JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

FEASIBILITY STUDY AND DESIGN OF MICROHYDRO POWER PLANT

(CASE STUDY ON MERIBO RIVER, SOUTH EASTERN OROMIA REGION, ETHIOPIA)

M.Sc. Thesis

By

ABERA ESHETU

The thesis Submitted To Faculty of Electrical and Computer Engineering, Jimma University; in Partial Fulfillment for the Requirement for Masters of Degree in Electrical Power Engineering.

January, 2019

Jimma Ethiopia

JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

FEASIBILITY STUDY AND DESIGN OF MICROHYDRO POWER PLANT

(CASE STUDY ON MERIBO RIVER, SOUTH EASTERN OROMIA REGION, ETHIOPIA)

M.Sc. Thesis

By

ABERA ESHETU

Main Advisor: Dr. Kemal Ibrahim, PhD

Co-Advisor: Getnet Zewde

January, 2019

Jimma Ethiopia

DECLARATION

This thesis is my original work and has not been done for a degree in any other university.

RESEARCH SUBMITTED BY

ABERA ESHETU ________ __________

SIGNATURE DATE

APPROVED BY ADVISORS:

ADVISOR: Kemal Ibrahim (PhD) ________ Oct 05/2018

SIGNATURE DATE

CO-ADVISOR: ____________________ ________ __________

SIGNATURE DATE

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

FEASIBILITY STUDY AND DESIGN OF MICROHYDRO POWER PLANT

(CASE STUDY ON MERIBO RIVER, SOUTH EASTERN OROMIA REGION, ETHIOPIA)

M.Sc. Thesis

By

ABERA ESHETU

APPROVED BY EXAMINERS

Tafesse Asrat (PhD) ------------------------------------ ------------------------------------

EXTERNAL EXAMINER **SIGNATURE**

-- ------------------------

INTERNAL EXAMINER **SIGNATURE**

-- --------------------------

CHAIRMAN OF EXAMINE COMMITTEE **SIGNATURE**

Abstract

Ethiopia has a huge renewable energy (micro-hydropower, solar PV and wind energy) potential that has not been used for rural electrification. The Ejersachumlugo village which has Ejersa and Chumlugo parts found at south east Ethiopia far 343km from Addis Ababa and not electrified. The specific studies area is Chumlugo part which far from the grid 15.6km on Meribo River. In this thesis, assessment of micro hydropower (MHP) potential of "Meribo River has been done. Some of the data needed has been gathered from Ministry of Water Irrigation and Energy of Ethiopia (MoWIE), central statistical Agency of Ethiopia and the rest is collected, measured from field work. Some part of the Local load estimation for the village has been done with lighting, cocking, radio and TV loads considered as home loads, clinic ,mosque and school lighting considered as general community loads. MATLAB software used for Modeling and simulating the general system of the village. The calculated result shows that the generated electricity is more enough to supply the local loads considered with the generated energy of 9.37kW.

Key words: Micro hydropower, MATLAB, Renewable energy, Small scale power generation, rural electrification.

Acknowledgement

First of all thanks to almighty God, next I would like to thanks my advisor, Dr. Kemal Ibrahim, PhD from School of Electrical Engineering and Computing Addis Ababa Science & Technology University (AASTU) and Co-advisor Mr. Getnet Zewde from Jimma Institute of Technology University faculty of electrical and computer engineering for they have done their best to help me.

Table of Contents

Abstract I

Acknowledgement II

List of Figure VII

List of Table IX

List of Abbreviations and Symbols X

CHAPTER 1 1

INTRODUCTION 1

1.1 Background 1

1.2 Statement of the problem 3

1.3 Objective of the study 4

1.3.1 General objective: 4

1.3.2 The Specific Objectives are: 4

1.4 Significance of the research 4

1.5 Scope and limitations of the study 4

1.6 Methodology and Materials 5

1.7Organization of the Thesis 6

CHAPTER 2 8

LITERATURE REVIEW AND THEORY 8

2.1 Basic Theory 8

2.1.1 Basic concept of Hydropower 8
2.1.4 Classification of micro-hydropower by facility type 10
2.1.5 Components of Diversion & canal micro-hydropower plants 13
2.7 Electrical and Mechanical Equipment for Micro-Hydro Power Generation 18
2.7.1 Types of Turbines used in Micro Hydro Power Generation 18
2.7.2 Types of Generator used in Micro Hydropower Generation 21
2.8 Rural Electrification in Ethiopia 21
2.9 Advantage and Disadvantage of MHP 22
CHAPTER 3 24
SITE DESCRIPTION AND SYSTEM ANALYSIS 24
3.1 Site Mapping 24
3.2 General Description about Meribo River 25
3.3 Load Estimation. 26
CHAPTER 4 29
POWER GENERATION SYSTEM DESIGN AND MODELING 29
4.1 Micro Hydro Power Generation 29
4.1.1 Proposed Scheme Layout of Micro Hydro Power Generation 29
4.1.2 Turbine Selection 30
4.1.3 Sizing of Cross Flow Turbine 30
4.1.4 Turbine Efficiency 32

4.1.5 Sizing of Penstock 32

4.2 Power available from Meribo River 34

4.3 Hydro Turbine Governor 36

4.3.1 Mathematical Model of Hydro Turbine Governor System 37

4.4 Modeling of Controller 39

4.5Modelling of Electro Hydro Servo System 41

4.6Modeling of Hydraulic Turbine 43

4.7 MATLAB/Simulink Model of Hydro Turbine Governor 46

4.8 Synchronous Generator Models 47

4.8.1 Model of Mechanical System 48

4.8.2 Model of Electrical System 49

4.9. MATLAB/Simulink Model of Micro Hydro Power Plant 50

4.10Simulation Results of Micro Hydro Power Plant Model 51

CHAPTER 5 55

COST ANALYSIS 55

5.1 Cost Evaluation of Micro-Hydro Power Generation 55

5.1.1 Cost Calculation of Penstock 55

5.1.2 Turbine (Cross Flow) Cost 55

5.1.3 Cost Generator 55

5.1.4 Civil Work cost 56

5.1.5 Transmission Line cost 56

5.1.6 Installation Cost 58

5.2 Financial Evaluation 59

5.2.1Micro Hydro Power Generation capital cost 60

CHAPTER 6 61

CONCLUSION AND RECOMMENDATION 61

6.1 Conclusion 61

6.2 Recommendation 61

REFERENCES 63

APPENDIX-A: - Annual report of daily flow rate data of Meribo River 66

APPENDIX-B: - Population Data 69

List of Figure

Figure 1.1 Meribo River 2

Figure 2.1 Example of a diversion hydropower plant No dam was required [7] 11

Figure 2.2 RoR hydro plant [1] 12

Figure 2.3 Storage hydropower 13

Figure 2.4 Cross flow turbine [11] 19

Figure. 2.5 Francis turbine [11] 20

Figure 3.1 Map of Study Area 24

Figure 4.1 Proposed schematic diagram of micro hydroelectric power plant 29

Figure 4. 2 Typical system efficiency of micro- hydro power generation 35

Figure 4.3 Functional Block Diagram of a Hydraulic Power Plant.. 37

Figure 4.4 Simulink Model of a Controller 41

Figure 4.5 Model of Hydro-Electric Servo System 42

Figure 4.6 MATLAB/Simulink Model of Hydro Turbine 46

Figure 4.7 Block Model of Hydro Turbine Governor 47

Figure 4.8 Schematic picture of a synchronous machine with salient poles is shown. 49

Figure 4.9 Block Diagram of Synchronous Machine 50

Figure 4.10 MATLAB/Simulink Model of a Hydro Power Plant 51

Figure 4.11 Synchronous Generator Speed Characteristics 51

Figure 4.12 Stator Three Phase Current Characteristics for 0.02sec at Steady State 52

Figure 4.13 Active Power Characteristics of Hydro Power Plant 53

Figure 4.14 Reactive Power Characteristics of Hydro Power Plant... 54

Figure 4.15 Phase Voltage Characteristics of Stator 54

List of Table

Table 2.1 Classification of hydro power plants based on their size 9

Table 2.2 Turbine classification 18

Table 3.1 Annual Average flow rate Report of Meribo River since 2009 25

Table 3.2 Annual Average flow rate of Meribo River since 2007 to 2009.............................. 25

Table 3.3 House hold daily energy demand:- 26

Table 3.4Daily energy demand for school and clinic 26

Table 4.1Classification of micro hydro turbines according to head, flow rate and power output [5] 30

Table 4.2. Typical values of inertia, H for different types of synchronous machines [21]...... 49

