PERFORMANCE ASSESSMENT AND UPGRADING OF WALGA MICRO-HYDRO POWER STATION

BY

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A THESIS SUBMITTED TO

THE CENTER OF ENERGY TECHNOLOGY

PRESENTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

(ENERGY TECHNOLOGY)

ADDIS ABABA UNIVERSITY

ADDIS ABABA, ETHIOPIA

JULY 2017

This is to certify that the thesis prepared by Teklu Bekele, entitled: Performance Assessment and Upgrading of Walga Micro-Hydro Power Station and submitted in partial fulfillment of the requirements for the degree of Master of Sciences (Energy Technology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ACKNOWLEDGEMENTS

First of all I would like to thank the Ethiopian Ministry of Water, Irrigation and Electricity for sponsoring my MSc. program in Energy Technology in Addis Ababa University. Next, my sincere gratitude goes to my supervisor, Dr. Engineer Edessa Dribsa for his great encouragement, ideas, comments and continuous support throughout the process of this thesis accomplishment. My special thanks also go to Mr. Tezazu Bireda for providing valuable guidance on electrical circuit design for dummy load construction during this thesis work and Mr. Mekonnen Debela for his assistance during the performance test on the site.

I also would like to thank the authors of the reference materials used to furnish this thesis work. Last but not least, my special thanks to my colleagues, friends and brothers who helped me in numerous ways to make this thesis a success.

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ACRONYMS AND ABBREVATIONS

A	Cross sectional Area
AC	Alternating Current
B	Optimum width of canal bed
CFL	Compact Fluorescent Lamp
DC	Direct Current
D_p	Diameter of pipe
DVD	Digital Video Disc
ELC	Electronic Load Controller
f	frequency of the system
F	Female
g	Gravitational constant
GPS	Global Position surface
H	Height
H_f	Frictional Head
H_g	Gross head
H_n	Net Head
HOMER	Hybrid optimization model for Renewable Energy
Hz	Hertz
kg	Kilo gram
kVA	Kilovolt Ampere
kW	Kilo Watt
kWh	Kilo Watt Hour
L_p	Penstock Length
M	Male
m/s	Meter per second
m/s^2	Meter per second square
MHP	Micro Hydro Power
MHPP	Micro Hydro Power Plant

MHPS	Micro Hydro Power Station
MOWIE	Ministry of Water, Irrigation and Electric
MS	Micro Soft
MW	Mega Watt
NASA	National Aeronautics and Space Administration
n_p	Manning's coefficient of the penstock material type.
NPC	Net Present Cost
N_s	Turbine specific speed
O & M	Operation and Maintenance
P_f	Power factor
P_g	Generator electrical power output
P_h	Hydraulic power supplied to the turbine
P_t	Power out of the turbine shaft
PV	Photovoltaic
Q	Flow Rate
R	Hydraulic radius
RPM	Revolution Per Minute
SHP	Small Hydro Power
T	Torque
TNPC	Total Net Present Cost
TV	Television
V	Velocity

ABSTRACT

This research deals with the performance assessment and upgrading of Walga micro hydro power plant owned by government and fitted with cross flow turbine. Walga site is located in Oromia Regional State, South West Shoa zone, Wonchi Woreda Azer_Keransa Kebele. Walga site is located in a remote area. Currently, even though the village has the opportunity to get power from micro hydro power plant that was installed in 2014 by the Ministry of Water, Irrigation and Electricity, still the plant lacks reliability, sustainability and safety problems. The key reasons for the performance assessment and up grading of the existing Walga micro hydro power station were to know the efficiencies (turbine and unit efficiencies) and to determine the electrical power output of the plant. And also to know the power demand gap between supply side from the existing micro hydro power generator and demand side obtained from the village power demand assessment during the field survey. Therefore, performance assessment and testing, power need assessment of the community, determination of the power gap between the supply side from the existing Walga micro hydro power station and demand side were the purpose of this thesis work.

In this study, performance assessment of existing Walga micro hydro power station was carried out and performance indicators were identified. Based on the performance test results and the village power demand assessment findings, the power demand gap of Walga village was known., Two options were proposed to meet the power demand gap of the village. The first option is developing a PV/micro hydro hybrid power supply system and the second option is developing micro hydro resource existing at the site.

System designing and modeling by using Hybrid Optimization Model for Electric Renewable software for the two options were done and the simulation results were presented. Based on the Hybrid Optimization Model for Electric Renewable software simulation results, the performance and economic evaluations of each system were presented. Option I is characterized by as initial cost 8,719,300 Birr ($379,100), operating cost 276,690 Birr ($12,030), total NPC 12,618,812 Birr ($548,644) and cost of energy 8.70/kWh Birr (0.378$/KWh). The second option (Option II) is characterized by initial cost 1,357,000 Birr ($59,000), operating cost 54,510 Birr ($2,370), total NPC2,125,269 Birr ($92,403) and cost of energy1.47Birr/kWh (0.064$/KWh).

Finally, the performance evaluations and economic evaluations made for the option I and option II. From the evaluation results, option II was selected as better option to fill the power demand gap of Walga village.

Key Words: Assessment, Micro-hydro, Hybrid System, HOMER

CHAPTER ONE

INTRODUCTION

Performance assessment is a systematic process of obtaining information to be used to assess and improve a project. It helps to compare the performance of a system with others or with the same system over time. Typically performance test of a Hydro Power plant includes: Inspection of all components, systems and station auxiliaries, functional checks of simpler devices and systems, testing of measuring instruments, secondary injection tests on protective relays, operational tests on control systems, measurement of the parameters critical for generation, measurement of maximum power output of generating units and determination of efficiency of generating units, combined and individually [1].

Performance test of Electromechanical Equipments is part of the contract obligation and also provides strategic input for revisiting the design and manufacturing process [2]. Also reconfirms the accuracy and authenticity of the claimed model tests results. The "performance" of a turbine is quantified generally under the following reference: the efficiency of the machine within specified range of output and head variation should meet the guaranteed efficiency; the turbine power output should meet the guarantee as a function of the net head and discharge available [2]. The performance also includes safe operation of the machine without being subject to cavitations or fatigue in the specified head range.

One of the major potential sources of renewable energy is the utilization of hydropower systems in producing electricity and mechanical power. It has various applications and this could be an alternative source of power in the power station. Available micro hydro systems which are gaining popularity in providing electrical and mechanical power in the power stations are not subjected to performance testing before they are being installed for actual operation. Hence, they are not being maximized for different conditions.

Continuous effort should be done for the performance assessment of the condition and performance of the plants on the basis of various performance indicators in order to find out the potential areas for improvement. The assessment enables to analyze the entire fleet of plants owned by an enterprise such that the plant that needs more focus can be identified and timely decision can be made accordingly. If the improvements that can be made are economically and financially justified then decision must be made accordingly.

Walga village is one of the rural areas which have no sufficient power demand. The community requires electricity for household (TV, radio, lighting and charging) and for public sectors require for lighting and others.

The power demand gap of the community determined from the performance assessment of the existing Walga MHPP and its performance test results and from power demand assessment for the households and public sectors. The performance test results obtained are not as expected (lower power output and lower turbine efficiency). The power demand for the community was carried out for 257 households, one elementary school, two churches and street lights.

Based on the calculated power demand gap of the community, two options were presented to fill the gap. Option I is developing a PV/Micro hydro hybrid power supply system. And Option II is developing micro hydro resources available at the site assessed during the field survey on site.

Finally, selection of components for the two options, system designing and modeling for both option by using HOMER software were carried out. HOMER simulation results for both options were presented and each result was evaluated technically and economically. From the evaluation made option I and option II were compared and conclusion was made as option I is better than option II based the evaluation criterion.

1.1 Project Description

The Walga MHPS in this study is located at Walga village in Oromia regional State, South West Shoa zone Wonchi Woreda Azerer Keransa kebele. For the purpose of analysis, a micro hydro power station named Walga MHPS (Walga Micro Hydro Power Station) is selected. Walga MHPS site is located in Oromia Regional State, south West Shoa zone, Wonchi Woreda Azer_Keransa Kebele at longitude $37^0$54’45.06”E and latitude $8^0$42’46.74” N. The micro hydro power plant was set up by Ministry of Water, Irrigation and Electricity (by Alternative Energy Technology Development and Promotion Directorate) of Ethiopia as a pilot project. It was established in the year 2014. The geography of the Walga village is presented in Fig.1.1. As presented in Fig1.2, the electrical loads are scattered all over the village.

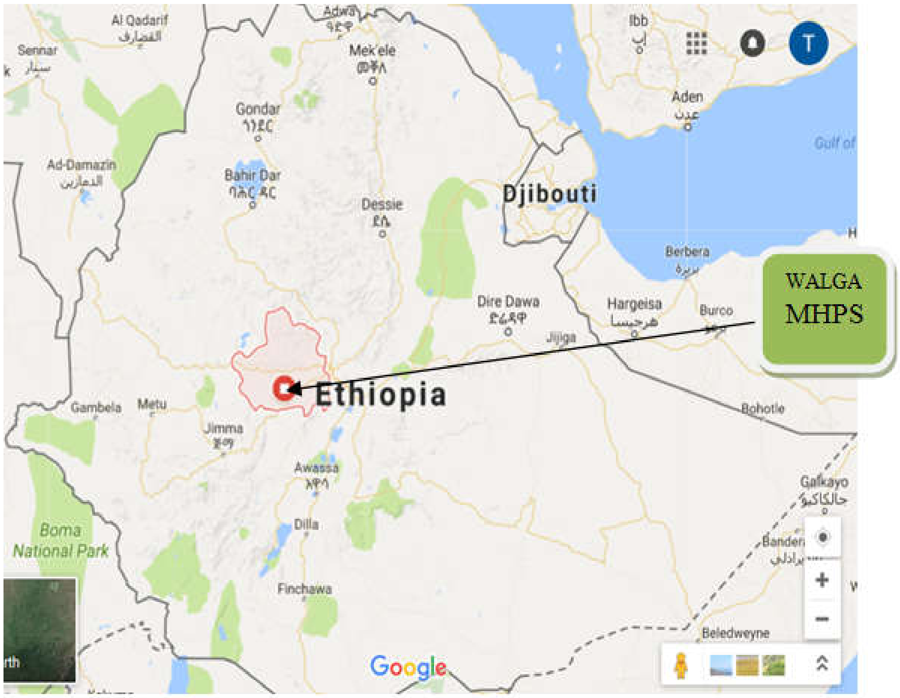


Fig.1.1: Map of Walga Village (source: Google Map)

Fig.1.2: Map of Geography allocation of Walga Site

Fig.1.3 below represents the existing Walga MHPS found in the Walga village.

Fig.1.3: Walga Micro Hydro Power Station

1.2 Details of Existing Walga Micro Hydro Power Plant

1. Name of power plant: Walga Micro Hydro Power Station
2. Owner of power station: Ministry of Water, Irrigation and Electricity
3. Location
    - Nearest town with distance: Woliso
    - Region: Oromia
    - Zone :S/W/Shoa
    - Woreda: Wonchi
    - Kebele: Azer-Keransa
    - Latitude: $8^0$42’46.74”N
    - Longitude: $37^0$54’45.06” E
    - Altitude: 2422m
4. Type of power station : Run-off- river type

5. Source of water: Wonchi Creator Lake
6. Number of generating unit: one
7. End-uses:
    - Milling
    - Lighting
    - Others

1.2.1 Generating Unit

Turbine

- Type: T_3 Cross-flow
- Shaft : Horizontal
- Make: Ministry of Water, Irrigation and Electricity Workshop
- Rated head: 10 m
- Rated discharge: 172Liter per second
- Rated Power output:4.74kW
- Speed increaser used: Flat Belt

Fig.1.4: Locally Manufactured Cross-flow Turbine

Penstock

- Length :15.96 m
- Inner Diameter: 0. 40 m
- Thikness:3 mm

- Material : Steel
- Number of Junctions :5
- Number of Bend: 0

Fig.1.5: Penstock

Generator

- Type: Synchronous
- Make: Fuan Liyuan Electrical Machinary Co.,LTD China
- Rated speed:1500 RPM
- Generator Ratings
  - KW: 15
  - Pf: 0.8
  - Kva: 18.75
  - Frequency: 50 Hz
  - Phase:3

Fig.1.6: A.C Synchronous Generator

1.3 Research Questions

The focus of the study is a performance assessment and testing of Walga MHPS, and knowing the power/energy supply side (from the existing Walga MHPP) then, power/energy needs assessment of the community and determining the demand side. Finally, by determining the power/energy gap between the supply side and demand side designing an appropriate system that can meet the power/energy demand of the community of Walga village in way that cost-wise and better environmental friendly. Therefore the research and analysis has been guided by addressing and answering the following questions:

- How performance test of Walga micro-hydro power plant and power/energy need assessment of Walga community will be carried out?
- What is the gap between power/energy supply side (existing Walga micro-hydro power plant) and demand side of Walga village?

1.3.1 Sub Questions

- What is power generating capacity and efficiency of Walga micro-hydro power plant?
- What are deficiencies of the existing micro hydro power station?
- What is power/energy supply of Walga micro-hydro power plant?
- What is the power/energy demand of the community of Walga Village?
- What is the appropriate system design that can meet power/energy demand of Walga Village?
- What is the appropriate suggested controlling system for Walga micro hydro power station?

1.4 Objective of the study

1.4.1 Main Objective

The main objective of this thesis is to carry out performance test of the existing Walga micro-hydro power plant at Walga site, power/energy needs assessment of the community and determination of the gap. And also to design an appropriate system either a photovoltaic system that can operate together with the existing micro-hydro plant or new hydro system and to fill the power/energy gap of the community in the area.

1.4.2 Specific objectives

- Undertake quantitative checks to confirm that all parts, systems and auxiliaries in the power station are performing their assigned functions correctly by visual inspection.
- Take measurements and tests to determine the efficiency of the power station and its principal components and
- Assess the power/energy need of the community, determine the gap and design a photovoltaic system that can operate together with the existing micro-hydro power plant or design new MHP system.
- Compare the results

1.5 Scope of the Study

The scope of this study is assessing the performance of Walga MHPS, performance test of the plant, power need assessment of the community and determination of the gap and designing photovoltaic system that can operate with the existing micro-hydro power or designing new MHP system to fill the gap. This study will investigate different methods of performance testing of locally manufactured hydraulic turbines.

This study shall collect and analyze relevant data and information to examine the performance of Walga MHPS and recommend necessary action, necessary measures that configure a system to accommodate the current and near future electrical energy demand for the village.

1.6 Methodology

More details of this methodology can be explained as follows:

- Collecting important data needed and making logical assumptions, the data are available gross head, available flow rate, electrical output of the generator, electricity consumption of households and public utilities.
- Find potential renewable energy resources in the village from NASA surface meteorology.
- Using data that had been collected to calculate the efficiency of the turbine and plant, available hydraulic power, and to make curves electrical power output versus efficiency of the cross flow turbine and the likes. The maximum electrical output from existing MHP plan will be known, total energy demand of community is calculated depending the interview made. The gap between the supply (from the existing MHPS) and the demand of the community will be calculated.
- Select appropriate photo voltaic system components depending on the energy gap identified.
- Design a photo voltaic system that can operate with the existing MHP plant as one option to fill the gap and simulate by HOMER software and evaluate the system.
- Developing a micro hydro resources existing at the site as the second option.
- Reassessment for more potential sites of Walga River and collecting data.
- Using the data collected from the new site and required parameters design and simulate by using HOMER software the system. Evaluate it technically and economically.

- Finally, compare the presented options and select better one.

1.7 Thesis Outline

The main aim of this thesis work is to know the power/energy gap between the supply and demand sides of Walga village and to upgrade the existing Walga MHPS and filling power/energy gap of the village.

Though the existing Walga MHPS that was installed by MOWIE contributes a lot on the life style of community of Walga village, its electricity supply was limited to one shift (during night) and not satisfactory in relative to the potential of renewals in the village. Keeping that in mind, this topic is chosen for this thesis work.

This thesis consists of six chapters. Chapter one mainly presents the introduction and description of the existing Walga MHPS, research questions, objective and scope of this research. It also provides the general development of method used in the modeling of micro hydroelectric power system.

Chapter two describes theoretical background at the beginning of the study will provide information regarding the principle that is used to generate electricity by using the water from the water source. The principle components (civil work and powerhouse components) of the MHPS (Micro Hydropower Power System), design parameters, performance evaluation of micro hydro power plant, power/energy demand assessment, photovoltaic system technology and PV/micro hydro hybrid system components and characteristics are also described to facilitate the understanding of the system components and to explain how micro hydro project works in an interconnected manner. The technical specifications or design parameters that are required to design MHPS will be also derived from literature review and explored further; because these are the most relevant information that are conducive to the design and implementation of MHPS (Micro Hydropower System) in a practical context.

Chapter three presents the power demand gap assessment section of the study that describes data collection and analysis approach, highlighting Walga village conditions and power/energy demand of the village. And also highlights about performance assessment of the existing Walga MHPS.

Chapter four presents about options to meet the power demand of Walga village (option I and II), PV/micro hydro hybrid system design and modeling process, the parameters for the hybrid and micro hydro only systems are established, system design size and simulated in HOMER software for reliable operation and cost effective. Two options are presented (PV/micro hydro hybrid and micro hydro only) and leading to better cost effective and environmental friendly proposed system.

Chapter five discusses the results obtained from the simulations of the hybrid system in HOMER software. The results of the optimization and sensitivity analysis, the selection of the optimal hybrid configuration and the performance of the selected system for varying conditions of load, solar and hydro resource will be discussed in this chapter. Better optimal system concerning both cost and environmental issues will be selected. The performance test result of the existing Walga MHPS also will be discussed in the chapter.

Chapter six concludes the thesis with a summary of the results, discussion and some recommendations.

CHAPTER TWO

LITERATURE REVIEW

Different researches accomplished in remote area electrification but few of them has been selected and reviewed and evaluated in the following paragraphs.

Kusakana, K., Munda, J. L., & Jimoh [3] used HOMER software to investigate the possibility and feasibility of using an off-grid solar/micro hydro power system for cost effective power generation which can meet the power demand of a typical remote rural area. Here optimization is effectively to improve the technical and economical performances of the hybrid system.

Saheb-Koussa, D., Haddadi, M., & Belhamel, M. [4] in their study, they deal with the design of hybrid system. Techno-economic optimization o two renewable sources that are photovoltaic and wind with diesel and battery storage have been obtained. Their aim was to find the suitable standalone hybrid system that will provide the energy supply of remote area with minimum COE. This paper has been selected, because it has the same target as the one that the researcher has in his thesis work.

Demiroren, A., & Yilmaz, U. [5] carried out a study based on HOMER software to develop a system to meet the daily load demand of Gokceada in Turkey, using renewable power generation technology.The hybrid system is consisting of components of solar panels, wind turbines and batteries for power back up.Values of components are determined by simulations. The cost of energy is also considered carefully, so that it can be minimized.

Gebreyohannes, B. [6] presented a case study of rural area in Ethiopia entitled “Modeling and simulation of Micro/Wind Hybrid Power Generation System for rural Area of Ethiopia” by using HOMER software. His aim was to develop a hybrid power supply system cost competitive to supply power for remote villages for a model community of 660 households, one primary school, two churches, one mosque and one health center. He presented two options Wind/micro hydro hybrid system and micro hydro only system by comparing the cost of energy to select the cost competitive for the remote village.

The above reviews show the well known of HOMER software as a tool to analyze electricity supply system. However, most of the researches do not account electricity demand in rural areas carefully (considered samples only). As the optimal system configuration is obtained to meet the power demand, demand assessments and analysis play an important role. Without this consideration, most of the power demand remains less accurate and remain theoretical in nature.

According to Berihun [6], the COE of Wind/Micro hydro hybrid system is \$0.112/kW and COE of standalone micro hydro system is \$0.0 35/kWh.He concluded micro hydro is the most economical and can only satisfy the energy demand of the village and technically feasible option.

If he considered solar resources in the hybrid system, his hybrid system may be cost effective regarding to his title

Micro hydro schemes are smaller in size and they refer to systems capacity ranging from 1kW to 100kW which can be used to supply independent local micro grid but do not necessarily feed electricity to the national grid [7].

Micro hydro units have been used for many years, especially for their mechanical power, but recent increases in the value of electrical energy. Incentive programs have made construction and development of MHP plants more attractive.MHP systems are the best options for electrification of village far from the national grid and for which constant stream flow is available.

In this fast developing world however the way of consumption of water power is changed from its direct way to indirect way, a more efficient and easily usable electrical energy. In the case of hydropower electricity production, the prime movers are water wheels or turbines. These prime movers convert the power available in the water to rotational or mechanical energy. Then the generator acting as an energy converting unit converts the rotational or mechanical energy to electrical energy. This is the principle of hydropower engineering, the technology involved in converting the pressure energy and kinetic energy of water into electrical energy.

2.1 Run-Off River Hydropower Station

Run-off-river hydro power plant is a micro hydro power plant without any reservoir or storage capacity. Flow and head are the most important parameters for the design of hydro power plant.

A typical micro hydro power system is arranged as shown in Fig.2.1. The principal components that are used in the MHS (Micro Hydropower System) could be further classified into civil components, powerhouse components and transmission and distribution lines.

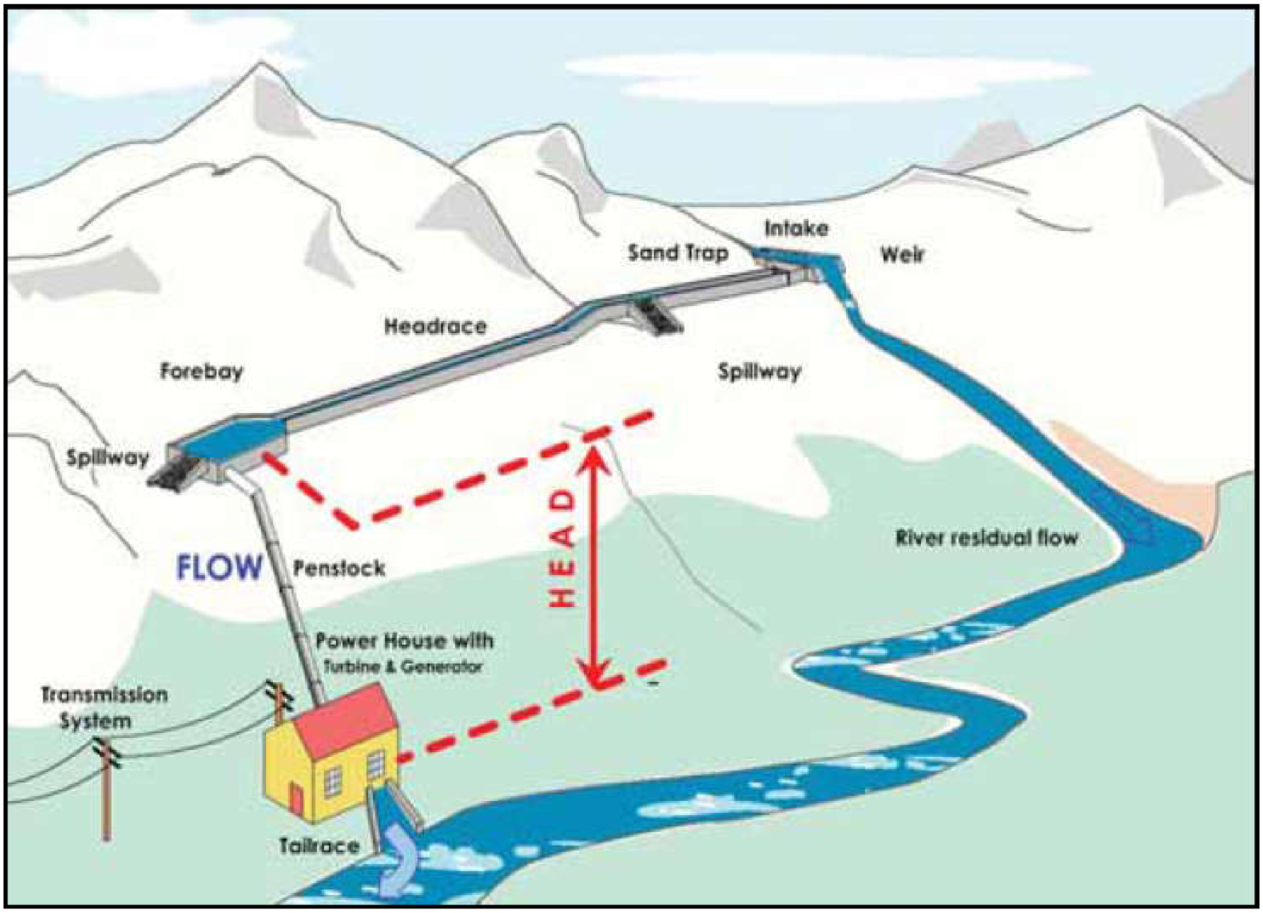


Fig.2.1: Typical example of run-off- river hydro power plant [8]

2.2 Basic Components of MHP System

The basic components of MHP system classified into civil works components and powerhouse components.

2.2.1 Civil Work Components

The civil components described in this section are those major components such as the intake, sand trap, spillway, headrace canal, settling basin, fore-bay tank, penstock pipes and tailrace.

Intake (water diversion) is the highest point of a hydro system where water is diverted from the stream to the penstock that feeds the turbine. Side intake and bottom intakes are the common

Headrace Canal is conveyance system that conveys designed discharge from one point to another. Generally, canal systems are used in all micro hydropower schemes whereas pipe systems are used for specific difficult terrain. A canal can be unlined or lined (stone masonry or concrete). The typical canal cross sections used in micro hydropower schemes can be rectangular or trapezoidal or triangular or semi-circular in shape.

Settling Basin is the civil component that settles sediments down in the basin for periodical flushing. Since sediment is detrimental to civil and mechanical structures and elements, the specific size of specified percentage sediment has to be trapped, settled, stored and flushed. This can only be achieved by reducing turbulence of the sediment carrying water. The turbulence can be reduced by constructing settling basins along the conveyance system. Since the settling basins are straight and have bigger flow areas, the transit velocity and turbulence are significantly reduced allowing the desired sediments to settle. The sediment thus settled has to be properly flushed back to the natural rivers.

Spillway: is a structure that diverted excess water safely to river.

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

Fore-bay Tank: is the civil component that steady flow into the turbine through the penstock.

For-bay also acts as the last settling basin and allows the last particles to settle down before the water enters the penstock. Fore-bay can also be a reservoir to store water depending on its size. A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trash rack need to be installed to prevent large particles to enter the penstock.

Penstock Pipe: is the pipe, which conveys water under pressure from the fore-bay tank to the turbine. It is not only moves water to the turbine, but is also the enclosure that creates head pressure as the vertical drop increase. The penstock focuses all water power at the bottom of the pipe, where the turbine is.

2.2.2 Powerhouse Components

Powerhouse consists of electro-mechanical equipments such as turbines, generator and drive systems.

Turbine is a machine that converts energy in the form of falling water (water pressure) into mechanical shaft power, which can be used to drive electric generator.

The selection of the best turbine for particular hydro site depends on the site characteristics. All turbines have a power speed characteristics. This means they will operate most efficiently at a particular speed, head and flow combination. Thus the required speed of the generator coupled to the turbine also influences the selection. Another important point is whether the turbine is expected to generate power at part flow condition or not. The design speed of a turbine is mainly determined by head under which it operates.

Turbine Classification

Turbine can be classified as high-head, medium head and low-head machines. But this is relevant to the size of the machine. Low for head for large turbine can be high head for a small turbine.

Table 2.1 Classifications of hydro turbine according to head, flow and power [9]

Classification	Turbine Name	Head (m)	Flow (m^3/s)	Power output (kW)
Impulse	Pelton	50-1000	0.2-3	50-15000
	Turgo	30-200	0.2-5	20-5000
	Cross-flow	2-50	0.01-2	0.1-600
Reaction	Kaplan & Propeller	3-40	3-20	50-500
	Francis radial flow	40-200	1-20	500-15000
	Francis mixed flow	10-40	0.7-10	100-5000

Generator

A generator transforms the mechanical energy into electricity. In hydro power plants, this combination of generator and turbine is called generating unit.

AC generators are typically used with systems producing above 3 kW. AC voltage is also easily changed using transformers, which can improve efficiency with long transmission lines. Depending on our requirements, we can choose either single-phase or three-phase AC generators in a variety of voltages [10].

Drive systems

The main purpose of the drive systems is to transmit the power from turbine to the generator at a stable voltage and frequency at a required speed. The drive systems consist of generator shaft, turbine shaft, bearings, couplings, gearboxes and belts and pulleys. The different types of drive systems common in MHS are direct drive, “V” or wedge belts and pulleys, timing belt and sprocket pulley and gearbox drive systems. A direct drive system is one in which the turbine shaft is connected directly to the generator shaft. In contrast, “V” or wedge belts and pulleys are the most commonly used type of drive systems in MHS. However, in very small systems (less than 3 kW) where efficiency is critical, timing belt and sprocket pulley are commonly used [10].

Controls

Alternating current is directly used by loads directly from the generator and excess electricity is burned off in dump loads (usually resistance heaters). Governors and other controls help that and AC generator constantly rotates at constant angular speed. Most commonly, micro hydro system is controlled by managing the load in the generator [11].

All MHS will have to have switchgear in order to separate the power flow when necessary and also to control the electrical power flow.

2.3 Determination of Design Parameters of a MHP System

In this section, the design parameters that are needed to design a MHS are reviewed.

