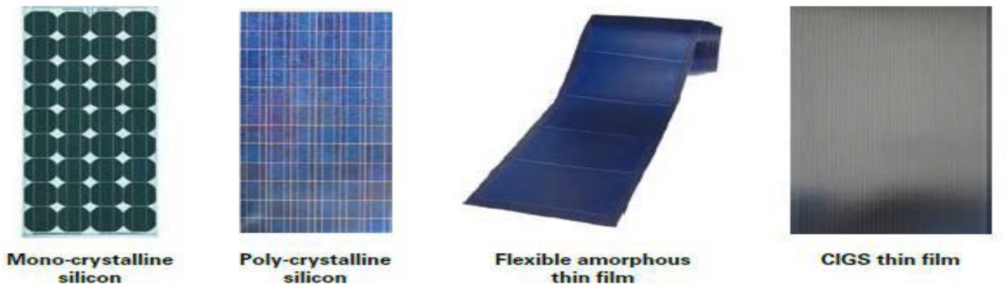


Figure 2.6 Common PV module technologies (16)

iv. 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 2.2 Technology and Module Efficiency of PV [16]

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 2.6. 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.

2.5.2.2 ELECTRICAL CHARACTERISTICS OF THE SOLAR CELL

i. ELECTRICAL EQUIVALENT CIRCUIT OF PV CELL

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in figure 2.7 below. The following parameters called for consideration. The current/at the output terminals is equal to the light-generated current I_{ph} (less the diode I_d) and the shunt-leakage current I_{sh}/. The series resistance R_s represents the internal resistance to the current flow, and depends on the p-n junction depth, impurities and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to the ground. In an ideal PV cell R_s=0 and R_{sh}= 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.

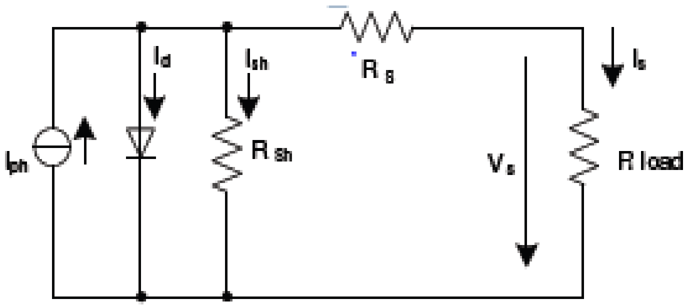


Figure 2.7 Equivalent circuits for a PV cell [16]

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

$$V_{oc} = (I_{ph} - I_d)R_{sh} \dots\dots\dots\dots\dots\dots\dots .2.2$$

The diode current is given by the classical diode current expression

$$I_d = I_o e^{(\frac{qV_{oc}}{AKT})} - 1 \dots\dots\dots\dots\dots\dots .2.3$$

Where I_o 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/°K), and T is temperature on absolute scale °K.

Thus, the load current is given by the expression:

$$I_s = I_{ph} - I_d - I_{sh} \Rightarrow I_s = I_{ph} - I_o[e^{(\frac{qV_{oc}}{AKT})} - 1] - \frac{V_{oc}}{R_{sh}} \dots\dots\dots\dots\dots\dots\dots .2.4$$

The last term is the leakage current to the ground. In practical cells, it is negligible compared to I_{ph} 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_{sh}) 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_{ph}.

The maximum photo voltage is produced under the open-circuit voltage. Again by ignoring the ground leakage current, equation 2.5 with I give the open-circuit voltage as follows:

$$V_{oc=\frac{AKT}{q}} \ln\left(\frac{I_s}{I_o}+1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.5$$

ii. 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 voltageV_{oc}. The curves are used to obtain performance levels of PV systems (cells, modules, arrays) [Solar energy, renewable energy and 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, I_{sc}, and the open-circuit voltage, V_{oc}. The I_{sc} 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. The **V**oc 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 [16].

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) time's 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 [15, 16]. 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** (I_{SC}) 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, I_{sc} 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 1,000W/m^2, a PV cell temperature of 25^{0}C, and a standardized solar spectrum referred to as an air mass 1.5spectrum (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** (I_{MP}) 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** (V_{MP}): corresponds to the maximum power point on the array's current-voltage (I-V) curve.

- **Maximum power** (P_{MP}): 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 (I_{MP}) and voltage (V_{MP}). 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 (**V**P) of the majority of nominal 12V modules varies from 15V (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. The power produced by a crystalline PV module is affected by two key factors: Solar irradiance and module temperature. Figure 2.8 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 2.9 shows the effect that temperature has on the power production capabilities of a module [17].

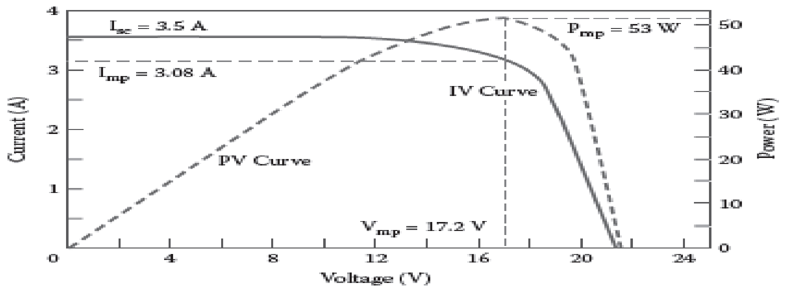


Figure 2.8 Typical I-V and power curves for a crystalline PV module operating at 1,000W/m^2 (STC) [17]

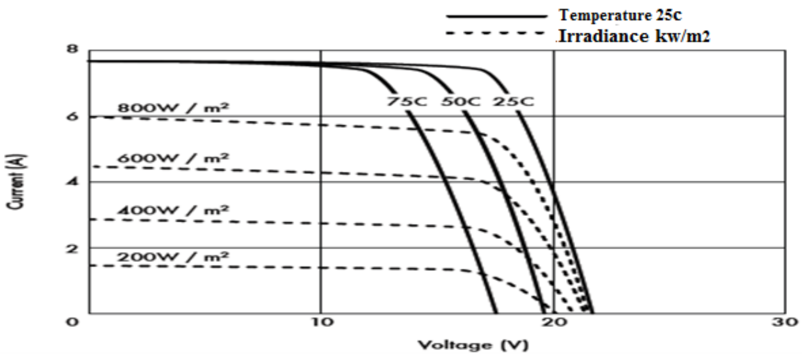


Figure 2.9: Different IV curves, the current (A) changes with the irradiance, and the voltage (V) changes with the temperature [17].

iii. SERIES-PARALLEL CONFIGURATION OF PV CELLS

In order to obtain high currents and voltage (reaching up to kilovolts), PV cells are connected in series-parallel. Usually PV cells inside the PV module are manufactured with very similar characteristics to avoid circulation of internal currents among the cells. Therefore, it can be assumed that the PV cells are identical when they are connected in series or parallel. Connecting PV cells in series results in increase of the voltage across PV panels, whereas connecting PV cells in parallel results in the increase of the output current from PV panels. The efficiency of a solar panel is given by [16]:

$$\eta = \frac{P_{electrical}}{P_{illumination}} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

$$P_{electrical=IV\ or\ PV\ out\ put\ power} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.7$$

$$P_{illumination=effective\ illumination\ area*radiation\ intensity} \ldots\ldots\ldots\ldots\ldots 2.8$$

"As an example, suppose that a manufacturer's data sheet provides effective illuminating area = $0.16m^2$, $\mathbf{V_P}$ =20.6V, and $\mathbf{I}_p$ = 1.8A for the standard test conditions (1000W/m^2, 25 ^oC, air mass 1.5)" [16]. Then efficiency of the solar panel will be equal to = [(20.6*1.8)/ (1000*.016)]*100% = 23.175%.

2.5.3. DIESEL GENERATOR

i. ENGINE GENERATOR ELECTRICITY

Generator runs on a variety of fuels, including petrol, diesel, propane and bio-fuels. Compare to renewable energy installations, generators have low capital costs and produced power on demand. Disadvantage of generator operation include fuel dependence, transport and storage costs, high maintenance cost and exposure to noise and pollution.

Diesel generators are most common generators in a large number of small and remote power systems throughout the world. The system provide a dependable AC output but diesel fuel at these locations can often be very expensive due to the additional transport cost involved. Diesel generators are available in size ranging from 1kw to over a megawatt.

ii. **GENERAL WORKING**

Generators consist of an engine driving electric generators .This generators are often run at low load with poor efficiencies, which can lead to increased engine maintenance requirements. Thus a major characteristic of motor generators is its fuel consumption which may vary from generator to generator.

iii. OPERATING ISSUES

Generators should be run at high load level to maximize fuel efficiency. Low load operation results in increased cylinder glazing, high frictional loses and fuel deposition which in turn lead greater maintenance costs and lower fuel efficiency.

Frequent start-up increases wear because oil films have drained away at stand still and increasing cylinder pressure promote were at contact points. It is common practice to install dump load which deliberately dissipate energy to protect diesel engine when useful demand is low.

Improvements to diesel operations would be aiding engine warming up, lessening peak pressure at star-up and avoiding partial load conditions.

iv. DESIGN

A diesel generator should be designed such that it meets the load reliably but also run at average load levels. It is used a backup power to overcome the shortfalls in energy production during peak Periods.

The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the engine generator to be installed, following two cases should be considered:

- If the diesel generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load, and

- If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than CAh/5 A, where CAh is the ampere hour capacity of the battery.

Overall efficiency of diesel generator is given by [18]

$$\eta_{over-all} = \eta_{break\ thermal}\, x\, \eta_{generator} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.9$$

Here $\eta_{break\ thermal}$ is brake thermal efficiency of diesel-engine. Normally, diesel generators are modeled in the control of the hybrid power system in order to achieve required autonomy in the presence of battery. It is observed that if the generator is operated at 70–90% of full load then it is economical. Diesel generators are normally used for meeting load requirements or for battery charging in absence of peak demand based on dispatch strategy selected in homer.

2.5.4. CONVERTER

A converter is a device that converts electric power from dc to ac in a process called inversion, from ac to dc in a process called rectification or both. It has an inverter and a rectifier to do the conversions from DC to AC and inverter for AC to DC. 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. That means when you select an inverter you must have a DC voltage equal to your inverter DC voltage and have an AC voltage and frequency equal to your home and utility values.

CHAPTER THREE

3.1 RENEWABLE ENERGY RESOURCES ASSESSMENT, LOAD ESTIMATION AND DEMAND PROJECTION

3.2 DESCRIPTION OF THE AREA

Maji district is one of the districts of Benchi Maji Zone in Southern Nation Nationality Peoples Region of Ethiopia. It is bordered in the south by the Kibish River which separates it from South Sudan and by Surma, Meinit Shasha and the Omo River in the West, North and East respectively. The major portion of the district is included in the Omo National Park. According to 2007 Census conducted by the CSA, this district has a total population of 31,088, of which 16,016 are females. The largest ethnic group in the district is called Dizi. Dizi is spoken as a first language by the majority of the population living in the district. The district has a total of twenty two kebeles and its administrative center is Tum town. All kebeles in this district have no access to electricity from national grid yet. And other energy access options are found to be the best solutions to the area. Tum was purposefully selected for this thesis work for the reason that it is the administrative center of the district.

The topography of the area is characterized by mountainous and rivers with poor wind but good solar energy and biomass. Site altitude is approximately 1479 meters. Tum is located at (35˙31E) and (6˙15N). It is surrounded by Mountains and Tum River. Its landscape consists of flat grazing plains with plenty of long and thick grass**.**

The main economic activities of the communities are agriculture including crop cultivation like Maize, Sorghum, and Rice, coffee, fruits and vegetables of different types such as Avocado, Mango, Banana, Papaya, and Sugarcane. There are also livestock like cattle and goats. Local gold mining is another job opportunity there and trading is the main activities of the communities who has no farm lands mainly peoples who migrate there from different regions of the country.

Tum town has a total population of 3960; out of which 1890 are females. There are twenty six (26) public sectors offices in the district. Flour mills, high school (9-10), Primary school (1-8), Elementary School (1-4) and Kindergartens, telecommunication tower, office, cafes, restaurants, churches, mosque, TVET Center (under construction), Shops, photo studio, video hall are available in the town. Source [City administration office].

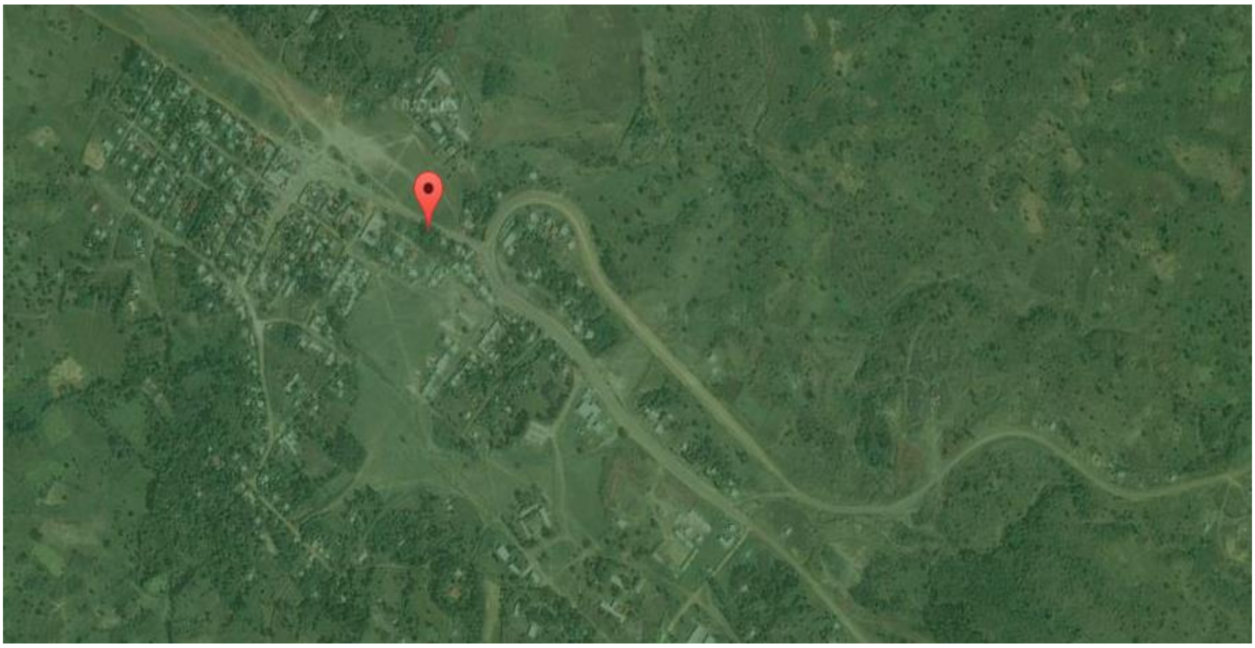


Figure 3.1: Google map of Tum town.