Table 4.3. Typical values of reactance's for synchronous machines [21] 50

Table 5.1 Total cost estimation for the micro hydro power generation.................................. 58

Table A-1 Daily flow rate of Meribo River.. 66

Table B-1 Population data from Statistical agency of Ethiopia 69

List of Abbreviations and Symbols

A	Cross sectional area
A_t	Gain of turbine
AC	Alternating current
CSA	Central Statistics Agency
CO_2	Carbon dioxide
DC	Direct current
D	Damper winding
d_p	Diameter of penstock
D_{runner}	Diameter of runner/blade
EEA	Ethiopian Energy Agency
EEP	Ethiopian Electric Power
EMA	Ethiopian mapping agency
ENMSA	Ethiopian National Metrological service Agency
FRE	Fiber Reinforced Epoxy
G	Gravitational force
G	Gate opening
GW	Giga Watt
GWh	Giga Watt-hour
H	Inertia constant
H_{eff}	Effective load of water column
HDPE	High density polyethylene
H_g	Gross head of water column
H_l	Conduit head loss
H_{net}	Net head
HPP	Hydropower plant
HV	High Voltage
ICS	Interconnected System
IMAG	Induction motor as generator
K_a	Servo motor gain constant
K_d	Derivative constant

Kg/m^3	Kilogram per meter cube
K_i:	Integral constant
K_p	Proportional constant
Km	Kilometer
K_u	Water proportional constant
kV	Kilovolt
kW	Kilowatt
KWh	Kilowatt hour
L	Length of conduit section
L_p	Length of penstock
L_{runner}	Length of runner/blade
L_t	Length of transmission line
MHP	Micro Hydropower
M	Meter
Mm	Millimeter
m/s^2	Meter per second square
m^3/s	Meter cube per second
MoWIE	Ministry of Water Irrigation and Energy of Ethiopia
MW	Mega Watt
N_t	Mechanical rotational speed of turbine
P	Power
PID	Proportional Integral Derivative
PJ	Pico joule
P_m	Mechanical power
PVC	PolyVinyl Chloride
Q	Flowrate of river
Q_d	Design flowrate
Q_{nL}	No load flowrate
Q_p	Peak flowrate
Q_r	Peak flowrate
Q	Per-unit turbines flow
R	Radius of pipe
REF	Rural Electrification fund

RoR	Run off river
rpm	Revolution per minute
SHP	Small Hydropower
sq.km	Square kilometer
t_a	Servo motor time constant
t_{jet}	Thickness of water jet
TWh	Tera watt hour
T_{wr}	Water starting time
U	Velocity of water
uPVC	Unplastified polyvinyl chloride
V	Voltage
V_f	Field voltage
W	Watt
Wh	Watthour
η	Efficiency
τ_m	Mechanical torque
$\boldsymbol{\rho}$	Number of pole
ω_e	Electrical frequency of the system
ω_s	Mechanical angular velocity of rotor
X_d	reactance's in d-axis
X_q	reactance's in q-axis

CHAPTER 1

INTRODUCTION

1.1 Background

The socio-economic development and increased living standards with the fast growing industry has led to a major increase in electricity demand and generation. Being the basic input of all kinds of economic activity, electrical energy has become an indispensable component of social life. As a result of rapid increase in energy consumption and global warming threatening the environment together with the unbalanced and unpredictable increases of the fossil fuel prices has increased the importance of renewable energy sources such as micro hydropower. In this respect, small hydropower (micro hydropower) has emerged as an energy source which is accepted as renewable, easily developed, inexpensive and harmless to the environment. These features have increased small hydropower development in value giving rise to a new trend in renewable energy generation [9].

According to the report from the Ethiopian electric power corporation (EEP) the electric energy converge in Ethiopia is around 47%. From the energy that is distributed to the customers 86% is generated from hydropower plant [6]. EEP has planned to increase the generating capacity of the country to fill the gap between the energy demand and the existing generation capacity. Hence, due attention should be given to development and diversification of the power system with renewable energy sources which are cost effective in reaching the remote areas. From the diversified renewable energy sources solar, micro hydropower and biomass energies are abundantly found in Ethiopia. The research is focus on a micro hydropower.

The selected off-grid remote rural village for this thesis is Chumlugo village. It is a small village found in Adaba woreda in Ejersachumlugo kebele. Adaba is one of the woredas in the Oromia Region of Ethiopia; it shares the name of its administrative center, Adaba. Part of the West Arsi Zone, Adaba is bordered on the southwest by Nensebo, on the west by Dodola, on the northwest by the Shebelle River which separates it from the Gedeb Asasa, and on the east and south by Bale Zone and it found on 345km far from Addis Ababa located at 07°0' 15.06"N and 39°23'26.67" E and has an average elevation of 2418 meters.

Most rivers at Adaba woreda are tributaries of the Shebelle River and include the Meribo, Leliso, Furuna, Ashiro and Mancha Kara. All of these rivers flow through the year and Shebelle river is tribute in MelkaWakena which is located close to Bale Mountains [3].Meribo River (Figure 1.1) starts at Kaka intermittent river in Adaba sub catchment and also Aligebero intermittent river in Dodola sub catchment and then stretch to the downstream in Adaba sub catchment to join Major River after a number of rivers join it, including both Furuna and Lelliso rivers. The area covered by Meribo Adaba gauging station is 185 sq.km. The geographic location of this station is 7:0:0N and 39:20:0E. The record of the station used for this study has recorded since2009 G.C. [see appendix A]

Figure 1.1Meribo River

According to the A survey by the Central Statistics Agency (CSA) projection for the year 2016, the total number of population in Adaba is 167,599. Out of this 16,949(10.11%) lives in urban Area and 150,650 (89.89%) lives in rural Area [see Appendix B].The Rural area population is characterized by scattered settlement pattern which not challenge to select load center position, & far away from the main grid, which leads for high expense of transmission line, this makes difficult for the inter connected system to electrify this rural villages [5]. A survey of the land in this woreda shows that 16.9% is arable or cultivable, 23.3% pasture, 52.2% forest, and the remaining 7.6% is considered swampy, mountainous or otherwise unusable [22].

The woreda have 24 villages; of these villages Ejersachumlugo is one and has two part Ejersa and Chumlugo. The Chumlugo part of the village which is specific studies area located at 06°52' 58.13"N and 39°23'26.07" E and has an average elevation of 2936 meters. The village far from main grid 15.6km and extending the national grid to this area is very costly because of the high cost of transmission line.

But electrification of the rural communities is very essential especially to ensure the socio economic development of the community and hence of the country. It is known that the development of any country depends upon availability of electrical energy and it's per capital energy consumption, which is regarded as an index of national standard of living in the present civilization. Therefore, energy is considered as the basic input for any country for keeping the wheels of its economy moving.

1.2 Statement of the problem

Most of Ethiopian people lives in rural areas where renewable energy access is almost negligible, <5% [5]. A possible reason is that these areas are either farther away from the national grid or the people living rural are sparsely populated. Extending the national grid to these areas is difficulty to the economic capacity of the country because of the high cost of transmission line. But electrification of the rural communities is very essential especially to ensure the socio economic development of the community.

As the population increases faster, the energy demand will also increase faster. In the selected site, almost all house-holds are using kerosene and biomass combustion as their energy supply. According to a 25-year master plan, EEP focused on the development of small, medium and large hydropower plant even though the country has substantial rivers and streams suitable for small scale hydropower development [9, 19]. In Ejersachumlugo village there are perennial rivers combined with good topography, which makes micro hydropower suitable near this village. Having these facts in mind the potential for micro hydropower for this region on Meribo River has been assessed.

1.3 Objective of the study

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

1.3.1 General objective:

- To study feasibility and design of micro hydropower plant at Adaba Woreda Chumlugo village on Meribo River.

1.3.2 The Specific Objectives are:

- To assess potential of micro-hydro power on Meribo River
- To assess the energy consumption of the community around the site.
- To design a micro hydropower system
- To model a micro hydropower system using MATLAB software.

1.4 Significance of the research

Use of renewable energy sources in a distributed generation system is the current focus of expertise who is working in energy area. The research will assess the micro hydro power energy potential available in the area and this potential will used to generate the electrical energy for households. The study which is going to take place in this rural area, Chumlugo will benefit the community by

- Providing renewable energy source that is available through a year.
- Providing clean energy source.
- Minimize the deforestation rate, soil erosion and the environmental pollution.