2.3.1 Head Measurement

The head is defined as the vertical height in meters from the level where the water enters the penstock to the level where the water leaves the turbine housing (tailrace). The higher the head, the faster the waterfalls and the more force it exerts on the turbine blades. We can use altimeter, GPS and topographic maps to estimate the vertical drop of a stream.

Gross Head and Effective Head

The gross head is the vertical distance, between the water surface level at the intake and at the tailrace for reaction turbines and the nozzle level for impulse turbines. Effective head is less than the gross head (Fig.2.2) due to the pressure losses in the penstock. Once the gross head is known, the net head can be computed by simply subtracting the losses along its path. There are a number of factors which affect the frictional losses in the pipe including the viscosity of the fluid, the roughness of the internal surface of the pipe, the change in elevation between the ends of the pipe, the length of the pipe through which the fluid travels, velocity of the flow and the size of the internal pipe diameter.

There are different methods for calculating the frictional losses in pipes but Darcy-Weisbach formula is considered as the most accurate pipe friction loss formula [12].The Darcy-Weisbach formula is as follows:

$$H_L = f\left(\frac{Lp}{Dp}\right)\left(\frac{V^2}{2g}\right) \quad (2.1)$$

Where,

H_L=Head loss due to friction given in units of length

f=Darcy friction factor (obtain from Moody diagrams)

L_P=Pipe Length

D_p=Pipe Diameter

V=Flow velocity

g= Gravitational acceleration

The equation contains a dimensionless friction factor known as the Darcy friction factor. This is not a constant value and is system specific. It is dependent on the parameters of the pipe and the properties of the fluid flowing through it but is known to an extremely high accuracy for certain flow regimes. This friction factor can be obtained through various theoretical calculations or can be acquired from various published charts. The most commonly utilized types of these charts are known as Moody diagrams, named after L.F.Moody and so the factor is sometimes called the Moody friction factor [13]. Moody charts link several key factors which contribute to the overall frictional losses in the system and these are the Reynolds number and the relative roughness.

The Reynolds number "R_e" is defined as:

$$R_e = V\frac{D_p}{v} \quad (2.2)$$

Where

V = Mean speed of the flow (m/s)

D = A nominated characteristic length of the system (in the case of a hydropower penstock, the diameter),

v = the kinematic viscosity of water = 1.004×10^{-6} (m²/s)

The energy balance will be maintained in a pipe (penstock) but energy will be lost in proportion to the inner surface of the pipe as defined by the Reynolds number.

The value of the Reynolds number therefore depends on the temperature of the water, the site conditions, the penstock diameter and the water flow which can be calculated from values of V (measured mean speed of the water), D_p (measured diameter of the penstock) and kinematic viscosity of water v .

The Moody chart can be split into two flow regimes; laminar and turbulent. Laminar flows occur for values of Reynolds number less than 2000 and this is unlikely to occur for water flow. Laminar flow tends to occur in more viscous fluids such as oil. Instead water flow is most likely to be turbulent and this occurs for values of Reynolds number in excess of 3000.

Both the friction coefficient and the Reynolds number must be determined to calculate the head loss. The friction coefficient depends on the surface roughness height (e) of the pipe relative to the diameter of the pipe (D_p).

Once e/D (relative roughness) is obtained, the friction coefficient can be obtained from the "Moody Diagram" as shown in Appendix C.

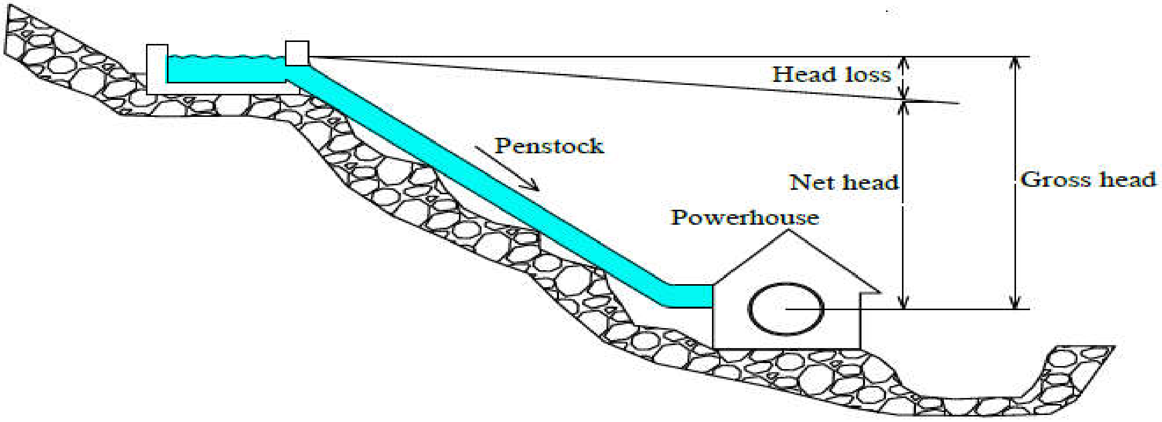


Fig.2. 2 : Net head remains after pipe loss [14]

2.3.2 Measuring Water Flow Rate

The second major steps step in evaluating the hydro power potential of a site is measuring the flow of the stream. It has been defined as the quantity of water flowing past a point at a given time.

Direct measurement of flow rate is not possible, but must be calculated from velocity and cross-sectional area of the stream.

Once the velocity (v) and cross-sectional area (A) of the stream are obtained, the calculation of discharge (Q) would be:

$$Q = A.V \tag{2.3}$$

Ultrasonic Flow meter method (IEC 60041 (1991)/ IS 14197:1994:5)

An ultrasonic flow meter is a type of flow meter that measures the velocity of a fluid with ultrasound to calculate volume flow. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow or by measuring the frequency shift from the Doppler Effect. Ultrasonic flow meters are affected by the acoustic properties of the fluid and can be impacted by temperature, density, viscosity and suspended particulates depending on the exact flow meter.

2.3.3 Calculating Potential Power

The potential power that can be generated from the micro hydro power plant is often calculated from the survey of the site [15]. With net head and flow measurements one can estimate the power output of the stream.

The hydraulic power or hydro potential available from a river is directly related to the flow rate, head and the force of gravity as given by.

Hydraulic power:

$$P_h = g\ H_n \rho Q \tag{2.4}$$

The turbine power derived from hydraulic power is given by:

Turbine power (KW) = $P_h \eta_t$

$$P_t = g\ H_n\ \rho\ Q\eta_t \tag{2.5}$$

ρ is water specific density (1 kg/m^3)

Q is flow rate, quantity of water flowing into turbine (m^3/second)

g is gravitational constant (9.81 m/s^2)

H_n net head in meters

η_t is turbine efficiency

The turbine power output is directly proportional to river flow and the vertical distance that the water falls. Theoretically, a river with twice the amount of flowing water should produce twice much energy, but in reality there is pipe loss due to the friction of pipes which decreases the output power.

However, there will be some loss of power while the available water energy is converted by the hydropower plant.

It can be seen clearly from the equation that the power generated by the water available depends upon the flow rate of the water, elevation head (elevation difference between intake and exit of water), and gravitation force, density of water and efficiency of the hydropower system. The goal of the hydro power is to convert the available water energy into mechanical or electrical energy

2.4 Penstock Design

Penstocks (pipes) are used to conveying water from the intake to the power house. They can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock materials, the ambient temperature and the environmental requirements. The internal penstock diameter (D_p) can be estimated from the flow rate, pipe length and gross head as [16]:

$$D_p = 2.69\left(n_p^{\,2}\, Q^2\, \frac{L_p}{H_g}\right)^{0.1875} \qquad (2.6)$$

Where

n_p = Manning's coefficient of the penstock material type.

L_p = penstock length in (m).

H_g = gross head in (m).

The wall thickness of the penstock depends on the pipe materials, its tensile strength, pipe diameter and the operating pressure. The minimum wall thickness in millimeter is recommended as [17]:

$$t_p = \frac{Dp+508}{400} + 1.2 \text{ (mm)} \qquad (2.7)$$

Where,

n_p = Manning's coefficient.

Q = water flow rate (m3/s).

L_p = penstock length in (m).

H_g = gross head in (m).

400 is tensile strength of welded steel

1.2 represents Corrosion allowances.

2.5 Selection of Hydraulic Turbine

The type and size of a turbine for a hydropower system differ for one project than the other depending on many factors. Therefore using these factors as criteria, the type and size of turbine for a particular hydropower system can be determined.

2.5.1 Turbine Selection Criteria

The type, geometry and dimensions of the turbine will be fundamentally conditioned by the characteristic of each given site. These important criteria are described as follows:

Net Head

The first criterion to take into account in the selection of the turbine is the net head. It is primarily the head measurement that determines the selection of a suitable turbine [18].The basic turbine classification is given in the Table 2.1.

The selection is particularly critical in low-head schemes, where large discharges must be handled.

Range of Flow volume and Discharges through the Turbine

A single value of the flow has only very little significance. It is necessary to know the flow regime of a site.

The rated flow and net head determine the set of turbine types applicable to the site and the flow environment. To determine the correct turbine type one solution is to use graphical tools which show the suitability of different turbine designs in relation to head, flow volume and power output. The approximate range of head, flow and power applicable to different turbine types are summarized in Fig.2.3 (up to 50KW). This approximate depends on the precise design of each manufacturer.

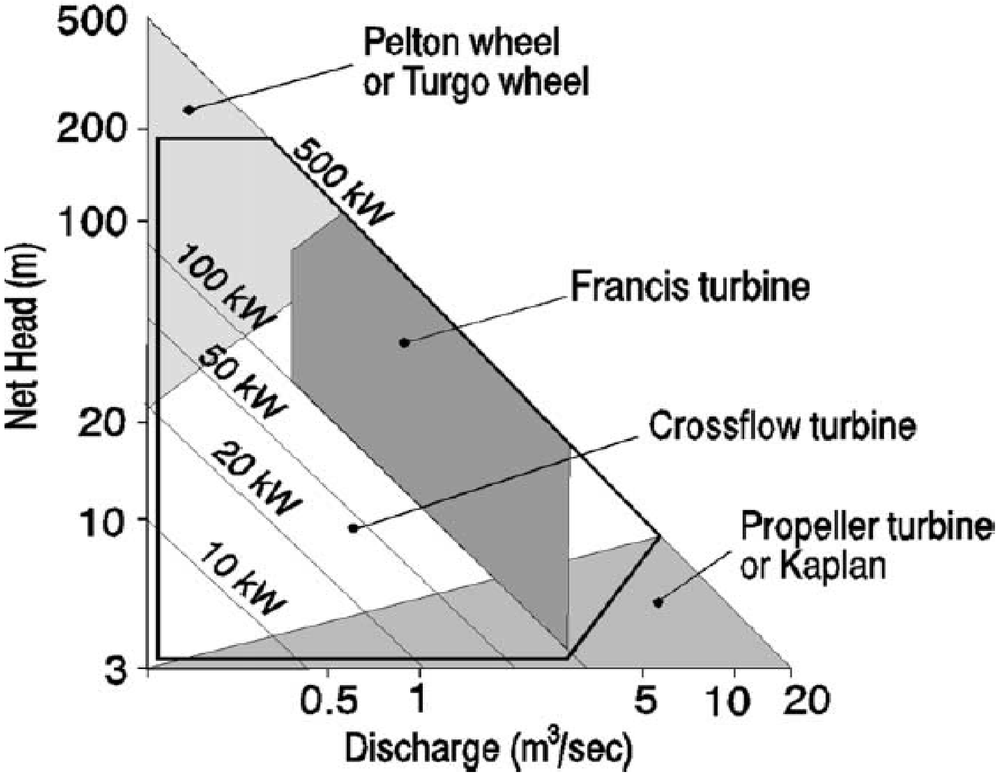


Fig.2.3 : Micro Hydro Turbine Selection Chart [19]

From Fig.2.3 propeller turbine is appropriate for the low heads and high flow rates. Cross-flow turbine is appropriate for flows up to $5m^3/s$, net head varying from 3m to 200m and can give output power up to 500kW.Francis turbine is appropriate for flow rates from $0.5m^3/s$ to $4m^3/s$, net head from 3m to 100m and can generate power output from 100kW to 500kW.Pelton wheel is appropriate for flows up to $1m^3/s$, net head varying from 20m to 500m and can generate power from 20kW to 500kW.

All types of the turbines type overlapped on the desired operational region appropriate for the specific job. Now it will be necessary to compute installed power and electricity output against costs before taking a final decision about which type to use. It should be remembered that the "envelopes" vary from manufacturer to manufacturer and they should be considered only as a guide.

Specific speed (N_s)

One of the important parameters of a turbine is the specific speed. Specific speed of a turbine can be defined as the speed of an ideal, geometrically similar turbine, which yields one unit of discharge for one unit of head. The specific speed is also a very reliable criterion for the selection of an appropriate turbine.

Given a flow and head for a specific hydro site, and the rpm (revolution per minute) requirement of the generator it becomes easy to calculate the specific speed.

The turbine type can be estimated by comparing the calculated net head and specific speed with those given in Table 2.3.

The specific speed constitutes a reliable criterion for the selection of the turbine. If we wish to produce electricity in a scheme with H_n (m) net head, using a P (kW) turbine directly coupled to a standard N (rpm) generator we should begin by computing the specific speed according to equation:

$$N_s = N \frac{\sqrt{P}}{H_n^{1.25}} \tag{2.8}$$

Where,

N_s is turbine specific speed

N is running speed of the turbine (RPM)

H_n is net head (m) and

P is the power to be generated (kW)

After computing the specific speed, it is possible to choose which turbine type to use or to decide whether to use a speed increaser like belts and gears. Using all this tools one can have appropriate selection of the turbine that is to be used for the site at hand.

Table 2.2 Range of Specific speed [20]

Turbine Type	Specific speed range
Pelton one nozzle	5≤Ns≤ 25
Pelton two nozzles	7≤Ns≤ 35
Pelton four nozzles	10≤Ns≤ 50
Cross-flow (Banki-michell)	20≤Ns≤ 200
Francis	50 ≤Ns≤ 350
Kaplan and propel	200 ≤Ns≤ 1550

To obtain constant frequency from a generator driven by a water turbine, it must run at a constant speed and drive the generator through a fixed gear-ratio. The speed of the water turbine is controlled by a governor which opens or closes a valve or gate to hold the speed constant as the load changes. Both mechanical and electrical hydraulic governors are used to control the flow of water through the turbine by adjusting the gate position [21].

2.6 Turbine Efficiency

A significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. Figure 2.4 shows how the efficiency of selected turbines varies with the percentage of turbine flow.

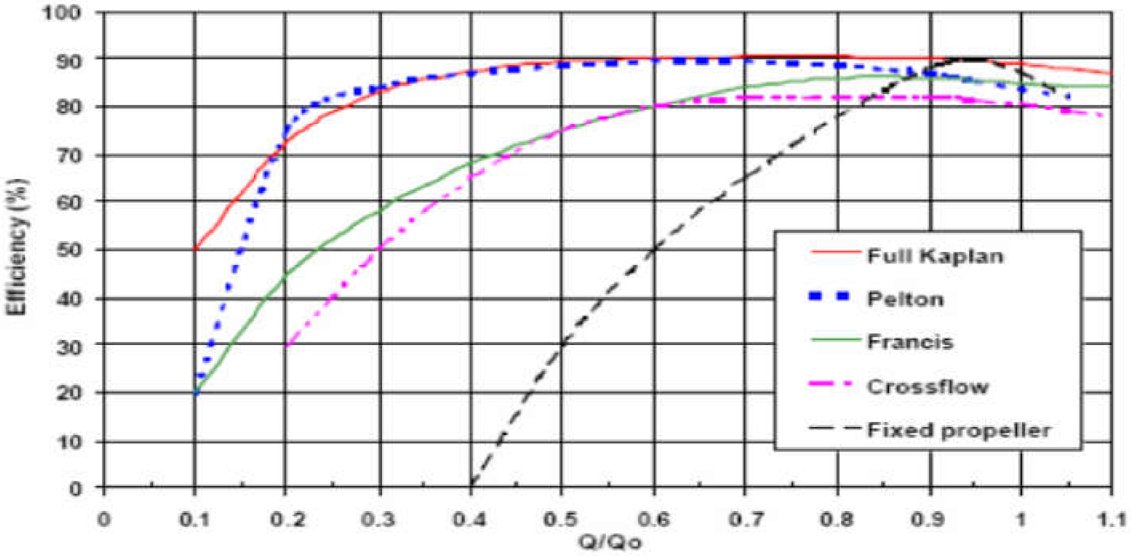


Fig.2. 4: Efficiency of Various Turbines based on Discharge rate [22]

It can be observed from the efficiencies comparison chart in Fig.2.4, that for Kaplan turbines a maximum efficiency of 90% is achieved when the percentage of turbine flow is between 50 and 90%. It can also be seen that when the percentage flow drops below 30% the efficiency quickly deteriorates. For Pelton turbines when the percentage flow is below 20% the efficiency drops away rapidly though this turbine is capable of reaching efficiencies of 90% when the percentages flow is 60-70%. Therefore, it can be concluded that Pelton and Kaplan turbines retain high efficiencies when running below their design flow. Though, Francis turbine can be observed to have less maximum efficiency, they have the widest range of application among the various turbines in terms of size and operating heads. It can be noted that when the turbines flow rate drops below 80% the efficiency of the turbine drops off rapidly. Both in the case of the cross-flow turbine and the Francis turbine the efficiency falls away rapidly as they are operated below half their design flow.

2.7 Generator Selection

Micro-hydro generators are low speed machines of salient pole type, having a large number of poles, a large diameter and a short rotor.

Synchronous generator is used in most MHP systems because it has the ability to establish its own operating voltage and maintain frequency while it is operating in a remote location

Table 2.3 Selection of Generator Type [23]:

Size of scheme	Up to 10 kW	10 to 15 kW	More than 15 kW
Generator	Synchronous/Induction	Synchronous/Induction	Synchronous
Phase	Single or Three Phase	Three Phase	Three Phase

2.8 Performance Assessment of MHP System

Jyoti Prasad and Shiva Prasad [24] evaluated performance of five SHP projects based on Project efficiency, Plant outage and Utilization factor. They found low Plant outage and Utilization factor values. They identified the causes and suggested remedial measures. Verma and Arun Kumar [25] also tested and evaluated 18 new SHP to verify that all parts, systems and auxiliaries in power station are correctly performing their assigned functions. They concluded that the provisions expected in the power plant were missing; knowledge of personnel in the field of fluid dynamics and measurement techniques was not adequate. Micro-hydro power plants are evaluated based on their power output. Voltage fluctuations as well as user satisfaction are also assessed.

2.8.1 Performance Tests

Performance test of hydro turbines are part of commissioning and acceptance of the delivery electromechanical equipments. The tests of hydro turbines should be made in accordance with the International Electro-technical Commission (IEC) recommendations.

A hydro turbine must meet a guarantee of efficiency within a specified range of power output and head variation. The turbine power output must fulfill the guarantee as a function of the net head as well.

Performance testing of a MHP Performance testing of micro-hydro installations includes inspection of each electromechanical component like, turbine, generator, ELC, penstock and power transmission lines. Measurement of power output, voltage, and frequency at different parts of the transmission line are also done.

2.8.2 Test Principles

The efficiency of hydro turbines may be determined according to two different principles:

1. Measuring the output turbine power (P_t) and the available power (P_h) at the turbine inlet and calculate the efficiency of the turbine.
2. Measuring the electrical power output and the available power P_h at the turbine inlet and calculate the efficiency of the turbine.

2.8.3 Performance Indicators

Indicators are the variables or parameters that influence the performance of any hydro power project. The type of performance measures chosen depends on the purpose of the performance assessment activity. The general guidelines used to choose the Performance indicators are as follows:

- The indicators are based on a relative comparison of absolute values.
- The set of indicators is small, yet reveal sufficient information about the output of the system.
- Data collection procedures are not too complicated or expensive.
- The indicators relate to outputs and are bulk measures of the project

Average Head

The head acting on the turbine is the gross head less all hydraulic losses in water conductor system. Difference between reservoir level and Tail water level gives the gross head. The hydraulic losses will depend on the hydro power system layout. The power potential is governed by the head available at project site. The performance and efficiency of turbine varies with head.

Average Discharge

This is the volume in cubic meter per second of water available for power generation. When irrigation/ domestic/ industrial releases are used for power generation, the water available for generation should be strictly as per irrigation/ domestic/ industrial demand and generation will have to be synchronized with these releases.

Average Power Output

Power output depends on discharge, net head available and efficiency of turbine, generator and efficiency of power transmitters.

2.8.4 Performance Characteristics

By theoretical analysis and available methods for computation is not possible, even by advanced approaches to get exact results of the real flow state and performance of turbine. The accuracy will be poor especially for operating conditions far from the design flow [26].

Therefore, experimental research is necessary to carry out in laboratories on models of prototype turbine. Results from these model tests are valid for the prototype through the similarity relations and certain up scaling formula for the efficiency, provided that the model size is larger than certain minimum international standardized values. A model turbine has to be geometric similar to the prototype in all hydraulic passages from the turbine inlet to the outlet of the draft tube.

Parameters to be measured are those determining the power (P_h) delivered to the turbine and the power (P_t) transferred to the turbine shaft. These powers determine the efficiency [28],

$$\eta_t = \frac{P_t}{P_h} \tag{2.9}$$

Turbine shaft power can be given By:

$$P_t = T^*\omega \tag{2.10}$$

Where ,

P_t is the power out of the turbine shaft

P_h is the hydraulic power

T is the torque

ω is the angular velocity of the turbine

ρ is the density of water

g is the acceleration of gravity

For the determination of η_t the hydraulic parameters Q and H_n, and the mechanical parameters T and ω have to be measured in each test point.

The electrical power output of generator is given as:

$$P_g = P_t \times \eta_g \times \eta_m \tag{2.11}$$

($\eta_g = 0.88$, $\eta_m = 0.97$) [20] (Coupled with transmitter or flat belt)

$$P_t = \eta_t P_h \tag{2.12}$$

Where,

P_g is the electrical power output

η_g is the generator efficiency

η_m is the transmitter efficiency

By using (2.5) and (2.11) the overall efficiency of the power system is given by:

$$\eta_0 = \frac{P_g}{P_h} = \eta_t \eta_g \eta_m$$

$$\eta_o = \eta_t \eta_g \eta_m \tag{2.13}$$

The turbine efficiency is given by:

$$\eta_t = \frac{\eta_o}{n_g n_m} \tag{2.14}$$

2.9 Power Demand Assessment and Load Estimation of a Village

2.9.1 Power Demand Assessment

Community participation is the best and most accurate method to estimate the demand from any specified community. To gain quick understanding of the usage pattern and future growth of energy demand of a community accurate method would be selected. During the demand assessment to identify the power demand gap interviewing the community regarding their energy need can be used as best accurate method.

During energy assessment of a village, the energy needs includes the existing energy access in the village. Additionally, we assess the existing community resources (such as, government initiatives, civil society organizations, financial institutions, and private sector actors) and supply chain infrastructure, in order to understand what type of technologies could potentially be brought to scale to address the community's energy needs.

2.9.2 Load Estimation of a Village

Energy demand assessment is basically the total energy presently being consumed for different end uses. The assessed and calculated energy demand is expressed in standard units of electricity in kilowatt hour (KWh) and is used for deciding the size of the system that would meet the demand.

a. Household Needs

Rural household energy consumption is not as large as urban household. Rural household needs energy for lighting, TV, radio and for charging appliances.

Demand can be calculated using the simple table using a calculator or computer (MS Excel). One of the better ways is to make this table in MS Excel on a computer and fill in the formulas. Thus when a field investigator puts in the raw data, the Spreadsheet calculates the connected load in KW and demand in KWh/day for each connected device and end use.

b. Irrigation Needs

Energy demand for irrigation can be estimated on the basis of existing energy consumption and future planning. This would need good interaction with the community and detail assessment.

The topography of the site should be considered during demand assessment for irrigation. If the topography is appropriate, the total energy demand for irrigation will be calculated on the basis existing number of each type of pump, their ratings, average hours of operation per day and average days of operation in a year. It is also possible to plan for new pumps in the future.

c. Small Industries Need

This information has to be collected for every industry in the village

This information has to be collected for every industry in the under study. Typically industries in a village under study include flour mills, milk processing, weaving and others. Most of these are operational for a few hours during the day. The energy load from small industries is treated as additional load to be met in combination with other loads such as lighting or irrigation. Because, it is assumed that the small industries will be operated during those hours of the day when the load from other devices is either low. This is important for ensuring a good plant load factor. If this condition of load is not possible, then it leads to the cost of necessary higher capacity system may not be economically viable. Hence, the household loads and small industries load should be planned separately.

2.10 Photovoltaic Technology System

Photovoltaic system or solar power system is one of renewable energy system which uses PV modules to convert sunlight into electricity.

The sun is the most essential source of energy for the existence of life and also permanent source of most renewable energy sources. Solar energy can be used in photovoltaic cells to generate electricity.

2.10.1 Photovoltaic Cells

Solar electricity is generated using photovoltaic cells. The word 'photovoltaic' is derived from two words 'photo' which means light and 'voltaic' and 'volt' being the unit of electromotive force which in turn refers to electricity i.e. electricity obtained from light [28].

Photovoltaic cell can turn cell energy from the sunlight directly into electricity. This electricity can be used immediately or stored in a battery for later use, fed back into grid line or combined with one or more other electricity generators or more renewable energy source [29].

Renewable energy sources have various advantages like they are eco-friendly, have abundant supply, etc. But they have some demerits also. For example a system using solar energy alone will face the problem of unavailability of optimum amount of solar radiation during night time or cloudy weather condition. And using a hydropower system alone will be unable to meet the load demand if the force of water flow is not optimum. Considering all these factors, here a hybrid energy system consisting of solar energy and hydro power is taken into account.

Broadly defined, solar radiation is referred to the total frequency spectrum of the electromagnetic radiation originated by the sun. This spectrum consists of both visible light and invisible radiation, for example X-rays, ultraviolet radiation, infrared radiation and radio waves. Several factors are used to measure the effective solar radiation which can be converted into energy as follows.

2.10.2 Solar Irradiance

Solar irradiance denotes the solar radiation received in a particular area and recorded during a specific span of time. It is also referred to as 'insolation'. If the specific span of time is an hour or a day then the solar irradiance is called 'hourly irradiation' or 'daily irradiation' accordingly. The unit of such measurement is generally KWh/m2/time [30].

2.10.3 Diffuse Solar Radiation

The solar radiation originated from the sun directed towards the earth is scattered to some extent by the various molecules and suspended particles in the atmosphere and then reflected back sometimes to the earth's surface. This part of the solar radiation is known as diffuse solar radiation [30]

Direct Normal Irradiance (DNI)

Global Horizontal Irradiance is the total solar radiation incident on a horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and ground-reflected radiation. HOMER uses Solar GHI to compute flat-panel PV output [31].

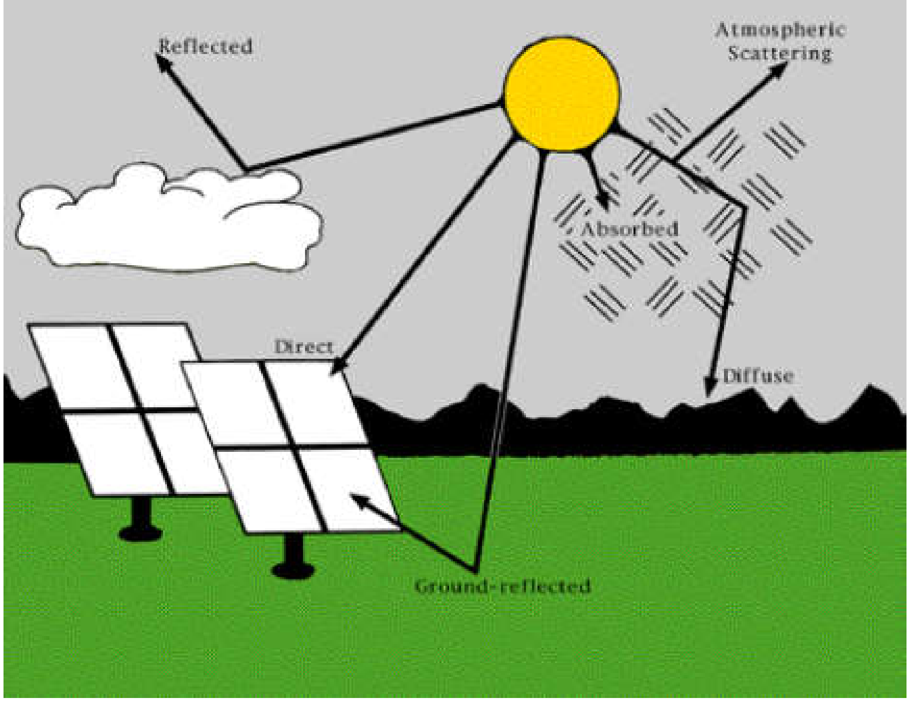


Fig.2. 5 : DNI, DHI and Ground Reflected radiation [31]

2.10.4 Extra-Terrestrial Radiation

The total part of solar radiation never reaches the earth's surface since some part of it is absorbed by the interceding atmosphere or clouds. The amount of solar radiation that would have reached the earth's surface, ideally in absence of any cloud or atmosphere in between the sun and the earth's surface is known as extra-terrestrial radiation. This is considered as the reference amount for comparing with the actual solar energy measurement [30].