3.3 ELECTRIFICATION SCENARIO IN TUM

3.3.1 STATUS OF ELECTRICITY IN TUM TOWN

i. ELECTRICITY GENERATION

As per the information obtained from the town administration office during the field survey, the main loads are lighting and few TV's at homes and bars. There are twenty three (23) small diesel generators owned by individuals and institutions which give service for 3-4 hrs in average within a day, among which, (3) belong to religious institutions and (9) belong to local government service sectors, which give service during office working hours. All flour mills have their own dynamos. The communities are largely using kerosene for lighting, very few with home solar sources and batteries for mobile charging.

After getting a broad picture of the town, survey was conducted to get information on the cost and operation of electricity. Interviews were conducted with households, diesel owners and representatives of district administration office.

ii. ELECTRICITY CONSUMPTION PATTERN IN THE TOWN

In order to understand the electricity consumption pattern, questionnaires were distributed to the community. Major information was obtained from district administration office and the major findings were as follows:

The most common load in the town is Light bulb (CFL) and TV (along with DVD player owned by some), and few Audio Amplifiers and refrigerators (few grocery owners). In local government office, computers, printers, copy machines are available. The households which get around 3.5 hours of electricity every day (6pm to around 9.30 pm) from diesel generators and pay a fixed price of electricity per appliance as listed below:

- Lamps (~15 W): 1.67Birr/ night (for 3.5 to 4 hours)
- TV with DVD player (~90 W): 3 Birr/ night (for 3.5 to 4 hours)

This indicates that the household pays 1.67 Birr for 53Wh of electricity consumption. This translates into a cost of electricity of 32 Birr/kWh. The result indicates how expensive the cost of electricity is due to the diesel generators. For lighting requirements beyond 9.30p.m most people were using kerosene lanterns.

The following facts have been collected from the site:

- The cost of kerosene in town is 18Birr/liter.
- Cost of diesel is 20Birr/liter.
- Average cost of charcoal consumption per month per household is 60 – 100 Birr.
- Cost for Mobile Charging per item at hotels and DSTV center is 3 Birr.
- Cost for mobile charging at Diesel Station one time is 5 Birr.
- Cost for hand battery charging one time is 5 Birr.
- Laptop charging per item costs 5 Birr.
- Cost of candle per piece is 6 Birr.
- People showed desire of having refrigerators and TVs in the near future.
- People mentioned that the supply of electricity from the available sources is very irregular and encounter frequent flickering of lights.
- People have expressed their willingness to pay for electricity services.

3.4 Renewable Energy Resources Assessment of the area

The village has various potentials of renewable energy resources that can be harnessed. These resources include solar, hydro and biomass. But for this thesis study, only solar and hydro renewable resources are considered.

3.4.1 Potential of Solar Energy

Studies indicate that for Ethiopia as a whole, the yearly average daily radiation reaching the ground 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 6.55 kWh/m^2 in February and March. On regional basis, the yearly average radiation ranges from values as low as 4.25 kWh/m^2 in the areas of Itang in Gambella regional state (western Ethiopia), to values as high as 6.25 kWh/m^2 around Adigrat in Tigray regional state (northern Ethiopia) and in Afar and Somali Region of Eastern Ethiopia[48].Samuel Tesema[1] and Getachew Bekele[2] (2014) on International Journal of Energy and Power Engineering publication confirm the study by SWERA for the solar radiation potential of the Somali region which is the highest potential value of 7.5kWh/m^2 in Ethiopia for Werder Zone [48].

3.4.2 Solar radiation estimation

Ideally, the data required to predict the solar potential of any site are several years of measurements of irradiance on the proposed collector plane. These are rarely available, so the required data has to be estimated from meteorological data available either:

(i) From the site, or

(ii) From some nearby site having similar irradiance, or

(iii) From an official solar atlas or database.

Here, the sunshine duration data from the nearby station is used to analytically calculate(estimate) the monthly average solar radiation using the modified version of angstrom equation [32, 33, and 34].

$$H = H_o \left(a + b\frac{n}{N}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.1$$

Where: H→ monthly average daily radiation on horizontal surface (MJ/m^2).

H_0→ monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m^2).

n→ monthly average daily number of hours of bright sunshine.

a and b are regression coefficients and has been calculated from the relationship given by [58]:

$$a = -0.11 + 0.235\cos\phi + 0.323\left(\frac{n}{N}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.2$$

$$b = 1.449 - 0.553\cos\phi - 0.694\left(\frac{n}{N}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.3$$

Finally their average value have been taken as a =0.33 and b=0.43 and used in equation 3.1.

N →the maximum possible daily hours of bright sunshine given by equation below:-

$$N=\frac{2}{15}\omega_s \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.4$$

More over the values of monthly average daily extraterrestrial radiation (*Ho*) are calculated for days giving average of each month as:-

$$H_o = \frac{24*3600*G_{sc}}{\pi}\left[1 + 0.033 * \cos\left(\frac{360 n_d}{365}\right)\right] * \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \dots\dots\dots\dots\dots\dots 3.5$$

Where:

G_{SC} = 1367W/m^2, the solar constant,

n_d is day number of the year starting at January 1st as 1

ϕ is latitude of the site under consideration (^{0})

δ is solar declination angle (^{0}) and given by

$$\delta = 23.45 \sin\left(360 \frac{240 + n_d}{365}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.6$$

ω_S is the sunset angle and given by

$$\omega_S = \cos^{-1}(-\tan^{-1}\phi\, tan\delta) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.7$$

The Ethiopian Meteorological Service collects only the average sunshine hours for some cities of the country and the solar radiation is calculated from the average sunshine hours. The solar radiation is estimated as shown in table below by using the equations given above. To make the data of a sound conformity, a cross-check was made using statistical test method called root mean square error (RMSE) with a 22 years of data recorded by over 200 satellites from Surface Meteorology and Solar Energy data base (SMSE) – Sponsored by NASA and the PVGIS data set (which is based on measurements made on the ground to get radiation values at any point).

$$RMSE(\%) = \left[\frac{1}{m}\sum_{i=1}^{m}(H_{ic} - H_{me})^2\right]^{\frac{1}{2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots 3.8$$

Where: i= 1, 2……, m and H_{me} the data obtained from NASA and PVGIS. The root mean square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. RMSE is a good measure of precision. The value of RMSE is always positive, representing zero in the ideal case. The RMSE provides information on the short-term performance of the correlations by allowing a term by term comparison of the deviation between the calculated and measured values [63].

In general, the result shows that as there is good availability of solar energy potential in the area.

Table 3.1 Table Monthly solar radiation of Tum

Mid of the Month	n_d(hrs)	δ (^{0})	ω_s(^{0})	N(hrs)	n(hrs)	**H_o(kWh/ m^2/d)**	**H(kWh/ m^2/d)**	**NASA**	**PVGIS Africa**
January 15	15	-21.2694	87.46	12.29	7.1	9.30	5.50	5.55	5.64
February 15	45	-13.6197	88.41	12.61	6.4	9.88	5.57	5.92	5.97
March 15	74	-2.81887	89.68	12.29	6.1	10.38	5.70	5.73	5.83
April 15	105	9.41488	91.08	11.37	5.6	10.47	5.53	5.51	5.25
May 15	135	18.79192	92.22	6.94	5.5	10.20	5.33	5.37	5.02
June 15	166	23.31441	87.19	14.20	4.8	9.91	5.03	5.03	4.62
July 15	196	21.51733	92.53	12.53	3.7	10.02	4.60	4.86	4.31
August 15	227	13.78344	91.60	14.00	3.3	10.28	4.59	5.14	4.65

September 15	258	2.216904	90.25	6.89	4.4	10.35	5.04	5.48	4.90
October 15	288	-9.5994	88.90	10.46	5	10.01	5.12	5.31	5.19
November 15	319	-19.1478	87.73	10.82	5.3	9.42	4.94	5.19	5.03
December 15	349	-23.3352	87.18	6.22	6.1	9.09	5.05	5.34	5.16
Average							**5.16**	**5.37**	**5.13**

Fig. 3.1 below shows Solar energy profile of Tum town with latitude of 6.5 north and longitude 35.5 east .The annual average solar radiation was scaled to be 5.16kWh/m^2/Day and the average clearness index was found to be 0.519.

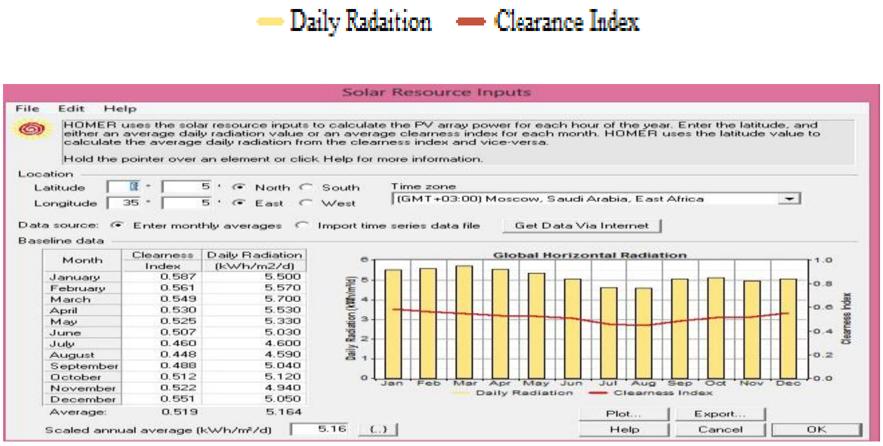


Figure 3.1 Solar energy profiles inputs into HOMER

3.4.3 SMALL HYDRO POTENTIAL ASSESSMENT OF TUM

According to the Resource Potential Assessment Study Conducted for the region Omo-Gibe Basin, Baro-Akobo Basin, Rift Valley system and the Awash Basin are known for their water resources [45]. And the small hydropower potential in different parts of the region is estimated to be more than 186,730 kW. There are numerous streams, canals and rivulets with drops at many places in the region. Therefore, it is possible to set up a large number of micro (from 50 to 500 kW) and mini (above 500kW) hydro plants that are essential for rural electrification and establishment of small industries in remote area. Though the water flow is big enough to provide electricity for most of the time in the year, there is no accurate data of stream flow for the Tum River. But according to the survey conducted in 2008[4] and district energy office information it has a minimum flow of approximately 2045L/s during the dry season. My observations during field survey also confirm this from the study conducted by [22] because of the procedure followed by [4] was similar with [22, 60] for an estimation of the stream flow rate.

The flow volume varies by season. On average, June to September have higher water flow than other months. December, January and February have lower volume. A stream flow profile was created for the proposed river based on the seasonal weather of the site [4] and is shown in Fig 3.3. Head can be measured using either of altimeter, pressure gauges, clear hose method, satellite images, sighting meter or level method [22]. For this study, the selected sites have steep waterfalls so that their head is measured using rope. The gross head of the water fall is around 30meters.

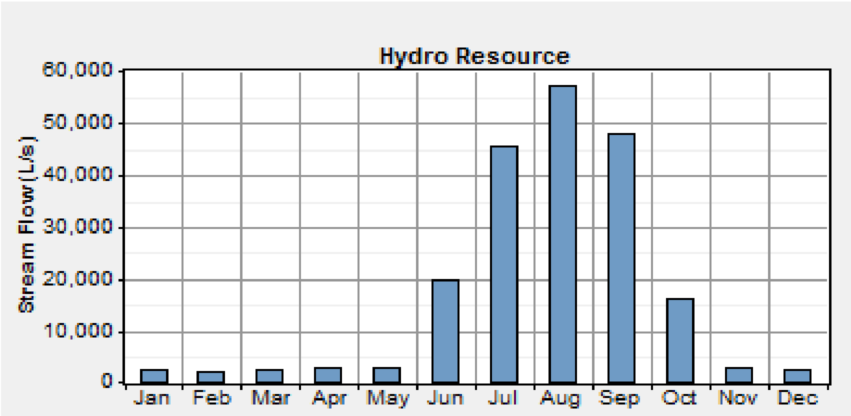


Fig 3.2: Estimated hydro resource [4].

Fig 3.3: Tum River

3.4. LOADS ESTIMATION AND PROJECTION FOR TUM TOWN

The assessments of current load demand for electricity as well as forecasting of future growth in demand are essential [37]. The optimal system performance is closely linked to an accurate demand assessment. The relevance results from the fact that over sizing of the hybrid system inherently increases the overall system costs, while underestimation of load demand is likely to entail frustration on poor system performance due to excessive consumption.

However, making adequate load estimation is frequently a very difficult task since end-use service demand is affected by the cost of energy but also by other factors such as climatic conditions, affordability (or income of the decision-maker), preference for the end-use service, etc. Similarly, demand for end-use appliances depends on the relative prices of the appliances, relative cost of operation, availability of appliances, etc.

The approach of simply asking households for their potential electricity demand is not sufficient, as the World Bank describes (ESMAP, 2000a). The so far knowledge of non-electrified households, on their real demand for electricity, is very limited and the corresponding financial burden in terms of the monthly bills for electricity supply cannot be overviewed by them.

For this reason, the World Bank proposed the need for assessing electricity demand by surveying adjoining, already-electrified regions with similar characteristics (ESMAP, 2000a). By doing so, not only the actual demand for electricity, but also the history of load growth can be determined and taken into consideration.

The assessment of not only actual demand for electricity, but also of potential future growth is of major importance for power systems. The electricity demand is likely to increase substantially, and may soon lead to dissatisfaction of consumers if future growth is not accurately forecasted in advance. Thus, two different situations need to be distinguished (ESMAP, 2000a):

- If the system is to be installed in a region, which is likely not to be connected to conventional grid during the lifetime of the system, then the growth in demand during the whole lifetime has to be accounted.

- If the system is to be installed in a region, which expects grid-based electrification in medium-term perspective, which is lower than the system’s lifetime, then this period has to be accounted for growth projections.

The population itself can play an important role in assessing energy demand. Involvement of rural population through a rural electrification committee can contribute much to obtain information on demand and future growth (Barnes, D.; Foley, G., 1998).

The existence of large scale inequity and poverty, dominance of traditional life styles and markets in rural areas, transitions of populations from traditional to modern markets, existence of multiple social and economic barriers to capital flow and technology diffusion make developing countries’ energy systems significantly different from that of developed countries Pandey (2002).

Carrying out a rural survey is vital for the accuracy of estimations, as assuming rural loads from an urban perspective would give a false picture of the rural demand. Where the main use of electricity is expected to be for lights and small appliances, typically rural areas, there is no reason to apply the design standards used for much more heavily loaded urban systems. Although consumption normally grows, this is usually at a slow pace and provided the necessary design provisions are made, systems could be relatively cheaply upgraded later [6].