1.5 Scope and limitations of the study

The study will explore the micro hydropower potential in the area depending on the data which is found from Ministry of water Irrigation and Energy and Central Statistical Agency of Ethiopia. Thirty years of historical stream flow data is generally considered to be the necessary to assure statistical reliability in the study of hydropower. The research might be limited to the software modeling and simulation. There is no open to transportation service from Adaba town to Chumlugo village. This research doesn't include ~~civil cost and~~ the practical implementation.

1.6 Methodology and Materials

The methodology followed in the study consists of site identifications, data collection and survey, data analysis, feasibility study and design.

Site identification

The village, which is the study area located at 06°52' 58.13"N and 39°23'26.07" E and has an average elevation of 2936 meters with 15.6km from the main grid. The area covered by Meribo Adaba gauging station is 185 sq.km. The geographic location of this station is 7:0:0N and 39:20:0E.

Data Collection

Relevant data is collected from three main sources. The first is from organizations and agencies like Central Statistical Agency and Ministry of water irrigation and Energy recorded population data and flow rate data of the river respectively. The second source is the site itself. Geographical layout, population distribution, surrounding environment in relation to the system design, primary loads of the village and geological characteristics are collected by visiting the sites and questioning number of household at the kebele. The third one is from different websites, especially related to cost of turbines, generator and other micro hydropower component.

Computer programs intended for modeling hydro mechanical equipment (for instance, turbines), such as Computational Fluid Dynamics, geotechnical and other relevant hydropower engineering and project cost issues including detailed design studies, are considered beyond the scope of this thesis and are not discussed.

Data Analysis and Feasibility Study

The head of the **stream** has measured directly from the site by using meter (pole and level technique for measuring head) and to identify the appropriate position for system installation of the sites [for power house, high head point (Fore bay) and others positions through Meribo River during data collection and analyzing respectively. After measuring the head and take stream flow rate, the power output of the hydropower system can be obtained analytically by equation (1.1):

$$P = \eta\ g\ Q\ H_{eff} \tag{1.1}$$

Where: P -power output [kW],

η -system efficiency [%],

Q-stream flow $\left[\frac{m^3}{s}\right]$ and

H_{eff} -effective head water column[m] [4]

An overall modeling of the micro hydropower system is carried out using MATLAB Simulink.

1. **Materials used in this study**

- Google Earth and Arch GIS: for site (study area) location indication.
- Software: MATLAB for the system design and MS Excel for pre- and post-processing
- Digital Camera: important photos related to the study have taken and documented.
- Meter on measuring head and length of different position.

1.7Organization of the Thesis

The thesis work start with an introductory back ground followed by basic theory of hydro power systems, their potentials and about the energy demand of the village. The introduction part discusses, statement of the problem, objectives and related works to this thesis has presented at chapter one. Chapter two reviews literatures about potential of renewable energy in Ethiopia and technique of renewable energy technology Small scale hydropower. Chapter three presents locations of the selected villages, specific location of micro hydro power generation site, and location of data collection stations and environmental impacts of the power generation system. Chapter four describes power generation system design and analysis, cost analysis of micro hydropower energy system. Chapter five presents conclusion and recommendation. Appendixes presents flow rate of the river by ministry of water irrigation and energy, and population data from central statistical Agency of Ethiopia.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Basic Theory

2.1.1 Basic concept of Hydropower

Early hydropower plants were much more reliable and efficient than the fossil fuel-fired plants of the day [16]. Hydropower plants (HPP) today span a very large range of scales, from a few watts to several GW. the thesis focus on feasibility study and design the micro hydropower potential. A hydro scheme requires both water flow and a drop in height (referred to as 'Head') to produce useful power. Main parts of a hydro plant are shown on Figure 2.1. [3, 4].

To determine the power potential of the water flowing in a river or stream it is necessary to determine both the flow rate of the water and the head through which the water can be made to fall. The flow rate is the quantity of water flowing past a point in a given time. The head is the vertical height, in meter's, from the turbine up to the point where the water enters the intake pipe or penstock.

The potential power can be calculated as follows:

Theoretical power = Flow rate x Head x Gravity

Where flow rate (Q) is in cubic meters per second, head (H) in meter's and g = 9.81 m/s^2 then,

$$P = 9.81 \times Q \times H \text{ (kW)} \qquad (2.1)$$

However, energy is always lost when it is converted from one form to another. Small water turbines rarely have efficiencies better than 80% [3].

2.1.2 Classification of Hydropower Plants

There are a number of criteria for classification of hydropower plants, such as head, flow rate, hydraulic nature, purpose and size. Although there is no standard classification of hydropower plants, the more widely used classification is summarized below (based on size). Hydropower plants range in size from large power plants that supply many consumers including industrial and commercial load to small and micro plants that provide electricity for small numbers of houses or villages. Though different countries have different criteria to classify hydro power plants depending on their magnitude, a general classification of hydro power plants is as follows

Table 2.1 Classification of hydro power plants based on their size

Type	Capacity
Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 – 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either standalone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	From a few hundred watts up to 5kW

Small hydro plants are also classified according to the “Head” or the vertical distance through which the water is made to impact the turbines:

- High head: - 100 meters and above
- Medium head: - 30 – 100 meters
- Low head: - 2 – 30 meters

According to Dilip Singh, 2009-Most of the small hydro power plants are “run-of-river” schemes, implying that they do not have any water storage capability [2]. The power is generated only when enough water is available from the river or stream. When the stream/river flow reduces below the design flow value, the generation ceases as the water does not flow through the intake structure into the turbines. Small hydro plants may be stand-alone systems in isolated areas/sites, but could also be grid connected (either local grids or regional/national grids). The connection to the grid has the advantage of easier control of the electrical system frequency of the electricity, but has the disadvantage of being tripped off the system due to problems outside of the plant operator's control.

2.1.3 Definition of Micro-Hydropower

The definitions of small-hydropower, mini-hydropower and micro-hydropower generations vary among different countries and organizations. Classification of hydropower stations according to power capacity may differ through countries. Since there is no a common defined ranges for Micro-Hydropower here in Ethiopia it is necessary to make appropriate definition of Micro-Hydropower before proceeding to the evaluation of existing sites. In different countries Micro-Hydropower is defined as having generation capacity between 5kW and 100kW [4, 9].

According to Keneni 2007-defined Micro-Hydropower as having generation capacity less than 500kW [16]. On the other hand the Ethiopian Energy Agency defines Micro Hydropower as having capacity of 11-500kW, mini hydropower as 501-1000kW, Pico hydropower as 1-10kW. But MoWIR defines MHP to have a capacity of 5kW up to 100 kW which is the definition used to this study. Micro hydropower from the natural flow of streams and small rivers can be harnessed to bring clean, reliable electricity to remote communities, providing light to study and work by and helping small businesses grow. Micro-hydro power is bringing electricity and prospects for a better future to remote communities across the world. As well as replacing polluting and dangerous kerosene for lighting, it can also power radios, TVs and machinery, providing new education, leisure and livelihood opportunities.

2.1.4 Classification of micro-hydropower by facility type

Hydropower plants are often classified in three main categories according to operation and type of flow. Diversion and canal, Run-off-river (RoR), storage (reservoir) and pumped storage HPPs all vary from the very small to the very large scale, depending on the hydrology and topography of the watershed.

A. Diversion & canal

A Diversion and canal HPP draws the energy for electricity production mainly from the available flow of the river. Such a hydropower plant may include some short-term storage (hourly, daily), allowing for some adaptations to the demand profile, but the generation profile will to varying degrees be dictated by local river flow conditions. As a result, generation depends on precipitation and runoff and may have substantial daily, monthly or seasonal variations. When even short-term storage is not included, Diversion and canal HPPs will have generation profiles that are even more variable, especially when situated in small rivers or streams that experience widely varying flows.

In a Diversion and canal HPP, a portion of the river water is diverted to a channel or pipeline (penstock) to convey the water to a hydraulic turbine, which is connected to an electricity generator as shown in Figure 2.1. Installation of Diversion and canal HPPs is relatively inexpensive and such facilities have, in general, lower environmental impacts than similar-sized storage hydropower plants.

Figure 2.1 Example of a diversion hydropower plant No dam was required[7]

B. **Run-off-River**

In Run off River (RoR) hydropower the normal flow of the river is not disturbed, as there is no significant storage in the river system. In order to get head a weir or barrage is built across the river and the low head created is used to generate power. The power house is in the main course of a river as shown in Figure 2.2.