Power Output by PV Array

The following equation can be used to calculate the output of the PV array:

$$P_{PV} = \mathrm{Y}_{\mathrm{PV}}\, f_{\mathrm{pv}} \left(\frac{G_T{}'}{G'_{T,STC}}\right)\left[1 + \partial_{p(T_c - T_{C,STC})}\right] \tag{2.15}$$

Where,

P_{PV} is the rated capacity of the PV array, meaning its power output under standard test conditions (KW)

f_{pv} is the PV de-rating factor (%)

$G'_{T,STC}$ is the solar radiation incident on the PV array in the current time step (kW/m^2)

$G'_{T,STC}$ is the incident radiation at standard test conditions (1 kW/m^2)

∂_{p} is the temperature coefficient of power (%/°C)

T_{c} is the PV cell temperature at the current time step

$\mathrm{T}_{\mathrm{C,STC}}$ the PV cell temperature under standard test condition (25$^{\mathrm{o}}$C)

If we do not consider the effect of temperature on the PV array, so that the above equation simplifies to:

$$P_{PV} = \mathrm{Y}_{\mathrm{PV}}\, f_{\mathrm{pv}} \left(\frac{G_T{}'}{G'_{T,STC}}\right) \tag{2.16}$$

PV de-rating factor is a scaling factor that HOMER applies to the PV array power output to account for reduced output in real-world operating conditions compared to the conditions under which the PV panel was rated.

2.10.5 Efficiency of PV Panels Available in the Market

PV module selection is based on the performance characteristics given by the manufacturers. The selection is actually based on the efficiency and maximum power of the module.

Table 2.4 The most efficient solar panels available in the market [32]

Manufacturer	Technology	Model	Efficiency
Sunpower	Monocrystalline	X21-345	21.50%
Panasonic	Silicon Hetro-structure (HIT)	N240	19.00%
Phono Solar	Polycrystalline	PS330P-24/T	17.00%
Kaneka	Thin Film Hybrid	U-EA120	9.80%
First Solar	Thin Film CdTe	FS-4105A	16.3%
Spectrolab	Multijunction	NeXt Triple Junction	29.50%

Detail of the PS330P-24/T is given Appendix B

2.11 Hybrid Systems

Hybrid system is a system where different sources of power are used to generate electricity. It could include any combinations of wind, photovoltaic system and MHS (Micro Hydropower System). There are several advantages of hybrid systems over single type of system, because it is possible to offset the low peak period of one source by high peak period of the alternate source. For example, when wind and photovoltaic sources are installed together, wind speeds might be low in summer but then sun shines brightest and longest at the same period of time, making it possible to generate power when it is required [33].

2.11.1 Hybrid System Components Characteristics

In this HOMER analysis, solar PV, and run-off river micro hydro power are the principal resources. Batteries and converter will be used for storing and converting from one form to other form system of electricity, respectively. The performance and cost of each of the system's components is a major factor for the cost results and the design.

Numerous configurations of hybrid energy systems have been installed in a variety of countries over the last three decades. This has provided the necessary experience to identify the strengths and weaknesses of different configurations.

Thus good performance models have been developed, that are able to prioritize the functionality of the power supply systems in such a way as to achieve cost reductions and improve system reliability.

Depending with the kind of voltage system and bus that interconnect the sources, there are many different types of hybrid system.

- DC coupled system,
- DC/AC coupled system
- AC coupled hybrid system

In this study, the researcher prefers to use the AC coupled hybrid system where all electricity generating sources are connected to the AC bus because of the following reasons:

DC coupled Hybrid system all sources are networked to the DC bus. This means that the PV generating source is equipped with charging controller and AC generating micro hydro source with rectifier, this means that the power generated by the alternator is first rectified and then converted back to AC which reduces the efficiency of energy conversion due to several power processing stages. Due to this reason, the DC coupled hybrid system has not been selected for this study.

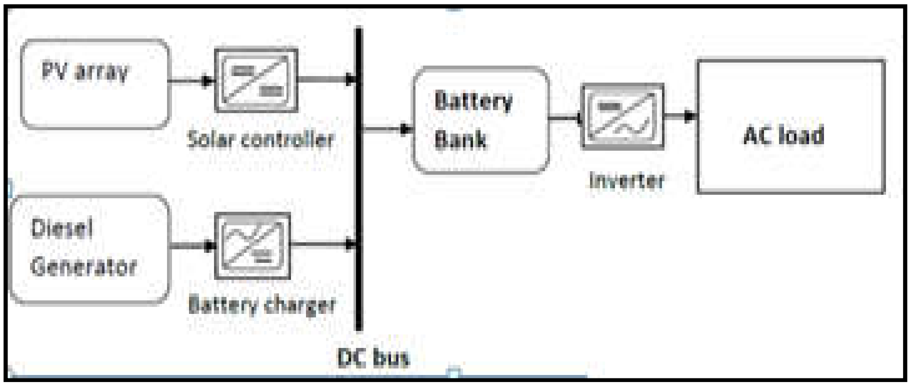


Fig.2. 6: Series PV-diesel Hybrid System [34]

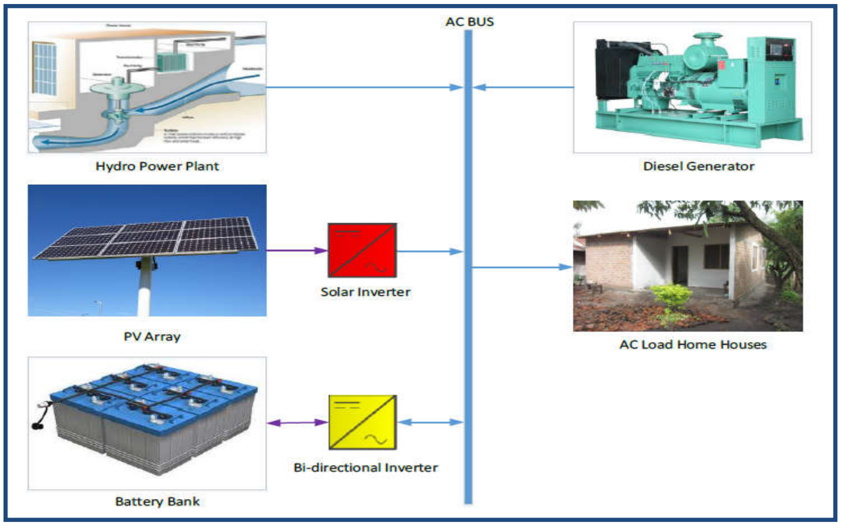


Fig.2. 7: AC coupled Hybrid System [35]

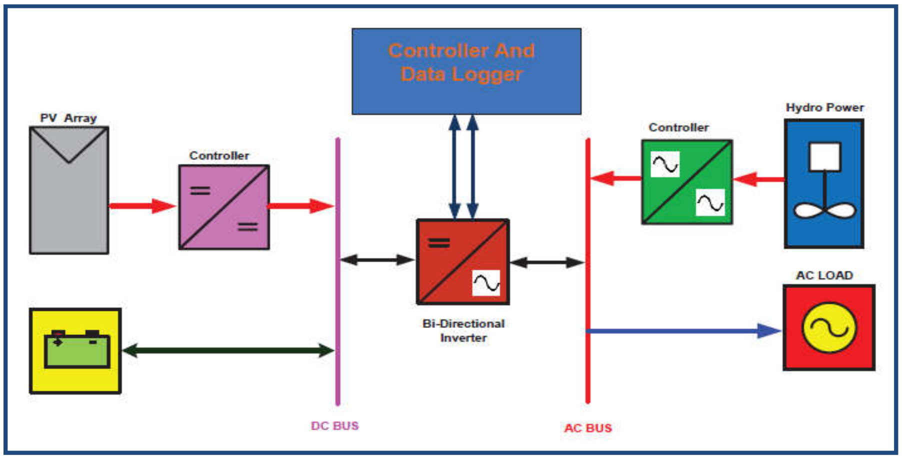


Fig.2. 8: DC/AC coupled Hybrid System [36]

2.12 HOMER Software

HOMER (Hybrid optimization of Multiple Electric Renewable), the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid connected power systems for a variety of options. It is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the design of micro power system and to facilitate the comparison of power generation technologies across a wide range of application.

HOMER models a physical behavior of power generating system and its life cycle cost, which is the total cost of installation operation of the system over its lifetime. HOMER allows the modeler to compare many different design options based on their technical and economic performances.

HOMER performs comparative economic analysis on a distributed power System. Inputs to HOMER will perform an hourly simulation of each possible combination of components entered and rank the systems according to the user defined criteria, such as cost of energy, total net present cost and capital costs. HOMER can also perform Sensitivity analysis in which the values of certain parameters are varied to determine their impact on the system configuration.

Simulation: is the accurate analysis of time varying loads and resources in hour-by-hour analysis for the entire year.
Optimization: finding the least cost solution based on the Net Present Cost (NPC).
Sensitivity Analysis: is determining the sensitivity of the output to changes in the data entered.

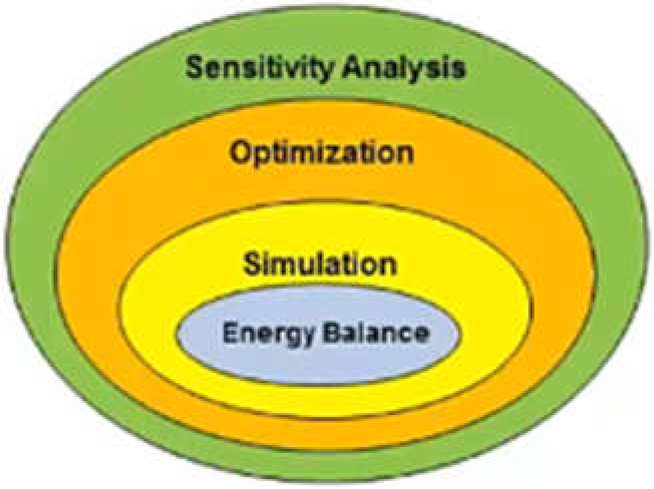


Fig. 2.8: HOMER Analysis Layers

HOMER can model grid-connected and off-grid micro power system serving electric and thermal load, and comparing any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, micro turbines, fuel cells, batteries and hydrogen storage. System analysis by using HOMER needs information on village demand load, components, storage, converter, renewable resources, economics, system controls and system constraints.

2.13 Economic Evaluation of a Power System

An economic evaluation of an energy system can help us to evaluate the cost effectiveness of multiple energy options.

Economics play an integral role both in HOMER's simulation process, wherein it operates the system so as to minimize total net present cost, and in its optimization process, wherein it searches for the system configuration with the lowest total net present cost.

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

HOMER uses the total net present cost (NPC) to represent the life-cycle cost of a system. The total NPC condenses all the costs and revenues that occur within the project lifetime into one lump sum in today's dollars, with future cash flows discounted back to the present using the discount rate. The modeler specifies the discount rate and the project lifetime.

HOMER uses the following equation to calculate the total net present cost [37]:

$$\mathrm{CNPC} = \frac{C_{\mathrm{Ann,tot}}}{\mathrm{CRF(i,T)}} \tag{2.17}$$

Where,

$C_{\mathrm{Ann,tot}}$ is the total annualized cost,

i is the annual real interest rate (the discount rate),

T is the project lifetime, and

$\mathrm{CRF(i,T)}$ is the capital recovery factor, given by the equation [37]:

$$\mathrm{CRF(i,T)} = \frac{i(i+1)^N}{(i+1)^N - 1} \tag{2.18}$$

Where i is the annual real interest rate and N is the number of years.

HOMER assumes that all prices escalate at the same rate over the project lifetime. With that assumption, inflation can be factored out of the analysis simply by using the real (inflation-adjusted) interest rate rather than the nominal interest rate when discounting future cash flows to the present. The HOMER user therefore enters the real interest rate, which is roughly equal to the nominal interest rate minus the inflation rate.

The real interest rate is given by [37]:

$$i = \frac{i' - f}{1 + f} \tag{2.19}$$

Where,

i= Real discount rate

f= Expected inflation rate

i'= Nominal discount rate

HOMER defines the levelized cost of energy (COE) as the average cost/KWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production.

HOMER uses the following equation to calculate the levelized cost of energy [37]:

$$\text{LOE} = \frac{\text{Total Annualized Cost } (\frac{\text{USD\$}}{\text{yr}})}{\text{Annual Load Served } (\frac{\text{Kwk}}{\text{yr}})} \tag{2.20}$$

To calculate the salvage value of each component at the end of the project lifetime, HOMER uses the equation [37]:

$$S = \text{CRep} \frac{R_{Rem}}{R_{Com}} \tag{2.21}$$

Where

S is the salvage value,

C_{Rep} is the replacement cost of the component,

R_{Rem} is the remaining life of the component, and

R_{Comp} is the lifetime of the component

All systems are ranked according to net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost.

All costs in HOMER are real costs, meaning that they are defined in terms of constant dollars.

2.13.1 Ethiopia Interest Rate Forecast 2016-2020 [37]

Interest Rate in Ethiopia is expected to be 5.00 percent by the end of 2016 fourth quarter, according to Trading Economics global macro models and analysts expectations. Looking forward, we estimate Interest Rate in Ethiopia to stand at 6.00 in 12 month’s time. In the long-term, the Ethiopia Interest Rate is projected to trend around 5.00 percent in 2020, according to our econometric models.

The real interest rate and inflation rate for Ethiopia is 5% [38] and 7.5% [37] respectively.

CHAPTER THREE

POWER DEMAND GAP ASSESSMENT

Power demand gap assessment of Walga village was required, because the actual power supplied by the existing MHP and the power demand of the community was not know. During the assessment, the performance of the existing plant was assessed and performance test of the plant was done on site and the required data were collected. And also the power demand of Walga community living in region 2km radius from the power plant was assessed. Questionnaire (Appendix D) were prepared and filled by interviewing each family head and head of the public service. From the questionnaire survey, a list of criteria were prepared and managed in a hierarchical manner.

The data is based on both primary and secondary data field. Primary data was taken from field survey and field performance test of cross flow turbine to know the electrical power output of the generator, efficiency of the turbine and overall efficiency of the power plant. Secondary data were collected from other various sources. Analysis was carried out on the plant as a whole from its intake section to generator output power. Empirical data were obtained from electrical power output, frequency, angular speed of generator shaft readings by controlling the flow rate by adjusting the guide vane and by connecting the generator to different dummy load for each flow rate.

3.1 Primary Data Collection

The primary data were collected by site visit to identify performance indication by visual inspection of electromechanical parts of Walga MHPS. At the site condition assessment form was filled by observing all the necessary parts by the help of plant operators. After conducting the survey discussions were held regarding brief overview of the operation of the plant, and conditions of equipment along with their maintenance and replacement of the generator. The data for performance test of the turbine were collected using various instruments used for taking readings and measurements during the field efficiency test.

Table 3.1 Number of Populations of the villages in the base year 2016 (Primary data)

NO	NAME OF SUB-VILLAGE	NUMBER OF FAMILY/VILLAGE	M	F	TOTAL POPULATION/VILLAGE
1	AFCHALA	17	37	36	73
2	ARBA TENNES	20	42	52	94
3	AREWA TULU	8	17	11	28
4	BILLO	27	76	68	144
5	GOJJE	27	77	67	144
6	JELISSA	40	86	90	176
7	KEL'A SHEBA	42	116	115	231
8	MENDELI	13	15	16	31
9	ODDO	6	17	15	32
10	TERAME	44	123	84	207
11	WALGA	13	29	31	60
	GRAND TOTAL	257	635	585	1220

Source: Researcher’s compiled data from field survey

3.2 Secondary Data Collection

Secondary data was collected from different related publications, reports, literatures, studies, etc and related information was also collected from related web sites.

3.3 Actual Power Demand of Walga Village

When determining the electricity consumption of any community, some of the factors to consider include; the income of consumers, their affordable tariff (price per KWh or monthly cost), cost of competing or substitute services (fuel-wood, kerosene), cost of appliances, socio-cultural and economic factors etc. Detailed planning methods must put into consideration all these factors, but despite the need to consider all these factors, the ability to get accurate information and the lack of recorded data, especially in rural areas are among the challenges faced by researchers and planners.

During the power need assessment of the village by the researcher, it was found that there were 257 households, one elementary school, one Protestant church and one Orthodox Church within 2km radius from the power plant in Walga village.

Actual load forecasting consists of projecting peak demand requirements for the entire groups of users with the time period of five years. In this study, power estimated is based on consumption loads and patterns inferred from each household. It was taken from the interview that consisting of basically the number of room he/she had and his/her affordability to use radio and 19 inch color television.

In general, for Walga village as a typical rural residential consumption based on an assumption of lighting, TV, radio and for charging appliances such as mobile phone.

3.3.1 Residential Load

Estimating the village load is based on the assumption that all the households and public sectors use efficient appliances and power saving lamps or CFL (Compact Fluorescent Lamp). Traditional cooking methods utilizing firewood and cow dung are expected to remain unchanged. This is due to the electricity affordability associated with using modern cooking methods. Consumption patterns are thus derived based on ownership of appliances used for lighting, communication (radio and TV, phone chargers).

It is assumed that, the electrified household will use energy saving bulbs for indoor lights (depends on number rooms of the house hold). The determining factor of the usage of light bulbs is the setting of the sun. Since Ethiopia is right along the equator, the time for dusk is very constant throughout the year. The internal/indoor light bulbs are thus turned on at around 18:00 and turned off at around 24:00. It is assumed that all of the security/street lights turn on daily from 19:00 until 6:00.

It is also assumed that 100% of the households use a tape recorder type radio and 50% of them use 19 inch color TV. Radios and TV sets are used during varying hours of the day, but morning and evening hours are most common. News is a popular listening program, especially in the morning hours, thus it is assumed that most radios will be switched on early mornings for news broadcasts. It is also assumed that the popularity of TV sets will rise rapidly, with at-least 50% of the households owning a television set within the first year.

In a remote rural village the need for electricity is not high as match up to urban areas. Electricity requirement is for domestic use (for appliances such as radio, color television, compact fluorescent lamps (CFL), radio/DVD player, computer, community activities (such as in community churches and schools).

A survey of power demand in the village was conducted for collecting all the required data and to know the power gap of the village. The load profile of the village has been derived based on the basic energy need of each house hold by a means of interviewing one of the family members. The interview concerned about the amount the size of home or number of room/rooms, number of member of the family, ability to afford TV, Radio or both. Based on the interview conducted the power/energy demand of was estimated for each household in the village. The load profile of the village has been derived based assumptions by using the results obtained from the interviews with the households which have been conducted on the existing community connected to micro-grid of MHPP and area where the power extension have been reached in two kilometers radius. Survey form for Households power/energy demand assessment can be found in Appendix A.

The village consists of 11small sub-villages of total 257 families of total population 1220 (635 Male and 585 Female) in the base year 2016. The village has one elementary school (grade 1-4), one Orthodox Church and one Protestant Church in the base year of the study.

3.3.2 Population and Power Demand Projection of the Village

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

The population of the target year of the proposed village can be calculated by using the following formula [39]:

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

P_o is population in the base year.

P_t is the population in the target year

r Population growth rate

n is the number of years between the target year t and the base year.

The population growth rate of Walga village is considered equal to the population growth rate of Ethiopia that was 2.89% in 2016 [40], population in base year is 1220 (table 3.1) and the number of yea between the target year and base year (from 2016 to 2021) is 5 years.

Substituting the values into equation (3.1),

$$P_t = P_o(1+r)^n = 120(1+0.0289)^5 = 1408$$

The population of Walga village will be 1408 in the target year 2021.

Table 3.2 Power Demands and Population after Projection

NO	CONSUMER SECTOR	Base Year 2016 (KW/DAY)	Current Population	Population Grow Rate (%)	KW/DAY/ PERSON	FUTURE POPULATION	Annual Growth 2017-2021 (KWH/day)
1	HOUSEHOLDS	30.827	1220	2.89	0.0253	1408	35.577
2	SCHOOL	0.98				2	1.96
3	ORTHODO CHURCHES	0.41					0.41
4	PROTISTANT CHURCH	0.46					0.46
5	STREET LIGHT	1.25					1.25
6	POWER PLANT	0.15					0.15
	TOTAL	34.077					39.81

3.3.3 Load Estimation and Scheduling

As one of the data input to HOMER software, the power demand of the village is very essential. With data of the total number of households in the village and using typical household appliances that these people may use, this section discuses how the load profile of the village is obtained.

Table 3.3 Typical Loads used and their Scheduling

SECTOR	Electrical Appliances	Power Demand (KW)	Use Duration	Use Hours	Energy Consumption KWH/ Day
Household	Lighting	12.265	18:00-00.00	6	73.59
	Color TV 19"	11.45	18:00-23:00	5	57.25
			6:00-8:00	2	22.9
	Radio	8.9	16:00-23:00	7	62.3
			6:00-8:00	2	17.8
	Chargers	2.97	18.00-00.00	6	17.82
	Total	**35.585**			**251.66**
SCHOOL	Lighting Indoor	1	18:00-21:00	3	3
	Lighting Outdoor	0.2	19.00-6:00	11	2.2
	Megaphone	0.06	8:00-16:00	8	0.48
	Desktop Computer	0.4	8:00-16:00	8	3.2
	Ink-jet printer	0.1	8:00-16:00	8	0.8
	Photocopy machine	0.2	8:00-16:00	8	1.6
	Total	**1.96**			**11.28**

ORTHODOX CHURCH	Lighting Indoor	0.25	18:00-21:00	3	0.75
	Lighting Outdoor	0.1	19:00-6:00	11	1.1
	Megaphone	0.06	18:00-21:00	3	0.18
	Total	**0.41**			**2.03**
PROTISTENT CHURCH	Lighting Indoor	0.3	18:00-21:00	3	0.9
	Lighting Outdoor	0.1	19.00-6:00	11	1.1
	Megaphone	0.06	18:00-21:00	3	0.18
	Total	**0.46**			**2.18**
STREET LIGHT	Lighting	1.25	19:00-6:00	11	13.75
POWER PLANT	Lighting Indoor	0.05	18:00-00.00	6	0.3
	Lighting Outdoor	0.1	19.00-6:00	11	1.1
	Total	**0.15**			**1.4**
Grand Total		**39.815**			**282.3**

For each household in all the villages, the lighting loads are estimated depending on the number and size of his/her house. Power saving Compact fluorescent lamps (CFL) 11W and 15W are considered for a total 12.265KW power demand for the village for lighting starts operating from 18:00-0:00.Color TV19” that was assumed 50% of the total house hold in the village consuming total power of 11.45KW operates from 18:00-23:00 and radio that was assume for each household consuming total power 8.9KW operate from 16:00-23:00 and from 6:00-8:00 in the morning. A mobile charge was proposed for each household and consumes 2.97KW for the village operates from 18:00-0:00. School indoor lighting consuming 1KW power and outdoor lighting consuming 0.1KW power operate from 18:00-21:00 and 19:00-6:00 respectively. School megaphone, desktop computer, ink-jet printer and photo copy machine which consumes 0.06KW, 0.4KW, 0.1KW and0.2KW power respectively operates from 8:00-16:00.Light indoor

0.25KW and megaphone 0.06KW operate from 18:00-21:00 and light outdoor 0.1KW operates from 19.00-6:00 for Orthodox church. Light indoor 0.3KW and megaphone 0.06KW operate from 18:00-21:00 and light outdoor 0.1KW operates from 19.00-6:00 for protestant church. Street light consuming total power 25KW operates from 19:00-6:00.Light indoor consuming 0.05KW and light outdoor consuming 0.1KW for the power plant operate from 18:00-00.00 and 19.00-6:00 respectively.

A typical daily load curve with hourly resolution has been derived for the village and it is given in Fig.3.1 below.

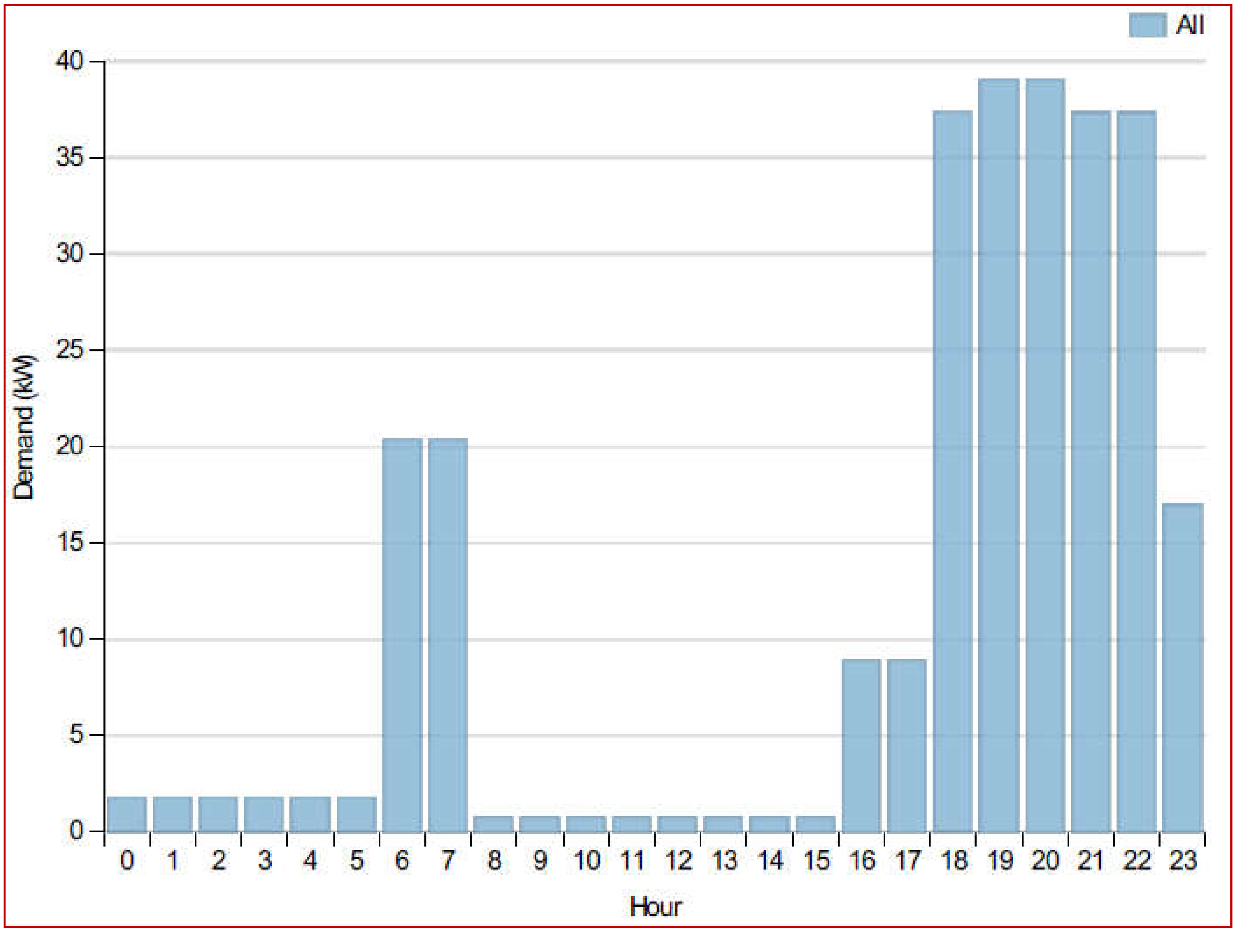


Fig.3. 1: Baseline Walga Village Load Profile

With respect to the derived load profile, the maximum demand of the village is around 39 kW but with the random variability of 5 % (standard deviation: daily and hourly noise to make the load data more realistic) for both day to day and time step to time step, this maximum demand can become 48 KW with the daily energy consumption of around 282.21 KWh.

3.4 Performance Testing of the Existing MHPP

Performance testing of a hydro power station is carried out to check and verify that all parts and systems in the power station are working fine and performing their assigned functions correctly and to test and verify that the generating units are operating efficiently. The scope of performance testing of Walga MHPS was bounded to inspection of all parts, systems and station auxiliaries, functionality checks on simpler devices / systems, operational tests on control systems, measurement of critical parameters such as flow velocity and head, measurement of maximum power output of the unit and measurement of efficiency of the generating unit.