The factors driving energy demand differ across economic agents and sectors [38]. Households consume energy to satisfy certain needs and they do so by allocating their income among various competing needs so as to obtain the greatest degree of satisfaction from total expenditure. Industries and commercial users demand energy as an input of production and their objective is to minimize the total cost of production. Therefore the motivation is not same for the households and the productive users of energy and any analysis of energy demand should treat these categories separately. Based on the recommendations of the researchers mentioned above, and own experiences and observation as well as interviews during the field work, the researcher tried to identify/categorize/ the customers and appliances to be used as described in the next sessions and appendixes under each customer type.

As mentioned in section 3.1, the town being under study has a sufficient potential for sustainable energy development. The fieldwork was carried out in Tum, the administrative town of Maji district. The town was established in 1981 and has not been yet connected to the national grid. The visit helped to understand the energy consumption pattern and what effects electrification would have on the village through interviews and observation.

The researcher had been also to nearby electrified village Jemu, which is 64km away from Tum, to collect data showing an electricity consumption pattern, Tum has almost adequate information (loads working based on diesel generators and dynamos for Flour Mills, Bars, Café, Restaurants, etc. to give clue for creating the basis in estimating load for the town as described in previous sections. However loads like wood work, metal work, hotels etc. shall be adopted and estimated from an electrified village. Hence; the data collected from both sites through the aforementioned methods can give information about how different customers use electricity based on type of appliance, when the appliances are used.

3.4.1. IDENTIFYING CUSTOMER AND LOAD TYPE

In order to identify customer and load type, customers were sorted into customer type. Customers were categorized as Domestic Uses, Productive Uses, Public Uses and Industrial Uses [46]. Thus; as per the literatures review, field survey and experience, this thesis load estimation was approached based on the electric appliances to be used by each customer of rural family households and different sectors by accounting the current and future situation of the local community.

More over; the loads supplied by the system can be categorized as whether the energy supplied is electricity or heat (thermal load). Within the electrical category, electricity loads are often divided into primary and secondary loads.

Primary loads are those that must be served immediately, at a specific time. Demand associated with lights, TV, household appliances are examples of primary energy loads (Farret, 2006a). Secondary loads are associated with load management, and they may be further divided into what are known as deferrable and optional loads.

Deferrable loads have some flexibility when they are served (within a defined time interval). The inherent storage ability of battery-charging stations and water pumps, as well as the flexibility as to when the system can serve them, classifies them as deferrable loads. Optional loads, as the name refers, are only served if there happens to be sufficient excess energy available to do so (Farret, 2006a).

In this thesis, only primary and deferrable loads are considered. Microsoft Excel was used to pre-process these load data and organize it in the format accepted by the HOMER model.

3.4.2. ESTIMATION OF PRIMARY LOAD

The load determination of the village was performed for 792 household numbers with average of five family members per household; that depicts a population number of 3960(source: city administration). The household and business loads are separately considered. This is important for ensuring a good Plant Load Factor and to minimize the cost of higher capacity system which may not be economically viable. Load estimation was done by identifying the type, daily hours of operation; quantity of the appliances and the ratings of appliances used under the domestic load and its electricity consumption were estimated using the general formula:

Energy consumption (kWh) = ((number of appliance used x power rating of each appliance (w) x hours of operation)/1000)…………3.6

i. DOMESTIC LOAD

Domestic load refers to household consumption as per this thesis and while calculating energy consumption of the base year it was assumed that all the households cannot have all the appliances listed down at one time and hence some percentage was allotted for calculating energy. For example it was assumed that only 60%, 40%, 7% the households will have Tape recorder, Television and injera Mitad respectively at the base year and the forecast was also done accordingly [9].

Table 3.2: Domestic Load Estimation

No.	No. of house holds	Type of Appliance	Power ratting (W)	Qty. of Appliances	Run time (h/day)	Energy (kWh)/day
1	792	CFL lamp	13	4	6	247.10
		Tape Recorder	50	1	8	190.08
		Television	70	1	5	110.88
		injera mitad	2800	1	2	310.46
		Refrigerator	100	1	24	95.04
		Stove	1000	1	6	475.20
		Fan	40	1	6	9.50
		Boiler	1400	1	3	166.32
		Wireless telephone	10	1	24	38.02
		Mobile phone charger	84	1	1	13.31
		Other miscellaneous	2000	1	8	633.60
	Total energy consumption of domestic load(KWh)					2289.51

ii. PUBLIC/ SRVICE AND COMMERCIAL LOADS

Under public service category the electric requirement of public offices, churches, mosque, schools and health center are included; in addition for commercial appliances tools, device or piece of equipment that could be used in a business are considered. Flour mills, rice mills, café, restaurants, and shops are some of the examples and their energy consumption are indicated in tables 3.3 below.

Table 3.3 Community and commercial loads estimation

No.	Description		Sub detail of the electric appliances(Rating*Qty*Operating hours)	Energy Consumption in KWh/day
1	Public Loads	Schools(pre-school, primary & secondary)	Indoorlight(13W*80*2hrs),Externallight(36W*9*12hrs),TapeRecorder(50W*2*8hrs),Television(70W*2*8hrs),Computers(60W*100*8hrs), HP DeskJet(3 in 1) (44W*10*3hrs), Ceiling fan(40W*20*8hrs), science laboratory (1000W*1*2hrs), Microphone (10W*2*8hrs), Amplifier (200W*2*1hrs), Wireless Telephone(10W*10*12hrs), Auto-mechanic laboratory(2000W*1*2hrs), Electricity laboratory(3000W*1*2hrs), ICT laboratory(9000W*1*3hrs), cafeteria(3000W*3*8hrs).	174.812
		Public administration Offices of all sector	Indoorlight(13W*400*8hrs),Externallight(36W*60*12hrs),TapeRecorder(50W*2*8hrs),Television(70W*2*8hrs),Computers(60W*200*8hrs), HP DeskJet(3 in 1) (44W*28*3hrs), Ceiling fan(40W*120*8hrs), Lab top (40W*26*6hrs), Microphone (10W*5*2hrs), Amplifier (200W*2*1hrs), Wireless Telephone(10W*52*12hrs), Meeting hall(300W*1*2hrs),	600
		Health Center	Indoorlight(13W*80*2hrs),Externallight(36W*9*12hrs),Television(70W*1*8hrs),Computers(60W*100*8hrs), HP DeskJet(3 in 1) (44W*10*3hrs), Ceiling fan(40W*20*8hrs), laboratory (1000W*1*2hrs), Wireless Telephone(10W*10*12hrs), Laboratory equipment(1000W*1*8hrs), cafeteria(3000W*1*8hrs),	40
		Church& Mosque	indoorlight(13W*80*2hrs),Externallight(36W*9*12hrs),TapeRecorder(50W*2*8hrs),Ceilingfan(40W*20*8hrs),Microphone (10W*2*8hrs), Amplifier (200W*2*1hrs), Wireless Telephone(10W*10*12hrs),	50
2	Commercial loads		Indoor light (13W*10*2hrs), External light (15W*6*12hrs), Tape Recorder (50W*6*6hrs), Television (250W*8*8hrs), Refrigerator (400W*4*24hrs. Tea & coffee m/c(1000W*6*12hrs), Coffee grinder(2000W*6*1hrs), Shave machine(10W*6*8hrs), video hall, (300W*4*6hrs), ATM machine for banking (1000W*2*24hrs), Photo studio(500W*4*6hrs), Tire Repair(3000W*3*6hrs), Bakery(15000W*3*4hrs),Fuel Station(1000W*1*24hrs), Store House(1000W*2*6hrs), Garage(15000W*2*6hrs), Shops(100W*20*8hrs), Barber(100W*6*8hrs), Animal Clinic(1000W*2*8hrs), Pharmacy(500W*3*8hrs), Clinic(2000W*2*12hrs), Hotel(5000W*4*14hrs), Restaurants & Bar(3000W*8*16hrs),, Animal Slaughter(1000W*2*3hrs), Butchery(700W*4*8hrs), Sew engine(100W*6*8hrs), flat iron(1000W*4*4hrs), Metal work(15000W*3*6hrs), Wood work(15000W*4*6hrs), Flour Mills(12000W*6*8hrs)	2732
	Total Power Demand for public service [KWh]			**3596.812**

iii. ELECTRIC LOAD FORECASTING

A forecast of electricity demand of the village is made based on a method known as energy approach. In this approach the annual energy sales for residential and non-residential customers are forecasted using appropriate growth rates and the total sum of each category is converted to the peak demand requirement using loss rate and load factor. Other parameters like population growth rates, customer growth (market penetration) and growth rates of consumption per connection used in the forecast for each customer type [9, 16].

The total electric load estimated for the town under each customer group was summed up to get the required load to be supplied by the system. The total estimated installed load is not the actual peak load that will be seen by the system, because all the loads are not switched on and off at the same time. Therefore, a coincident factor of 0.8 is considered. In addition to that the following are taken into consideration during load forecasting [42].

- Growth rate is 5% per year
- Design margin (loss rate) is assumed 10%.
- Operating reserve is assumed 10%. Operating (spinning) reserve is surplus electrical generating capacity that is operating and can respond instantly to a sudden increase in the electric load or a sudden decrease in the renewable power output.
- The peak power demand of the village was calculated using total energy requirement of the village and load factor. The load factor value of 40 % at base year with load factor growth rate of 1% per year was taken into account [16].

Table 3.4 Load forecast for 25 years project life for each sector

Year	HH Electricity Cons. (KWh/day)	Public sector Electricity Cons. (KWh/day)	Commercial Sector Energy Consumption(KWh/day)	Street Light Electricity Cons. (KWh/day)	Total Energy Cons. (KWh/day)	Total Energy Requirement (KWh/day)	Load Factor	Peak Power Demand in KW
2017	934	183	319	17.94	1,453	1,017	0.40	105.94
2018	822	332	576	21.62	1,751	1,471	0.40	151.72
2019	734	445	769	24.36	1,973	1,658	0.41	169.26
2020	663	521	894	25.97	2,104	1,767	0.41	178.68
2021	607	555	947	26.36	2,135	1,794	0.42	179.54
2022	563	593	1002	26.97	2,184	1,835	0.42	181.85
2023	529	632	1061	27.77	2,249	1,889	0.42	185.41
2024	503	675	1123	28.75	2,329	1,956	0.43	190.08
2025	484	720	1189	29.90	2,422	2,035	0.43	195.72
2026	470	768	1258	31.21	2,528	2,124	0.44	202.26
2027	462	820	1332	32.67	2,646	2,223	0.44	209.62
2028	457	874	1410	34.27	2,776	2,332	0.45	217.74
2029	456	933	1493	36.02	2,918	2,451	0.45	226.59
2030	458	996	1580	37.92	3,071	2,580	0.46	236.14
2031	462	1062	1673	39.96	3,237	2,719	0.46	246.38

2032	469	1133	1771	42.17	3,415	2,869	0.46	257.41
2033	476	1209	1875	44.50	3,605	3,028	0.47	269.00
2034	485	1290	1985	47.00	3,807	3,198	0.47	281.28
2035	495	1377	2101	49.66	4,023	3,379	0.48	294.27
2036	507	1469	2224	52.50	4,252	3,572	0.48	307.99
2037	519	1568	2354	55.51	4,497	3,777	0.49	322.45
2038	533	1673	2492	58.72	4,756	3,995	0.49	337.69
2039	547	1785	2638	62.12	5,032	4,227	0.50	353.73
2040	562	1904	2793	65.74	5,325	4,473	0.50	370.61
2041	578	2032	2957	69.58	5,636	4,734	0.51	388.37

3.4.3. DEFERRABLE LOADS

Deferrable load is an electrical demand that can be met anytime within a certain time span, which exact timing is not important [36]. Water pumping and battery-charging are examples of deferrable loads because the storage inherent to each of those loads allows some flexibility as to when the system can serve them. The ability to defer serving a load is often advantageous for systems comprising intermittent renewable power sources, because it reduces the need for precise control of the timing of power production. If the renewable power supply ever exceeds the primary load, the surplus can serve the deferrable load rather than going to waste.

To distribute water fairly to the rural community, pumping it first to the reservoir and then distributing it from the reservoir by using gravity is recommended [40]. This way, enough pressure can be built up at the water reservoir to distribute water by gravity. In addition, water will continuously flow in the reservoir, which helps to reduce the growth of bacteria. Thus, the deferrable load considered here is water pump for water provision to the central distribution reservoir for household's and other community services. For this study, a pump with rating 746.65W is recommended and it could run for an average of 6:00 hours per day at a rate of 3.805lit/sec. The required amount of water needed per family is ~100 liter/day, for public service and commercial sectors it is assumed ~5000liter/day. The above assumption is based on country average consumption of water per person and study conducted by previous researchers. Thus, the total consumption of water per day is around 82.2m^3/day. A water storage capacity for three days is recommended. Moreover; an assumption of 10% decrement in months of June, September and October and 30% decrement in months of July and August in water requirement is made as per previous study [36].

Table 3.5. Summary of water supply pump for households and community service.

Power rating(W)	Running hours	Energy consumption (KWh/day)	Peak deferrable (KW)	Energy storage (KWh)
746.65	6	4.48	0.74665	13.44

Table 3.6 Monthly Energy consumption of deferrable load

Months	Jan	Feb- May	June	Jul-Aug	Sep-Oct	Nov-Dec
Deferrable Load(KWh)	4.48	4.48	4.032	3.136	125	4.48

CHAPTER FOUR

4.1 MODELING OF A HYBRID FOR TECHNO-ECONOMIC ANALYSIS BY HOMER

One of the aims of this thesis is to find out the best configuration which can supply electricity to the selected town at the lowest price with an accepted level of availability. In order to determine optimal renewable energy system that can cover the load for the town under the study I used HOMER. It requires considering several combinations of renewable energy resources and diesel generator with different component capacities.

4.2 HOMER SOFTWARE DESCRIPTION

The HOMER (Hybrid Optimization of Multiple Energy Resources) is computer software navigates the complexities of building cost-effective and reliable micro grids that combine traditionally generated and renewable power, storage, and load management. It is established global leader for micro grid design optimization and feasibility.

It is developed by the U.S National Renewable Energy Laboratory (NREL) used for developing and analyzing technically and financially of the options for grid connected and off-grid energy systems for remote, stand alone and distributed generation applications. The program allows for combination of many different RETs (PV, wind turbines, hydro, and hydrogen) and conventional options such as diesel generators or grid connection with consideration of available renewable resources and predicted energy consumption. It has many options for adjusting the system for example constrains such as minimum renewable energy fraction, operating reserve or maximum allowable amount of fuel that can be used in a year. It fully analyses the financial part of the design allowing for input of all costs associated with the project (initial, on-going and replacement costs) during its lifetime, considers annual real interest rate and produces expected cost of energy per kWh for the end consumer[24].