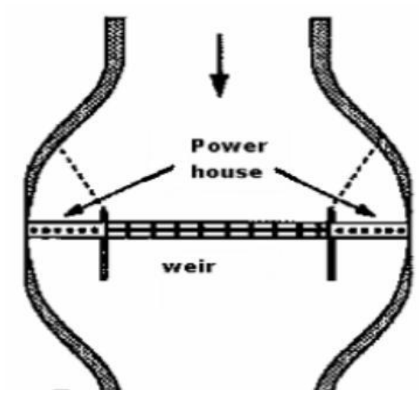


Figure 2.2 RoR hydro plant [1]

C. **Storage Hydropower**

Hydropower projects with a reservoir are also called storage hydropower since they store water for later consumption. The reservoir reduces the dependence on the variability of inflow. The generating stations are located at the dam toe or further downstream, connected to the reservoir through tunnels or pipelines as shown in Figure 2.3. The type and design of reservoirs are decided by the landscape and in many parts of the world are inundated river valleys where the reservoir is an artificial lake. In geographies with mountain plateaus, high-altitude lakes make up another kind of reservoir that often will retain many of the properties of the original lake. In these types of settings, the generating station is often connected to the lake serving as reservoir via tunnels coming up beneath the lake (lake tapping) [2]

Figure 2.3Storage hydropower[1]

2.1.5 Components of Diversion & canal micro-hydropower plants

(Dilip Singh, 2009) Stated that a micro hydropower station essentially needs water to be diverted from the stream and brought to the turbines without losing the elevation/head [2]. Some of the important factors that must be kept in mind while designing a micro hydropower system are:

Available head: The design of the system has effects on the net head delivered to the turbine. Components such as the channel and penstock cannot be perfectly efficient. Inefficiencies appear as losses of useful head of pressure.

Flow variations: The river flow varies during the year but the hydro installation is designed for almost a constant flow. If the channel overflows there will be serious damage to the surroundings. The weir and intake must therefore be designed for such eventualities and divert only the required amount of flow irrespective of whether the river is in low or in high flow. The main function of the weir is to ensure that a constant flow in the channel is maintained when there is less flow in the river. The intake structure is designed to regulate the flow to within reasonable limits when the river is in high flow. Further regulation of the channel flow is provided by the spillways.

Sediment: Flowing water in the river sometimes carry small particles of hard abrasive matter (sediment) which can cause wear to the turbine if they are not removed before the water enters the penstock. Sediment may also block the intake or cause the channel to clog up if adequate precautions are not taken. But around the site selected for the study the river flow near to upper flow (basin) and covered by stone; so that it has very small sediment.

Floods: Flood water will carry larger suspended particles and will even cause large stones to roll along the stream bed. Unless careful design principles are applied, the diversion weir, the intake structure and the embankment walls of the river may be damaged.

Most common civil structures used in a MHP scheme are:

Weir and intake: A micro hydropower system necessitates that water from the river to be diverted and extracted in a reliable and controllable manner. The water flowing in the channel must be regulated during high river flow and low flow conditions. A weir can be used to raise the water level and ensure a constant supply to the intake. The intake of a MHP is designed to divert only a portion of the stream flow or the complete flow – depending upon the flow conditions and the requirement [17].

Power Channels: It a channel conducts the water from the intake to the forebay tank. The length of a channel depends upon the topography of the region and the distance of powerhouse from the intake. Also the designing of the MHP systems states the length of the channel – sometimes a long channel combined with a short penstock can be cheaper or required, while in other cases a combination of short channel with long penstock would be more suitable.

Settling basin: The water diverted from the stream and carried by the channel usually carries a suspension of small particles such as sand that are hard and abrasive and can cause expensive damage and rapid wear to turbine runners. To get rid of such particles and sediments, the water flow is allowed to slow down in 'settling basins' so that the sand and silt particles settle on the basin floor. The deposits are then periodically flushed. The design of settling basin depends upon the flow quantity, speed of flow and the tolerance level of the turbine (smallest particle that can be allowed). The maximum speed of the water in the settling basin can thus be calculated as slower the flow, lower is the carrying capacity of the water. The flow speed in the settling basin can be lowered by increasing the cross section area [2].

Spillways: Spillways along the power channel are designed to permit overflow at certain points along the channel. The spillway acts as a flow regulator for the channel. During floods the water flow through the intake can be twice the normal channel flow, so the spillway must be large enough to divert this excess flow. The spillway can also be designed with control gates to empty the channel. The spillway should be designed in such a manner that the excess flow is fed back to the without damaging the foundations of the channel.

Fore-bay tank: According to (Zelalem, 1992) A fore-bay is constructed at the end of the headrace, in front of the penstock, in order to maintain a constant head on the turbine and to store surplus water [20]. Usually the fore-bay is a small basin, but it should store enough water to maintain two or three minutes at maximum discharge without resupply in order to cope with sudden variations in load, to which headrace flow could not respond well. Fore-bay also acts as the last settling basin and allows the last particles to settle down before the water enters the penstock [2].

Penstock: The penstocks are pipes of large diameter, usually steel or concrete used for covering water from the source (reservoir or fore bay) to the power house, i.e. the penstock is the pipe which conveys water under pressure from the fore-bay tank to the turbine. They are usually high pressure pipe lines designed to with stand stresses developed because of static and water hammer pressures created by sudden change in power demand (i.e. value closure and openings according to power rejection and demand) [11].

Penstock is a significant component of the MHP scheme and needs to be designed and selected carefully as it represents a major expense in the total budget (for some high head installations this alone could cost as much as 30% of the total costs). Here the main aspects to consider are head loss and capital cost. Head loss due to friction in the pipe decreases dramatically with increasing pipe diameter.

While designing penstocks, the first principle is to identify available pipe options and then to decide upon acceptable head loss (5% of the gross head is generally considered). A smaller penstock may be lighter on pocket, but the extra head loss may account for lost revenue from generated electricity each year. The factors to be considered while deciding upon the material to be used for a particular penstock are:

- Terrain,
- Soil type
- Weather conditions
- Weight and ease of installation,
- Accessibility of the site
- Likelihood of structural damage
- Availability
- Surface roughness,
- Design life and maintenance
- Method of jointing
- Design pressure,
- Relative cost.

The following materials can be considered for use as penstock pipes in micro hydro schemes:

- Wooden planks or tree bark (for very small installations)
- Spun ductile iron
- Mild steel,
- Unplastified polyvinyl chloride,
- Light density polyethylene,
- Cement,
- Pre-stressed concrete,
- Glass reinforced plastic.

Mild steel, uPVC and HDPE are the most common used materials.

Penstock joining

Pipes are generally available in standard lengths (it is easier for transportation also) and have to be joined together on site. There are several methods of joining penstock pipes and the factors to be considered when choosing the best joint system for a particular scheme are:

- pipe material,
- whether any degree of joint flexibility is required,
- ease of installation
- skill level of personnel,
- Costs.

Generally, the pipes are joined by one of the following four methods:

- flanged,
- spigot and socket,
- mechanical,
- Welded.

Burying or supporting the penstock

Penstock pipelines can either be laid upon the surface or buried underground. This generally depends upon the material of the pipe, the nature of the terrain and environmental and cost considerations. While burying a penstock, it is very important to ensure proper installation because any subsequent problems such as leaks are much harder to detect and resolve. Burying the pipeline carefully and correctly enhances the life of the MHP scheme and greatly reduces the chances of disruption in power generation especially in hilly terrain with heavy landslides. Support piers are used basically to bear the weight of the pipes plus water being carried.

Turbines: While there are only two basic types of turbines (impulse and reaction), there are many variations. A reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged a feature which reduces turbulence. In theory, the reaction turbine works like a rotating lawn sprinkler where water at a central point is under pressure and escapes from the ends of the blades, causing rotation. An impulse turbine is a horizontal or vertical wheel that uses the kinetic energy of water striking its buckets or blades to cause rotation. The wheel is covered by a housing and the buckets or blades are shaped so they turn the flow of water about 170 degrees inside the housing. After turning the blades or buckets, the water falls to the bottom of the wheel housing and flows out. Beyond the operating, turbines canal so be classified as high head, medium head or low head machines. The basic turbine classification is given in Table 2.2:

Table 2.2 Turbine classification [24]

	High head	**Medium head**	**Low head**
Impulse turbine	**PeltonTurgo**	○ **Cross-flow** ○ **Multi-jet Pelton** ○ **Turgo**	**cross-flow**
Reaction turbines	---	○ **Francis**	**Propeller** **Kaplan**

The difference between impulse and reaction can be explained simply by stating that the *impulse* turbines convert the kinetic energy of a jet of water in air into movement by striking turbine buckets or blades - there is no pressure reduction as the water pressure is atmospheric on both sides of the impeller. The blades of a reaction turbine, on the other hand, are totally immersed in the flow of water, and the angular as well as linear momentum of the water is converted into shaft power - the pressure of water leaving the runner is reduced to atmospheric or lower.