3.4.1 Experimental Setup, Equipments/Instruments used in the Performance Testing

Experimental Setup

The experimental setup used to collect data for the efficiency calculation of the cross flow turbine of Walga MHPS is shown in Fig.3.2

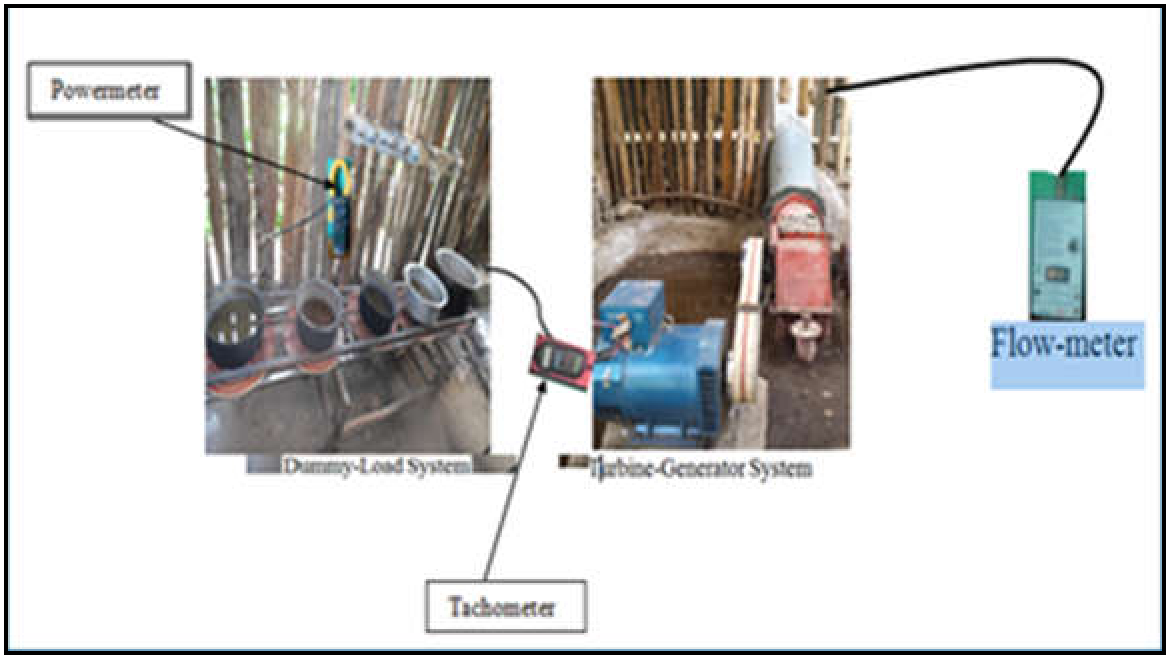


Fig.3. 2: Schematic Diagram of the Experimental Set-up

The setup includes a three phase A.C synchronous generator of capacity 15KW, connecting cable, a 32A circuit breaker, five 16A circuit breakers and dummy loads.

Equipments/Instruments used in the Performance Testing

To take any measurement the required materials should be collected. The equipments listed in table 3.4 below were used for performance testing of Walga MHPP on the site.

Table 3.4 List of major test Equipments used during performance Test

NO	TEST EQUPMENT/INSTRUMENTS	NUMBER
1	Contact/Non-contact Tachometer	1
2	Hand-Held True-RMS Digital Multi-meters	3
3	Hand-Held Ultrasonic Doppler Flow meter	1 set
4	1Φ/3Φ 1000 Amp True RMS Power Clamp-On Model 380976	1 set
5	Global Positioning System (GPS)	1
6	Measuring Tape	3m
7	Dummy Loads	5
8	Screw Driver	1 set
9	Resisters 1000w and 600w	20
10	Stove /Mitad 40mm diameter	5
11	Circuit breakers 16A	5
12	Circuit breaker 25A	1
13	Electric cable 3X1.5	20m

a. Gramin 60 GPS

b. Hand-Held Ultrasonic Doppler Flow meter

c. Contact and Non-contact Tachometer

d. 1Φ/3Φ 1000 Amp True RMS Power Clamp-On Model 380976

e. Hand-Held True-RMS Digital Multi-meters

Fig.3. 3: Equipments used during the performance test of Walga MHPP

Dummy Load Design and Construction

The electrical power output from a turbine shaft may be measured by one of the following primary methods.

i. Mechanical brake
ii. Water brake
iii. Electrical brake and
iv. Torsion dynamometer

All the above methods involve the simultaneous measurement of net torque (T in mkg) and shaft speed (in RPM) from which the net power output (in KW) may be computed from the following expression.

$$P=\frac{2\pi*n*T}{60} \tag{3.2}$$

Where,

P is the net power output in KW

n is shaft speed in RPM

T is Torque in mkg

However, due to the lack of equipments/instruments to measure the torque the researcher was forced to determine integrated efficiency of the turbine-generator, design and used a dummy load to measure the electrical power output of the generator coupled to the cross flow turbine in this thesis work.

The dummy loads used in measuring electrical output of the generator was constructed by using three resistor of capacities 1000W and another three resistors of capacities 600W connected in star connection. Star connection was chosen due to the simplicity of construction. Five dummy loads are constructed with assumed capacities. The assumed load capacity from the three 1000W resistors connected in star connections is about 3KW and from 600W resistors star connection is about 1.8KW.

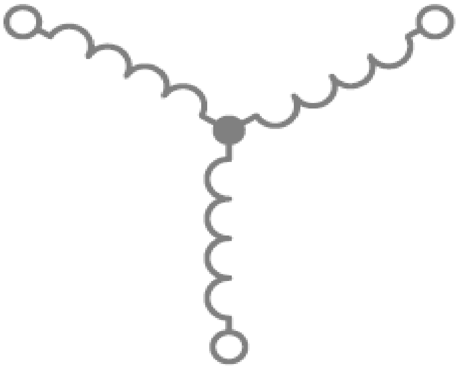


Fig.3. 4: Wye or Star connections

The dummy load is connected as follows:

- Stretching the resistors to an appropriate length about 0.5 m for 600w and about 1m for 1000w resistor respectively.
- Installing the resistors on the 40cm diameter mitad. Take a terminal from each three resistor that will be connected to the three phase lines of the generator output and take one common terminal (combination of the three) at the center of the mitad that will be connected to the neutral line of the generator output.
- Tight the coil to the surface of the mitad.
- Attach a connecter for each node.

Fig.3. 5: Front views of the Dummy Load and b. Back view of the Dummy Load

3.4.2 Test Procedures

A. With the turbine stopped(by closing the main water gate):

- Connect each side terminal of the dummy load to respective generator phase lines and connect the central terminal of the dummy load to the generator neutral line.
- Install five circuit breakers for the loads (Load1, Load2, Load3, Load4 and Load5) and one main circuit breaker.
- Connect the dummy load system and circuit breakers to the generator output terminals.
- Check the continuity of the circuit.
- Open the turbine valve fully and put all the circuit breakers ON.(Starting by maximum flow)
- Open the main water gate and allow the maximum flow of the power plant.

B. With turbine rotating:

- Make sure that no flow variation.(Visually)
- Install the flow meter by following the instruction given on the manual.
- Fix the generator angular speed at 1500RPM by controlling the flow.
- Take the reading on the flow meter and record the data.(Flow velocity in m/s)
- Measure generator power output using the power meter and record the data.
- Repeat these steps by varying the load.

Taking Measurements

Measurements are taken by controlling the flow by adjusting the guide vane or valve and keeping the rotational speed of the generator shaft constant at 1500RPM and frequency 50Hz.The RPM is measured by using contact and noncontact tachometer.

A. Measuring Flow Rate

The choice of method for measuring discharge may be affected by different factors. Some of the factors are:

a) Limitation caused by the design of the plant
b) Cost of installation and special equipments
c) Limitation caused by plant operating conditions

In this thesis work the researcher used Ultrasonic Flow meter method. While using this method he measured the flow velocities in the penstock and calculated flow rate for each respective measured flow velocity.

Fig.3. 6: Flow Velocity Reading on the site during the test

B. Measuring Electrical Power Output

In electrical power output measuring, the power output can be measured either by measuring voltage and current directly or the power output. During the performance test on site, the electrical power output of the generator was measured by using Clamp on Power meter Analyzer and data was taken after the generator outlet by fixing the rotational speed at 1500RPM.

3.5 Results Analysis and Determination of Power Demand Gap

In this section, the power demand of Walga village, the electrical power output of the existing MHPP and the power demand gap between the demand side and supply side will canalized and determined.

3.5.1 Analysis of Power Demand and Population Projection

The population in the base year 2016 was 1200 which was found from the survey and the target year will be 2021.Taking the difference between target year and the base year we obtain five years. The population growth rate of Ethiopia in 2016 was 2.89% by demographic statistics [40].

The population in the launch year can be computed using the values:

P_o = 1200 people, r = 2.89% and n = 5 years

By substituting the values into equation (3.1) [39],

$$P_t = 1200\,(1+0.0289)^5$$

$$P_t = 1408$$

Assume that the population of the study village increases by the same rate from the base year to the target year. The number of school will double and the other public services considered in this thesis work will remain the same in the target year.

In the projection of the power demand of the study village, the total power demand of each consumer sector was estimated and divided by its total number the obtaining the power growth rate of each consumer sector. The total power demand of the village in the launch year is obtained by summation of product of growth factor and number of populations in the launch year. The summary of the population and power demand projection of the study village is given in table 3.2 above.

3.5.2 Analysis of the Performance Test Results

Table 3.5 Measurements that were Taken and Constants Used

No	Parameters	Units
1	Head race elevation (H_h)	2451m
2	Tailrace Elevation (H_t)	2441m
3	Penstock inner Diameter (D)	0.4m
4	Penstock Length (L)	15.96m
5	Density of water (ρ)	1000kg/m^3
6	Gravitational Acceleration(g)	9.81m/s^2

The headrace and tailrace elevations were taken by using Gramin 60 GPS and the penstock inner diameter its length were recorded by direct measuring on the site.

Table 3.6 Data of Readings calculated and values during the Test

LOADS	LOAD1	LOAD2	LOAD3	LOAD4	LOAD5
Velocity Readings (m/s)	0.853	0.945	1.067	1.158	1.376
Calculated Flow rate (m^3/s)	0.107	0.119	0.134	0.146	0.172
Power Readings (KW)	1.5	2.22	3.37	3.91	4.74
Frequency (Hz)	50	50	50	50	50
Angular Speed (RPM)	1500	1500	1500	1500	1500

From table 3.6 we can see that, the electrical power output reading varies as the flow velocity varies. But the frequency and angular speed of the generator remain unchanged. The maximum electrical power output of the generator obtained as 4.74KW at the maximum flow velocity 1.376m/s.

Determination of Power Demand Gap

The power demand gap is the difference between the village's peak demand of 48KW after projection and the power supplied by the existing MHPP (4.74KW).

That is:

Power Demand Gap = 48KW- 4.74KW= 43.26KW

Therefore, the power demand gap of the village was identified as about 43.26KW.

Flow Rate Calculation for the Existing MHP

Flow rate of water through the penstock calculated by using eqn. (2.3) as follows:

Q = A.V

$A = \pi r^2 = \pi D_p^2 = \frac{\pi D^2}{4}$

Substituting the values from tables 3.5 and 3.6,

$A= \frac{\pi 0.4^2}{4}=0.1256m^2$

Q= 0.1256x1.376 =0.172 m^3/s (the maximum flow rate obtained at maximum velocity during the test).Using the same formula, the other flow rates can be calculated each flow and load variations.

Hydraulic Power Calculation

By eqn. (2.1) and values from table 3.5 and 3.6,

$R_e = V \frac{D_p}{v} = 1.376 \frac{0.4}{1.004x10^{-6}} = 5.5 \text{ x}10^5$

e = 0.1 (for lightly corroded steel for partially rusted commercial steel) [41]

Relative roughness = $\frac{e}{D_p} = \frac{0.1}{400}$ =0.00025

From Moody chart (given in broken line),

f = 0.022

Substituting the values from tables 3.5 and 3.6 into eqn. (2.1)

$H_f = 0.022\left(\frac{15.96}{0.4}\right)\frac{1.376^2}{2*9.81}$ = 0.085m and taking its 5% [27] for other loses

H_{orher} = 0.0042m

H_L = 0.085 + 0.0042 =0.089m (0.89% of gross head)

H_n = 10-0.089 =9.911m

The hydraulic power available for the existing Walga MHP can be calculated by using eqn. (2.4).

$P_h = g\ H_n\ \rho\ Q = 9.81x9.91x1000x0.172 = 16.7Kw$

Turbine-generator Efficiency Calculation

$$\eta_o = \frac{\text{Electrical power output of genertor}}{\text{Hydraulic power input to turbin}} = \frac{\text{Pe}}{\text{Ph}}$$

Substituting the values,

$$\eta_o = \frac{4.74KW}{16.66KW} = 28.45\%$$

Calculating Turbine Efficiency η_t

The turbine efficiency is given by eqn. (2.25) as:

$$\eta_t = \frac{\eta_o}{\eta_g\ \eta_m}$$

$$(\eta_g = 0.88,\ \eta_m = 0.97)\ \ (Coupled\ with\ transmitter)[27]$$

$$\eta_t = \frac{0.2845}{0.88x0.97} = 33.33\%$$

The next chapter deals with the options by which the gap could be addressed.

CHAPTER FOUR

OPTIONS TO MEET THE POWER DEMAND GAP

The site of Walga is an interesting site for its good hydro and solar resources. As discussed in the preceding chapter the existing MHP system alone cannot meet the power demand of the village. Realizing the fact that there is high power demand gap for Walga village two options (Option I and Option II) were considered to meet the power demand gap of the village.

4.1 Option I: Developing a PV/Micro Hydro Hybrid Power Supply System

Exploitation of the complementary of hydro and solar resources of energy seems necessary to maintain a constant level of electricity production favorable sites. The aim of developing PV/hydro hybrid power supply system is to ensure the village load demand is met and for further development of the village future load increase. This is achieved by adding PV generator to the existing MHP system.

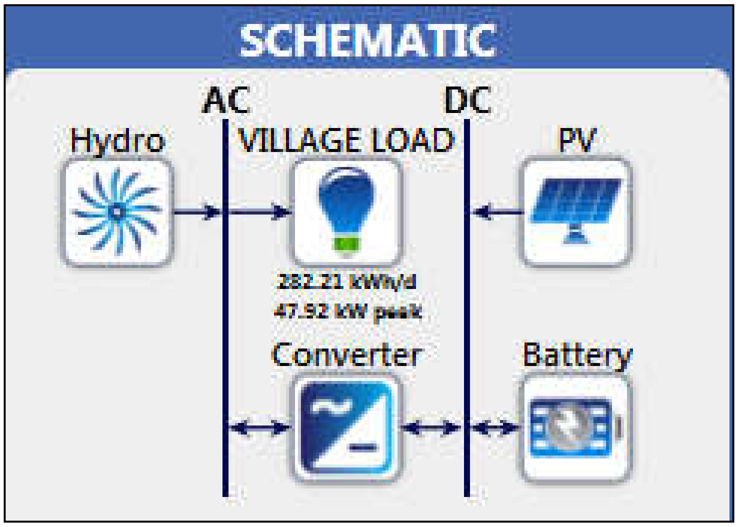


Fig.4. 1: HOMER Model of PV/ Hydro/ Battery Storage Hybrid System

4.1.1 Design of a PV System to be Hybrid with the Existing MHP and Components selection

The configuration of a hybrid power system depends on three factors. They are renewable resources, load and cost of components. Through software modeling, theoretical planning and analysis of the behavior of a rural electrification system can be done [42]. In this study, HOMER software is used to size and simulate supply configurations and performance elements of the PV/hydro hybrid power supply system.

A. Hybrid System Design

The Hybrid in Parallel Configured

A hybrid power system for Walga village is designed as one option to meet power demand of the village where PV module has been combined with the existing micro hydro and energy storage or battery. It also consists of conversion device such as bidirectional converter.

In the design of a hybrid power supply system, the choice and sizing of the components, and the most adequate control and management strategy must be obtained [43].

A parallel configuration (see Fig.4.1) allows all energy sources to supply the loads separately depending on the demand, as well as meeting an increased level of demand by combining the various energy sources. The bi-directional inverter (acting as a rectifier) charges the battery when excess energy is available from the other generators, as well as act as DC-AC converter (inverter) under normal operation.

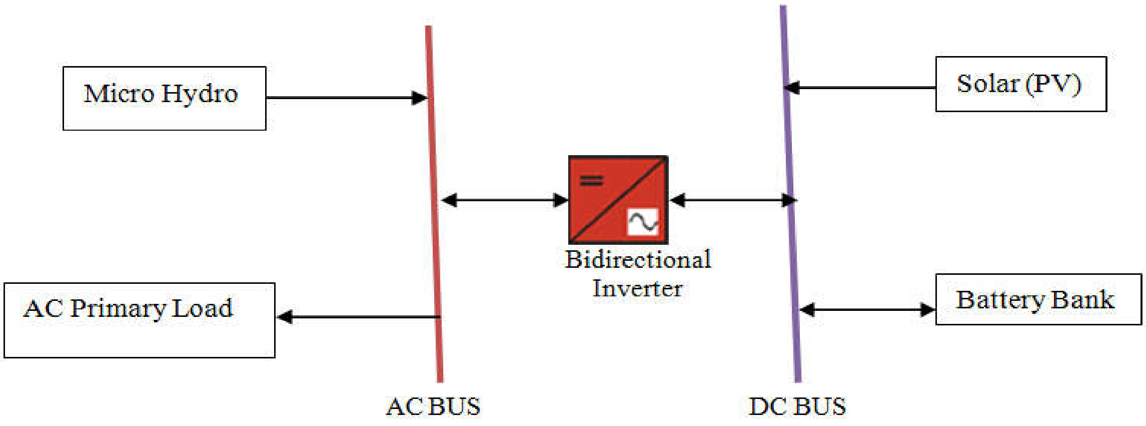


Fig.4. 2: Parallel PV/Micro Hydro/ Battery Hybrid System

The main advantage of this system is improved system efficiency and reliability through optimal operation and sizing of the generation components to meet the demand. While the main disadvantages to this system are, its complexity, and thus the need to automate the different controls; and also specialized training to operate the system [44].

B. Components Selection And Costs

The major problem faced by power generation using the hybrid power supply system is the variation in load and renewable resources. Therefore, the major concern in the design of an electrical power system that utilizes renewable energy sources is the accurate selection of system components that can economically satisfy the load demand.

I. Selection of PV Module and its Cost

The PV module selected in this paper was selected from the list of different PV modules provided in HOMER Pro software tool under the PV library. The selection is based on the module efficiency stated under the module selected. To estimate the module cost and know basic characteristics of the module, searching of similar module on internet was done and found that Phono Solar polycrystalline model PS330P-24/T has the same characteristics as the selected module. Appendix B

The selling price of Phono Solar polycrystalline model PS330P-24/T module on international market is $270.60[45].The researcher tried to assess the module price in the local market and use local module price but lacks the efficient module selected above.

The cost per watt of the module can be calculated as:

Cost per watt = $\frac{Module\ Price}{Module\ Power\ rating} = \frac{\$270.60}{330W}$ = $0.82/W

And the module price per KW could be $820.

The capital cost of PV module includes: Module cost, transportation cost, cables and mounting structures cost, installation and other relevant costs. The costs were estimated as follows [35].

- The estimated transportation cost 20% 0f a module cost = $164/KW
- Mounting structure cost and relevant materials cost 23% of module cost = $188
- Installation and relevant costs 40% 0f module cost = $328

Capital cost = $820 + $201+$287+$492 = $1500

Therefore, the estimated capital cost and replacement cost for a 1KW of the PV system are taken as $1500 and $1800 respectively. As there is very little maintenance required for PV, only $30/year is taken for O&M costs.

II. Cost of MHP

In order to know the direct cost of construction for MHPP, it is required to know the quantity for every work or material based on the design. For example, in case of headrace made of stone masonry, quantities of excavation, foundation rubble stone, stone masonry, backfill, and plastering shall be estimated.

The costs to develop a hydropower potential are relatively low. In fact, hydro installation in Ethiopia costs about US$1,200 per installed KW, or about half the cost of most other plants being built in eastern Africa [46]. Thus, unit generation costs of planned hydropower plants are calculated to be below USD 0.05 per kWh.

III. Storage Battery and its Cost

Batteries are used as a backup in the system and to maintain a constant voltage during peak loads or a shortfall in generation capacity. The battery chosen from HOMER storage tool for this study is Trojan IND17-6V. It is a 6V battery with a nominal capacity of 1202 Ah (7 KWh). It has a lifetime throughput of 9,300KWh. Trojan IND17-6V was chosen for its highest capacity and availability in the local market. The current selling price on international market IND17-6V is $1327 [47]. By taking 2% cost the battery for transportation and relevant cost per piece, the capital cost, replacement cost and O&M costs for one unit of this battery were considered as $1350, $1350, and $30/year respectively.

IV. Bidirectional Inverter

SI5048, Sunny Island Battery-based Inverter Charger, 5000W, 48V was chosen in this thesis work. The Sunny Island is a complete power center with 5KW of sine wave output power, low idle losses, high efficiency, and integrated battery disconnect, 100A battery charger, and integrated data monitoring and system control, all in a compact wall-mounted package. The current selling price on international market for SI5048, Sunny Island Battery-based Inverter Charger, 5000W, 48V is $4,495.00 [48]. By considering 4.5% of this cost for transportation ($205) per unit, the capital cost, replacement cost and O&M costs of the converter for 5KW systems be estimated as $4,700, $4,700, and $30/year respectively. The lifetime of the converter is 15 years, inverter efficiency of 98% and rectifier efficiency of 95%.

4.1.2 Modeling of the System with HOMER Software

Principles of Operation of HOMER Software

A. Define the village Load

The daily load profiles were determined by calculating the power demand (KWh/day) for all load types in the village.

Table 4. 1 Walga Village Load and use time

PERIOD	LOAD(kW)	PERIOD	LOAD (kW)
00:00 - 01:00	1.75	12:00 - 13:00	0.76
01:00 - 02:00	1.75	13:00 - 14:00	0.76
02:00 - 03:00	1.75	14:00 - 15:00	0.76
03:00 - 04:00	1.75	15:00 - 16:00	0.76
04:00 - 05:00	1.75	16:00 - 17:00	8.9
05:00 - 06:00	1.75	17:00 - 18:00	8.9
06:00 - 07:00	20.35	18:00 - 19:00	37.365
07:00 - 08:00	20.35	19:00 - 20:00	39.055
08:00 - 09:00	0.76	20:00 - 21:00	39.055
09:00 - 10:00	0.76	21:00 - 22:00	37.335
10:00 - 11:00	0.76	22:00 - 23:00	37.335
11:00 - 12:00	0.76	23:00 - 00:00	16.985

From table 4.1 above, the village load peaks maximum (39kW) from 19:00-21:00 period and very low from (0.76kW) 6:00-16:00 period.

Name: VILLAGE LOAD

January Profile

Hour	Load (kW)
0	1.750
1	1.750
2	1.750
3	1.750
4	1.750
5	1.750
6	20.350
7	20.350
8	0.760
9	0.760
10	0.760
11	0.760
12	0.760
13	0.760
14	0.760
15	0.760

Time Step Size: 60 minutes

Random Variability

Day-to-day (%): 5

Timestep (%): 5

Peak Month: January

Metric	Baseline	Scaled
Average (kWh/d)	282.21	282.21
Average (kW)	11.76	11.76
Peak (kW)	47.92	47.92
Load Factor	.25	.25

Load Type: ● AC ○ DC

Scaled Annual Average (kWh/d): 282.21

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

Lifetime (yr): 10

Fig.4. 3: Primary Load Inputs

The load type served is A.C load.

Primary Load: is the one to be met immediately in such way that no unmeet load.

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.

Two techniques to generate baseline demand data are: Either by HOMER to synthesize data or by importing hourly demand data from a file.

The system of synthesize is just put at least one load profile, that is a set of 24 hourly values of electric load. It is possible to enter different load profiles for different months and for weekdays and weekends also. But if only one load profile has been entered, it will be used throughout the year like the load used in this paper.

Daily and hourly noise input: Help to add randomness to the load data to make more realistic.

Constant load profile for the baseline case has been assumed, but hourly and daily randomness has been added to this load profile in HOMER to generate realistic load profile [49]. The researcher added 5 % randomness for both these cases. Adding 5 % randomness to the projected load profile results increase in annual peak demand to 48 KW and the load factor of 0.25. HOMER calculates the parameters, annual average of the daily demand, peak load and load factor based on the load profile and the random variability inputs given by estimation.

B. Renewable Resources

In order to judge the applicability of a hybrid renewable energy system for supplying electricity, it is required to assess the potential of renewable resources at the selected area and power demand of the selected community at the beginning [42].The available renewable resources should be sufficient to meet the required demand.

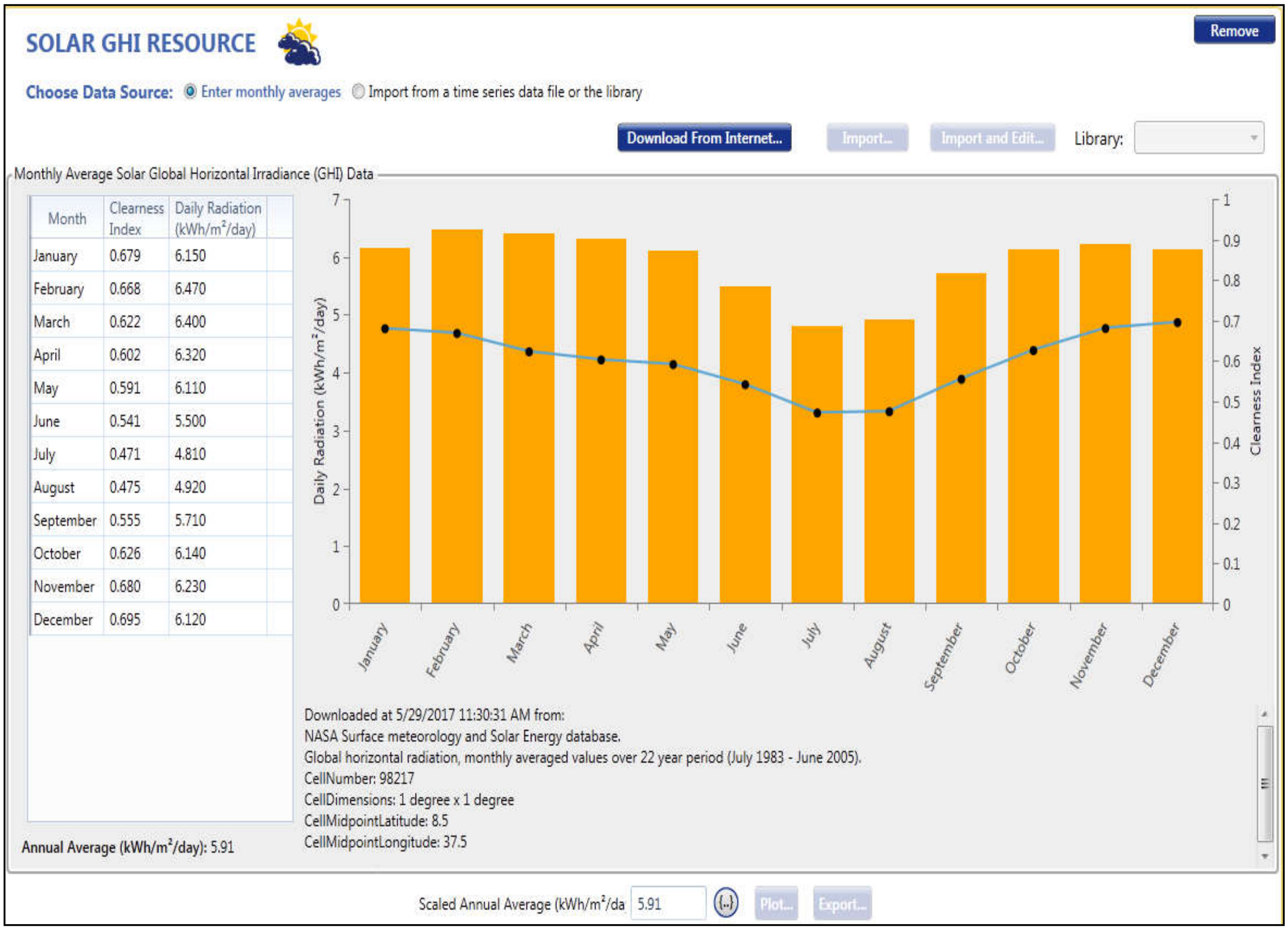
Hydro Resource

Walga River is situated in the South-East of Lake Wonchi. This gives a good stream flow throughout the year for it. A performance test, done by the researcher on the site, showed that the maximum flow rate that is passing across the penstock is 172 liters per second at 9.91metres of net head. The existing MHPP was designed at minimum flow available during the worst month (dry season of Ethiopia) and the flow rate would normally be available throughout the year. At this flow, a locally fabricated cross flow turbine coupled to an AC synchronous generator would be able to provide an electrical output capacity of 4.74KW, at 28.45% turbine-generator efficiency and turbine efficiency of 33.33%. From the test result and observation made during the dry season of Ethiopia, total flow rate of Walga River could estimate at 250 liters per second.

Solar Resource Assessment of the Village

Ethiopia location along the equator, and this guarantees that the village receives some of the highest solar irradiation values throughout the year. Photovoltaic systems are a proven technology, and numerous experiences around the world have proven their technical reliability and economic applicability in rural electrification programs [43].

The solar data used for the selected village at a location at $8^0$42'N latitude and $37^0$54'E longitude was taken from the NASA Surface Meteorology and Solar Energy database [50]. Data of Global Horizontal radiation monthly averaged values over 22 years period are given in Fig.4.4 below. In addition, the clearness index and the annual average solar radiation was found 5.91 KWh/m^2/day by the software are given [50].



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.679	6.150
February	0.668	6.470
March	0.622	6.400
April	0.602	6.320
May	0.591	6.110
June	0.541	5.500
July	0.471	4.810
August	0.475	4.920
September	0.555	5.710
October	0.626	6.140
November	0.680	6.230
December	0.695	6.120

Annual Average (kWh/m²/day): 5.91

Downloaded at 5/29/2017 11:30:31 AM from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 98217
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 8.5
CellMidpointLongitude: 37.5

Scaled Annual Average (kWh/m²/da 5.91

Fig.4. 4: Solar Resource Inputs Window, from Homer Pro

System Components Inputs to Homer

C. Components Selection

System analysis with HOMER software requires information on: Load, components (PV, Hydro, Storage and converter), resources (Hydro and solar resources), economics, control and constraints.