It was designed to overcome the complexity of micro power systems due to a large number of design options, uncertainty in key parameters or intermittent nature of renewable resources. It allows for adding of sensitivity values for many parameters and also produces synthetic hourly data sets for various parameters (wind speed, solar radiation, and load) in order to simulate as it happens in reality.

It performs three main tasks: simulation, optimization and sensitivity analysis. In the simulation step HOMER performs analysis of the system configuration for each hour in the year to determine technical feasibility and life-cycle cost. In the optimization step software looks for a configuration which will satisfy the technical constrains at the lowest life cycle cost, many different configurations are analyzed at this point. In sensitivity analysis HOMER performs multiple optimizations with regards to various input assumptions to check the effects of uncertainty or changes in the model inputs.

HOMER hybrid model requires several inputs which basically describe the technology options, component costs, component specifications and resource availability.

4.2.1 SIMULATION DATA

In order to estimate the cost of a hybrid power system, it is required to provide availability of renewable energy over a period of one year, load profile and details of each component. The available renewable resources and load estimations are already discussed for the selected site. The details of each component include capital cost, replacement cost, operation and maintenance cost, diesel cost and some other constraints which will be introduced in the following discussion. HOMER simulates the system with different combinations of the available sources. The output includes the capital cost, net present worth, energy per kWh cost, component size and other electrical characteristics.

I. LOAD INPUT

LOAD PROFILES FUNDAMENTALS: Use of the products created by electric power (e.g. light, radio, TV, computers etc.) varies as a function of time of day, day of week, and season of year. As a result, the electric load varies. A load profile plots electric consumption as a function of time. Load profile shape depends on the connected load (appliances), the activity and lifestyles of the consumers in an area. Nevertheless differences between the electric demand patterns of otherwise similar types of customers occur because of differences in climate, demographics, appliance preferences, and local economy [42]. A number of definitions can be introduced to characterize load profiles and below are used in this thesis:

- **Demand and peak load**

Demand is the average value of load over a period of time (i.e. the demand interval). Demand can be measured on any interval (seconds, one minute, day, etc.). The average value of power during the demand interval is found by dividing the kWh accumulated during the interval by the number of hours in the interval. The peak and minimum usage rates during the interval may result quite different from this average. Peak demand, also called peak load is the maximum demand measured over a measurement period. This value is often used as a capacity target in engineering studies, i.e. the maximum amount of power the system must deliver.

- **Load factor**

Load factor (LF) is the ratio of the average demand to the peak demand during a particular period. Load factor is usually determined by dividing the total energy accumulated during the period by the peak demand and the number of demand intervals in the period. Considering hourly demand periods over a day, load factor is defined as:

$$LF = \frac{E_L}{24hrs * P_L} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.4.1$$

Where:

- E_L represents the total electric usage during a day
- P_L represents the peak load during the day

Load factor gives an indication of the degree to which peak demand levels were maintained during the period under study. Or it is an indicator of the excess generating capacity that is required to serve peak loads, as well as the 'peakiness' of the load.

It also indicates how efficiently the customer is using peak demand. It is typically calculated on a daily, monthly, seasonal, or an annual basis. In addition it is used for determining the overall cost per unit generated [42].

- **Coincident factor (Ks)**

Usually, coincident load behavior is summarized by the coincident factor (**Ks**). Coincident factor is defined as "the ratio of the maximum coincident total power demand of a group of consumers to the sum of the maximum power demands of the individual consumers comprising the group, both taken at the same point of supply and for the same period of time" [42]:

$$K_s = \frac{P_{L,class}}{\sum_{i=1}^{Ni} P_{L,i}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.4.2$$

Where:

- **K_s** : coincident factor
- $P_{L,class}$: represents the total power demand of a class of consumers;
- $P_{L,i}$: represents the maximum power demands of the individual consumers comprising the class.

Population habits, community and business practices, weather and other climatic conditions exert a great influence on the degree of coincidence in the consumers' use of electric service. These conditions are not subject to precise mathematical formulation, and their resultant effect will be different for different communities and different climatic, social, and political conditions. But for any given community, operating under a given set of conditions, the resultant effects of population habits community and business practices, weather and other climatic conditions on the manner of use of electric service usually fall into some general pattern and thus result in some determinable values of degree of coincidence of individual consumer's use of service [42], [43].

- **Demand factor**

Demand factor is the ratio of the maximum demand of a system, or part of a system, to the total connected load on the system, or part of the system under consideration. Demand factor is always less than one.

These factors are taken into consideration during load forecasting for 25 years of the project life cycle as per the energy model of Ethiopian Electric Power/ Utility (EEP/EEU) for rural electrification purpose. But initially I was estimated the loads by identifying the customer category, appliances used under each customer category, hours of operation and quantity of appliances as discussed in previous section. Thus primary loads will be added to the system from the Add/Remove window in HOMER. Each hour, HOMER calculates the power produced by the elements of the system to serve the total primary load [24].

The baseline data is a number of 8,760 values that represent the average of electric demand and it is expressed in kW, and this value is taken for each hour [24].

Two techniques to produce baseline data: Either by HOMER to synthesize data, or by importing hourly data from a file [24].

The technique of synthesize, just put at least one load profile, which is a set of 24 hourly values of electric load [24]. For this thesis I used this technique and enter different load profiles for weekdays and weekends. In figure 4.1 below the daily load profile of the town under consideration with an average of 152KW, peak load of 388KW, energy consumption of 3637kwh/day and load factor of 0.4.

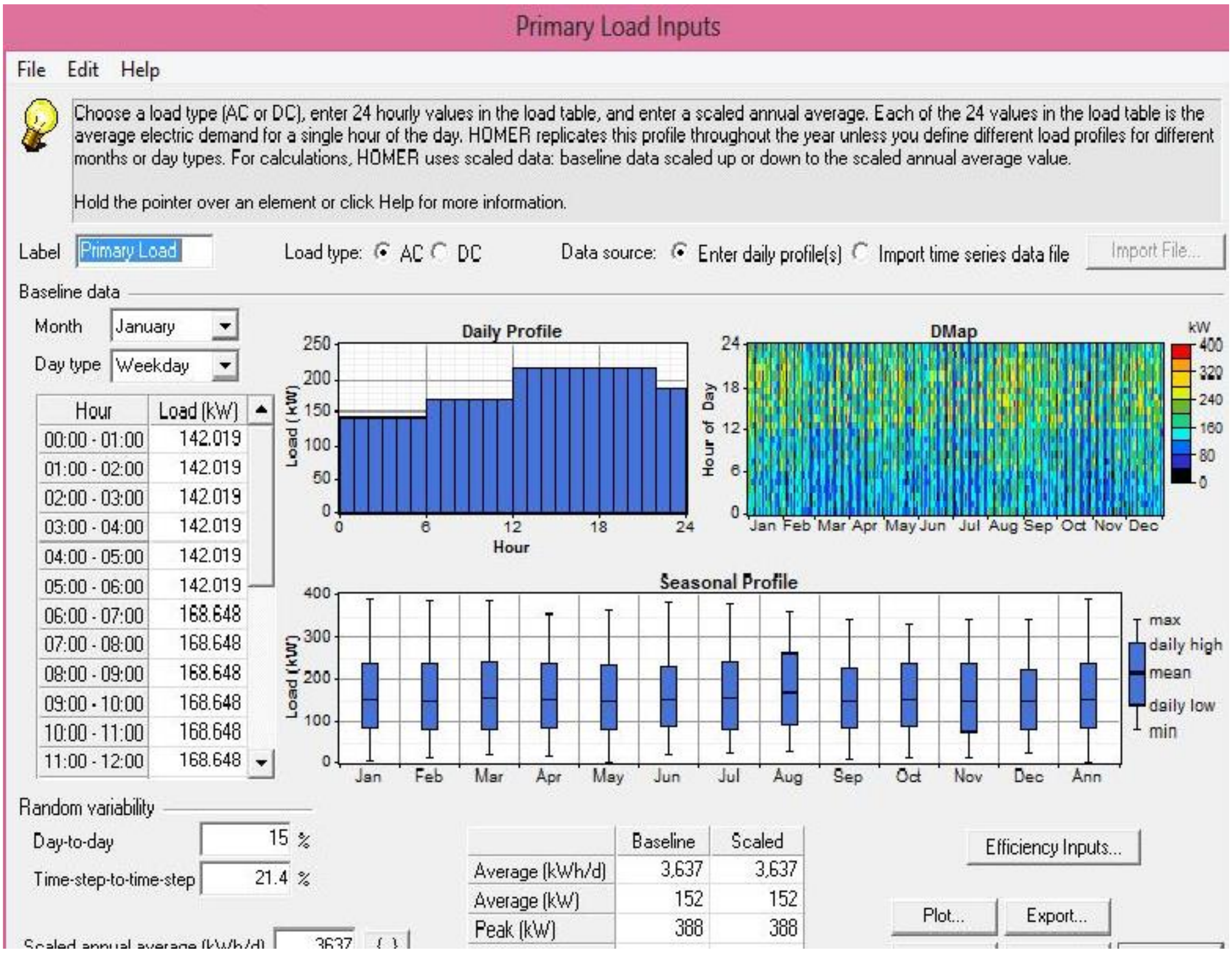


Figure 4.1: Primary load inputs

HOMER adds randomness according to the values entered for daily noise and hourly variability. These standard deviations come up with more realistic load demand. For this thesis the randomness is made 15% daily and 21.4% hourly and it is as indicated in figure 4.2.

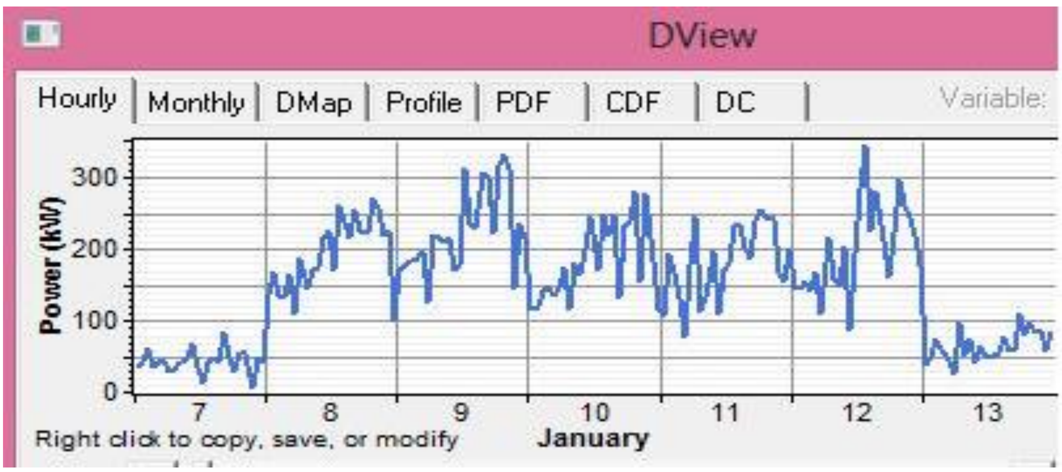


Figure 4.2: Statistically-modified HOMER profile

As explained in section 3.5.3 the monthly variation of deferrable load is due to an assumption of decrement during rain seasons as discussed in [36].

Figure 4.3: Monthly deferrable load

In this section the study of capital, replacement, and O and M costs of the main components of the hybrid system; PV, micro hydro, converters and diesel generator have been done. The capital costs include the cost to purchase, install, and to transport the components. The project life considered here is 25 years(the lengths of time over which the cost of system occur) which is used to calculate the annualized replacement and capital costs of each components, as well as the total net present cost of the system. To obtain the input data for the cost estimate to HOMER; information was collected from research literature, manufacturers and market survey.

II. MICRO-HYDROPOWER

The specific cost of micro-hydroelectric stations varies according to various items in which it is difficult to know the cost of everything due to most items require a lot of understanding. Moreover; the detailed cost of micro-hydroelectric varies from place to place depending on the project location.

In general, expenses are determined by the condition and cost of transportation, civil work, and technology offered in the topographic area. Thus after investigating, different micro-hydroelectric generators and civil work costs and finally capital, replacement, and O and M cost of the micro-hydropower system were estimated to be $750,000, $250,000 and $800/year respectively. HOMER considers only a single size of hydropower system. Instead, it designates the cost and properties of size of hydro to be considered [24].

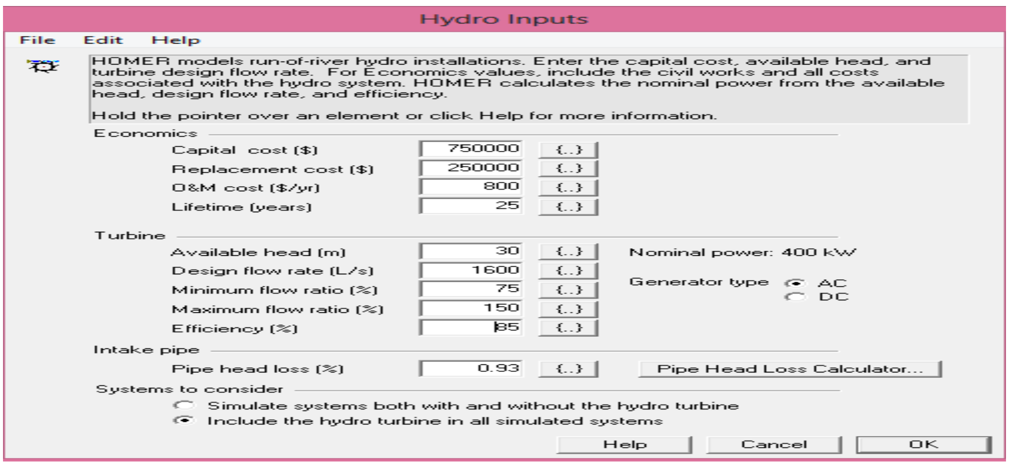


Figure 4.4: Hydro inputs

III. PHOTOVOLTAIC SYSTEM

In general, the PV costs \$0.73/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 transportation, labor, installation and structure costs. Different PV arrays costs were investigated on price list retrieve [51]. And finally a 1kW PV array cost was assumed to be \$2000 including civil work, labor wages, transportation and structural and any other related costs which is adapted from PV project of other country and taking in to consideration of our country situation. The replacement cost is the cost of replacing the PV array at the end of its useful lifetime, which is specified in years and usually, the replacement cost is equal to the capital cost .Operating and maintenance costs are not high for a PV system. The derating factor considered is 90% 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 slope. Fixed slope solar collectors normally face towards the equator and the tilt angle is set to an angle which is equal to the geographical latitude of the collector location on the earth. This angle is good to maximize the annual performance of the collector [24]. In this thesis the slope would be 6.15 degree which is site latitude. If the azimuth angle of the system is set to be fixed then the modules will be orientated as 0° azimuth for the systems situated in the northern hemisphere and 180° azimuth for the systems situated in the southern hemisphere [24]. The ground reflectance (ρg) is the percentage of radiation that is reflected on the ground [24]. A grass-covered is 20 %. Snow areas may go as high as 70 % [24]. So for this thesis the ground reflectance of 20% is taken.