2.7 Electrical and Mechanical Equipment for Micro-Hydro Power Generation

The primary electrical and mechanical components of a micro - hydro plant are the turbine and generator.

2.7.1 Types of Turbines used in Micro Hydro Power Generation

There are two basic types of turbines, denoted as "impulse" and "reaction turbine". The "impulse turbine" converts the potential energy of water in to kinetic energy in a jet issuing from a nozzle and projected onto the runner buckets or vanes. The "reaction turbine" develops power from the combined action of pressure energy and kinetic energy of the water. Impulse turbines are further classified in to Pelton, Turgo and cross flow type, and Reaction turbines are classified as Kaplan, Propeller, and Francis turbines [11].

i. **Pelton Turbine**

A Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc. It is turned by jets of water which are discharged from one or more nozzles and strike the buckets. The Pelton bucket is designed to deflect the jet through 165 degrees which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet.

ii. **Turgo Turbine**

The Turgo turbine can operate under a head in the range of 30 to 300 meter. Like a pelton it is an impulse turbine, but its bucket are shaped differently and the jet of water strikes the plane of its runner at an angle of $20^{o.}$ Water enter the runner through one side of the runner disk and emerges from the other [18].

iii. **Cross flow Turbine**

Cross flow turbines are also called Banki, Mitchell or Ossberger turbine. A cross flow turbine comprises a drum shaped runner consisting of two parallel disc connected together near their firm by a series of curved blades. A cross flow turbine has its runner shaft horizontal to the ground in all cases. The cross flow turbine is easy to manufacture in developing countries and is selected turbine in this study.

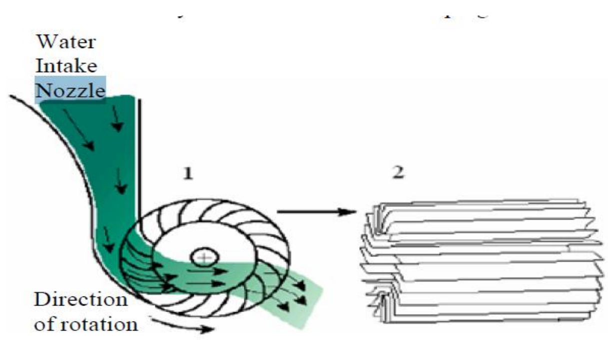


Figure 2.4 Cross flow turbine [11]

(1) Cross section through the turbine and (2) Arrangement of cross flow turbine blades

iv. **Kaplan and Propeller Turbines**

Kaplan and propeller turbines are axial-flow reaction turbines, generally used for low heads (usually under 16 m). The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide-vanes.

v. **Francis Turbines**

Francis turbines are radial flow reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. The runner is composed of buckets formed of complex curves. A Francis turbine usually includes a cast iron or steel fabricated scroll casing to distribute the water around the entire perimeter of the runner, and several series of vanes to guide and regulate the flow of water into the runner.

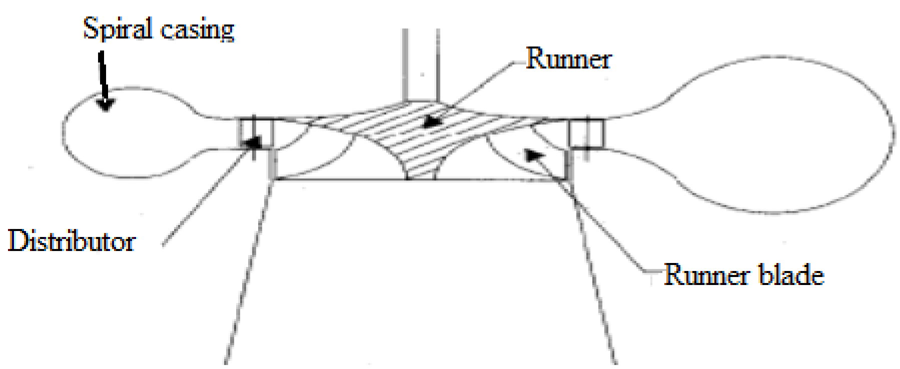


Figure. 2.5 Francis turbine [11]

vi. **Reverse Pumps as a Turbine (PAT)**

Centrifugal pumps can be used as turbines potential advantage is low cost owing to mass production, Local production and availability spare parts and its disadvantages are as yet poorly understood characteristic of turbine performance, lower typical efficiencies, unknown wear characteristics, and poor part flow efficiency, flow rate is fixed for a particular head. This can be overcome at some cost by using two units of different sizes, and switching between them depending on the flow rate [14, 8].

2.7.2 Types of Generator used in Micro Hydropower Generation

Electrical generators can produce either alternating current (AC) or direct current (DC). In the case of ac current, a voltage cycles sinusoidal with time from positive peak value to negative peak value. DC current flows in a single direction as a result of a steady voltage.

AC generators: There are two types of generators suitable for use in a micro hydro electricity supply scheme. These are synchronous generators (or 'alternators') and induction generators (in which induction motors used as a generator). Induction machine is simpler or more reliable machine than the synchronous generator [17]. Even though there are also a number of problems connected to induction motors used as a generator /IMAGs for power generation in MHP: Standard induction machines are not always available with suitable voltage ratings for use as generators. Modifications to the winding connections, or in extreme cases rewinding, may be required.

Furthermore, the application of IMAGs is not as straightforward as the use of standard generators. Whilst synchronous motors can be purchased ready for use, the induction machine will not work without capacitors of suitable value being fitted. The IMAG cannot generate magnetizing or reactive power by itself; to establish its magnetic field and to actually produce power; the IMAG requires reactive power to be supplied to it. This reactive power can be generated by capacitors, which are connected to the induction generator. Always calculations and/or tests are necessary to determine the correct capacitance for a system. One also has to keep in mind that the capacitors create additional costs and are an additional source of failure and might have to be exchanged in intervals.

Another problem when using IMAGs is connected to the starting of motors: Motors are more easily started with synchronous generators than induction generators. Induction motors; with a capacity that is large compared to the generator rating; can cause severe voltage dips or even loss of excitation when started from induction generators. Consequently, the synchronous generators were chosen in this study.

2.8 Rural Electrification in Ethiopia

As ErmiasTenkir, Rural electrification is the process of providing electrical services to rural areas; generally regions with sparse population where agriculture is the dominant livelihood [15]. The three most important rural energy sources, in their order of importance, are fuel wood, dung and agro-residue; while the three most important end-users are “mitad” baking, other cooking and lighting. The implication of this is that, if rural households are provided with electricity, even for lighting, the gain in terms of environmental protection of rural areas is significant. In view of the above there is a huge market for investors in the area of rural electrification. Rural electrification can be achieved through:

- Extensions of national or regional distribution systems, or grids, to rural areas.
- Isolated generators electrifying Mini-grids to supply a community, or
- Isolated generators electrifying a single house or facility.

In this study the rural electrification can be achieved through off-grid micro hydropower.

2.9 Advantage and Disadvantage of MHP

a) Advantage of micro hydropower

Clean energy source: Hydropower does not produce greenhouse gas emissions, which are the major cause of the international concerns about environmental problems. MHP is a clean energy source (it does not produce waste in the rivers, or air pollution) and renewable (the fuel for hydropower is water, which is not consumed in the electricity generation process)

Efficient energy source: Since MHP is a decentralized energy source located close to the consumers, transmission losses can be reduced although electricity can be delivered as far as a mile away to the location where it is being used.

No reservoir required: Micro hydro is considered to function as a ‘run-of-river’ system, meaning that the water passing through the generator is directed back into the stream with relatively minimal or no impact on the surrounding ecology but difficulty during maintenance period.

Cost effective energy solution: according to Building a small-scale hydropower system can cost from 1,000 - 20,000 $/kW, depending on site characteristics, power plant size and location. Maintenance costs are relatively small in comparison to other technologies. It is a long-lasting and robust technology the life of systems can be as long as 50 years or more without major new investments (the average life considered for investment purposes however is about 30 years)[2, 9].

Power for developing countries: Because of the low-cost versatility and longevity of micro hydro, developing countries can manufacture and implement the technology to help supply much needed electricity to small communities and remote villages.

b) Disadvantage of micro hydropower

Site specific technology: In order to take full advantage of the electrical potential of small streams, a suitable site is needed.