The considered hybrid energy systems for Walga village in HOMER simulation are PV arrays, hydro turbine, and generator and battery storage.

Table 4.2 Technical and cost data considered for existing Walga MHP and PV Hybrid systems

Component	Capacity($)	Capital Cost ($)	Replacement Cost ($)	O&M ($)
Hydro System	5.62kW	0	5,400	270
PV System	kWp	1,500	1,500	30/yr
Battery	1231AH	1,300	1,300	30/yr
Inverter/Charger	5kW	4,700	4,700	30/yr

The cost of PV panel, battery and bidirectional inverter were surveyed from international markets and was arranged by assuming the market condition of Ethiopia for the matter of simulation.

Hydro Inputs

The available head for the existing MHP is 10m (from field survey) and the calculated pipe loss is 0.089m which is 0.89% of the gross head. The design flow considered is 172L/s. The efficiency of the cross-flow turbine is 33.33% (from the test results) and the nominal capacity of the plant is calculated as5.62KW.

The MHP has already been constructed and hence its capital cost considered as zero. The replacement and O&M costs were estimated based on the estimated cost per KW in Ethiopia ($1200/KW as discussed in section 4.1.1).

Capital cost of MHP = Rated power xcost per KW

The available power of the existing MHP is 5.62KW

Its capital cost could be estimated as $6,700. But it has already existed; its capital cost is zero. We can take an estimation of 80% of the estimated capital cost for replacement cost and 4% for the O&M for HOMER simulation.

Therefore, the replacement and O&M costs are $5,400 and $270 respectively. The lifetime for the existing MHP is 23 years because it was installed in 2014 two years back from the base year 2016 of the project.

The minimum and maximum flow ratios considered here for HOMER are 50% and 100% respectively.

Available Head: The vertical drop between the intake and the turbine.

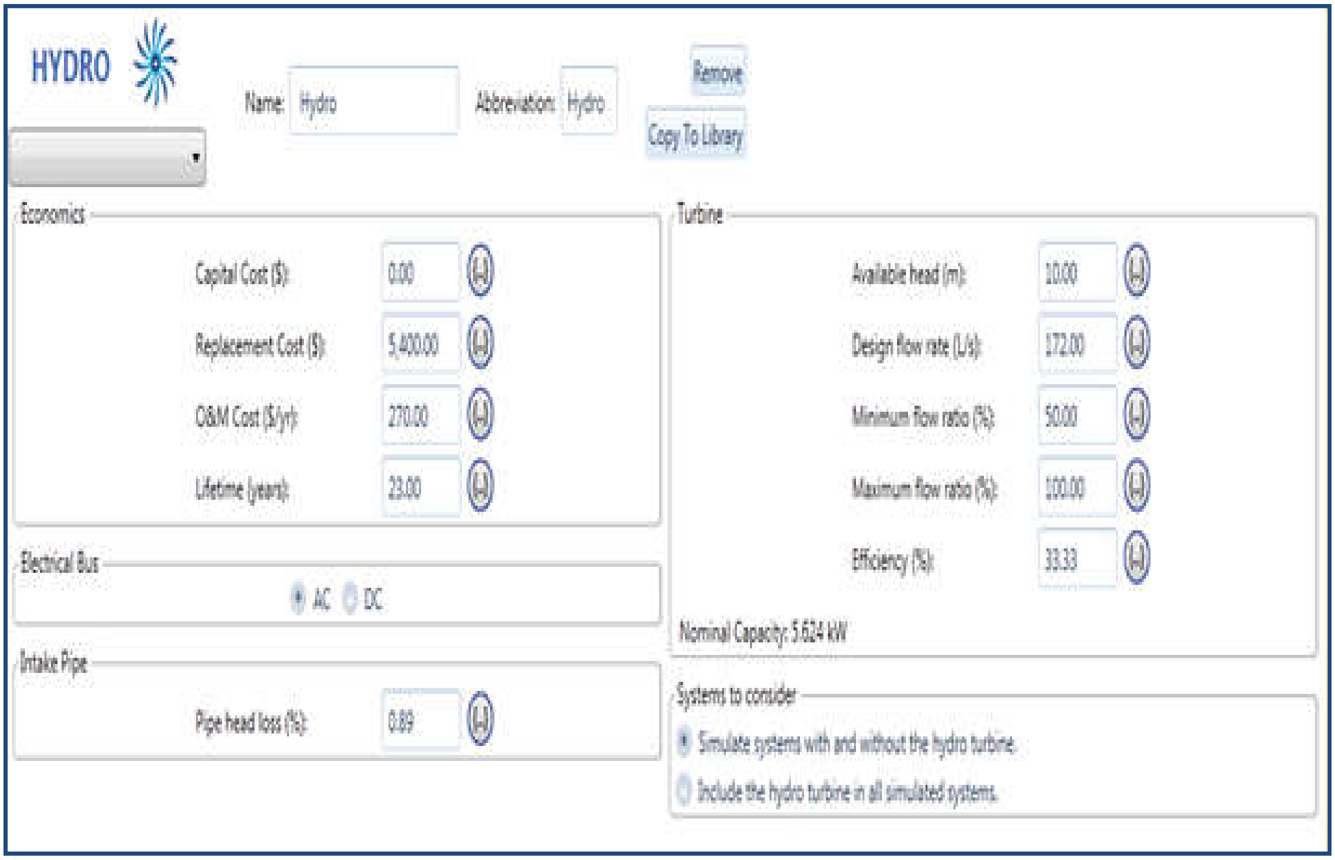
Design flow: The flow rate for which this hydro turbine was designed. It is often the flow rate at which the turbine operates at maximum efficiency

Minimum Floe Ratio: The minimum flow rate of the hydro turbine, as a percentage of its design flow rate. Below this rate, the turbine will produce no power.

Maximum Flow Ratio: The maximum flow rate of the hydro turbine, as a percentage of its design flow rate. The turbine will generate power at the specified efficiency up to this flow. Additional flow above this level will not increase turbine power output.

Hydro Turbine Efficiency: The efficiency with which the hydro turbine converts the mechanical power of the water into electrical power. HOMER uses this value to calculate the nominal hydro power and the actual output power of hydro turbine in each time step.

Nominal power of the hydro system: is the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine. The calculation of the nominal hydro power includes the efficiency of the hydro turbine, but not the pipe head loss.



Name: Hydro
Abbreviation: Hydro

Economics

Capital Cost ($): 0.00
Replacement Cost ($): 5,400.00
O&M Cost ($/yr): 270.00
Lifetime (years): 23.00

Electrical Bus

● AC ○ DC

Intake Pipe

Pipe head loss (%): 0.89

Turbine

Available head (m): 10.00
Design flow rate (L/s): 172.00
Minimum flow ratio (%): 50.00
Maximum flow ratio (%): 100.00
Efficiency (%): 33.33

Nominal Capacity: 5.624 kW

Systems to consider

● Simulate systems with and without the hydro turbine.
○ Include the hydro turbine in all simulated systems.

Fig.4. 5: HOMER Inputs for the Existing MHP Generator

PV Inputs

The PV input window requires the parameters like PV costs, lifetime, de-rating factor and slope in advanced input shown in Fig.4.6 below.

De-rating Factor: is a scaling factor that HOMER applies to the PV array power output to account for reduced output in real-world operating conditions compared to the conditions under which the PV panel was rated.

The de-rating factor considered here is 85% for each panel to approximate the varying effects of temperature and dust on the panels.

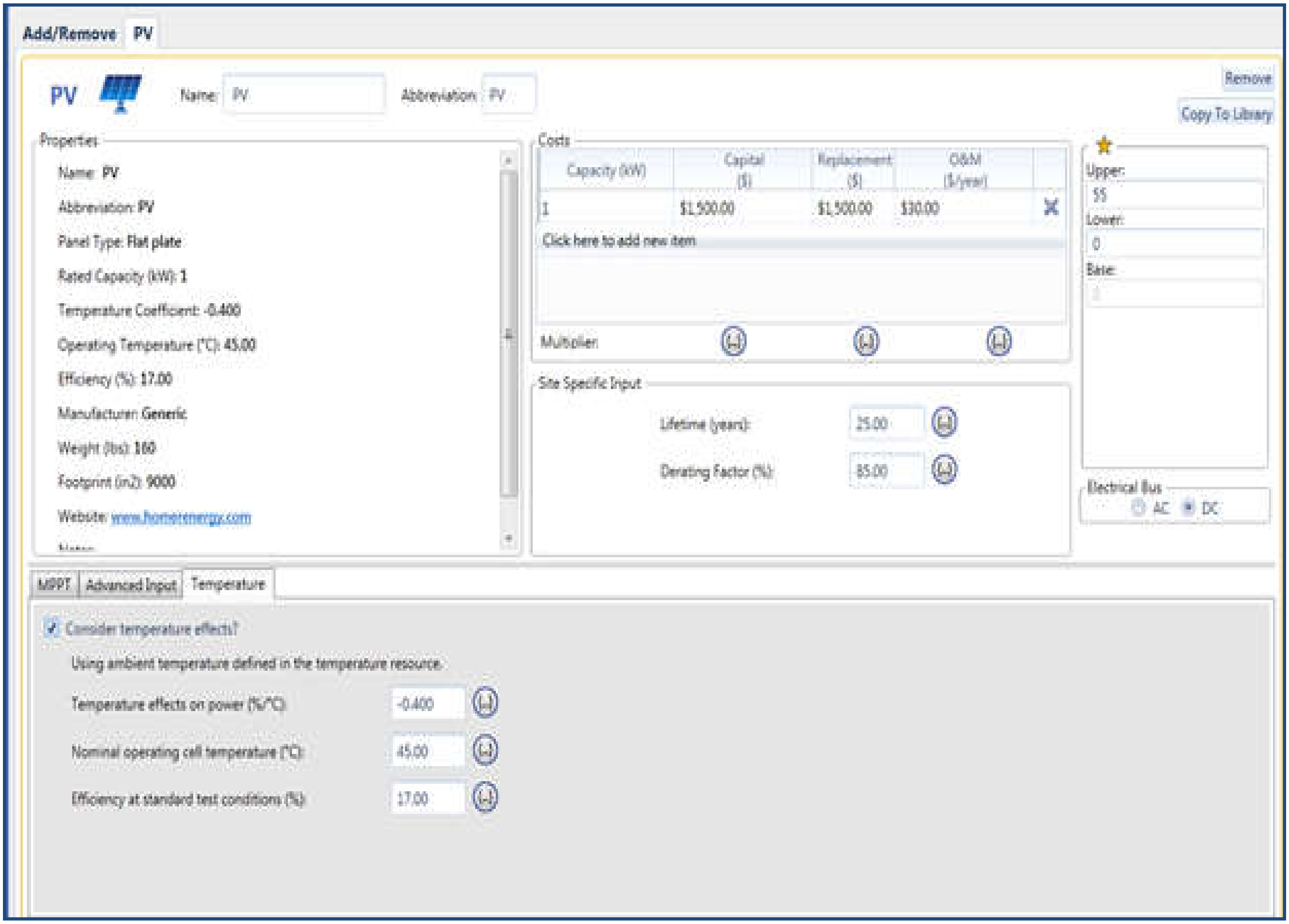
Slope: is the angle at which the panels are mounted relative to the horizontal. A slope of 0° corresponds to horizontal, and 90° corresponds to vertical. With fixed-slope systems, a slope roughly equal to the latitude will typically maximize the annual PV energy production.

The panels have no tracking system and are modeled as fixed titled due south at 0^0 with slope of $8^0$42’ which is equal to latitude of the location of the project.

The PV system for this project is connected to a DC output with a lifetime of 25years.

HOMER Pro 3.6.3 software tool provides lists of PV panels with different properties. For this paper efficiency was considered as basic criteria to select a panel from the lists. The flat plate PV panel with the most efficient one from the lists was selected and its costs are estimated as discussed in section 4.1.1.

As shown in figure below, the sizes of PV generator to be considered are: 0 lower value to 55KW upper value.



Name: PV
Abbreviation: PV

Name: PV
Abbreviation: PV
Panel Type: Flat plate
Rated Capacity (kW): 1
Temperature Coefficient: -0.400
Operating Temperature (°C): 45.00
Efficiency (%): 17.00
Manufacturer: Generic
Weight (lbs): 160
Footprint (in2): 9000
Website: www.homerenergy.com

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
1	$1,500.00	$1,500.00	$30.00

Multiplier:

Lifetime (years): 25.00
Derating Factor (%): 85.00

Upper: 55
Lower: 0
Base:

Electrical Bus ○ AC ● DC

☑ Consider temperature effects?

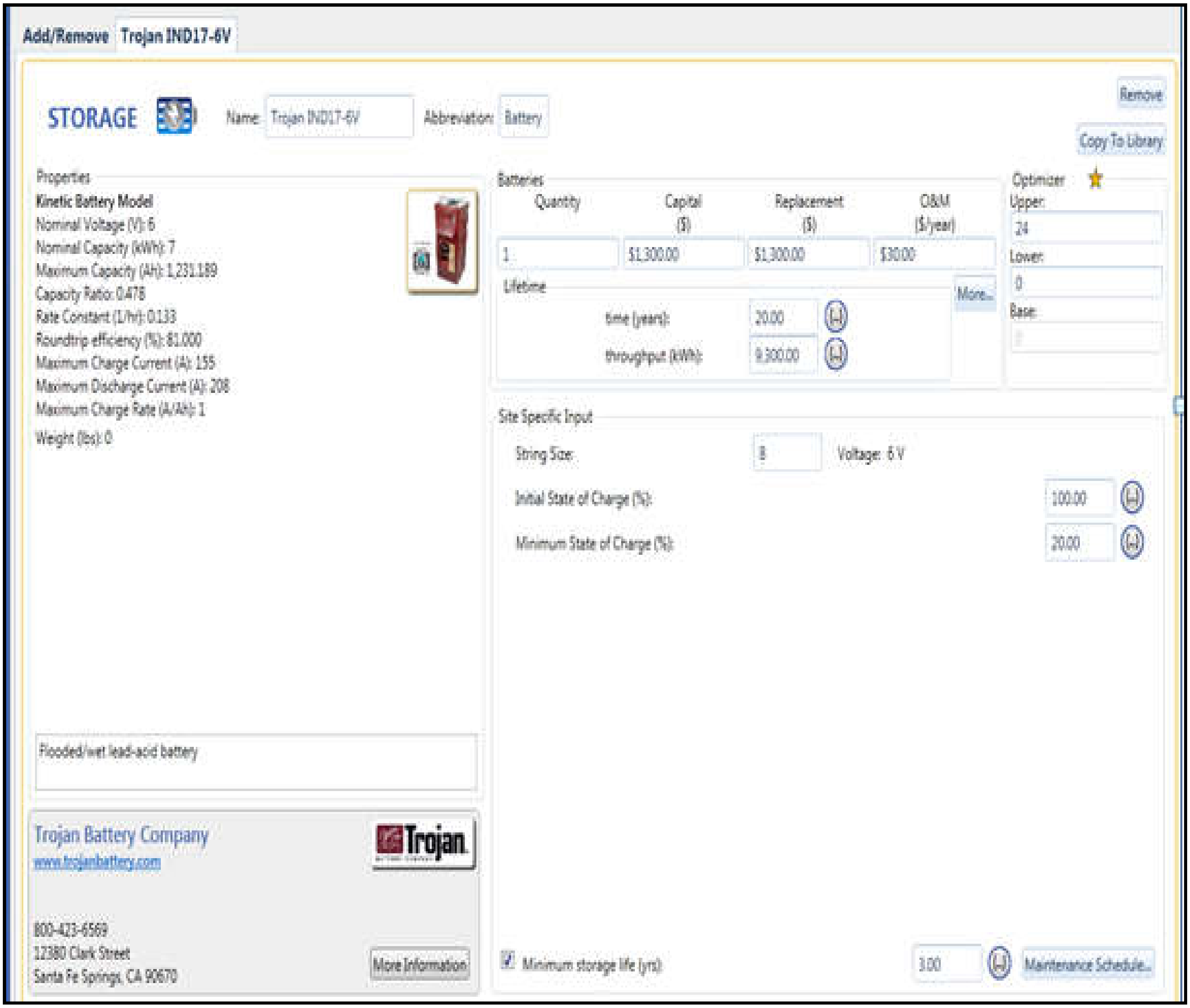
Using ambient temperature defined in the temperature resource.

Temperature effects on power (%/°C): -0.400
Nominal operating cell temperature (°C): 45.00
Efficiency at standard test conditions (%): 17.00

Fig.4. 6: Inputs for PV Generator

Battery Bank Inputs

The costs of the battery considered here were estimated based its current selling price on international market and adjusted in the case of our county. The system voltage selected is 48V and 8 string size batteries of 6V each were selected. The other inputs are taken from specification of the selected battery. Here, Trojan IDP-6V was selected because it is a high ampere-hour capacity battery that can be used for off-grid hybrid PV system.



Name: Trojan IND17-6V
Abbreviation: Battery

Properties
Kinetic Battery Model
Nominal Voltage (V): 6
Nominal Capacity (kWh): 7
Maximum Capacity (Ah): 1,231.189
Capacity Ratio: 0.478
Rate Constant (1/hr): 0.133
Roundtrip efficiency (%): 81.000
Maximum Charge Current (A): 155
Maximum Discharge Current (A): 208
Maximum Charge Rate (A/Ah): 1
Weight (lbs): 0

Flooded/wet lead-acid battery

Trojan Battery Company
www.trojanbattery.com
800-423-6569
12380 Clark Street
Santa Fe Springs, CA 90670

Batteries

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$1,300.00	$1,300.00	$30.00

Lifetime
time (years): 20.00
throughput (kWh): 9,300.00

Optimizer
Upper: 24
Lower: 0
Base: 0

Site Specific Input
String Size: 8 Voltage: 6 V
Initial State of Charge (%): 100.00
Minimum State of Charge (%): 20.00
☑ Minimum storage life (yrs): 3.00

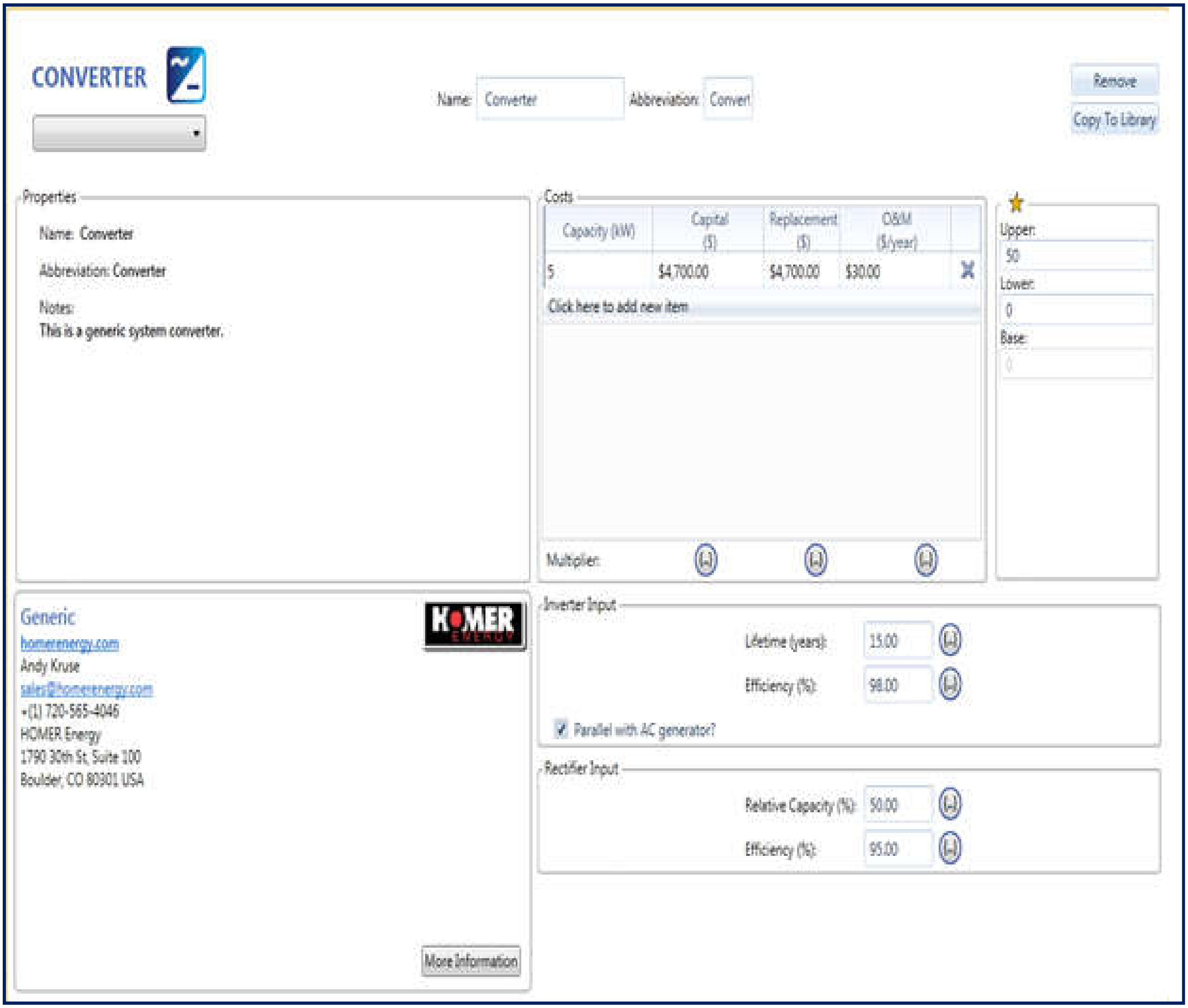
Fig.4. 7: Inputs to Battery Bank

As shown in the above Fig4.7, the quantity of strings to be considered is: 0, 8, 16 and 24

Converter Inputs

Costs inputs for converter was taken from its adjusted cost in section 4.1.1 above and from specification. The lifetime of converter considered here is 15 Years.

As show in the below in Fig.4.8, the sizes to be considered are: 0 lower and 50KW upper values.



Name: Converter

Abbreviation: Convert

Name: Converter

Abbreviation: Converter

Notes:
This is a generic system converter.

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
5	$4,700.00	$4,700.00	$30.00

Upper: 50

Lower: 0

Base: 0

Generic
homerenergy.com
Andy Kruse
sales@homerenergy.com
+(1) 720-565-4046
HOMER Energy
1790 30th St, Suite 100
Boulder, CO 80301 USA

Inverter Input

Lifetime (years): 15.00

Efficiency (%): 98.00

☑ Parallel with AC generator?

Rectifier Input

Relative Capacity (%): 50.00

Efficiency (%): 95.00

Fig.4. 8: Inputs to Converter

HOMERE Economics Inputs Window

You can enter the nominal discount rate and the expected inflation rate in the Economic Inputs window.

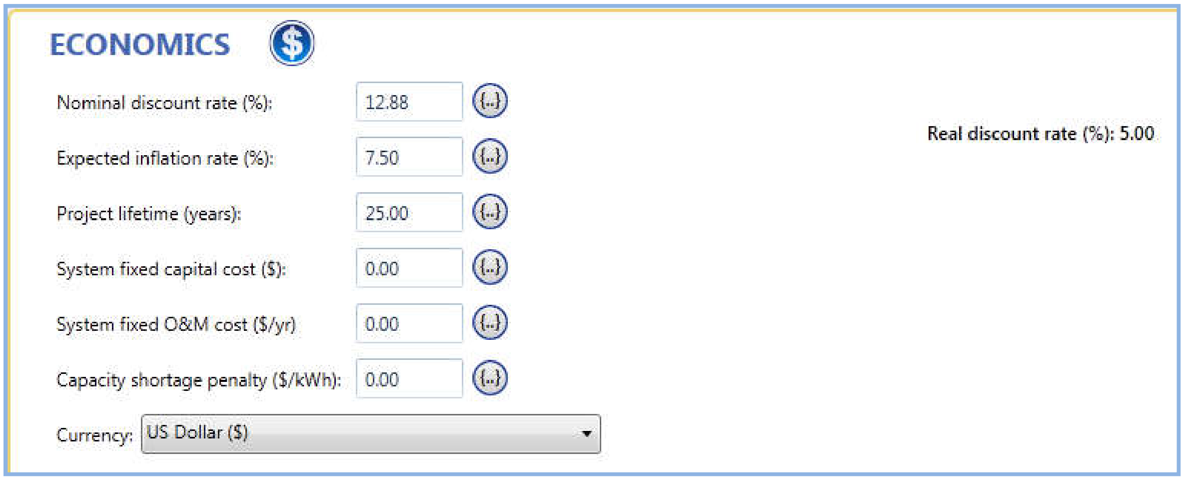
HOMER uses eqn. (2.19) to calculate the real discount rate:

$$i = \frac{i' - f}{1 + f}$$

$$i' = i(1+f) + f$$

$$i' = 0.05(1+0.075)+0.075 = 0.12875$$ [37][38]

$$i = 12.875\%$$



Nominal discount rate (%): 12.88

Expected inflation rate (%): 7.50

Project lifetime (years): 25.00

System fixed capital cost ($): 0.00

System fixed O&M cost ($/yr) 0.00

Capacity shortage penalty ($/kWh): 0.00

Currency: US Dollar ($)

Real discount rate (%): 5.00

Fig.4. 9: HOMER Economic Inputs window

4.1.1 Simulation of PV/Micro Hydro Hybrid Power Supply System and Performance Evaluation

SIMULATION

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

Systems that contain a battery bank and one or more generators require a dispatch strategy, which is a set of rules governing how the system charges the battery bank. HOMER can model two different dispatch strategies: load-following and cycle-charging. Under the load-following strategy, renewable power sources charge the battery but the generators do not. Under the cycle-charging strategy, whenever the generators operate, they produce more power than required to serve the load with surplus electricity going to charge the battery bank.

The simulation process serves two purposes. First, it determines whether the system is feasible. HOMER considers the system to be feasible if it can adequately serve the electric and thermal loads and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The life-cycle cost is a convenient metric for comparing the economics of various system configurations.

Performance Evaluation of the PV/Micro Hydro Hybrid Power supply System

The evaluation of performance of a power supply system is a very important point because it will help us to compare the technical capability of different power supply options to meet rural power demand. The performance of solar PV and micro hydro power supply system developed in this work is used to predict the performance of all components combined in the system.

is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. HOMER keeps track of such shortages and calculates the total amount that occurs over the year.

Unmet load: is electrical load that the power system is unable to serve. It occurs when the electrical demand exceeds the supply. For each system, HOMER calculates the total unmet load that occurs over the year, as well as the unmet load fraction. By default, HOMER considers any system that experiences unmet load infeasible, but you can change that by entering a non-zero value for the maximum annual capacity shortage.

Excess electricity: is surplus electrical energy that must be dumped because it cannot be used to serve a load or charge the batteries. Excess electricity occurs when there is a surplus of power being produced (either by a renewable source or by the generator when its minimum output exceeds the load) and the batteries are unable to absorb it all.

Fig.4. 10: HOMER- Monthly Average Electric production by Hybrid system

Monthly average electric power production from each unit in the hybrid system is shown Fig.4.10 we can see that the largest power is generated by the solar PV. Especially the generated power by the solar PV is higher during the months from September to May. On the other hand the average power generated by the PV is relatively smaller during the period of June to August. But the power generated by the micro hydro power system is constant throughout the year because the system was designed at the minimum flow rate of the river.

Table 4.3 summarizes the annual energy generation figures from the different components and other relevant performance indicators of the hybrid system. The PV generates the highest percentage 67.03% of the total annual energy generation while the hydro turbine generates 32.97% of the total. As shown in table 4.5, 17.6% of the total annual energy generation is excess, there is no electric unmeet load and no capacity shortage in the system.

Table 4.3 Annual Electrical Energy production by Option I

Description	KWh/yr	%
PV Array energy production	99,254	67.03
Hydro turbine Production	48,829	32.97
Total energy Production	148,083	100
AC primary load energy Consumption	103,007	100
Total energy Consumption	103,007	100
Excess Electricity	26085	17.6
Unmet Electric Load	0	0
Capacity shortage	0	0
Renewable fraction	1	
Maximum Renewable Penetration	8,826	

The estimated load of the village is 282.21KWh/d, 11.76KW average power and the peak of the village is 47.92KW. Hence, the designed PV/hydro hybrid system can meet the village peak demand load without any capacity shortage and without unmet load.

4.1.1 Economic Evaluation the PV/Micro Hydro Hybrid Power Supply System

The Costs of Components and other Relevant Costs

Net Present Cost

NPC (life-cycle cost of a component): is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each component of the system, and of the system as a whole.

The costs of the PV/micro hydro hybrid system are given in the following table 4.4.

As shown in table 4.4 below , the system net present cost of the capital cost, replacement cost, O&M costs and salvage costs are $379,100, $118,438,$ 112,473, and $ -61,363 respectively. Fuel costs are zero, because there is no diesel generator used in the system. And the system total present cost is $548,648 and the levelized cost of energy is $0.378/kwh.