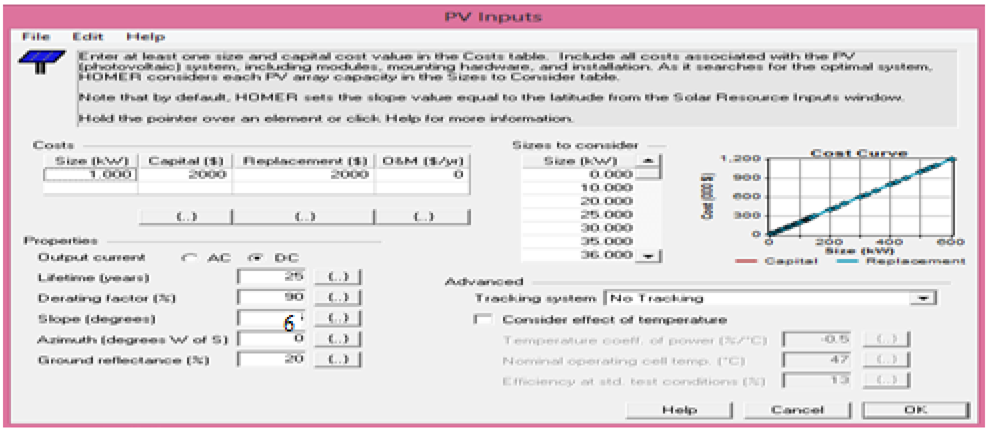


Figure 4.5: PV Inputs

IV. DIESEL GENERATOR

Diesel generator initial costs vary with size, model and design. It is obvious that cost (\$/kW) depends on the design (method of cooling) and rated power. For the same design the cost decreases as rated power increases. For the range of power taken in this case study analysis, the capital cost, and replacement cost, O and M costs of a 1KW generator is taken as \$960, \$800 and \$0.5/hr respectively [44]. The fuel cost considered was \$0.9 at the site during analysis.

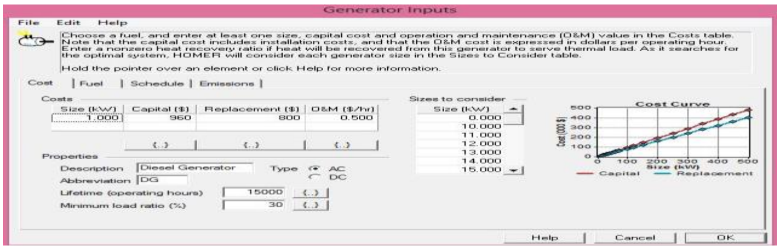


Figure 4.6: Diesel Generator inputs

V. CONVERTER

The capital cost, replacement cost and O and M costs for 1KW systems are estimated at $700 and $2/year respectively [38]. The lifetime of the converter is 15 years, inverter efficiency of 98% and rectifier efficiency of 95% [38].

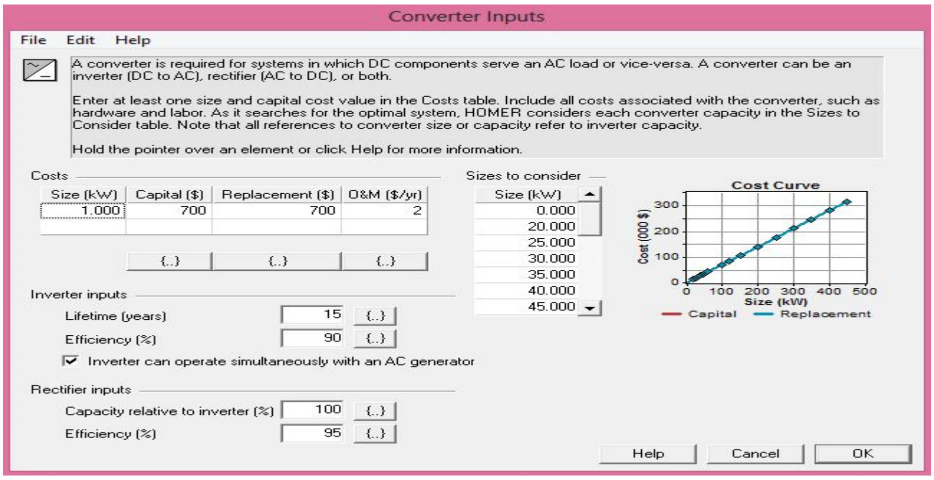


Figure 4.7: Converter inputs

4.2.2. OTHER IMPORTANT FACTORS INPUT TO HOMER

HOMER also considers factors like economic inputs, system constraints, load priority, operating reserve etc [24].

4.2.2.1 ECONOMIC MODELING

HOMER minimize the total net present cost (NPC) both in finding the optimal system configuration and in operating the system, economics play a crucial role in the simulation. The indicator chosen to compare the different configuration‘s economics is the life-cycle costs (LCC), and the total NPC is taken as the economic figure of merit. The advantages of these indicators are described in this section.

The main difference between renewable and non-renewable resources regarding to costs is that non-renewable resources usually have low capital and high operating costs, whereas for RES the costs are generally distributed in the opposite way: After a considerable investment in the beginning, the system can be operated at a comparatively low cost. To be able to compare the economics of numerous different system configurations with a varying share of renewable and non-renewable energy sources, HOMER has to take into account both the operating and capital costs. Since the LCC comprises of all costs incurred during the system‘s life span, it considers these factors and therefore this is the appropriate parameter to compare the different configurations economics [24].

This LCC is determined with the help of the NPC, which expresses all costs and proceeds occurring during a system’s life span in one total sum (in dollars). Future earnings are discounted back to the present using the discount rate, which is – just as the system’s life span – set by the system designer. The different items making up the NPC are the costs for construction, maintenance including component replacements, buying power from the grid and miscellaneous other costs. Furthermore, the NPC also considers salvage costs that is the residual value of system components after the project‘s end. [24 and 55].

HOMER factors inflation is analyzed with the help of the assumption that prices will increase at the same rate during the system‘s life span. This allows the modeler to apply an annual-real interest rate, which equals the nominal interest rate minus the inflation rate, and calculate all costs in constant dollars.

An alternative to the NPC is to compare the economics of various system configurations is the levelized COE, which is defined as the average cost for every kWh of electricity produced by the system. Yet, HOMER has chosen the NPC as primary economic figure of merit.

i. ECONOMIC INPUTS

Figure 4.9 shows the economic input window of Homer for project life of 25 years. The interest rate is another critical parameter that depends on factors that cannot yet be precisely specified. HOMER suppose the rate of inflation to be the same for all types of costs (fuel cost, maintenance cost, labor cost, etc.) occurring over the life of the project [30]. Homer models use a real interest rate, which is approximately equal to the nominal, or quoted, rate minus the expected inflation rate over the life of the project. For this analysis, a more conservative interest rate of 8% was assumed.

ii. SYSTEM FIXED CAPITAL COST

The fixed capital cost of the system is normally allocated for building a house for keeping generator, inverter and other relevant electrical instruments and constructing the distribution lines throughout the village. It also includes the site preparation cost, labor cost, engineering design cost and other various costs. Since the capital costs of each component have already taken into account an estimate of the fixed capital cost here is assumed for unconsidered costs including distribution network construction to be about $60,000.

iii. SYSTEM FIXED OPERATION AND MAINTENANCE COST

System fixed O and M cost firstly includes labor cost and insurance costs. Here also O and M cost already considered for all components though operating and maintenance costs are indefinite in real working condition.

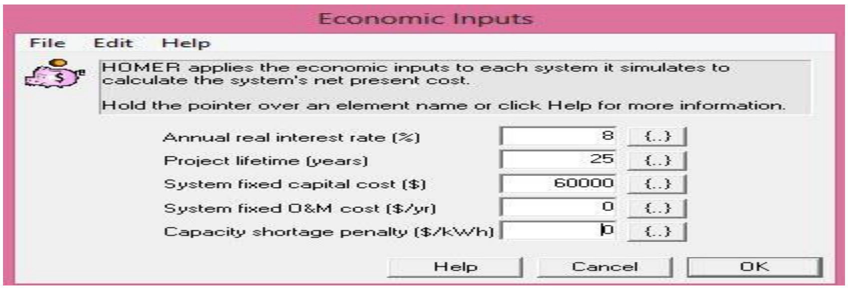


Figure: 4. 8. Economic input window.

4.2.2.2 SYSTEM CONTROL INPUTS

The diesel generator is the only non- renewable and dispatch able energy source used in this hybrid energy system. Since the energy output from renewable sources especially solar radiation considered in this thesis is highly intermittent and cannot be controlled by the user, and then it has to be used when it is available for supplying the load. If renewable energy systems are not able to meet the load then the diesel generator has to be auto-started so that it can supply the load without causing power interruptions. Therefore using a diesel generator is essential in hybrid systems to supply the load in a controlled mode to improve the availability of the system. Therefore, dispatch strategy also should be developed when optimizing the hybrid system. Two dispatch types [24]; i.e. “Load following” and “Cycle charging”.

i. Load Following (LF): The diesel generator is switched on when required and produce only the required amount of power that cannot be produced by the renewable sources to supply the load.

ii. Cycle Discharging (CC): The diesel generator starts when required and operates at its full capacity and excess energy is sent to the battery bank to charge the batteries.

4.2.2.3 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:

$$\boldsymbol{D_{grid}} = \frac{\boldsymbol{C_{NPC}CRF(i,N) - C_{power}L_{tot}}}{\boldsymbol{C_{cap}CRF(i,N) + C_{om}}} \quad \text{.......................................4.6}$$

where: C_{Npc}, is total net present cost of the stand-alone power system in USD, CRF is the capital recovery factor, N is project lifetime [yrs], L_{tot} is total primary and deferrable loads [kWh/yr]. C_{power} is cost of power from the gird [$/kWh] and C_{cap} is the capital cost of the grid extension [$/km] and C_{om} operation and maintenance cost and i is interest rate. The grid is found at a distance of 174KM from the town under consideration.

In order to compare standalone system with grid extension we can use the existing grid as standard bench mark reference and the capital, replacement and operation and maintenance costs are $120,000, $2500 and 0.06$/kWh respectively Ethiopian Electric Power/utility[EEP/EEU].

Table 4.1 Grid extension cost for Tum Town to be entered in HOMER

Name	Nearest Substation	Voltage level	Unit Cost /KM	Total Transmission cost	O and M cost	Total cost
Tum	Mizan Aman	132KV	125,000	21,750,000	435,000	22,185,000

The comparison of breakeven distance with stand alone has done in the following section after simulation has done with homer.

4.3 THE HYBRID SYSTEM STRUCTURE

The hybrid system under consideration is modeled in HOMER as shown in Figure 4.9.

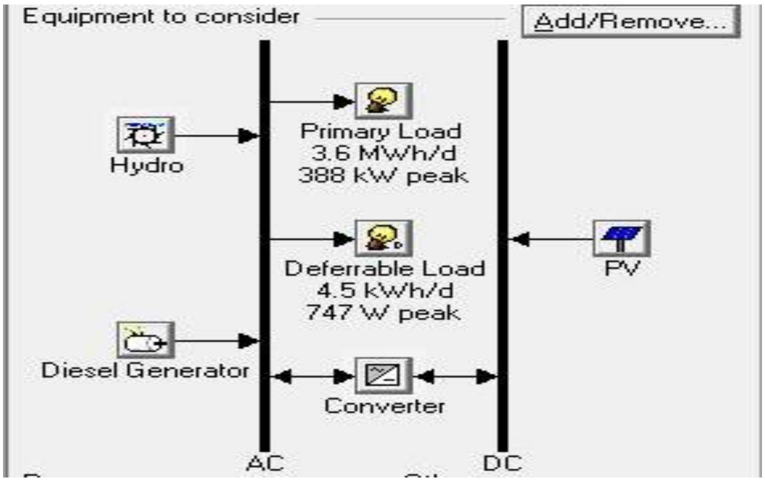


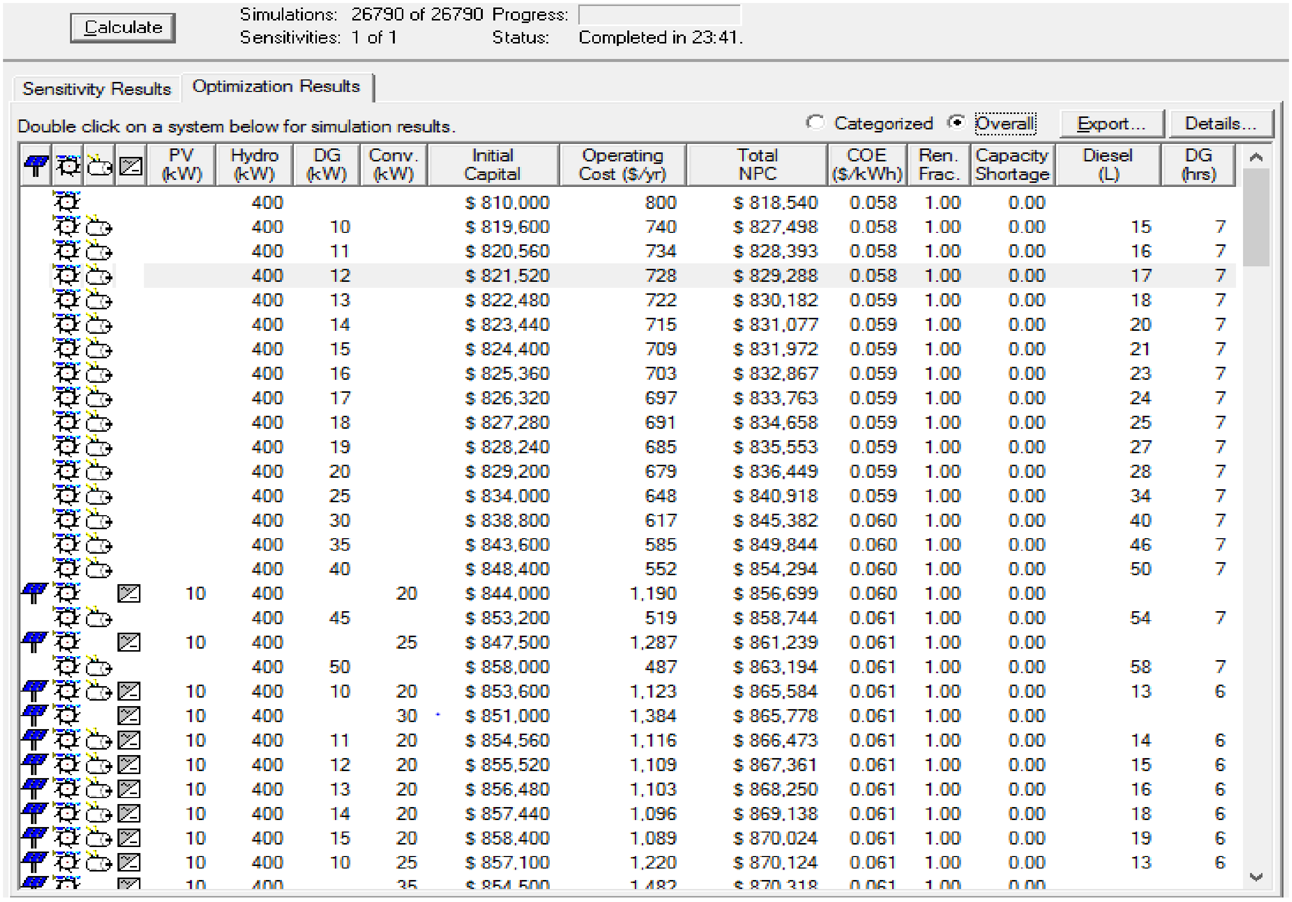
Figure 4.9: hybrid system structure

4.4 HOMER SIMULATION RESULTS AND DISCUSSIONS

The inputted data treated by the software describe the renewable energy availability, load demand, hybrid system component costs (PV array, hydro turbine, converter and diesel generator) and sizes as mentioned in previous sections.