Factors to consider are: distance from the power source to the location where energy is required (this is not very common to find), stream size (including flow rate, output and drop), and a balance of system components: - inverter, batteries, controller, transmission line and pipelines.

Energy expansion not possible: There is always a maximum useful power output (size and flow from small streams for example) available from a given hydropower site, which limits the increase in power generation and the level of expansion of activities which can make use of the power.

Seasonal variations: In many locations the flow in a stream fluctuates seasonally and this can limit the well-founded power output to quite a small fraction of the possible peak output. During summer months there is likely to be less flow and therefore less power output. Advanced planning and investigations are needed to ensure adequate energy generation and power demands are met.

Environmental and ecological concerns: MHP, like any energy-production activity, has impacts on the indigenous ecosystem (on the quality of river and river ecosystems, noise, landscape). However, new legislative frameworks, innovative technology, value-added methods of operating MHP and above all the willingness of all actors to integrate environmental concerns are steadily reducing these local environmental impacts. MHP plants, if well equipped, with fish ladders and environmentally friendly runner blades, are not an obstacle even for fish migration [1].

CHAPTER 3

SITE DESCRIPTION AND SYSTEM ANALYSIS

3.1 Site Mapping

The site representing area of micro hydropower potential identified considering data availability for rural electrification option. Chumlugo village found in Oromia region specifically in West Arsi Zone 345km from Addis Ababa city and 100km from Shashamane town in to direction of Bale Zone and 15.6 km to south direction from zonal town that is Adaba. In the village 245 households are found. At this place micro-hydro power generation system is supposed to be studied and design. The sources of data for the system (i.e. micro hydropower generation) are Ministry of water, irrigation and energy of Ethiopia (flow rate and degree location of the river), Central Statistical Agency of Ethiopia (population data) and Ejersa Chumlugo manager bureau (number of household in Chumlugo village).

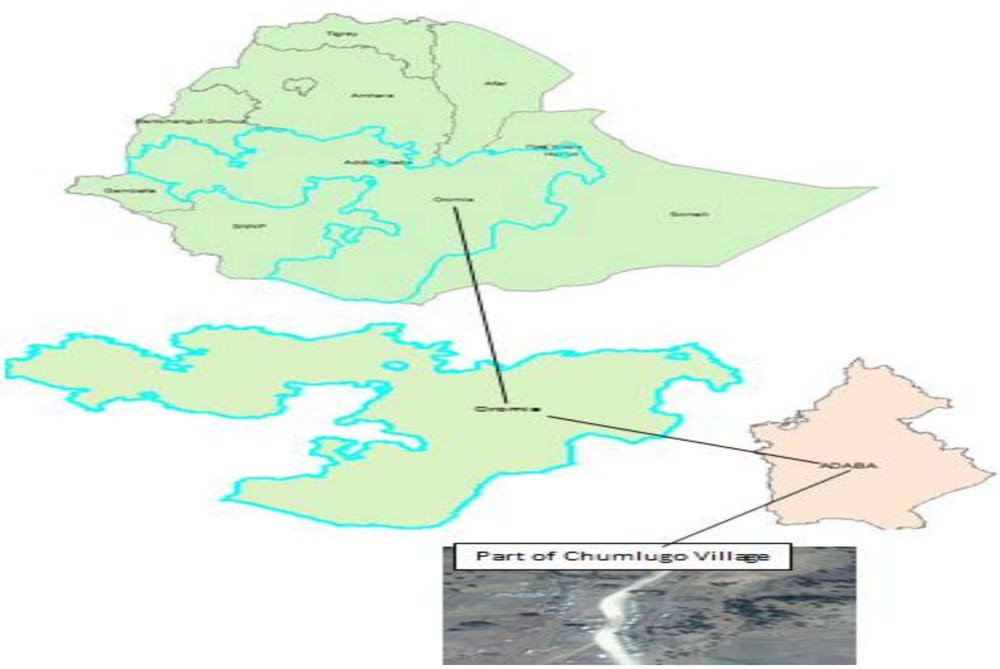


Figure 3.1 Map of Study Area

For Chumlugo village, the nearest station is Meribo station near to Adaba with geographical location 7:0:0N latitude and 39:20:0E of longitude. For micro hydro data the head is obtained through measurement but the discharge or the flow rate is obtained from Ministry of water, irrigation and energy collect it since 1991 up to 2009 G.C.

3.2 General Description about Meribo River

Meribo River is located 7km from Adaba town on the road to Addis Ababa between Ejersa Chumlugo village and Heraro town. The selected site is located at 15.6km from the road connecting Adaba town and Addis Ababa in south direction and the load center or households far 2km to east direction. Measured gross head of the river is around thirteen meters and the average flow rate from ministry of water irrigation and energy data since 2009G.C is 0.158m^3/s which is the minimum,(see appendix-A) and the average flow rate data since 2007 up to 2009 G.C is 0.18 m^3/s which is greater than 0.158m^3/s.

Table 3.1 Annual Average flow rate Report of Meribo River since 2009[see appendix A-1]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.477	0.298	0.221	0.872	1.609	3.298	5.476	11.82	8.226	4.763	1.653	0.569
Flow (MCM)	1.279	0.746	0.592	2.261	4.31	8.549	14.67	31.65	21.323	12.757	4.285	1.524
Maximum	0.909	0.451	0.322	2.316	2.861	5.484	11.41	21.06	15.242	11.489	2.837	0.804
Minimum	0.336	0.216	0.158	0.248	0.831	1.066	2.856	5.996	4.371	1.809	0.831	0.419

Below on the table 3.2 the average flow rate data since 2007 up to 2009 G.C is calculated and has the minimum value of 0.18 m^3/s

Table 3.2 Annual Average flow rate of Meribo River since 2007 to 2009[see appendix A-2]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.381	0.319	0.647	2.527	4.824	2.341	5.999	11.04	7.403	5.586	1.724	0.871
Flow (MCM)	1.023	0.778	1.734	6.551	12.921	6.068	16.067	29.56	19.19	14.961	4.469	2.333
Maximum	0.807	0.687	1.614	7.043	11.342	4.82	15.521	19.01	12.997	15.123	3.961	2.005
Minimum	0.275	0.18	0.217	0.678	1.724	0.989	2.069	5.965	3.789	2.185	0.874	0.442

On the above tables 3.1 and 3.2 the minimum flow rate of the river is 0.158m3/s and 0.18m3/s respectively. To ensure the feasibility of Meribo river potential for energy production on electrification of Chumlugo village using the minimum flow rate is desirable. Accordingly in this research flow rate will be used is 0.158m3/s.

3.3 Load Estimation.

The estimated load shown on the table 3.3 is daily energy demand of the house hold in the village.

Table 3.3 House hold daily energy demand:-

No.	Appliance	Rate in watt(W)	Daily use/hour	Daily Energy Consumed[Wh]
1	Lamp 1 (salon)	7	4	28
2	Lamp 2 (kitchen)	7	3	21
3	Lamp 3 (bed room)	7	3	21
4	Radio/caste player	8	6	48
Subtotal		29	16	118*245house holds = 28,910
5	TV	32	8	256 * 245house holds =62,720
6	Stove for cooking	2000	3	6000
Total		2089		97,748

Table 3.4 Daily energy demand for school and clinic

Name	Appliance	Rate in Watt	Daily use/hour	Daily Energy in Wh
School	3Lamps/room x 15 class rooms	11	5	2,475
	1 color TV	60	6	360
Clinic	2 lamps	11	12	264
	1 Fridge	80	12	960
	1 TV	32	12	384
Total		194		4,443

Water pump for irrigation:-

Another load considered at village is water pumping machine for irrigation. A pump is a basic but important mechanical device that supplies the force to move fluid at a specific flow rate. Like any device that does work (transfers energy across a distance), its effectiveness is measured in power. Although watts and kilowatts are more common units of power measurement, horsepower is still commonly used for high-output electrical devices in the world. In this context, 1 horsepower is equal to 746 watts.

Calculating Water Horsepower:-

- Water horsepower = minimum power required to run water pump
- TDH = Total Dynamic Head = Vertical distance liquid travels (in feet) + friction loss from pipe

Assume that friction loss of a pipe is negligible, Total Dynamic Head is equal with vertical distance liquid travels (in feet). Therefore, the measured head of the river is 13m with calculated net head of 12.09m which is equal with 39.67 ft.

- Q = flow rate of liquid in gallons per minute

From table 3.1 the flow rate of the river is 0.158 cubic meter per second which is equivalent to 41.74 gallons.