Table 4.4 Net Present Costs of Option I by Component type

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	82,500	0	23,256	0	0	105,756
Hydro	0	1,758	3,806	0	-1,456	4,108
Battery	249,600	94,072	81,182	0	-55,281	369,573
Converter	47,000	22,608	4,229	0	-4,626	69,211
System	379,100	118,438	112,473	0	-61,363	548,648
Levelized COE ($/KWh)	0.378					

4.2 Option II: Developing the Micro Hydro Resource Existing at the Site

Because of the availability of an undeveloped and attractive site with a better head and flow rate it is an attractive location for the development of another micro hydro power system in the village. This section explores the feasibility of developing a new MHP at site upstream Walga MHPS.

4.2.1 Description of the 2nd Micro Hydro Resource

Water would be diverted to an intake at the edge of the hillside on the 2nd MHP. From the intake travels water through a channel of about 120m long to fore-bay. From the fore-bay, the water would travel down 40m long penstock to a turbine located at the end of the penstock.

The 2nd MHP site is located in Oromia Regional State, south West Shoa zone, Wonchi Woreda Azer_Keransa Kebele at longitude $37^0 54'24.8''$E and latitude $8^0 43'18.4''$N. The project gets its name from Walga River.

The 2nd MHP site is attractive and the best for the following reasons:

- Gross Head: 31.5m which is higher than head of the existing MHP (10m).
- Power Distribution Lines: The site is located near to the existing Walga Micro hydro Power Station and within the boundary of the existing micro-grid of Walga village.
- Property Status: The hillside is classified as constrained land, not suitable for development. A facility at this location is not likely to result in land use conflict.
- Minimum Ecological Impacts: A hydro project at this site would not divert water from any existing project areas. Water for this project would come from entirely from the river water system.

Before discussing the design of the components of 2nd Micro Hydro Power system it is necessary to discuss the primary data available through the feasibility survey of the study and performance test of the existing Walga MHPS. Measurements were carried out to locate the best position for intake, headrace cannel, spillway, fore-bay, powerhouse and tailrace during the field survey.

From the feasibility study done by Ministry of Water, Irrigation and Electric of Ethiopia in 2013 and from the observation during the field survey the water used by the existing MHP is half of the river flow. Based on these, the design discharge for the 2nd MHP could be taken as 200L/s in this thesis work.

Survey was carried out by the researcher from the beginning of 2016 to the beginning of 2017 to collect information regarding the most potential site (2nd MHP) and the demand for power in the locality. The survey also included the technical and socio-economic issues important for project but as highlighted in the limitation of this study. The survey included the hydrological and topographical information needed for the actual design of the new system (2nd MHP) components. Based on the data collected, appropriate locations for intake, headrace cannel, spillways, fore-bay, powerhouse and electrical transmission system were carried out. Site survey also included determination head needed for the required power output which was taken to be

48KW. Similarly, after desirable locations for the civil structures were determined by the survey, the head available and the distance between these various civil structures were measured.

The determination of head is very important steps in the design of micro hydropower system. The gross head measured was 31.5 meters on field survey by using of GPS (Global Positioning System).There are several methods of determining the water flow of river but in this thesis work the researcher used the information from Ministry of Water, Irrigation and Electric of Ethiopia (survey of 2013) and the performance test result of the existing MHP done by the researcher himself in 2016.

Fig.4. 11: Map of Location of Walga Village [51]

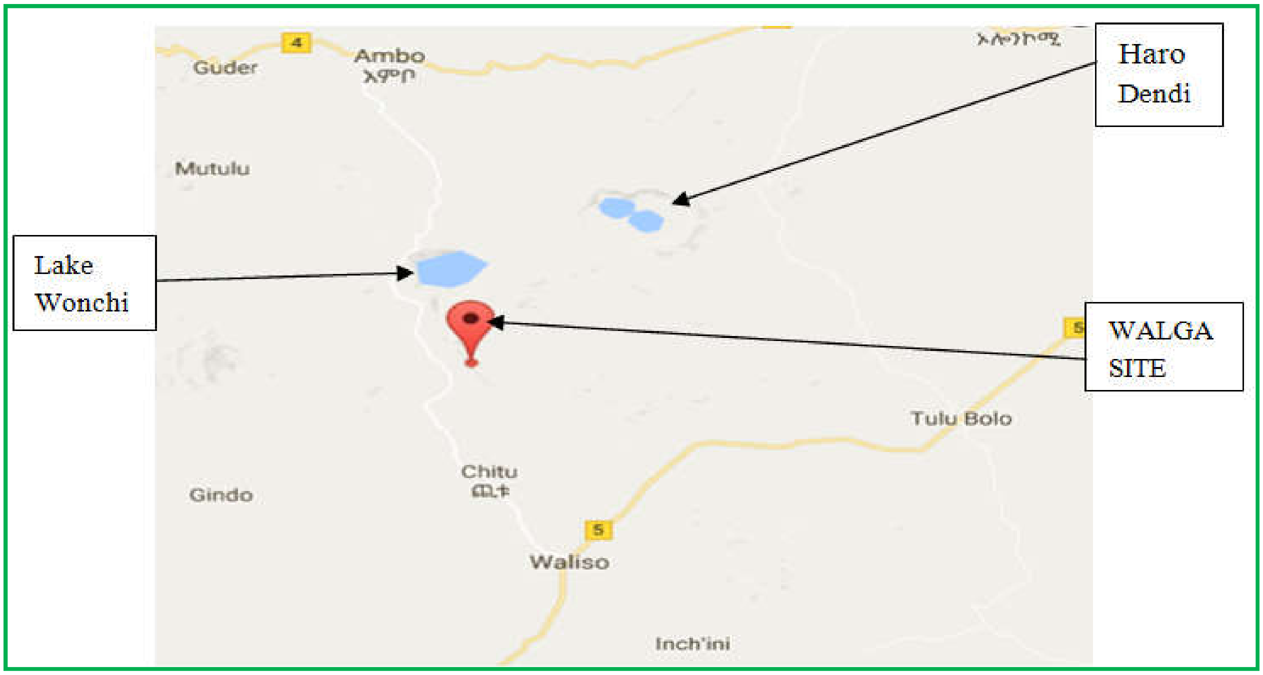


Fig.4. 12: Google Map of Walga Village [51]

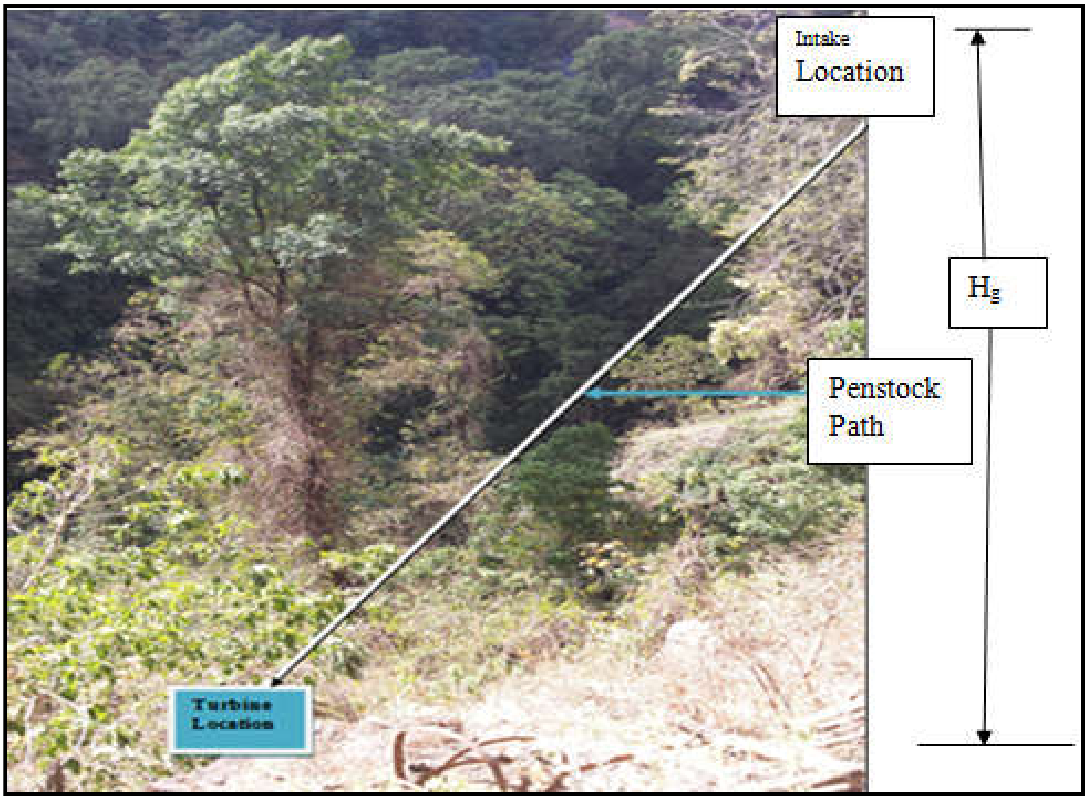


Fig.4. 13: Approximate Intake, Turbine Location and Penstock Layout

Head and Flow Measuring

The growth head of the 2nd MHP was computed by taking the elevation difference between the intake and turbine locations. And flow rate was estimated from the test results of the existing MHP and field survey.

The flow rate obtained from the test result was 172L/s, but based on the test result and feasibility study done by Ministry of Water, Irrigation and Electric (2013) and from field survey observation (January 2016 by the researcher) the design flow rate for the 2nd MHP was taken as 200L/s in this thesis work. The summary of the site data available and performance test result is provided in table 4.8 below.

Table 4.5 Summary of Field survey Data of the site

Features	Survey Data	Type of Data
Gross Head	31.5 m	Primary
Length of penstock	40 m	Primary
Measured Flow	0.172 m^3/s (June 2016)	Primary
Design Discharge	0.2 m^3/s	Secondary
River Source	Lake Wonchi	
Power	48 KW	Primary
No of households demanded	257 households	Primary
Length of Headrace Canal	120 m	Primary

Fig.4. 14: Water Falls on Walga River (Photo taken during field survey)

Net Head Calculation

The available head was determined by carrying out a site visit and measuring this manually. Once the gross head has been measured, an applicable factor must be determined to allow for losses through the penstock to calculate the net head available at the site. The net head is the gross head minus the applicable losses (the head loss, H_L).

Table 4.6 Manning coefficient n for several commercial pipes [52]

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

By equation (2.5):

$D_p = 2.69(n_p{}^2 * Q^2 * L_p/H_g)^{0.1875}$ m [16]

$D_p = 2.69(0.012^2 * 0.2^2 * 40/31.5)^{0.1875}$ m

$D_p = 0.293 = 293$mm

From equation (2.2) the velocity of the flow is given by:

$$V = \frac{Q}{A} = \pi\frac{D^2}{4}\ \frac{Q}{\pi\frac{D^2}{4}} = \frac{4Q}{\pi D^2} = \frac{4*0.2}{3.14*0.293^2} = 2.97\text{m/s}$$

Using eqn.(2.2), Reynolds number "R_e" is:

$$R_e = V\frac{D_p}{v} = 2.97\frac{0.293}{1.004x10^{-6}} = 3x10^5$$

e=0.045mm for commercial steel (Appendix C)

$$\text{Relative roughness} = \frac{e}{D} = \frac{0.045}{293} = 0.000154$$

Reynolds number of $3x10^5$, and calculated relative roughness 0.000154 and a friction coefficient (f) is determined by following the curved line from the relative roughness value (on RHS) to the intersection of the Reynolds Number line and from this point, a line is projected to the left to read the friction (resistance) coefficient.

It is often effective to solve for this friction factor using the above Moody Chart as follows:

1. The line referring to our relative roughness is on the right side of the diagram. In that case we have a printed line (correspond to 0.000154).
2. This line to the left curves until to reach the red vertical line, where corresponding to my flow's Reynolds Number ($3x10^5$). This point is marked on the Chart.
3. Using a straight edge, the point straight left, is followed parallel to the x axis, until one reaches the far left side of the chart.
4. We read off the corresponding friction factor which is 0.0159

By substituting the values into equation (2.1), the friction head loss is:

$$H_f = 0.0159\left(\frac{40}{0.293}\right)\left(\frac{2.97^2}{2x9.81}\right) = 0.976\text{m}$$

The loss for the bends is 5% of H_f .[20]

Loss for bend = 0.82 x 0.05 =0.0485m and

The total head loss is

$H_L = H_f + H_{Loss\ bend} = 0.976 + 0.0485 = 1.0245$m

Percentage of head loss = $\frac{H_L}{H_g} = \frac{1.0245}{31.5}$x100% = 3%

The head loss is about 3% of the gross head.

The net head is:

$H_n = 31.5-1.0245= 30.475$m

Calculation of Power Output

Once the net head (H_n) and water flow rate (Q) have been determined, the calculation of the net power output (P_t) by turbine shaft is straightforward and can be established from the formula given by equation (2.4) as:

$P_t= g\ H_n\ \rho\ Q\ \eta_t = 9.81_x30.475x1000x0.2x0.8 = 48KW$

Here the efficiency of the turbine considered is 80%.

The site has a potential of electrical energy generation 420,480kwh/yr.

4.2.2 Design of the 2nd Micro Hydro Power System and Components Selection

Based on the performance test result of the existing MHP and field survey as primary data source and design parameters discussed in unit two, the following information has been used in the design of the main components of the second MHP system.

Penstock Design

Penstocks (pipes) are used to conveying water from the intake to the power house. They can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock materials, the ambient temperature and the environmental requirements.

The internal penstock diameter (D_p) can be estimated from the flow rate, pipe length, and gross head as calculated in the previous section 4.2.1:

D_p =293mm

The wall thickness of the penstock depends on the pipe materials, its tensile strength, pipe diameter and the operating pressure. The minimum wall thickness is recommended as by equation (2.16):

$$tp = \frac{Dp+508}{400} + 1.2\ (mm)$$
$$tp = \frac{293+508}{400} + 1.2\ (mm)$$
$$tp = 3.2mm$$

4.2.3 Turbine and Generator Selection

a. Turbine Selection

The net head of the 2nd MHP system is 30.475m and the design flow rate is 0.2L/s, by using the turbine selection chart given in Fig.2.3, the appropriate turbine for this proposed system is the cross-flow turbine. Cross-flow turbine is suitable and is likely to be the most practical in terms of cost and availability.

b. Selection of Generator

Even though, this thesis work is not mainly concerned with the selection and use of generators in MHP system, it relevant to mention the major types generators used in hydroelectric generation by the proposed site. There are basically two types of generators that can be used in hydroelectric generation.

Based on the size of scheme and generator type used given as criterion in table 2.3 for the selection of a generator, synchronous generator is appropriate for the 2nd MHP scheme described in this paper.

4.2.4 System Modeling with HOMER Software for the 2nd MHP System

For the 2nd MHP system model the inputs to the software are new hydro resources such as head, flow rate and the previous load profile of Walga village. With all the data input to HOMER, the software simulates and gives list feasible solutions sorted by net present cost as discussed in the previous sections. Figure below shows HOMER models of the 2nd MHP system

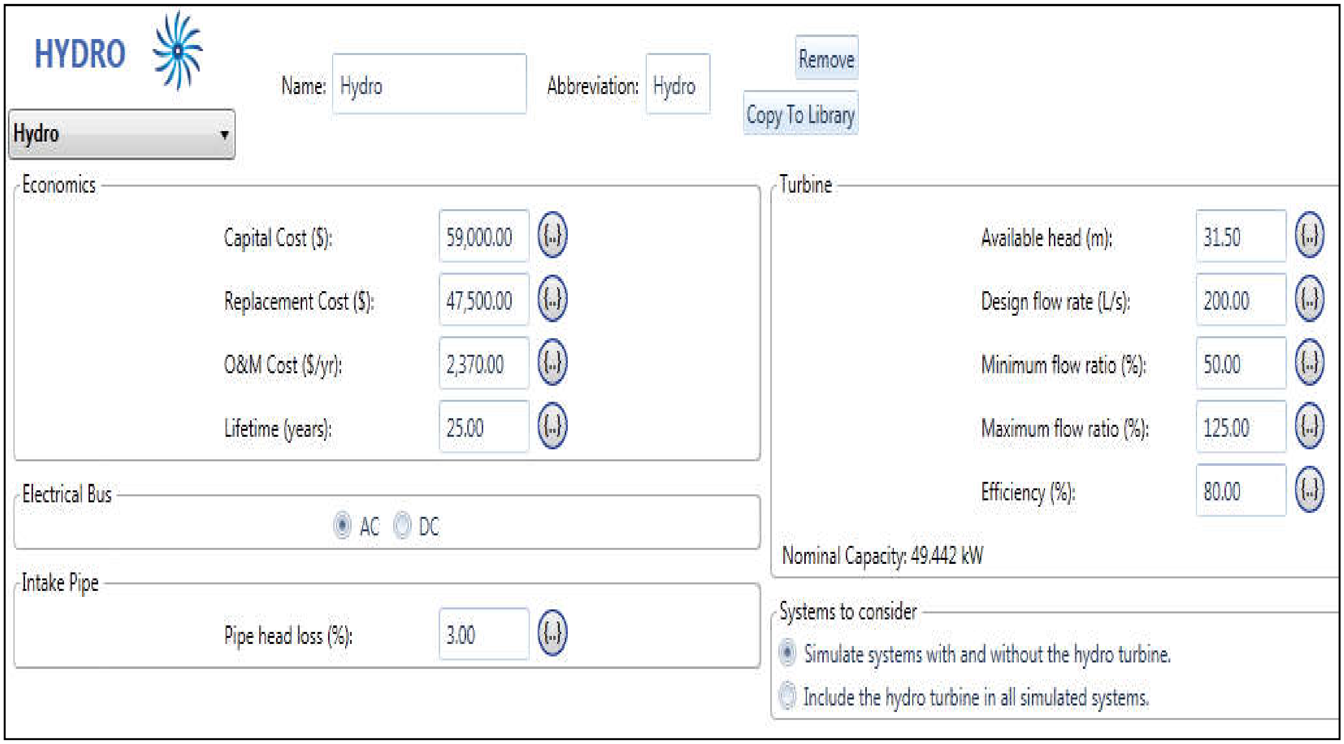
Hydro Input

Minimum flow ratio: The minimum flow rate of the hydro turbine, as a percentage of its design flow rate. Below this rate, the turbine will produce no power.

Maximum flow ratio: The maximum flow rate of the hydro turbine, as a percentage of its design flow rate. The turbine will generate power at the specified efficiency up to this flow. Additional flow above this level will not increase turbine power output.

Hydro power capital cost in Ethiopia costs about US$1,200 per installed KW [46] as stated in section 4.2.1.Therefor, the capital cost for 49.442KW power could be estimated as$59,000, its replacement estimated as 80% of the capital cost which is $47,500 and estimated its O&M cost as 4% of the capital cost which is $270 with lifetime of 25 years [53].

Small water turbines have efficiencies better than 80%. The efficiency of turbine considered here is 80% because small water turbines rarely have efficiencies better than 80% [54]. The available and design flow rate is taken from table 4.6 above. The calculated head loss is 3% of the available head.



Name: Hydro
Abbreviation: Hydro

Economics
Capital Cost ($): 59,000.00
Replacement Cost ($): 47,500.00
O&M Cost ($/yr): 2,370.00
Lifetime (years): 25.00

Electrical Bus
● AC ○ DC

Intake Pipe
Pipe head loss (%): 3.00

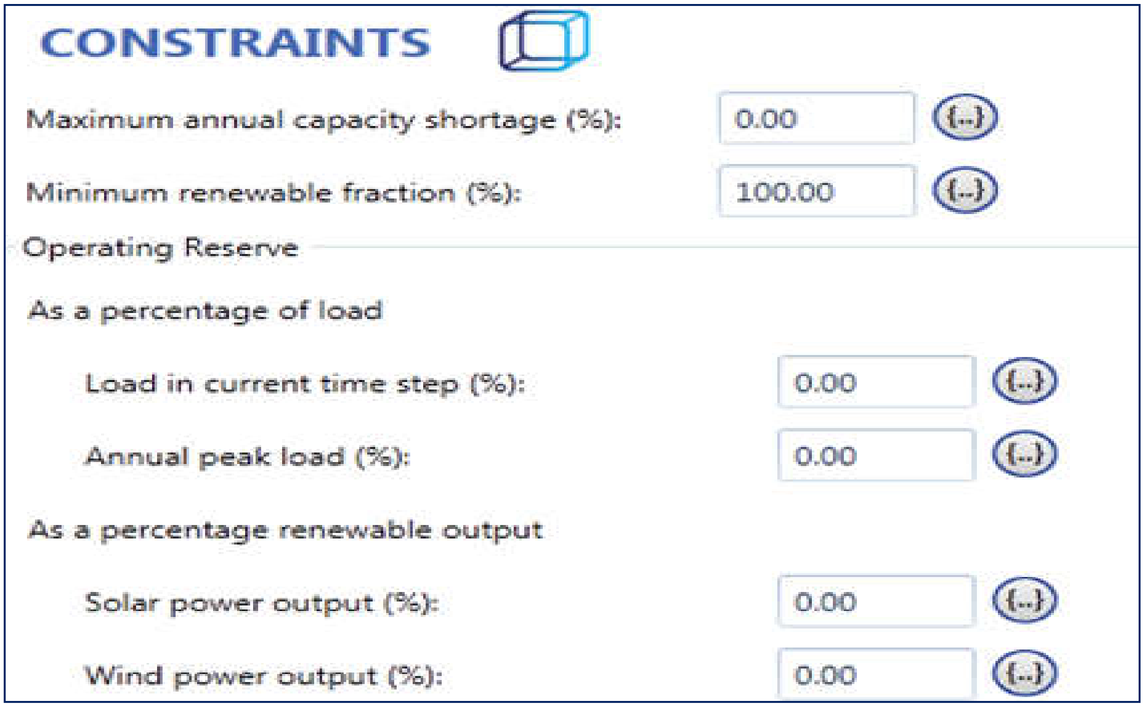
Turbine
Available head (m): 31.50
Design flow rate (L/s): 200.00
Minimum flow ratio (%): 50.00
Maximum flow ratio (%): 125.00
Efficiency (%): 80.00
Nominal Capacity: 49.442 kW

Systems to consider
● Simulate systems with and without the hydro turbine.
○ Include the hydro turbine in all simulated systems.

Fig.4. 15: Hydro input for the 2nd MHP Generator

CONSTRANTS

The maximum annual capacity shortage considered for the 2nd MHP is zero, minimum renewable fraction 100% (pure hydro) and no operating reserve.



CONSTRAINTS

Maximum annual capacity shortage (%): 0.00

Minimum renewable fraction (%): 100.00

Operating Reserve

As a percentage of load

Load in current time step (%): 0.00

Annual peak load (%): 0.00

As a percentage renewable output

Solar power output (%): 0.00

Wind power output (%): 0.00

Fig.4. 16: HOMER Constraints Input window for the 2nd MHP system

4.2.5 Simulation and Performance Evaluation of the 2nd MHP Supply System

The system indicated in Fig.4.17 below indicates village load of 282.21KWh/d and 47.92KW peak power. Hence, the 2nd MHP system can meet the village peak load.

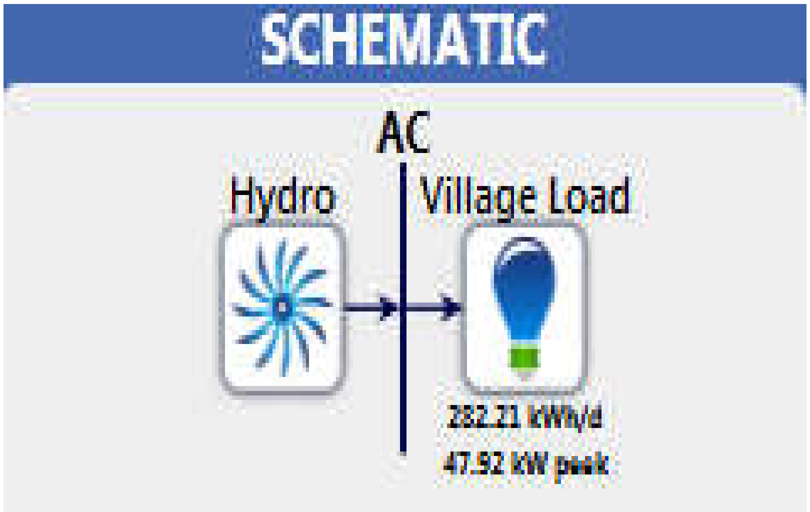


Fig.4. 17: HOMER Model for the 2nd MHP system

Fig.4. 18: Monthly Average Electric Production by the 2nd MHP System

Monthly average electric power production from the 2nd MHP system is shown fig.4.19. It can be seen that the whole power is generated by the hydro system. The power generated by the 2nd micro hydropower system is constant throughout the year because the system was designed at an average flow rate of the river.

Table 4.8 summarizes the annual energy generation figures from the 2nd MHP system and other relevant performance indicators of the system. The hydro turbine generates 100% of the total production. As shown in table 4.8, there is no electric unmeet load and no capacity shortage in the system. This system also generates high excess electricity (75.5%) which will allow the expansion of power distribution to nearby villages of Walga or expansion of small industries in the village like milk processing, barberry and the likes.

Table 4.7 Annual Electrical Energy production by Option II

Description	KWh/yr	%
Hydro turbine Production	420,141	100
AC primary load Consumption	103,007	100
Excess Electricity	317,115	75.5
Unmet Electric Load	0	0
Capacity shortage	0	0
Renewable fraction	1	

4.1.2 Economic Evaluation of the 2nd Micro Hydro Power System

The economics of the 2nd MHP supply system can be evaluated using the same principle of the one explained for the PV hybrid system. Hence, after HOMER software simulation from the output results we have noticed that initial capital cost of $59,000, operating cost of 33,403 , total NPC of $ 90,416 and COE as 0.064$/KWh were calculated for the 2nd MHP system. Although, the cost of the 2nd MHP system is much lower than the cost of the hybrid system, still the community cannot afford these costs. Therefore, the government will better to support the community by providing long term loan and community supporting incentives.

The costs of the 2nd micro hydro system is given in the following table 4.9-table 4.10.

Table 4.8 Net Present Costs of Option II

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
Hydro	59,000	0	33,403	0	0	92,403
System	59,000	0	33,403	0	0	92,403
Levelize COE ($/KW)	0.064					

Table 4.9 Annualized Costs of Option II

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
Hydro	4,186	0	2,370	0	0	6,556
System	4,186	0	2,370	0	0	6,556

The annualized system capital cost and O&M cost are $4,186, and $2,370 respectively. And the system total annualized cost is $6,556.

CHAPTER FIVE

DISCUSSION OF RESULTS

In this chapter we will discuss the performance test results of the existing Walga MHPS and results of power demand gap assessment of Walga village. And also will discuss the results of the proposed two options (Option I and Option II) to meet the power demand gap of the village obtained from the HOMER simulations that were presented in chapter four. Finally, discusses about technical and economic evaluation of the options and draws conclusions.

The optimal hybrid system is the one which can supply electricity needs at the lowest price or in other words, the system which is having the lowest total net present value, while supplying the electricity at the required level of availability.

This chapter discusses the results obtained from the performance assessment the existing MHP, Power demand assessment of Walga village and results of the options considered to meet the power demand gap of the village.

5.1 Results of Performance Assessment of the Existing MHP

Using the their respective formulas, the calculated head losses, gross head, net head, flow rate hydraulic power, electrical power, overall efficiency and turbine efficiency are summarized in table 5.1 below. The calculations are done by using Microsoft office Excel 2017.

Table 5.1 Summary of the Calculated Parameters of the performance test

Parameters											
V (m/s)	H_g	H_f (m)	H_i (m)	H_v (m)	H_L(m)	H_n (m)	Q (m^3/s)	P_h (KW)	P_e (KW)	η_0 (%)	η_t (%)
0.853	10	0.03604	0.01856	0.00371	0.05831	9.942	0.107	10.463	1.50	14.34	16.80
0.945	10	0.04417	0.02275	0.00455	0.07148	9.929	0.119	11.568	2.23	19.28	22.58
1.067	10	0.05631	0.02900	0.0058	0.09111	9.909	0.134	13.035	3.37	25.85	30.29
1.158	10	0.06638	0.03419	0.00684	0.1074	9.893	0.146	14.129	3.91	27.67	32.42
1.376	10	0.09308	0.04794	0.00959	0.15061	9.849	0.172	16.659	4.74	28.45	33.33

As shown in the above table 5.1, the flow velocity of water in the penstock varies from 0.853m/s to 1.376m/s, the net head remains 9.9m, the rate varies from 0.107m^3/s to 0.172m^3/s, the hydraulic power from 10.463KW to 16.659KW, electrical power from 1.5KW to 4.74KW, overall efficiency from 14.34% to 28.45% and turbine efficiency from 16.8% to 33.33%.

The existing Walga MHPS was designed to develop about 12.5KW power but the actual power measured during the performance test was much lower than the expected output (4.74KW). This is due to the overestimated hydro resources (head and flow) available at the site.

The system operates with very low efficiency 28.45% system efficiency and 33.33% turbine efficiency. This is due to the poor structures of civil components and powerhouse components observed during the field survey and performance test on the site. From the field survey, the plant was not commissioned. The basic characteristic curves of the cross flow turbine of the existing MHP system generated from table above by the help Microsoft office Excel 2007are shown below.

5.1.1 Characteristic Curves of the Turbine

By theoretical analysis and available methods for computation it is not possible, even by advanced approaches, to obtain exact results of the real flow state and the performance of turbo machines.