4.4.1 OPTIMIZATION RESULT

After simulation, HOMER provides several combinations of available power sources with their total net present worth, initial capital cost, energy per kWh cost, the total system configuration and component sizes that meet the load requirement. Simulation results which include each component size, each system configuration's costs and total net present worth are shown in below.



Calculate | Simulations: 26790 of 26790 | Progress: | Sensitivities: 1 of 1 | Status: Completed in 23:41.

Sensitivity Results | Optimization Results

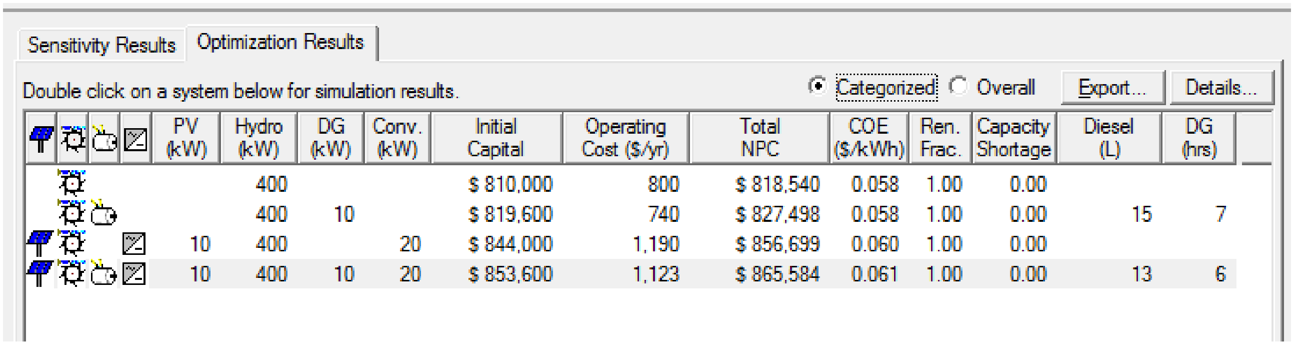
Double click on a system below for simulation results. Categorized | Overall | Export... | Details...

PV (kW)	Hydro (kW)	DG (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
	400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
	400	10		$ 819,600	740	$ 827,498	0.058	1.00	0.00	15	7
	400	11		$ 820,560	734	$ 828,393	0.058	1.00	0.00	16	7
	400	12		$ 821,520	728	$ 829,288	0.058	1.00	0.00	17	7
	400	13		$ 822,480	722	$ 830,182	0.059	1.00	0.00	18	7
	400	14		$ 823,440	715	$ 831,077	0.059	1.00	0.00	20	7
	400	15		$ 824,400	709	$ 831,972	0.059	1.00	0.00	21	7
	400	16		$ 825,360	703	$ 832,867	0.059	1.00	0.00	23	7
	400	17		$ 826,320	697	$ 833,763	0.059	1.00	0.00	24	7
	400	18		$ 827,280	691	$ 834,658	0.059	1.00	0.00	25	7
	400	19		$ 828,240	685	$ 835,553	0.059	1.00	0.00	27	7
	400	20		$ 829,200	679	$ 836,449	0.059	1.00	0.00	28	7
	400	25		$ 834,000	648	$ 840,918	0.059	1.00	0.00	34	7
	400	30		$ 838,800	617	$ 845,382	0.060	1.00	0.00	40	7
	400	35		$ 843,600	585	$ 849,844	0.060	1.00	0.00	46	7
	400	40		$ 848,400	552	$ 854,294	0.060	1.00	0.00	50	7
10	400		20	$ 844,000	1,190	$ 856,699	0.060	1.00	0.00		
	400	45		$ 853,200	519	$ 858,744	0.061	1.00	0.00	54	7
10	400		25	$ 847,500	1,287	$ 861,239	0.061	1.00	0.00		
	400	50		$ 858,000	487	$ 863,194	0.061	1.00	0.00	58	7
10	400	10	20	$ 853,600	1,123	$ 865,584	0.061	1.00	0.00	13	6
10	400		30	$ 851,000	1,384	$ 865,778	0.061	1.00	0.00		
10	400	11	20	$ 854,560	1,116	$ 866,473	0.061	1.00	0.00	14	6
10	400	12	20	$ 855,520	1,109	$ 867,361	0.061	1.00	0.00	15	6
10	400	13	20	$ 856,480	1,103	$ 868,250	0.061	1.00	0.00	16	6
10	400	14	20	$ 857,440	1,096	$ 869,138	0.061	1.00	0.00	18	6
10	400	15	20	$ 858,400	1,089	$ 870,024	0.061	1.00	0.00	19	6
10	400	10	25	$ 857,100	1,220	$ 870,124	0.061	1.00	0.00	13	6
10	400		35	$ 854,500	1,482	$ 870,318	0.061	1.00	0.00		

Figure 4.10 over all optimization results

In the overall list shown in Figure 4.10, the top-ranked system is the least-cost configuration with the micro hydro power system. The overall optimization results table in particular tends to show many system configurations whose total net present cost is only slightly higher than that of the best optimal configuration.

The categorized table displays only the most cost effective configuration from each system type. From categorized result of the simulation as shown in figure 4.11, the first optimal result is similar as indicated in figure 4.10. But the second system configuration is the combination of micro-hydropower and diesel generator. The diesel generator in this combination can be utilized only during peak time. And the third system configuration is the combination of solar arrays, micro-hydropower and convertor. In each combination the available energy by each renewable sources, when the peak demand is low will be consumed by deferrable load.



Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized | Overall | Export... | Details...

PV (kW)	Hydro (kW)	DG (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
	400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
	400	10		$ 819,600	740	$ 827,498	0.058	1.00	0.00	15	7
10	400		20	$ 844,000	1,190	$ 856,699	0.060	1.00	0.00		
10	400	10	20	$ 853,600	1,123	$ 865,584	0.061	1.00	0.00	13	6

Fig 4.11 categorized optimization results

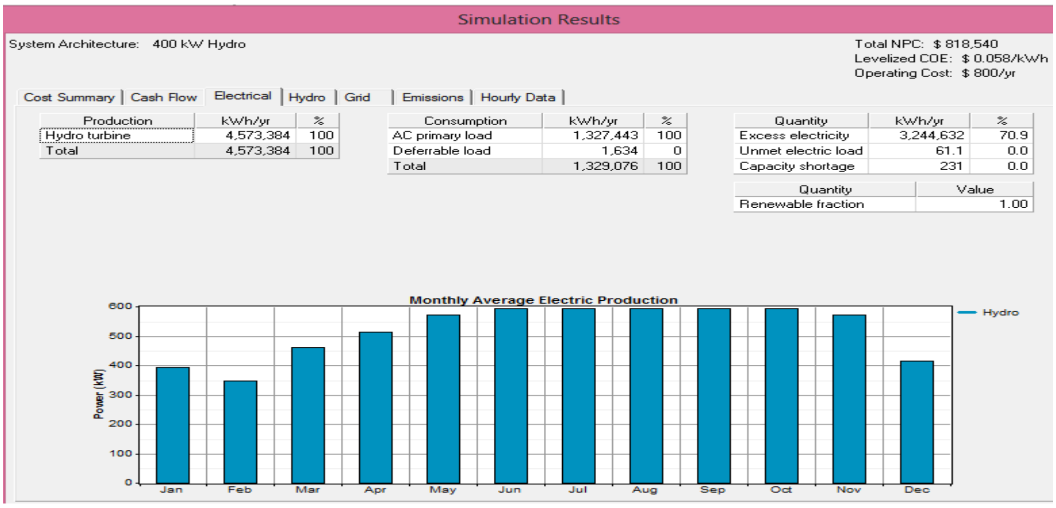


Figure 4.12 monthly average electrical production of the system

Figure 4.12 shows the monthly average electrical production of the system. Though the proposed design was the hybrid of PV, Micro-hydro and DG before simulation, due to huge amount of water resource in the area Homer optimization shows Micro-hydro system as best optimization results with NPC. As mentioned above HOMER considers only a single size of hydropower system, no search space for it and I have considered the maximum power to be produced from the resource available according to [60]. Thus, based on the first optimization result the most feasible hybrid configuration is 400kW hydropower with the NPC of $818,540 and the Levelzed cost of $0.058/kWh, which is higher than the current electricity tariff of Ethiopia for domestic load, i.e. $0.027/kWh Ethiopian Electric Utility [EEU] and incomparable with what the community is paying now for the diesel generator owners which is about $1.46/kWh for the usage of one lighting bulb. In the above figure, there is excess electricity of 70.9% which can be during huge rainy seasons and it is the result of HOMER simulation without control applied. If control is applied the generation during this time can be minimal. Otherwise the micro hydropower system in this site can supply other nearby villages or can handle other types of loads in the village.

The cost summary for the winning system configuration of the village is shown below in Figure 4.13.

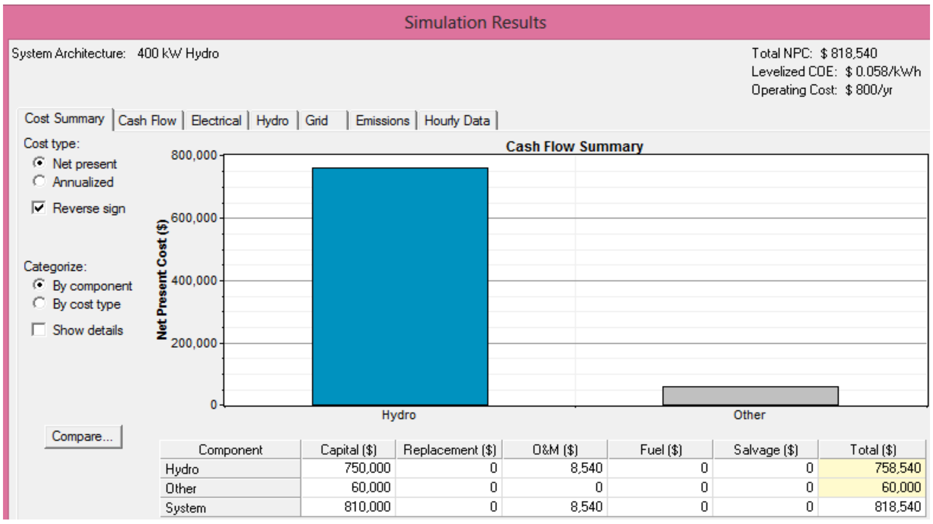


Figure 4.13 Cash flow of the system by component.

4.4.2 SENSITIVITY RESULTS

HOMER sensitivity algorithms are used to assess the effect of uncertainties in the input variables, in selecting the optimum hybrid system configuration. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs. One of the primary uses of sensitivity analysis is in dealing with uncertainty. But sensitivity analysis has applications beyond coping with uncertainty. A system designer can use sensitivity analysis to evaluate trade-offs and answer such questions as: How much additional capital investment is required to achieve 50% or 100% renewable energy production? An energy planner can determine which technologies, or combinations of technologies, are optimal under different conditions. A market analyst can determine at what price, or under what conditions, a product (e.g., a fuel cell or a wind turbine) competes with the alternatives. A policy analyst can determine what level of incentive is needed to stimulate the market for a particular technology, or what level of emissions penalty would tilt the economics toward cleaner technologies [24]. Here in this thesis I used sensitivity to deal with uncertainty.

Sensitivity analyses exclude all impractical configurations and ranks the feasible configuration by judging uncertainty of parameters [24]. Various sensitive variables can be considered to select the best suited combination for the hybrid system to serve the load demand. I have analyzed the uncertainties with the variation of stream flow, solar radiation and diesel price against each other. I took three sensitive cases for solar radiation, four cases for stream flow rate of hydro power and three cases for diesel price. HOMER performs a separate optimization process for each sensitivity case and presents the results in various tabular and graphic formats.

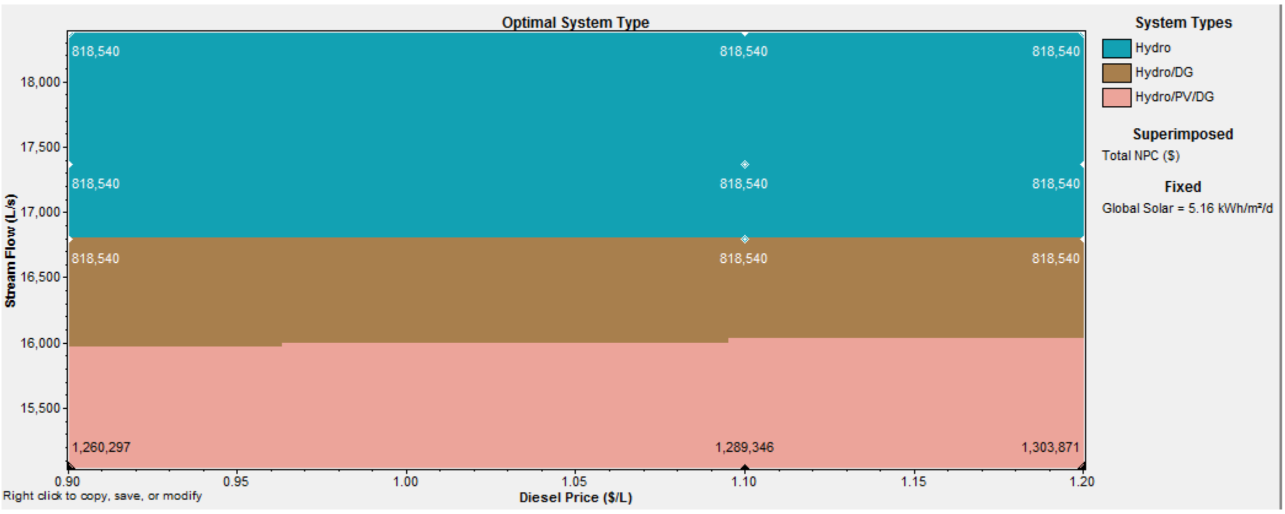


Figure 4.14: Sensitivity of diesel price and global radiation with graphic form of display

In Figure 4.14, 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 town under consideration. From the above figure for the three variations of diesel prices, it is observed that for a stream flow above 16,800 liter/second Homer suggests hydro system is favorable while for stream flow between 16,800 liter/second and 16,000 liter/second hydro and diesel generator favorable configuration and finally for the stream flow below 16,000 liter/second Homer suggests hydro/solar/diesel generator is the most favorable configuration. But as diesel price increases the combination of diesel generator usage became narrower on the graph and the solar radiation is inversely proportional with the net present value for the optimal system indicated on figure 4.14.