- SG = specific gravity of liquid (this equals 1 if you are pumping water)
- Water horsepower calculated using equation 3.1

$$\text{hourse power, hp} = \frac{\text{TDH} * \text{Q} * \text{SG}}{3960} \qquad (3.1)$$

$$\frac{39.67\ \text{ft}*2504.4\text{gpm}*1}{3960} = 25.0883\text{hp} = 18.70834\text{kW}$$

Where gpm = gallon per minute

From the table 3.3 and 3.4 above the daily energy consumption of the household becomes:-

= 91, 748Wh/day + 4,443Wh/day = 96,191Wh/day and

The annual energy consumption of the village can be calculated as:

96,191Wh/day x 30day/month x 12 months/year = 34628760Wh/year = 34.63MWh/year; which is sustainable through out of the year.

Again the daily energy consumption for water pumping become 3118.05W =3.118kW

Total daily energy consumption of the village becomes 3401.05W = 3.40105kW as summarized on table 3.5 below

Table 3.5 summary of estimated load

Energy demand for load at	Energy demand in Watt	Daily Energy in Wh
School and Clinic	194	4,443
house holds	2089	97,748
water pump for irrigation	3118.05	37416.6
Total	5,401.05	139,607.6

As summarized on the table 3.5 the total estimated load for the Chumlugo is 5.4011kW, which is 57.64% of available power on Meribo River with its minimum flowrate.

CHAPTER 4

POWER GENERATION SYSTEM DESIGN AND MODELING

4.1 Micro Hydro Power Generation

Actual power, P available from the micro hydro plant at any given flow value Q and gross head Hg can be obtained as mentioned in chapter three.

4.1.1 Proposed Scheme Layout of Micro Hydro Power Generation

The flow of water in a river may be regulated by means of a small dam or weir. The weir also slightly raises the water level of the river and diverts sufficient water into the conveyance system. The water is channeled to a forebay tank where it is stored until required and it forms the connection between the channel and the penstock. The penstock carries the water under pressure from forebay to the turbine. The penstock is a very important part of a hydro project as it can affect the overall cost and capacity of a scheme. The penstock connects to the hydraulic turbine, which is located within the powerhouse over the ground [11].

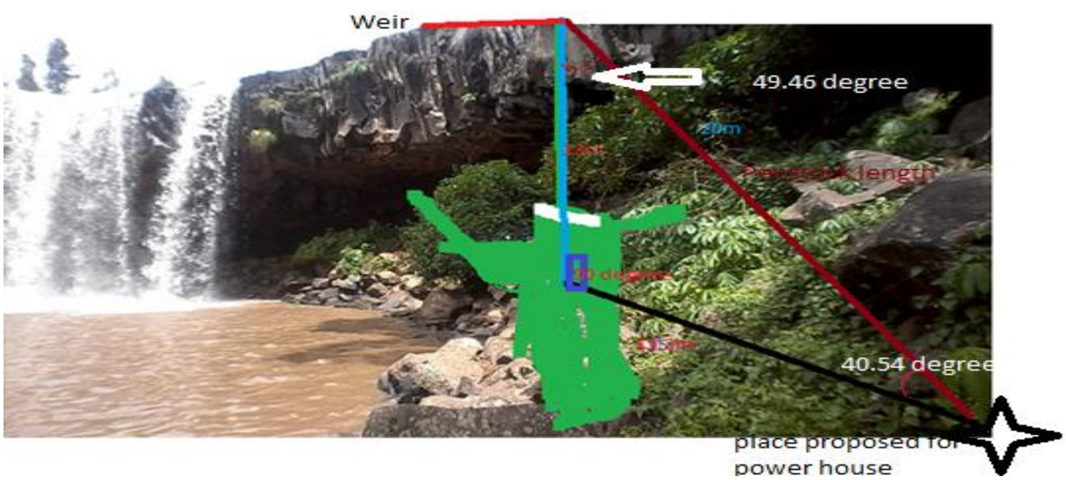


Figure 4.1 Proposed schematic diagram of micro hydroelectric power plant

4.1.2 Turbine Selection

A turbine converts energy in the form of falling water in a rotating shaft power. The selection of best turbine for a particular micro hydro site depends on the site characteristics, the dominant factor is the head available and the power required. Selection also depends on the speed at which it is desired to run the generator or other devices loading the generator [13].From table (4.1), a turbine type suitable for this site is impulse turbine typically cross flow type depending of the head available. [9, 12].

Table 4.1Classification of micro hydro turbines according to head, flow rate and power output [5]

Classification	Turbine Name	Head Range(m)	Flow Range(m3/s)	Power output(kW)
Impulse	Pelton	50 -1,000	0.2 -3	50 -15,000
	Turgo	30 -200	0.2 -5	20 -5000
	Cross Flow	2 -50	0.01 -2	0.1 -600
Reaction	Kaplan	3 -40	3 -20	50 -5000
	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

4.1.3 Sizing of Cross Flow Turbine

In sizing of cross flow turbine, the dimension of interest is the runner length (L_{runner}), diameter (D_{runner}) and jet thickness (t_{jet}). Assuming gear ratio 2 and alternator speed 1500 rpm,

$$D_{runner} = \frac{41\sqrt{H_{net}}}{N_t} \quad (4.1)$$

Where: - N_t: - Turbine speed

$$\text{Turbine speed } (N_t) = \frac{\text{alternator rpm}}{\text{gear ratio}} = \frac{1500}{2} = 750 \text{ rpm} \quad (4.2)$$

$$H_{net} = H_g - h_{hydr}, \; h_{hydr} \text{ is usually 2 to 7\% of } H_g \text{ [10]} \tag{4.3}$$

Using eqn. (4.3) $H_{net} = H_g$ - 7% of H_g =13m - 0.91m = 12.09m

Using eqn. (4.1) we get,

$$\mathbf{D_{runner}} = \frac{\mathbf{41\sqrt{12.09}}}{\mathbf{750}} = 0.19\text{m}$$

The jet thickness is usually one tenth of the runner (blade) diameter

$$t_{jet} = D_{runner} * 0.1 = 0.19 * 0.1 = 0.019\text{m} \tag{4.4}$$

Having $\mathbf{t_{jet}}$**,** the approximate runner length (*L runner*) can be obtained from the orifice discharge equation. The runner length will be equivalent to the jet width

$$Q = A_{nazzle}\sqrt{2gH_{net}} = t_{jet} * \text{L runner} * \sqrt{2gH_{net}}, \text{ for } Q = 0.158\text{m}^3/\text{s} \tag{4.5}$$

By rearrange the equation (4.5):

$$\text{L runner} = \frac{\mathbf{Q}}{t_{jet} * \sqrt{2gH_{net}}} = \frac{\mathbf{0.158m3/s}}{0.019\text{m} * \sqrt{2*9.81*12.09}} = 0.54\text{m}$$

$$\text{Length of pipe} = \sqrt{(1\mathit{horizontal\ distance}^2 + \text{gross head}^2)} \tag{4.6}$$

$$= \sqrt{(15^2 + 13^2)} \approx 20\text{m}$$

Average angle: An angle made by pipe line at head tank of power house.

$$\text{Average angle} = \frac{\text{height from head tank to power house}}{\text{length of penstock (Lp)}} \tag{4.7}$$

Using equation (4.7) Average angle become= $\frac{13m}{20m} = 0.65$, $\sin^{-1}(0.65) = 40.54^0$

4.1.4 Turbine Efficiency

For this condition, it is assumed that the three parameters design flow (Q_d), flow at any time (Q) and peak flow (Q_p) be equal [9, 14].

$$\eta_t = 0.79 - 0.15\left(\frac{Q_d - Q}{Q_p}\right) - 1.37\left(\frac{Q_d - Q}{Q_p}\right)^{14} \text{ For Q} = 0.158\text{m}^3/\text{s} \qquad (4.8)$$

Hence, turbine efficiency will be 0.79 where $Q_d = Q$or it is approximately equal to the calculated value.

But, $\eta_o = \eta_{\text{civil work}} \times \eta_{\text{penstock}} \times \eta_{\text{turbine}} \times \eta_{\text{generator}} \times \eta_{\text{drive system}} \times \eta_{\text{line}} \times \eta_{\text{transformer}}$

Usually

$\eta_{\text{civil work}}$: 1.0

$\eta_{\text{penstock:}}$ 0.90 ~ 0.95 (it's depends on length)

η_{turbine}: 0.70 ~ 0.85 (it's depends on the type of turbine)

η_{gross}: 0.80 ~ 0.95 (it's depends on the capacity of generator)

$\eta_{\text{drive system:}}$ 0.97

$\eta_{\text{line:}}$ 0.90 ~ 0.98 (it's depends on the transmission length)

$\eta_{\text{transformer}}$: 0.98

4.1.5 Sizing of Penstock

The size of penstock pipe to be selected is dependent on the material type to be used and its availability. To serve a given task with all the design parameters the same, penstocks designed from different materials will have different size.