The characteristic curves of the cross-flow turbine used in the generating unit of Walga MHPS are generated from table 4.3 above by help of Microsoft Office Excel 2007.

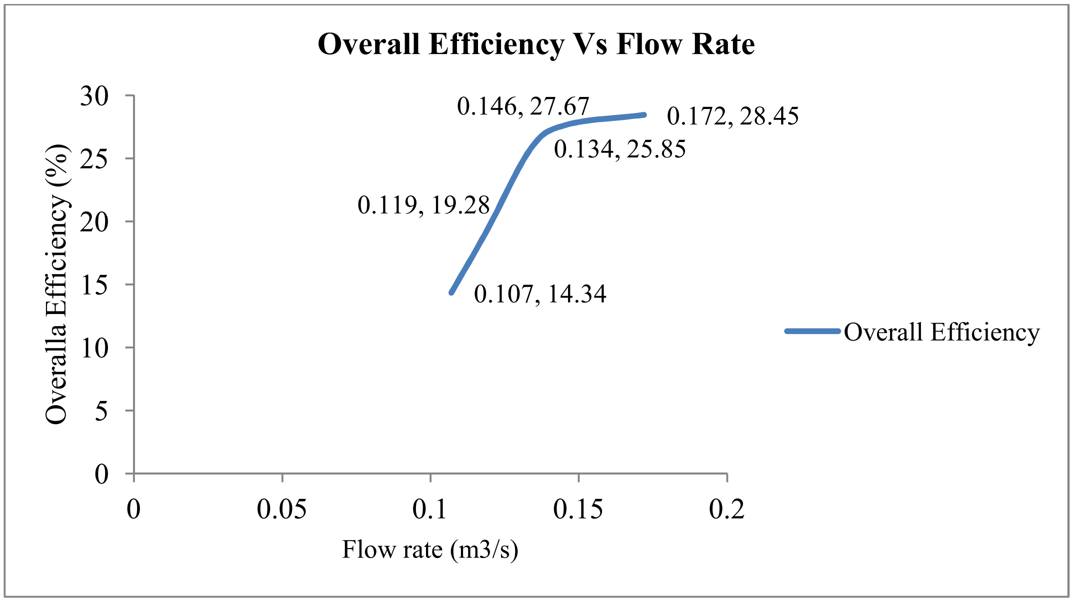


Fig.5. 1: Overall Efficiency versus Flow rate

The efficiency of the existing Walga MHP generating system reaches its maximum value 28.45% at maximum flow rate (valve fully opened) during the test on the site and turbine efficiency also reaches its maximum value (33.33%)

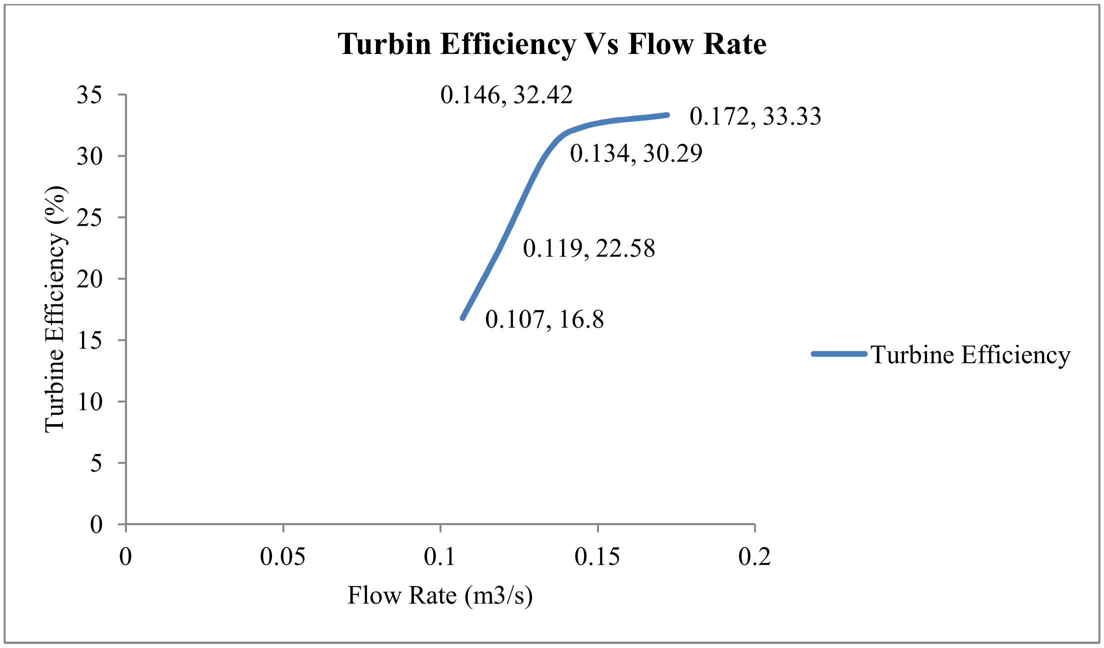


Fig.5. 2: Turbine Efficiency versus Flow Rate

Figure 5.17 show as the variation of efficiency versus flow rate. According to figure 4.14 the efficiency is maximum at flow rate of $0.172m^3/s$.

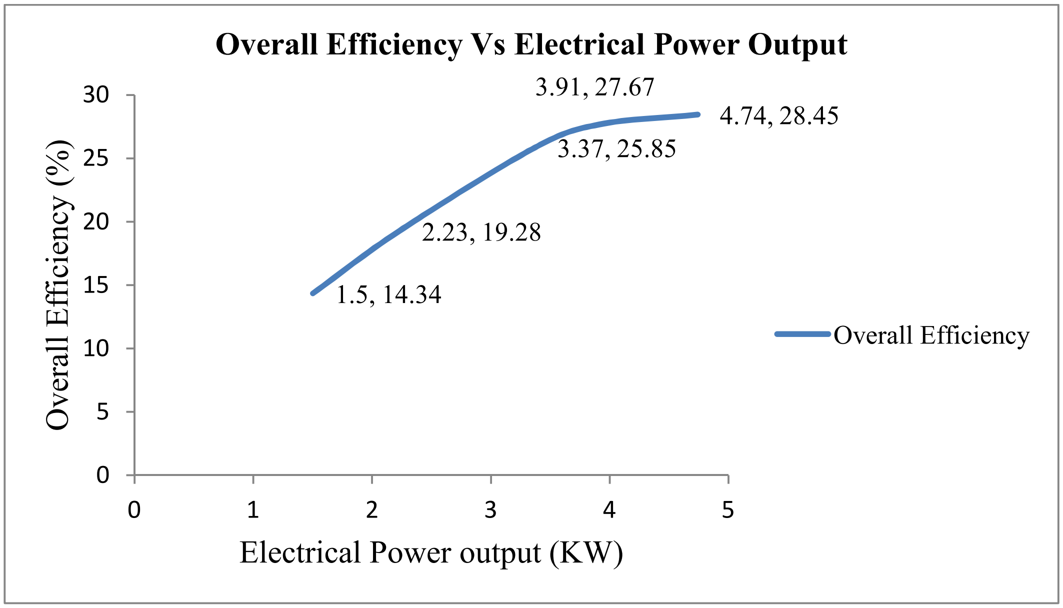


Fig.5. 3: Overall Efficiency Versus Electrical Power output

5.2 Results of Power Demand Assessment of the Village

The peak power demand of the village in the base year 2016 was 34KW and the peak power demand after projection is 39KW peak and with 5% daily noise and 5% hourly noise, the peak power demand is 47.92KW. As stated above the power supplied by the existing Walga MHP system is only 4.74KW. From these, it could be computed that the peak power demand gap is 43.26KWwhich is very high. Therefore, it is as good as having no power at the village.

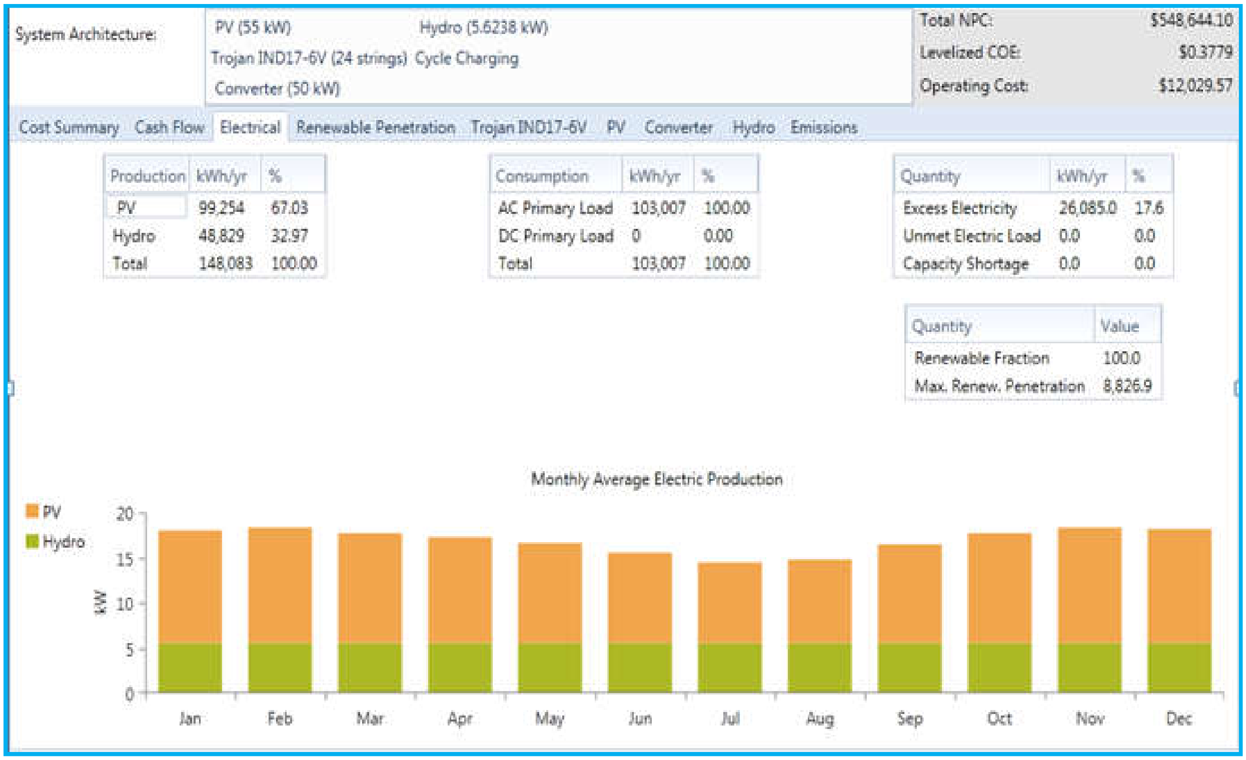
5.3 Results of the Two Options Considered to Meet the High Power Demand Gap

The first option is PV to be hybrid with the existing MHP system. And the second option if designing the new hydropower system. Each option was evaluated technically and economically.

5.3.1 Option I: Results

A. ELECTRICAL OUTPUT

The system architecture consists of 55KW PV cell, 24 battery strings, 5.62KW hydro, 50KW rating of converter and cycle charging dispatch strategy. The electrical energy production by PV array is 99,254KWh/yr and by the existing MHP is 48,829KWh/yr.



System Architecture: PV (55 kW) Hydro (5.6238 kW)
Trojan IND17-6V (24 strings) Cycle Charging
Converter (50 kW)

Total NPC: $548,644.10
Levelized COE: $0.3779
Operating Cost: $12,029.57

Production	kWh/yr	%
PV	99,254	67.03
Hydro	48,829	32.97
Total	148,083	100.00

Consumption	kWh/yr	%
AC Primary Load	103,007	100.00
DC Primary Load	0	0.00
Total	103,007	100.00

Quantity	kWh/yr	%
Excess Electricity	26,085.0	17.6
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	8,826.9

Fig.5. 4: Electrical Production by the hybrid system

The annual electrical production of the PV/micro hybrid system is 148,083kwh/yr. The total amount of electrical consumption (the total electrical energy that went to serve the system's AC electrical load) is 103,007KWh/yr. The amount of excess electricity (total amount of excess electricity occurred during the year) is 26,085/yr which can be expressed as a percentage of the total electrical production as 17.6%. There is no unmet electrical load (total amount of unmet load that went to not served because of insufficient generation during the year).There is also no electrical capacity shortage occurred during the year. Its fraction expressed as percentage of total electrical demand. The fraction of total renewable electrical production produced by the system is 100. And the maximum value of renewable penetration that occurs over the year is 8,826.9.

Technically, the designed hybrid system can meet the village peak demand without annual electrical energy capacity shortage and unmet load.

B. OPTION I: COSTS

Total Net Present Cost

Cost summary of option I is based on the components used. From Fig.5.4 above:

The system total NPC = $548,644.10 and

Levelized COE = 0.378$/KWh

System operating cost =$12,029.57

Refer table 4.4 for detail costs of the components.

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.

From Fig.5.5 below shows details of the Net Present cost of the hybrid system (option).From the Fig., highest costs of capital, replacement, O&M and salvage are resulted from the cost of battery used in the system. The higher cost of the system is the cost of PV followed by cost of the converter. The least cost of the components is cost for hydro.

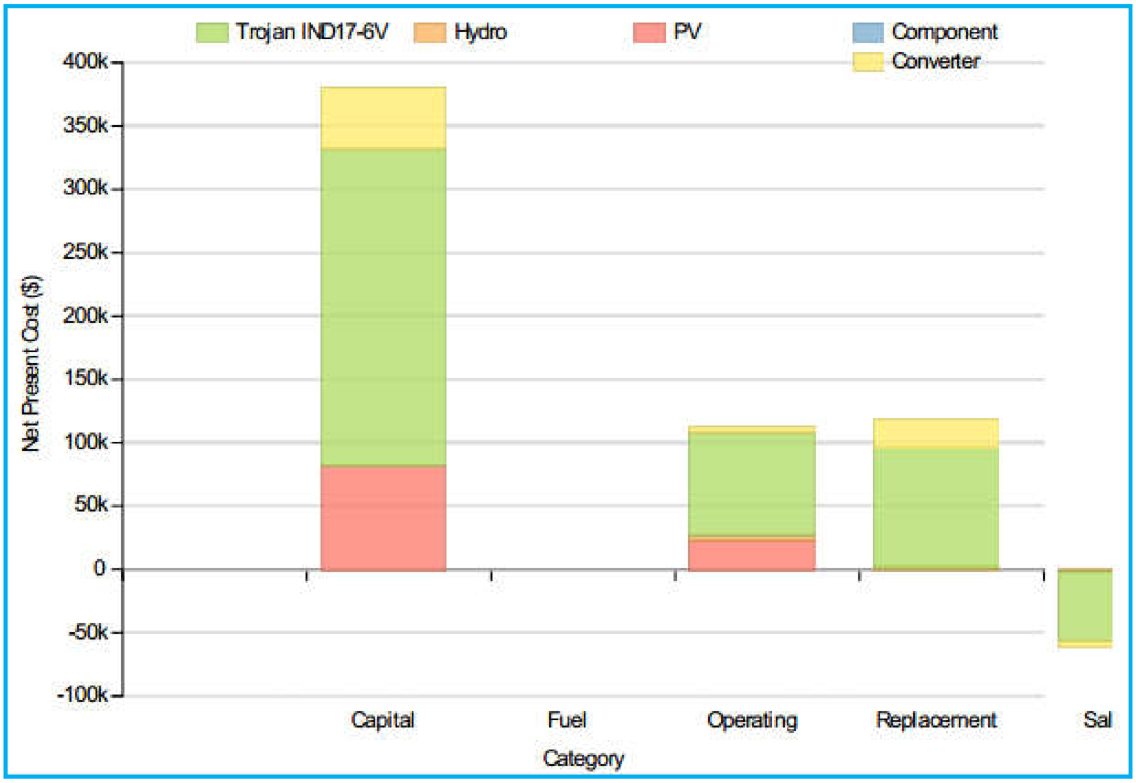


Fig.5. 5: Option I Net Present Cost by component type

Nominal cash Flow

The nominal cash flow of option I throughout 25 years is illustrated in Fig.5.6 below. From the Fig., we can see that, after 15 years, after 16years and after 20 years, replacements of components occur. And after 25 years, salvage cost of the components will be obtained.

Fig.5. 6: Nominal cash flow of the hybrid system by component type throughput 25 years

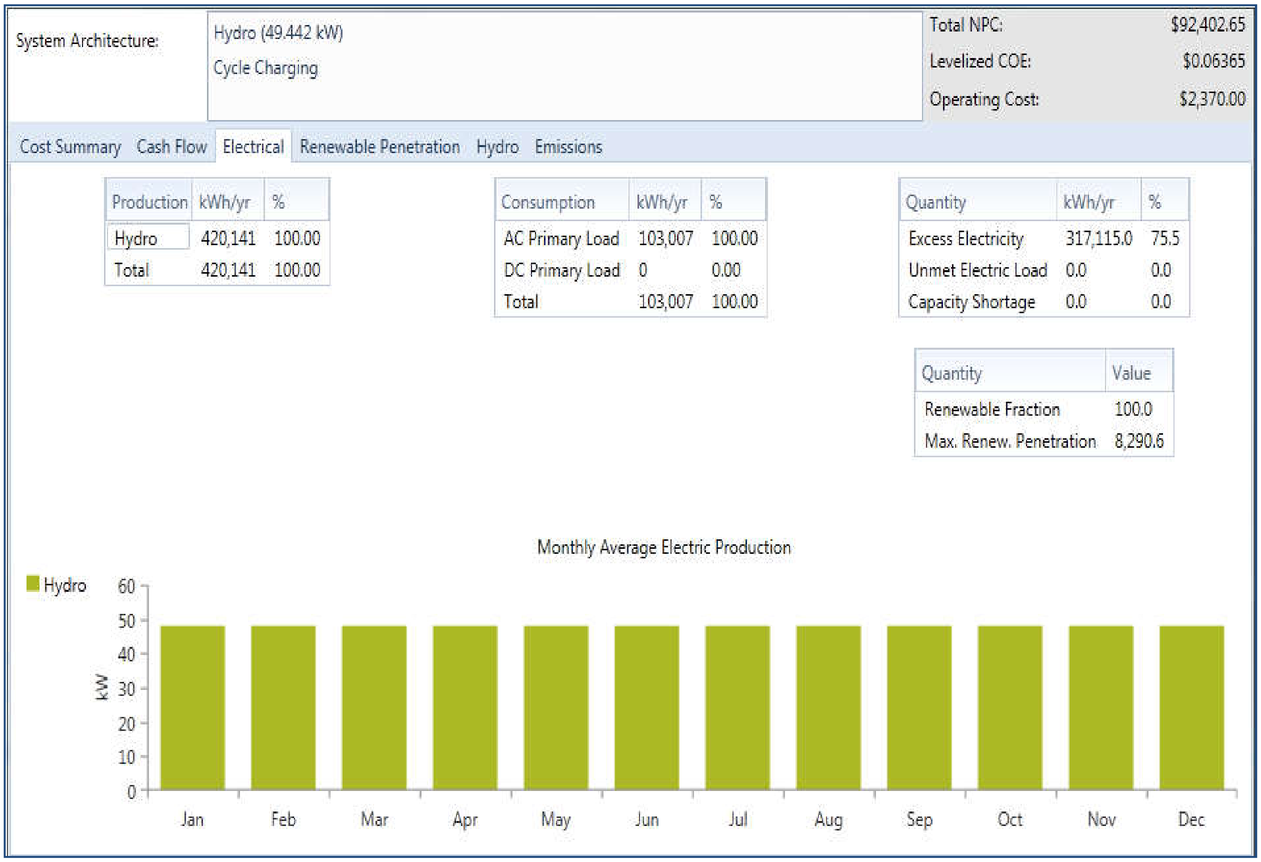
5.3.2 OPTION II: The 2nd MHP System Results

The results of the 2nd MHP system obtained from HOMER software simulation are the following.

A. ELECTRICAL OUTPUT

The system architecture of option I consists only micro hydro power generator of capacity 49.442KW and its dispatch strategy is cycle charging. The output results of the 2nd MHP system are described as follows.

The total annual electrical energy production by the system is 420,141kwh/yr. The total annual electrical energy consumption is 103,007 KWh/yr. The total excess electricity produced by the system is 317,115hwh/yr which is 75.5% of the annual total electrical energy production by the system. There are no unmet electrical load and electrical capacity shortage in the year. The fraction of total renewable electrical production produced by the system is 100. And the maximum value of renewable penetration that occurs over the year is 8,290.6.



System Architecture: Hydro (49.442 kW)
Cycle Charging

Total NPC: $92,402.65
Levelized COE: $0.06365
Operating Cost: $2,370.00

Production	kWh/yr	%
Hydro	420,141	100.00
Total	420,141	100.00

Consumption	kWh/yr	%
AC Primary Load	103,007	100.00
DC Primary Load	0	0.00
Total	103,007	100.00

Quantity	kWh/yr	%
Excess Electricity	317,115.0	75.5
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	8,290.6

Fig.5. 7: Electrical power production by the 2nd MHP system

B. COSTS

Total Net Present Cost

The total net present cost of the 2nd MHP system and the levelize cost of energy obtained from the simulation results $92,403 and $0.064/KWh respectively (Fig. 5.6 above)

The costs for this option are only capital cost and operating costs (table 4.9). There is no any components need replacement throughout the project lifetime.

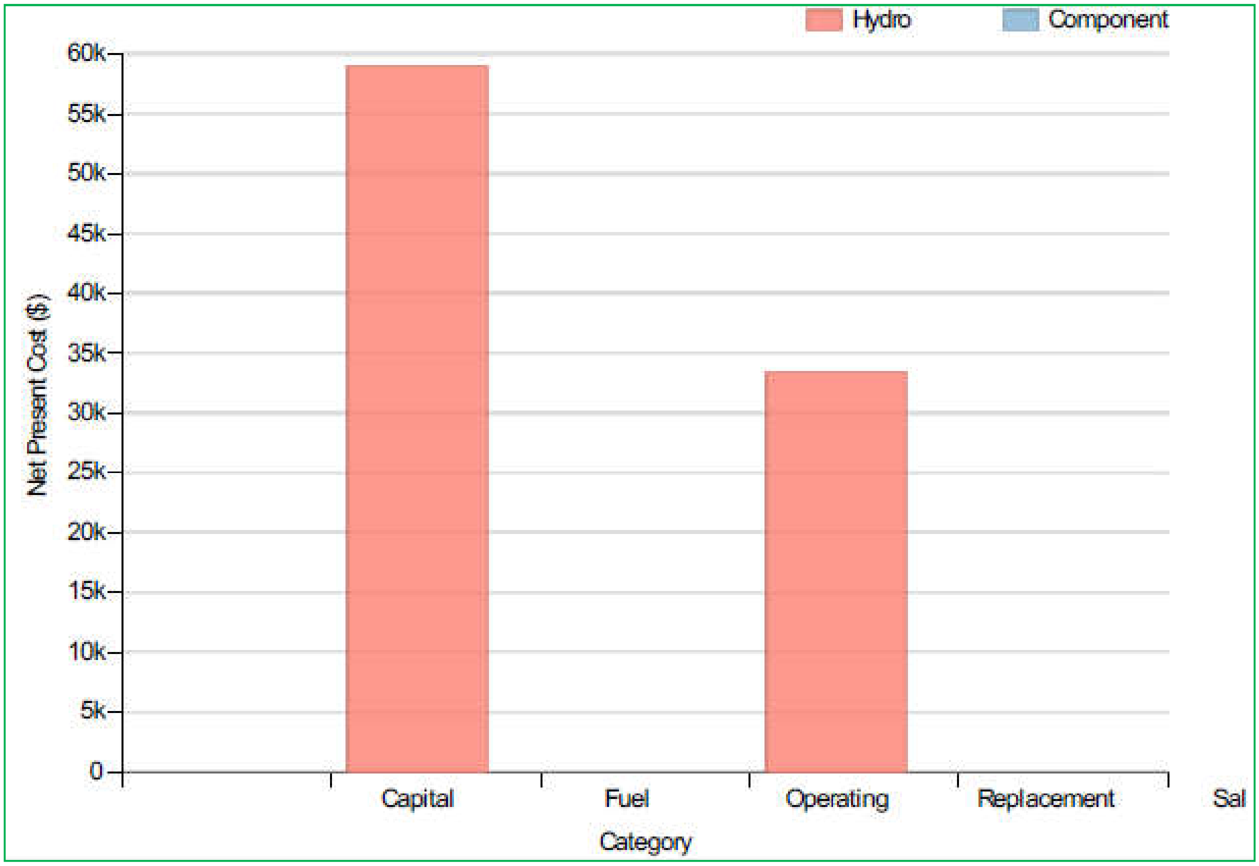


Fig.5. 8: Net Present Cost for the 2nd MHP system by component type

As show in fig above, the net present cost of 2nd MHP system are only capital cost and operating cost. Refer table

Nominal Cash Flow

The nominal cash flow of the 2nd MHP system throughout 25 years is illustrated in Fig.5.9 below. The nominal cash flow required is the capital cost and operation cost of the system.

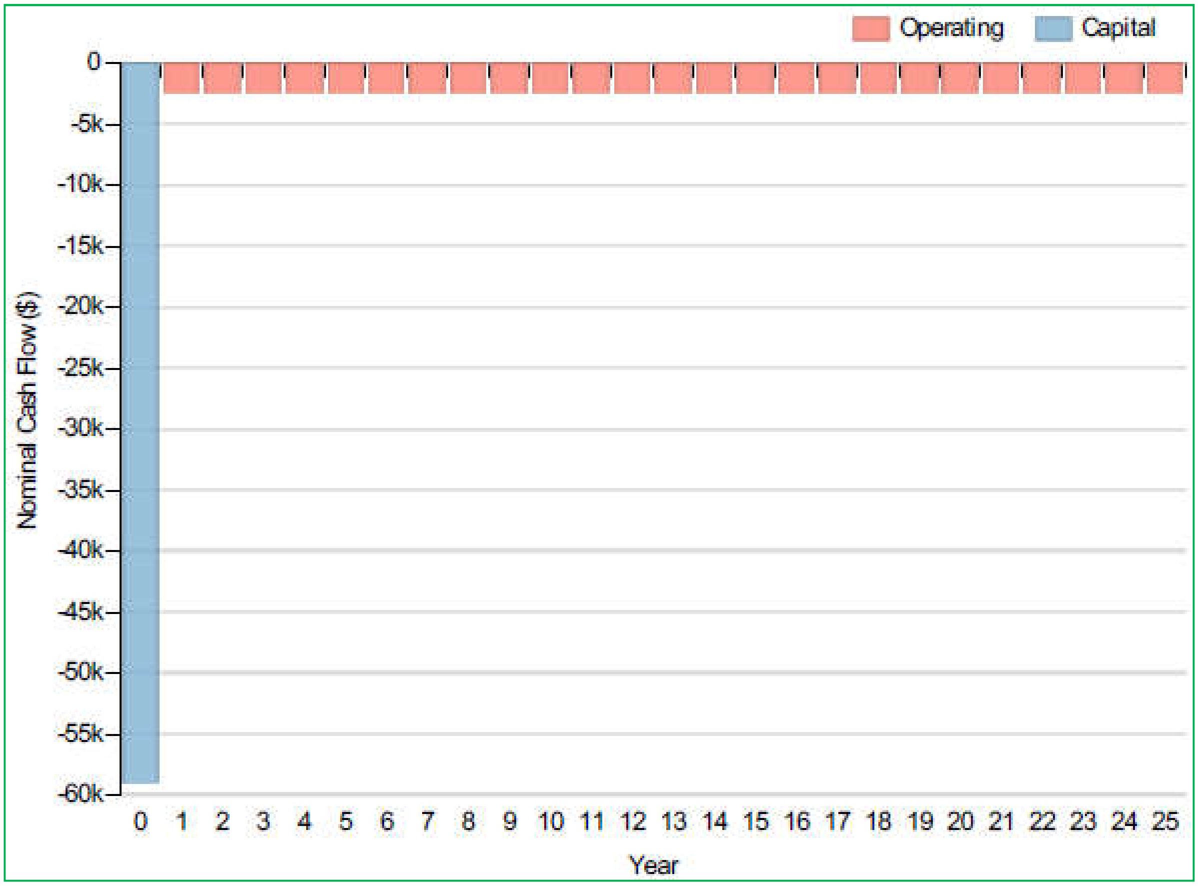


Fig.5. 9: Nominal cash flow for the 2nd MHP system by cost type

Summary and Conclusion

Table 5. 2 Option I and Option II Systems Architecture

Option	Component	Capacity	Dispatch Strategy
I	PV	55KW	CC
	Hydro	6KW	
	Battery	24 strings (192 Batteries)	
	Converter	50KK	
II	Hydro	49KW	CC

Table 5. 3 Option I and Option II Annual Electrical Energy

Option	Electricity Production (KWh/yr)	Electricity consumption (KWh/yr)	Excess Electricity (KWh/yr)	Capacity shortage (KWh/yr)	Unmet Load (KWh/yr)
I	14,8083	103007	26085	0	0
II	420,141	103007	317,115	0	0

Table 5. 4 Costs of Option I and Option II

OPTION	NPC ($)	COE ($/KWh)	Operating cost ($)	Initial capital ($)	O&M ($)
I	548,644	0.378	12,030	379,100	7,980
II	92,403	0.064	2,370	59,000	33,403

- From table 5.2, the system architecture of Option I cosmists of large number of batteries that has environmental constraint relative to Option II.
- From table 5.3, the two options can meet the demand without any annual capacity shortage and unmet load.
- From table 5.3, we can see that, Option I have much higher system NPC 126,188,122 Birr ($548,644) and 8.70 Birr (0.37$/kWh) levalized COE than option II with NPC of 125,268 Birr ($92,403) and 1.47Birr/kWh (0.064$/kWh) levelized COE to meet the energy demand gap of Walga village. (Currently $1=23Birr considered in this research).