Sensitivity Results | Optimization Results

Tabular / Graphic — Export... Details...

Double click on a system below for optimization results.

Solar (kWh/m²/d)	Stream Flow (L/s)	Diesel ($/L)	PV (kW)	Hydro (kW)	DG (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
5.160	16791.0	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	16791.0	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	16791.0	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	17365.4	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	17365.4	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	17365.4	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	15036.1	0.900	10	400	60	20	$ 894,630	34,255	$ 1,260,297	0.093	0.99	0.05	13,606	685
5.160	15036.1	1.100	10	400	60	20	$ 894,630	36,977	$ 1,289,346	0.095	0.99	0.05	13,606	685
5.160	15036.1	1.200	10	400	60	20	$ 894,630	38,337	$ 1,303,871	0.096	0.99	0.05	13,606	685
5.160	18376.6	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	18376.6	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
5.160	18376.6	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	16791.0	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	16791.0	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	16791.0	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	17365.4	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	17365.4	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	17365.4	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	15036.1	0.900	10	400	60	20	$ 894,630	34,261	$ 1,260,354	0.093	0.99	0.05	13,612	685
4.600	15036.1	1.100	10	400	60	20	$ 894,630	36,983	$ 1,289,416	0.095	0.99	0.05	13,612	685
4.600	15036.1	1.200	10	400	60	20	$ 894,630	38,344	$ 1,303,946	0.096	0.99	0.05	13,612	685
4.600	18376.6	0.900		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	18376.6	1.100		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		
4.600	18376.6	1.200		400			$ 810,000	800	$ 818,540	0.058	1.00	0.00		

Figure 4.15: Sensitivity of diesel price and global radiation with tabular form of display

4.4. Comparing Standalone System with 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.

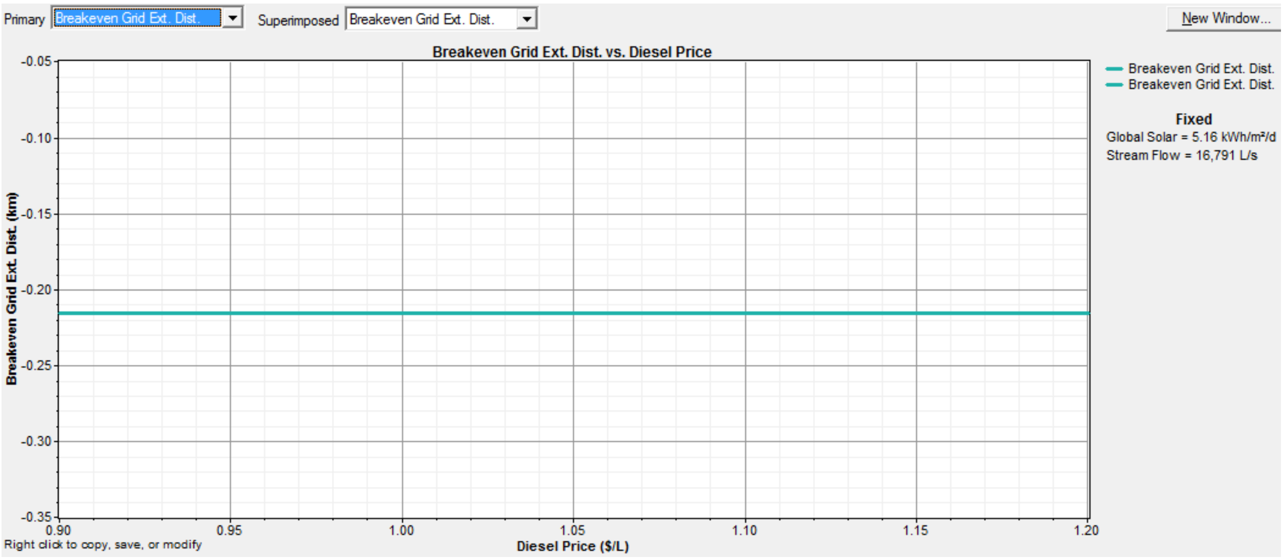


Figure 4.16: superimposed breakeven grid extension

Grid is found at 174km away from the town under the study and the cost of extending the grid is found $22,185,000 in previous section while the total Net present Cost of the best optimized system is found $818, 540. As shown in figure 4.16 for this study the break-even grid extension is negative on best optimized result (-0.216km) which implies the stand alone system is the best option for the town under consideration.

CHAPTER FIVE

5. 1 LOAD FLOW ANALYSIS USING ETAP FOR THE POWER SYSTEM DEVELOPED

The purpose of the electrical power system is to deliver high-quality, safe, and reliable electric power to homes, industrial plants, and commercial businesses. Electrical power system studies are conducted to determine safe and reliable performance on electrical power systems. Normally, studies are conducted using commercially available software packages. The software packages allow in evaluating the designed power systems. Load-flow, dynamic stability, transient, short-circuit, and protection are major types of power system studies.

In this section the Tum power supply is simulated by **ETAP (Electrical Transient Analyzer Program)** software to study load flow analysis.

5.2 LOAD FLOW STUDIES

Load flow or power flow studies are used to help determine the state of the power system. It determines system voltages, currents, the active and reactive powers, as well as the power factors. These parameters are used to determine system losses, conductor ampacity ratings, and voltage levels at particular connection points (busses) of the power system. Load flow studies are performed to ensure at least these basic steady-state operating requirements are met:

- Generation supplies the load plus losses on the system
- Maintain bus voltage near nominal or rated value
- Confirm transmission and distribution lines are not overloaded

5.3 ETAP

It is widely used commercial & fully-functional software package that is used for design, simulation, and operation, control, of transmission, distribution and industrial power systems. It has great simulation modules for power system analysis, real-time simulations, monitoring, optimized control, intelligent load shedding, energy management, cost analysis, and load management. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems and high-speed intelligent load shedding **[**44**]**.

ETAP combines the electrical, logical, mechanical, and physical attributes of system elements in the same database. For example, a cable not only contains data representing its electrical properties and physical dimensions, but also information indicating the raceways through which it is routed. Thus, the data for a single cable can be used for load flow or short-circuit analyses (which require electrical parameters and connections) as well as cable ampacity and derating calculations (which require physical routing data). This integration of the data provides consistency throughout the system and eliminates the need for multiple data entry for the same element, which can be a considerable time savings [44].

5.3.1. FUNCTIONS OF ETAP SOFTWARE

5.3.1.1 SPECIFICATIONS

i. MODELING

- Virtual reality operation
- Total integration of data (electrical, logical, mechanical, and physical attributes)
- Looped and radial systems
- Unlimited isolated sub-systems
- No system connection limitations
- True 32-bit or 64 bit programming designed for Windows® XP/2003/2008/Vista
- 3-phase and single-phase modeling including panels and sub-panels

ii. FEATURES

- Dynamic help line and error messaging
- Message logger to track program usage and access
- Multiple user access levels
- Merge independent ETAP project files
- Integrated 1-phase, 3-phase, and DC systems
- Simplicity in data entry
- Multiple sub-systems and swing machines
- User-controlled auto save and transaction
- User-controlled default settings for all components

iii. ALERT VIEW

ETAP displays this view to summarize possible problems with the electrical system including overloads, under/over voltage bus conditions, stressed devices, etc.

iv. OUTPUT REPORT MANAGER

ETAP Provides more than 250 Crystal Reports for different studies including the following subsections: complete, results, customizable, report, summary and input data.

v. LOAD FLOW ANALYSIS (LFA)

ETAP can perform LFA using Newton-Raphson, fast decoupled, and accelerated Gauss Seidel , New double-precision Newton-Raphson method with current injection, Advanced solution techniques for fast convergence, and others like Voltage drop calculations, Load forecasting, New alert view to display critical and marginal limit violations, Bus/transformer/cable overload warning, Single phase load flow display, Option to select any loading category, Global and individual bus diversity factors, Individual demand factors for continuous, intermittent, and spare operating, conditions, Option to update the database from load flow solutions, Lumped loads, Phase-shifting transformer, Power factor correction, Automatically adjust transformer tap and LTC/regulator settings, Generator governor/exciter control settings , New summary output report on bus loadings and overload conditions, Multi-Report Result Analyzer & Load Analyzer are features & capabilities of ETAP in the load analysis category.

And many other capabilities like :Panel and Single-Phase Systems, Short-Circuit Analysis, Time-Current Device Coordination/Selectivity (Star), Arc Flash IEEE 1584,Motor Acceleration Analysis, Harmonic Analysis, Transient Stability Analysis, User-Defined Dynamic Modeling , Generator Start-Up Analysis, Cable Derating Analysis, Ground Grid Systems Optimal Power Flow, Schedule Report Manager, DC Load Flow and DC Short-Circuit Analysis, Control System Diagram Reliability Analysis, Unbalanced Load Flow, Optimal Capacitor Placement, Real-Time Intelligent Load Shedding and Wind Turbine Generator (WTG)[44] .

5.4. THE STUDY CASE (LOAD FLOW ANALYSIS)

The Load Flow Analysis module in ETAP software works based on the voltages of all busses, power factors of the branches, currents and power flows which propagates throughout the electrical system. Different sources can be used as swing, voltage regulated, and unregulated power sources along with different power grids and different generator configurations. ETAP software can run the load flow study for both radial and loop electrical system configurations. As mentioned above ETAP offers different types of load flow calculation methods. For this study I used Newton-Raphson for its faster convergence and less iterations time.

The Load Flow analysis shows the way of running a load flow study, creating the output report or displaying the desired results throughout the one-line diagram.

5.4.1. REQUIRED DATA FOR LOAD FLOW STUDY IN ETAP

Different data are required to be feed into the software based on the study to be conducted and below are some of the data's for load flow analysis.

• Bus Data

The following data is required for load flow calculations of the buses:

- Nominal kV
- Initial percentage and angle of the voltage (if Initial Condition is selected to use Bus Voltages)
- Load Diversity Factor (if the Loading option is selected to use Diversity Factor)

• Branch Data

Branch data is defined in the Branch Editors. Branch includes Transformer, Transmission Line, Cable, Reactor, and Impedance. The following data is required for the load flow calculations of the branches:

- Z, R, X, or X/R values of the branches, tolerance and temperature only if applicable
- The length of the cable and transmission line
- Transformer rated kV and kVA/MVA, tap, and LTC settings
- Impedance base kV and base which can be in either kVA or MVA

• Synchronous Generator Data

- The following data is required for the load flow calculations of the synchronous generators:
- Operating mode (Swing, Voltage Control, or MVAR Control)
- Rated kV
- Initial value and the angle of the voltage sources for swing mode
- %V, MW loading, and MVAR limits (Qmin and Qmax) for Voltage Control mode
- MW and MVAR loading and MVAR limits for MVAR Control mode
- MW loading and PF, and MVAR limits for PF Control mode
- The Capability curve including all the information
- Synchronous reactance (Xd)

• PV generator Data

- Operating mode (Swing, Voltage Control, PF or MVAR Control)
- Rated kW
- PV panel in series & parallel
- Short circuit model
- Module characteristics

• Inverter Data

The following data is required for the load flow calculations of the inverters:

- Inverter ID
- Inverter DC and AC rating
- AC output voltage regulating data

•Static Load Data

Required data for load flow calculations for static loads includes:

- Static Load ID
- Rated kVA/MVA and kV
- Power factor
- % loading for desired Loading Category
- Equipment cable data

• Lumped Load

Data required data for load flow calculations for lumped loads includes:

I. Conventional

- Load ID
- Rated kV, kVA/MVA, power factor and % motor load
- % loading for desired Loading Category

II. Unbalanced

- Load ID
- Rated kV, kVA/MVA, power factor, % motor load, and % static load
- % loading for desired Loading Category

III. Exponential

- Load ID
- Rated kV, P0, Q0, a, and b
- % Loading for desired Loading Category

IV. Polynomial

- Load ID
- Rated kV, P_0, Q_0, p_1, p_2, q_1, and q_2
- % loading for desired Loading Category

V. Comprehensive

- Load ID
- Rated kV, P_0, Q_0, a_1, a_2, b_1, b_2, p_1, p_2, p_3, p_4, q_1, q_2, q_3, and q_4
- % Loading for desired Loading Category

- **Other Data**

Some additional information is required for some of the studies as follows:

- Load Flow Method (Newton-Rapson, Fast-Decoupled, or Accelerated Gauss-Seidel)
- Maximum number of Iterations
- Precision percentage
- Acceleration Factor (if Accelerated Gauss-Seidel method is selected)
- Loading Category
- Initial Voltage Condition
- Report format
- Update bus voltages and transformer LTCs using load flow result
- The study case related data is entered into the Load Flow Study Case editor.

5.4.2. ONE LINE DIAGRAM

Figure 5.1 below shows the one line diagram of the power system with the required inputted data and simulation result of the system under consideration. The blue colors are the inputted data and the results after simulation are indicated the red colors on one line diagram.

5.4.3. RESULT & DISCUSSION

5.4.3.1 LOAD BALANCE STUDY

While one line diagram is prepared, the load balance studies shall simultaneously be done to calculate the required power supply, transformer sizing and bus bars sizing. In addition, active power, reactive power and power factor for each bus and entire system is calculated. The base of the calculation is to obtain a sum of the active and reactive powers considering load factor from downstream (loads) to upstream (generator). From one line diagram in figure 5.1 it can be seen that the appearance of power is 409kVA so, the 500kVA upstream transformer will be a proper choice considering losses. In addition, the power factor is 81.5% but to improve this capacitor bank sizing can be done.