Therefore, the gap can be met by option II.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this thesis work, the performance assessment and upgrading of Walga micro hydro power station were carried out. Based on the performance test assessment of the existing Walga MHPS, power demand assessment of the village and simulation results presented previously, the following conclusion can be drawn:

- Even though, the existing Walga MHPS contributes a lot on the life style of Walga community, the test results are not encouraging. The turbine is obtaining maximum efficiency of 33.33% with net head of 9.91m at 100% guide vane opening. The maximum electrical power output of the generator measured during the test was 4.74KW at maximum flow rate of 172L/s in the penstock.
- A survey of power demand assessment in the village was conducted during the field visit by means of interviewing a member of each household by the help questioner prepared for collecting all the required data and to know the actual power demand of the village. Walga village has a population of 1,220 inhabitants in base year 2016 with 257 households all dependent on agriculture as the economic activity. Based on the power requirements for each household and the public sectors assessed during the field survey, the total power demand of the village estimated as 34.00KW in the base year. The target year assumed as after five years from the base year, the population and power demand of the village projected and computed 1408 people and 39KW respectively. And again by considering random variability of 5%, the actual power demand for the village estimated as 48KW peak. Based on the results of assessments, it was observed that there is a high power demand gap between the supply side and the demand side in Walga village.
- The researcher proposed PV/hydro hybrid system to fill the energy gap of the village. However, while doing the research, the poor performance test results and high levelized COE from HOMER simulation, an idea came to the researcher’s mind to propose developing hydro resources available at Walga site as option II to fill the gap.

- The required data for option II were collected from field survey reassessment of the site and fed to HOMER software and results were obtained and compared with results of option I.
- Design, HOMER software simulations of the systems, performance and economic evaluations for the two options were done and finally the results are compared and better option, option II was chosen to fill power demand gap of Walga village. The selected option II characterized is with total NPC of $92,403, and levelized COE 0.064$/KWh.
- Finally, the existing Walga MHPS was upgraded by the 2nd MHP system.
- The existing MHP will be used for graining milling.

6.2 Recommendations

From the performance test results, it has shown that the performance of existing Walga Micro Hydropower Station is slightly below the international best practice standards, but offers an avenue for upgrading of Walga MHPS. However, the researcher would like to recommend the following points.

- As the performance test results indicates, the existing Walga MHP system needs a detail study and redesign of all the electromechanical and civil works components. Hence, the concerned body would take responsibility.
- From the field survey observation during this thesis work, the existing Walga MHPS lacks both electrical and mechanical controlling systems. This is a risk for the community has been benefited from the plant the plant too. Therefore, the concerned body should atomize the controlling system of the power station.
- Although, the selected option offered quality services, energy cost was high in comparison to the energy tariff of Ethiopia. And given that community of Walga village are further constrained by lower incomes, alternative funding mechanism should be facilitated by the government for the affordability.
- The tariff of energy is challenging in developing counties like Ethiopia. To solve this issue, Ethiopian Government will be advised to adjust the electricity costs in rural villages, the rural community cannot afford to use the energy produced due to high price per KWh.

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APPENDICES

APPENDIX A

Table A 1 Questioner for Households of Non-electrified and Electrified Villages at Walga Site to know the Energy Demand of a Household

Household Number	
Name of Respondent	
Sub Unit of Village	
Village	

Circle the final result of the visit to this household
1. Completed 2. No household member at home or no competent respondent at home at time of visit 3. Postponed 4. Refused 5. Other (specify)

Interviewer's Name	
Date	
Time interview began	
Time interview completed	

Data input by	

Final Check by	

FAMILY PROFILE

Table A 2 Number of family members (Only living together in the same house)

Adult			Children			Grand Total	
M	F	T	M	F	T	M	F
Total Family Member							

Table A 3 Number of School going Children

University Student			High School Student			Junior High School			Elementary School		
M	F	T	M	F	T	M	F	T	M	F	T

1. HOUSING

Table A 4 Number of Homes of a family with their respective number of rooms, room size, and type of roof used

House	Rooms	Area of Room(m^2)	Required Power (W)	Type of Roof used Tick (✔)		Affordability of HHD to Use TV-set	Affordability of HHD to Use Radio and Cassette Recorder	Distance from the Plant (km)
				GI Sheet Roof	Thatched Roof			
1	1							
	2							
	3							
	4							

APPENDIX B

Table B 1 PHONOSOLAR

General	
Model ID	PS330P-24/T
Manufacturer	Phono Solar

Electrical Characteristics	
Watts (STC), W	330
Maximum Power (Vmp)	37.3 V
Maximum Current (Imp)	8.87 A
Open Circuit Voltage (Voc)	46.8 V
Short Circuit Current (Isc)	9.10 A
Module Efficiency	17.01 %
Watts (PTC)	No
Power Tolerance	±3 %

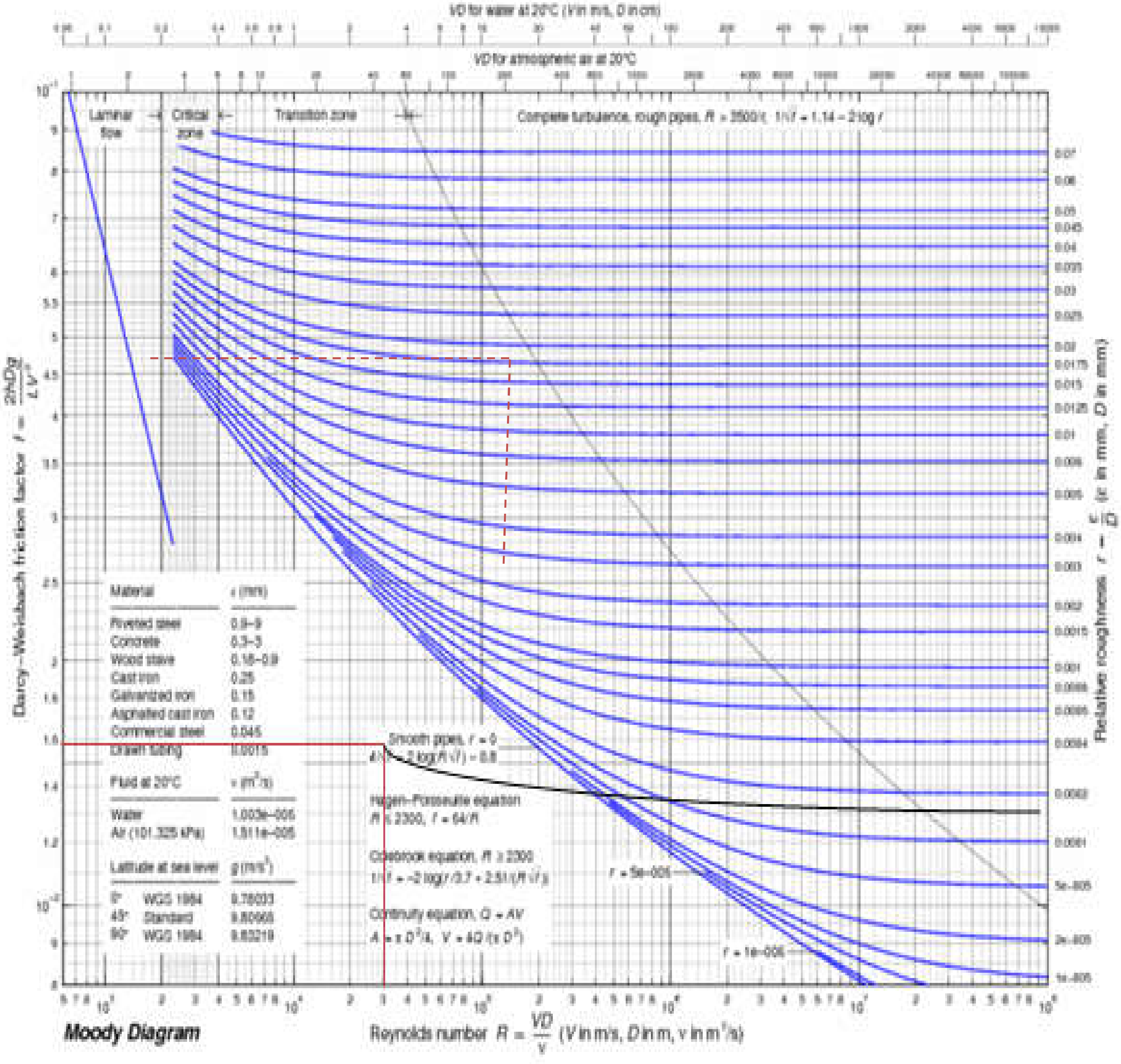
Mechanical Characteristics	
Cell Technology	Polycrystalline
Cell Size	156×156mm

Cells Qty	Standard 72 Cells, 6'
Weight (Kg)	26.0000
Dimension	1956x992x50 mm
Junction Box	IP 65
Output Cable	12 AWG
Module Color	Silver Frame
Moduel Connector	MC4 or Compatible

Operating Conditions	
Maximum System Voltage	1000 VDC
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	15 A
Max Snow Load	5400 Pa

APPENDIX C

THE MOODY DIAGRAM



Material	ε (mm)
Riveted steel	0.9–9
Concrete	0.3–3
Wood stave	0.18–0.9
Cast iron	0.26
Galvanized iron	0.15
Asphalted cast iron	0.12
Commercial steel	0.045
Drawn tubing	0.0015

Fluid at 20°C	ν (m²/s)
Water	1.003e–006
Air (101.325 kPa)	1.511e–005

Latitude at sea level		g (m/s²)
0°	WGS 1984	9.78033
45°	Standard	9.80665
90°	WGS 1984	9.83219

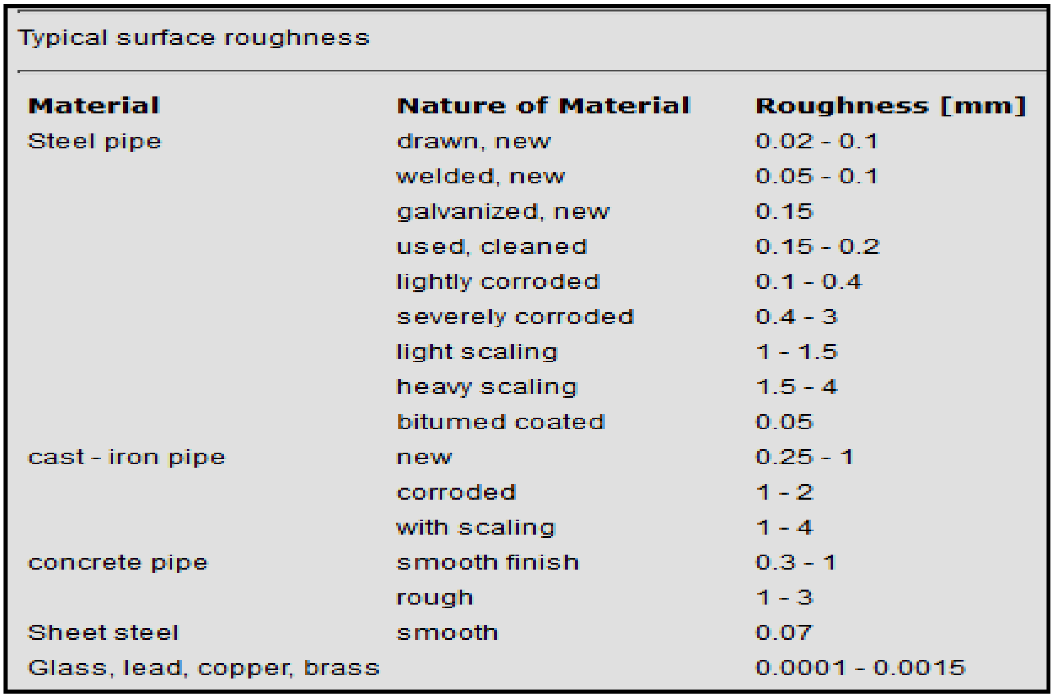
Hagen–Poiseuille equation
$R \le 2300,\ f = 64/R$

Colebrook equation, $R \ge 2300$
$1/\sqrt{f} = -2\log(r/3.7 + 2.51/(R\sqrt{f}))$

Continuity equation, $Q = AV$
$A = \pi D^2/4,\ V = 4Q/(\pi D^2)$

Fig. C 1 Moody Diagram

Table C 1Typical surface roughness



Typical surface roughness

Material	Nature of Material	Roughness [mm]
Steel pipe	drawn, new	0.02 - 0.1
	welded, new	0.05 - 0.1
	galvanized, new	0.15
	used, cleaned	0.15 - 0.2
	lightly corroded	0.1 - 0.4
	severely corroded	0.4 - 3
	light scaling	1 - 1.5
	heavy scaling	1.5 - 4
	bitumed coated	0.05
cast - iron pipe	new	0.25 - 1
	corroded	1 - 2
	with scaling	1 - 4
concrete pipe	smooth finish	0.3 - 1
	rough	1 - 3
Sheet steel	smooth	0.07
Glass, lead, copper, brass		0.0001 - 0.0015

Source: http://www.the-engineering-page.com/forms/dp/typ_eps.html

APPENDIX D

Table D 1 HOUSEHOLD ELECTRICAL LOADS AND THEIR POPULATION EACH

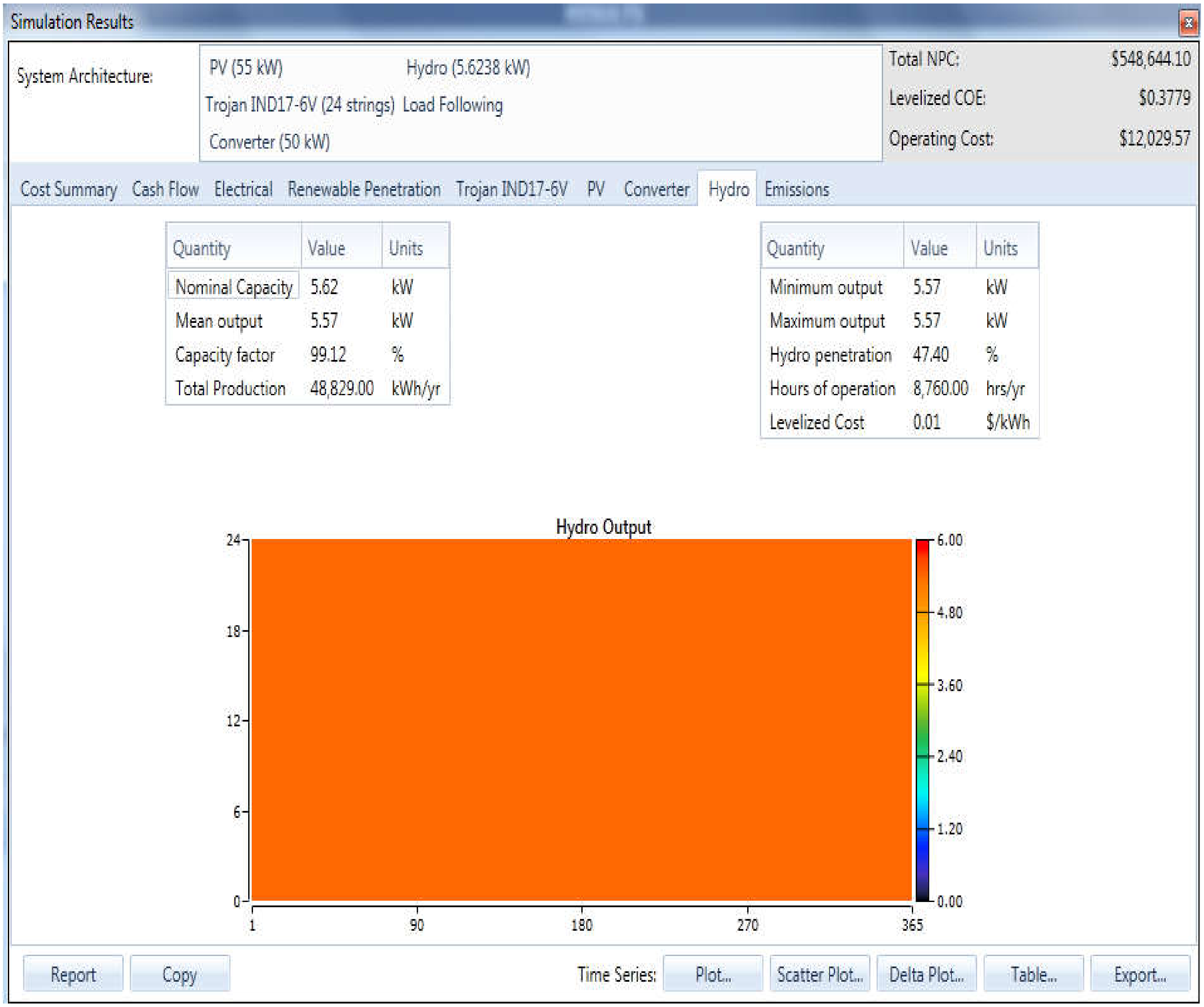
NO	NAME OF VILLAGE	NUMBER OF FAMILY/ VILLAGE	SEX		TOTAL POPULATION/ VILLAGE	APPLIANCES USED AND THEIR RATED POWER								TOTAL (KW)	TOTAL POWER/ VILLAGE (KW)
			M	F		11W (CFL)	15W(CFL)	TOTAL LIGHTING (KW)	COLOR TV 19" 80W	TOTAL (KW)	RADIO 30W	TOTAL (KW)	CHARGING 10W		
1	AFCHALA	17	37	36	73	24	30	0.714	8	0.64	17	0.51	17	0.17	2.034
2	ARBA TENNES	20	42	52	94	27	33	0.792	10	0.8	20	0.6	20	0.2	2.392
3	AREWA TULU	8	17	11	28	18	15	0.423	4	0.32	8	0.24	8	0.08	1.063
4	BILLO	27	76	68	144	47	49	1.252	13	1.04	27	0.81	27	0.27	3.372
5	GOJJE	27	77	67	144	19	59	1.094	13	1.04	27	0.81	27	0.27	3.214
6	JELISSA	40	86	90	176	59	56	1.489	18	1.44	40	1.2	40	0.4	4.529
7	KEL'A SHEBA	42	116	115	231	99	73	2.184	21	1.68	42	1.26	42	0.42	5.544
8	MENDELI	13	15	16	31	10	28	0.53	6	0.48	13	0.39	13	0.13	1.53
9	ODDO	6	17	15	32	4	10	0.194	3	0.24	6	0.18	6	0.06	0.674
10	TERAME	44	123	84	207	2	79	1.405	22	1.76	44	1.32	44	0.44	4.925
11	WALGA	13	29	31	60	20	22	0.55	6	0.48	13	0.39	13	0.13	1.55
	GRAND TOTAL	**257**	**635**	**585**	**1220**	**347**	**454**	**10.627**	**124**	**9.92**	**257**	**7.71**	**257**	**2.57**	**30.827**

Table D 2 ELECTRICAL LOADS FOR PUBLIC SECTORS IN BASE YEAR 2016

NO	NAME OF PUBLIC SERVICES	INDOOR LIGHT		OUTDOOR LIGHT		Megaphone		Desk top computer		Ink-jet Printer		Photocopy Machine		Sub Total
		25W (CFL) QNT	TOTAL	25W(CFL) QNT	Total	15w QNT	Total	100w QNT	Total	50w QNT	Total	100w QNT	Total	
1	SCHOOL	20	500	4	100	2	30	2	200	1	50	1	100	980
2	ORTHODOX	10	250	4	100	4	60							410
3	PROTISTENT	12	300	4	100	4	60							460
4	STREET LIGHT	50	1250		0									1250
5	POWER PLANT	2	50	4	100									150
Grand total		**94**		**16**		**10**	**150**	**2**	**200**	**1**	**50**	**1**	**100**	**3250**

APPENDIX E

HOMER Pro SIMULATION RESULTS OF OPTION I



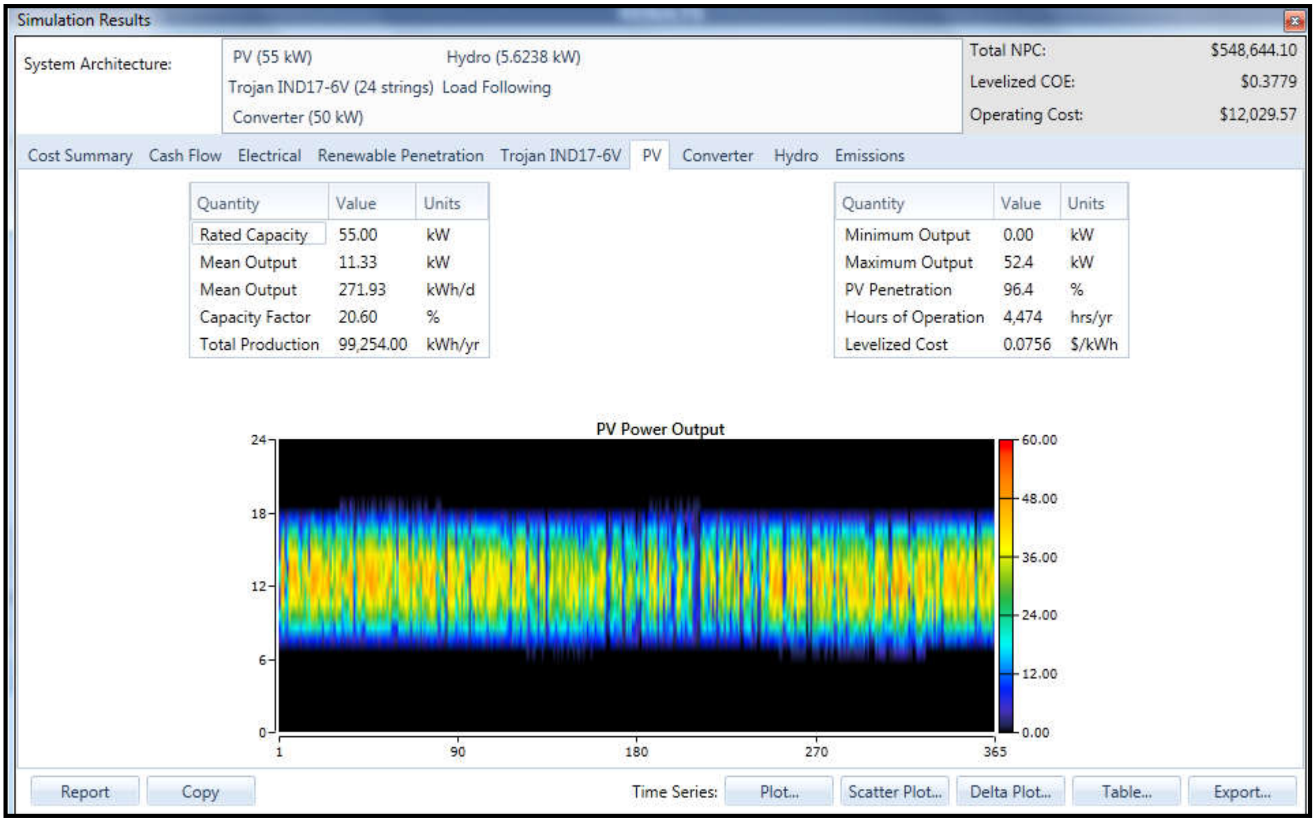
System Architecture:
PV (55 kW)
Hydro (5.6238 kW)
Trojan IND17-6V (24 strings)
Load Following
Converter (50 kW)

Total NPC: $548,644.10
Levelized COE: $0.3779
Operating Cost: $12,029.57

Quantity	Value	Units
Nominal Capacity	5.62	kW
Mean output	5.57	kW
Capacity factor	99.12	%
Total Production	48,829.00	kWh/yr

Quantity	Value	Units
Minimum output	5.57	kW
Maximum output	5.57	kW
Hydro penetration	47.40	%
Hours of operation	8,760.00	hrs/yr
Levelized Cost	0.01	$/kWh

Fig.E 1 Existing Walga MHP Output



Simulation Results

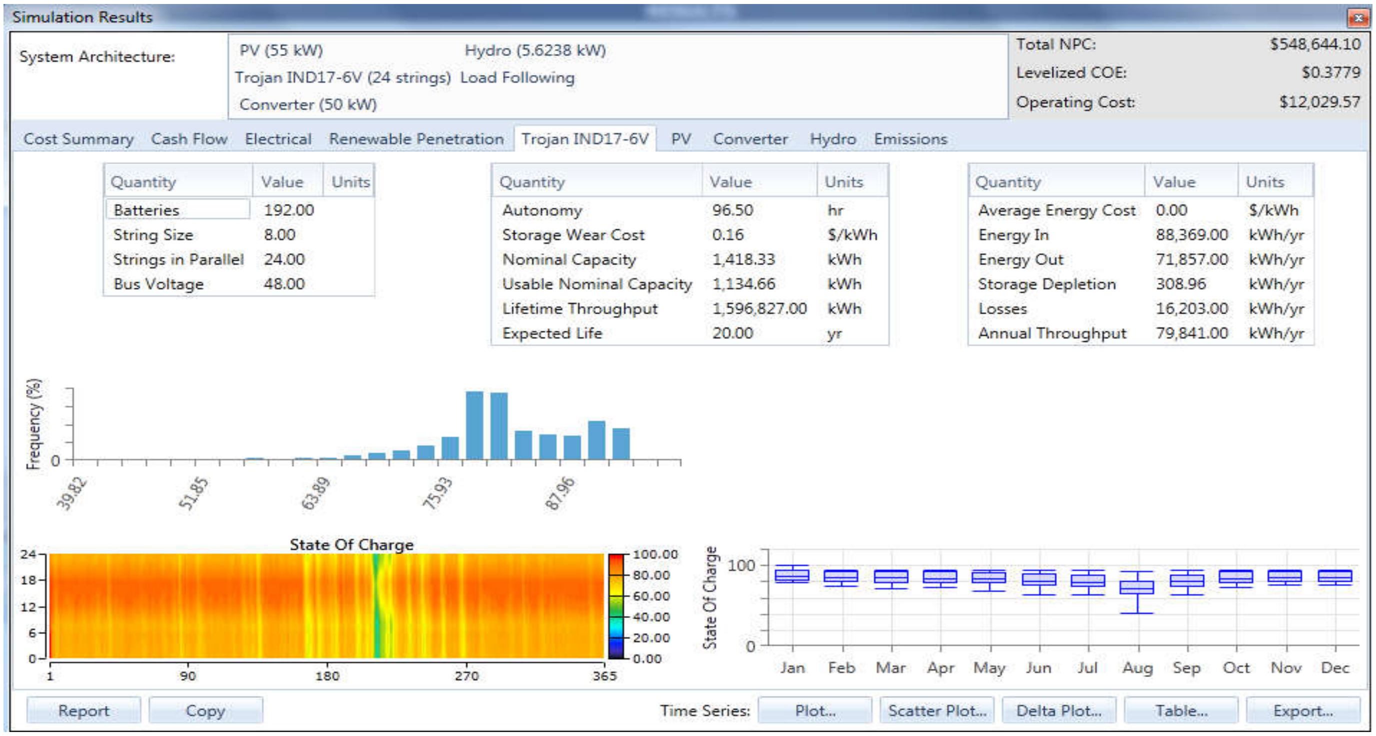
System Architecture: PV (55 kW) Hydro (5.6238 kW) Trojan IND17-6V (24 strings) Load Following Converter (50 kW)

Total NPC: $548,644.10
Levelized COE: $0.3779
Operating Cost: $12,029.57

Quantity	Value	Units
Rated Capacity	55.00	kW
Mean Output	11.33	kW
Mean Output	271.93	kWh/d
Capacity Factor	20.60	%
Total Production	99,254.00	kWh/yr

Quantity	Value	Units
Minimum Output	0.00	kW
Maximum Output	52.4	kW
PV Penetration	96.4	%
Hours of Operation	4,474	hrs/yr
Levelized Cost	0.0756	$/kWh

Fig. E 2 Option I PV Outputs



Simulation Results

System Architecture: PV (55 kW) Hydro (5.6238 kW) Trojan IND17-6V (24 strings) Load Following Converter (50 kW)

Total NPC: $548,644.10
Levelized COE: $0.3779
Operating Cost: $12,029.57

Quantity	Value	Units
Batteries	192.00	
String Size	8.00	
Strings in Parallel	24.00	
Bus Voltage	48.00	

Quantity	Value	Units
Autonomy	96.50	hr
Storage Wear Cost	0.16	$/kWh
Nominal Capacity	1,418.33	kWh
Usable Nominal Capacity	1,134.66	kWh
Lifetime Throughput	1,596,827.00	kWh
Expected Life	20.00	yr

Quantity	Value	Units
Average Energy Cost	0.00	$/kWh
Energy In	88,369.00	kWh/yr
Energy Out	71,857.00	kWh/yr
Storage Depletion	308.96	kWh/yr
Losses	16,203.00	kWh/yr
Annual Throughput	79,841.00	kWh/yr

Fig. E 3 Battery Output