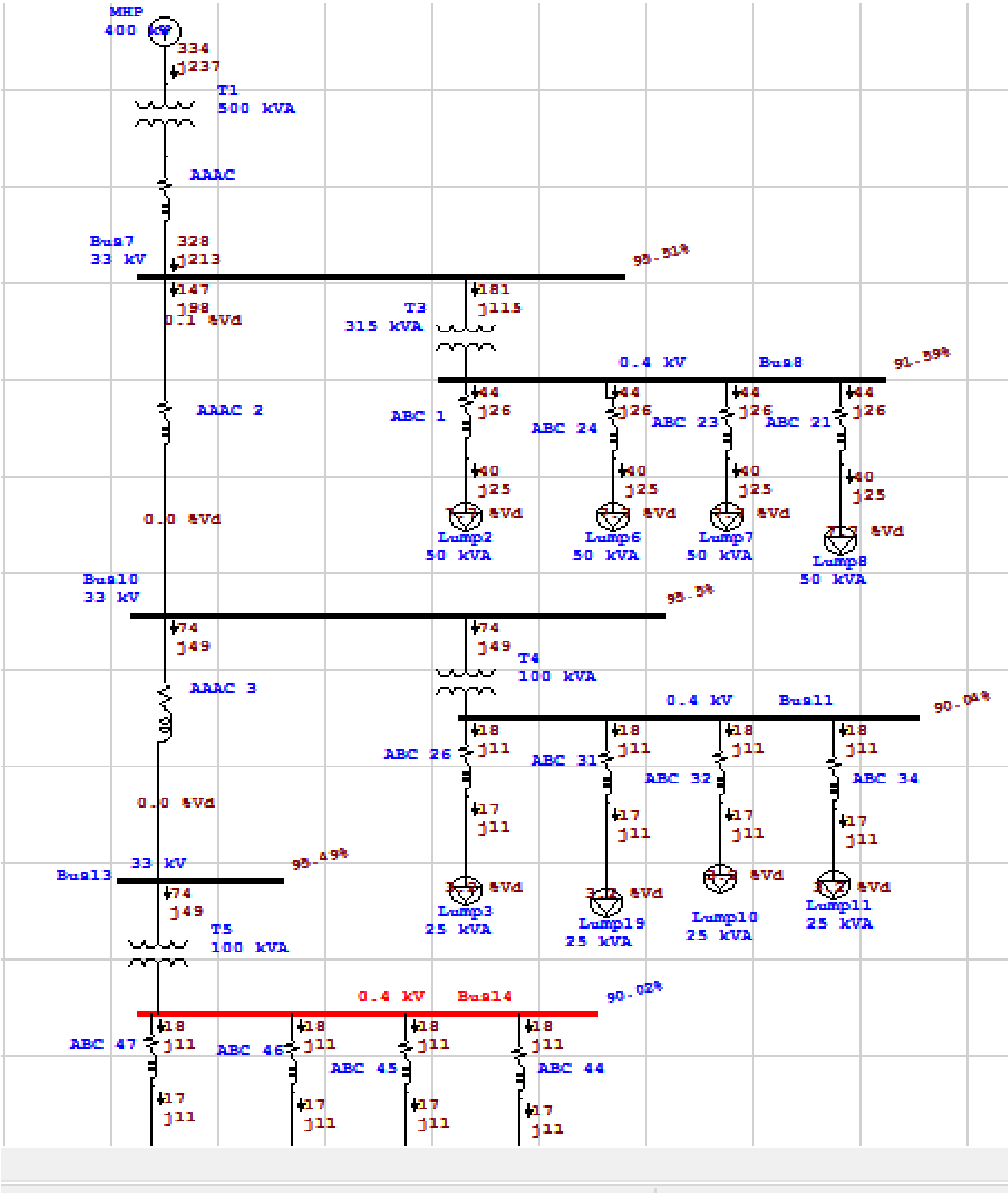


Figure 5.1: one line diagram of the power system

5.4.3.2 LOAD FLOW STUDIES

Load flow studies are carried out using ETAP in order to calculate all bus voltages, branch power factors, currents and power flows throughout the plant electrical system. The load flow reports shall tabulate the magnitude of active (real) power and reactive powers which have been supplied by each generator, transformer and bus bar with the total connected plant load. It is possible to indicate KW, KVAR figures, bus bar volts and voltage phase angles one line diagram after simulation.

5.4.3.3 LOAD FLOW REPORT OF SOFTWARE

10 percentages of tolerances on each bus are allowed. By studying the reports as shown in tables 5.1-5.3, it can be concluded that voltage drops are acceptable. The transformer capacity is adequate.

Table 5.1 Branch loading summary

CKT/ Branch	**Cable & Reactor**			**Transformer**				
ID	Type	Ampacity (Amp)	Loading Amp %	Capability(kVA)	Loading (input)		Loading (output)	
					kVA	%	kVA	%
ABC 1	Cable	138.54	80.91	58.40				
ABC 21	Cable	138.54	80.91	58.40				
ABC 23	Cable	138.54	80.91	58.40				
ABC 24	Cable	138.54	80.91	58.40				
ABC 26	Cable	138.54	33.39	24.10				
ABC 31	Cable	138.54	33.39	24.10				
ABC 32	Cable	138.54	33.39	24.10				
ABC 34	Cable	138.54	33.39	24.10				
ABC 44	Cable	138.54	33.38	24.10				
ABC 45	Cable	138.54	33.38	24.10				
ABC 46	Cable	138.54	33.38	24.10				
ABC 47	Cable	138.54	33.38	24.10				
T1	Transformer			500.0	409.3	81.9	391.1	78.2
T3	Transformer			315.0	214.2	68.0	205.4	65.2
T4	Transformer			100.0	88.4	88.4	83.3	83.3
T5	Transformer			100.0	88.3	88.3	83.3	83.3

* Indicates a branch with operating load exceeding the branch capability. So there is no any branch loaded beyond its capabilities from the report. In addition, the loading on each transformer is shown.

Table 5.2 Alert Summary Report		
	% Alert Settings	
Loading	**Critical**	**Marginal**
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
Overvoltage	105.0	100.0
Under Voltage	80.0	90.0
Generator Excitation		
Overexcited (Q Max.)	100.0	95.0
Under Excited (Q Min.)	100.0	

In table 5.2 by defining the limits, the system is checked and in case of wrong sizing of equipments, which will appeared in the Critical & marginal sections. But from the simulation result there is no equipments found with wrong sizing.

Table 5.3 Branch Losses Summary Report									
CKT/ Branch	**From-To Bus Flow**		**To-From Bus Flow**		**Losses**		**% Bus Voltage**		Vd % Drop in Vmag
ID	kW	kvar	kW	kvar	kW	Kvar	From	To	
T1	333.7	236.9	-327.8	-213.4	5.9	23.5	97.6	99.6	4.33
AAAC	327.8	213.4	-327.6	-213.2	0.1	0.2	99.6	95.5	0.05
AAAC 2	147.1	98.0	-147.1	-97.9	0.0	0.0	95.5	95.5	0.02
T3	180.5	115.2	-177.0	-104.2	3.6	11.0	95.5	91.6	3.92
ABC 1	44.2	26.1	-40.0	-24.8	4.3	1.3	91.6	90.7	7.67
ABC 21	44.2	26.1	-40.0	-24.8	4.3	1.3	91.6	90.7	7.67
ABC 23	44.2	26.1	-40.0	-24.8	4.3	1.3	91.6	90.7	7.67
ABC 24	44.2	26.1	-40.0	-24.8	4.3	1.3	91.6	90.7	7.67
AAAC 3	73.5	49.0	-73.5	-49.0	0.0	0.0	95.5	95.5	0.01
T4	73.5	49.0	-71.2	-43.2	2.3	5.8	95.5	90.0	5.46
ABC 26	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 31	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 32	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 34	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
T5	73.5	49.0	-71.2	-43.2	2.3	5.8	95.5	90.0	5.46
ABC 44	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 45	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 46	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
ABC 47	17.8	10.8	-17.1	-10.6	0.7	0.2	90.0	91.4	3.16
					37.1	**53.1**			

In Table 5.3, the losses of equipment and voltage drops are presented. It is within acceptable range. The negative values indicate that as the active and reactive powers are received from load to source.

CHAPTER SIX

6. 1 CONCLUSION AND RECOMMENDATION

6.2. CONCLUSION

In this thesis, the designs of off-grid electrification project based on hybrid MHP-PV/DG were proposed and analyzed using Homer software. But the optimization result showed that 100% of renewable energy fraction is achieved from micro hydro resources. Resource assessments, load estimation and forecasting have been done by literature review, site visiting and collection of data's. Monthly stream flow of water resource of the Tum River is estimated from previous study conducted in the site. Solar radiation is calculated from daily sunshine hour data obtained from NAMSA using empirical formulas and is equal to an average value of 5.16kWh/m^2/day. This result is very close to what is obtained from database of NASA and PVgis predictions.

The analysis was done using HOMER. During the analysis of the system set-up, it was done an optimization process based on the electricity load, climatic data sources, and economics of the power components in which the NPC has to be minimized to select an economic feasible power system.

HOMER simulation result displayed the most economical feasible system sorted by NPC from top to down, the prime system ranked first has renewable fraction of 100% with 400kW micro hydro power. This result confirmed the availability of huge utilizable hydro energy at the site. The NPC of the system is $818,540 and the Levelzed cost of energy for the system is $0.058/kWh, which is higher than the current electricity tariff of Ethiopia for domestic users, i.e. $0.027/kWh Ethiopian Electric Utility (EEU) but incomparable with $1.47/KWh for which the community are paying for diesel owner by using one lighting bulb.

Sensitivity analysis was also performed for the system, 36 sensitivity cases were used; 4 cases of stream flow, three values of solar radiation and diesel prices. The result shows that for a stream flow above 16,800liter/second hydro system is favorable while for stream flow between 16,800 liter/second and 16,000liter/second hydro and diesel generator is favorable configuration and finally for the stream flow below 16,000liter/second Homer suggests hydro/solar/diesel generator is the most favorable configuration.

Comparisons of grid extension and stand alone system has also done for the designed system and stand alone system found feasible for this case study. More over load flow analysis result shows generation supplies the load plus losses on the system, bus voltages are maintained to near nominal value and the system is not over loaded.

In conclusion, this study shows that developing a stand-alone power system is more cost effective and suitable for rural communities, while renewable energies are available, than running diesel generators. The result of this study encourages private investors and local community members, especially in Maji districts, to take advantage of renewable energy and be convinced that there is sustainability in investing in stand-alone power systems.

6.3. RECOMMENDATION

Across different corners of the country there are renewable energy resources which varies from site to site, thus can be used for electricity generation either in grid or off-grid system. Electricity generation using off-grid systems from local renewable alleviates the country's electricity shortage especially in Maji district where year round River flow is available rather than running diesel generators with high operating cost and the supply from these sources are very irregular.

6.3.1. Suggestions for Future Work

- This study focus on administrative town of the maji district and it doesn't cover all kebeles in the district. So, the future researchers should expand this research work in other kebeles and make the rural people beneficial with renewable energy resource.
- Reinforcing a proper financial and business model by analyzing the economic condition in Ethiopia as well as the selected rural community.
- Come up with a suitable operation and maintenance scheme which can ensure the sustainable operation of the system.
- Sorting of lumped loads as polynomials, Comprehensive, exponential or unbalanced should be done precisely as this thesis covers conventional load type only.
- Finally the software used in this study used are free trial versions, However the University/EEP/EEU should purchase licensed software for more reliable analysis. And high capacity computer should be ready for optimization, especially when considering various sensitivity cases analysis.

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Appendix

Some Pictures taken during site Visit

Figure.1 Household Cluster in tum town

Figure .2 Tele tower & office

Figure .3 Typical flour mills while giving service to the community in tum town

Figure .4 Typical shops in Tum

Figure.5 Water supply services to the community in Tum

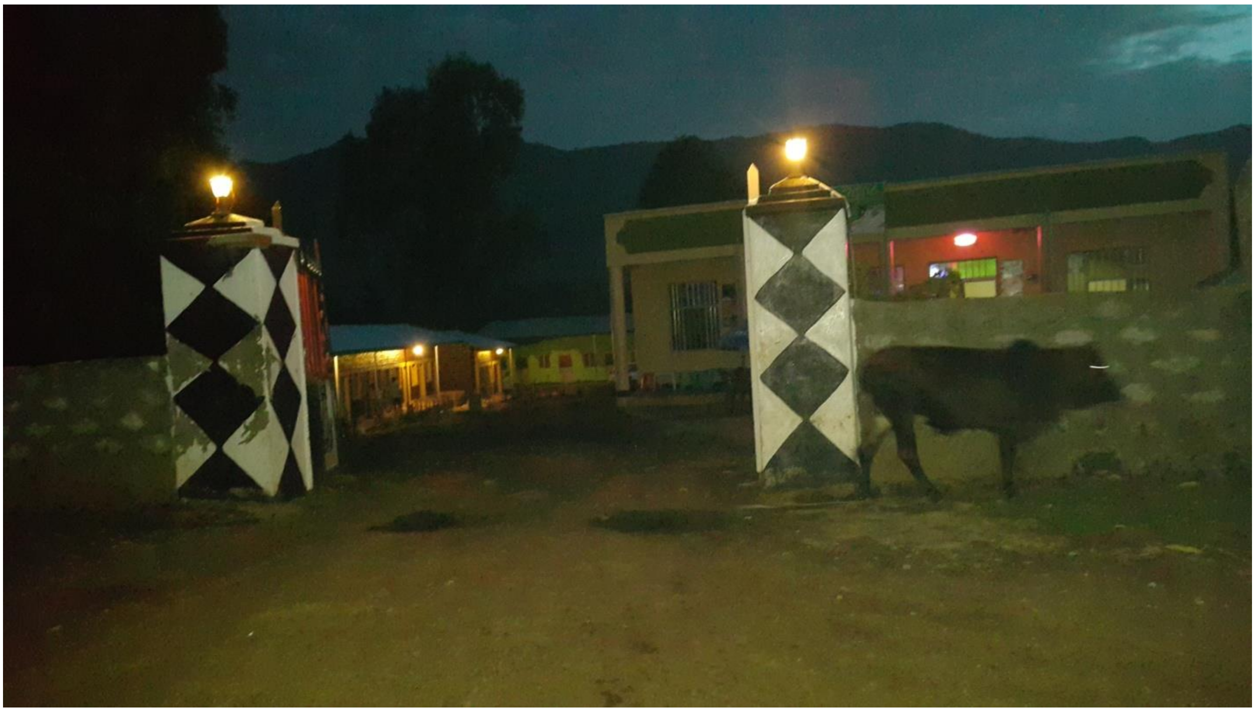

Figure.6 Typical grocery & pension in Tum

Figure.7 Health Center

Figure .8 Supreme Court Office

Figure.9 Woreda Administration Office

Figure.10 Primary School (1-8)