As the diameter of the pipe decreases the velocity of the water flow increases which increases the head loss due to the increased friction. And when the size of the penstock is increased, the head loss will be decreased; however the cost of the penstock increases drastically. Therefore, a proper sizing of the penstock is very important [5, 11].

Hence, it is good to see the types of materials used in penstock construction before going directly to the design. The most commonly used penstock materials are:

- ✓ PVC (PolyVinyl Chloride)
- ✓ Steel
- ✓ Polyethylene
- ✓ FRE (Fiber Reinforced Epoxy

The first thing to consider while sizing the penstock is selecting the proper penstock diameter corresponding to the design flow. This can be done in two ways: one by using developed formulas and the second method is by using graphs developed for this purpose [14].

Diameter of penstock can be calculated from discharge and head of the river

$$d_p = \frac{\left(\frac{Q_d}{n_p}\right)^{0.46}}{H_g{}^{0.14}} = 0.426\text{m} \tag{4.9}$$

Where

n_p = Manning's coefficient (steel pipe; n=0.12, plastic pipe; n=0.011)[15].

Q = water flow rate/discharge (m^3/s)

H_g = gross head in (m).

$$A = \pi r^2 = \pi(\frac{D}{2})^2 = \pi(\frac{0.426m}{2})^2 = 0.071265\text{m}^2 \approx 0.0713\text{m}^2 \tag{4.10}$$

Where, A is cross sectional area of pipe.

Then the velocity of water, U can calculate by

$$U = \frac{Q}{A} = \frac{0.158}{0.0713} = 2.22\text{m/s} \qquad (4.11)$$

Length of the penstock/pipe can be approximated from the layout of the scheme,

L_p = 20m as shown above.

Total weight of penstock in kilogram, penstock thickness in (mm), ts tensile strength, pipe diameter are important to estimate its cost and can be calculated at implementation stage.

$\eta_{penstock}$: 0.90 ~ 0.95 (it's depends on length)

4.2 Power available from Meribo River

Power input = power output + losses

The power input, or the total power absorbed by the hydro scheme is the gross power and the power usually delivered is the net power. The overall efficiency of the scheme is termed as η_o.

Using equation (2.1) we calculate the net power, P_{net} as shown below.

$$P_{net} = \rho g H_{net} Q \eta_o = 1000\text{kg/m}^3 \text{X } 9.81\text{m/s}^2 \text{ X } 12.09\text{m X } 0.158\text{m}^3\text{/s X } 0.50$$

$$\approx 9.370\text{kW}$$

$$Where\ \eta_o = \eta_{channel}\ x\ \eta_{penstock}\ x\ \eta_{turbine}\ x\ \eta_{generator}\ x\ \eta_{line} = 0.95 \text{ x } 0.9 \text{ x } 0.8 \text{ x } 0.85 \text{ x } 0.9 \text{ x } 0.96 = 0.50$$

From the above result apparent power, $S = \frac{P}{\cos\emptyset} = \frac{9.37\text{kW}}{0.8}$ = 11.712kVA and

Reactive power, $Q = S\sin\emptyset$ = 11.712 x 0.6 = 7.027kVar. It is known that the apparent power for three phase system can expressed as

$$S = \sqrt{3}VI \quad (4.12)$$

From equation 4.12 it is possible to calculate current as:

$$I = \frac{S}{\sqrt{3}V\cos\emptyset} = \frac{9.37\text{kW}}{\sqrt{3}\text{ x }15\text{kV x }\cos\emptyset} = 0.5\text{A}$$

Where, $\emptyset$= phase angle between the electrical potential (voltage) and the current

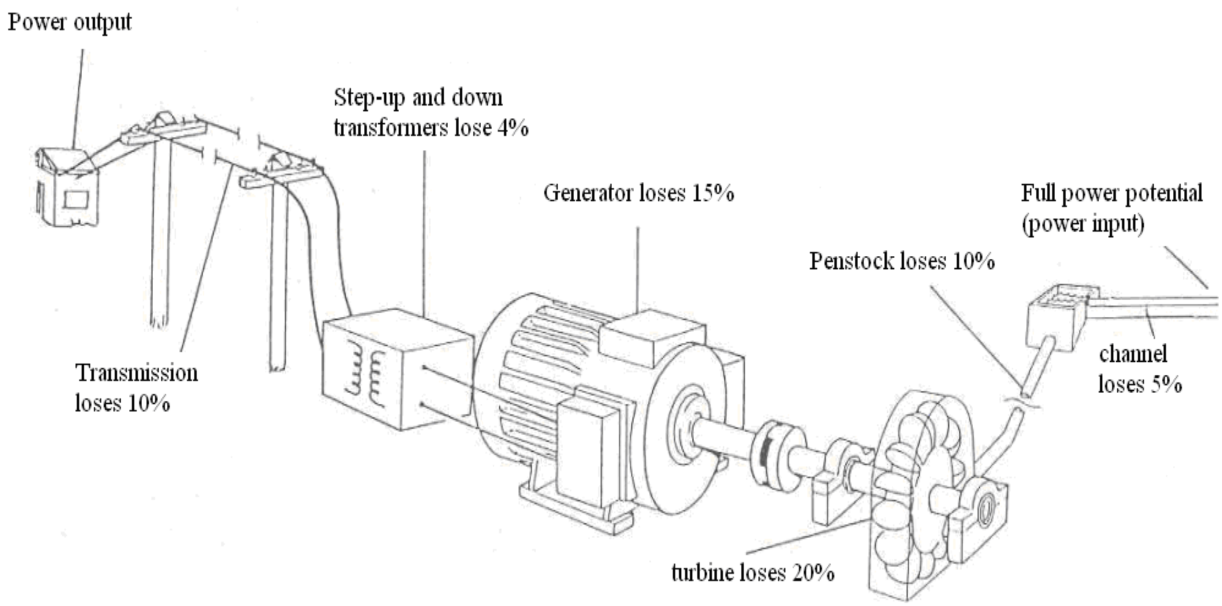


Figure 4. 2Typical system efficiency of micro- hydro power generation [9]

Hence, the actual power, p_{net} available from Meribo River micro hydro power generation is 9.688kW.

Capacity Factor

The plant capacity factor can be calculated by taking different factors in consideration. There are three lamps taking 7W power and functional one for four hours and two lamps for three hours each, radio/tape recorder taking 8W power functional for six hours in average, and television taking 32W power which is functional for eight hours estimated load per house hold (see table 3.1).

$$\text{Capacity Factor, C.F} = \frac{energy\ used}{energy\ available} \quad (4.12)$$

Using equation (4.13) capacity factor, C.F:-

$$C.F=\frac{\{\mathbf{0.028}\boldsymbol{k\ Wh}+\ \mathbf{0.021}\boldsymbol{k\ Wh\ x}\ \mathbf{2}+\mathbf{0.048}\boldsymbol{k\ Wh}\}\boldsymbol{x}\ \mathbf{245}\boldsymbol{households}+[\ \mathbf{0.48}\boldsymbol{k\ Wh}]\boldsymbol{x}\ \mathbf{245}\boldsymbol{households}}{\mathbf{23,2512}\ \boldsymbol{Wh}}$$

$$C.F = 0.63$$

The daily energy production become 9.688kW x 24hrs x 0.63 = 146.5k Wh/day

The annual energy production become 9.688kW x 8760hrs x 0.63 = 53,466.1344kWh/year

But daily energy consumption calculated is 96,191Wh/day and the annual energy consumption of the village is 34,628,760 Wh/year as calculated in the previous chapter.

Hence 18,837,374.4 W or 35.23% excess energy and the residents may use this energy for other works for instance stove for cooking.

4.3 Hydro Turbine Governor

Micro hydro power plant is the conventional source of energy. It has basically its two main sections, firstly the mechanical part of the plant which includes hydraulic turbine, penstock, controller, hydraulic servo motor, control valve etc. Second part of the plant is electrical section which mainly consists of generator and load. The combined form of hydraulic turbine, controller and hydro-electric servo system is known hydro turbine governor. In order to explain the mathematical modeling of hydro turbine governor, this chapter is introduced.

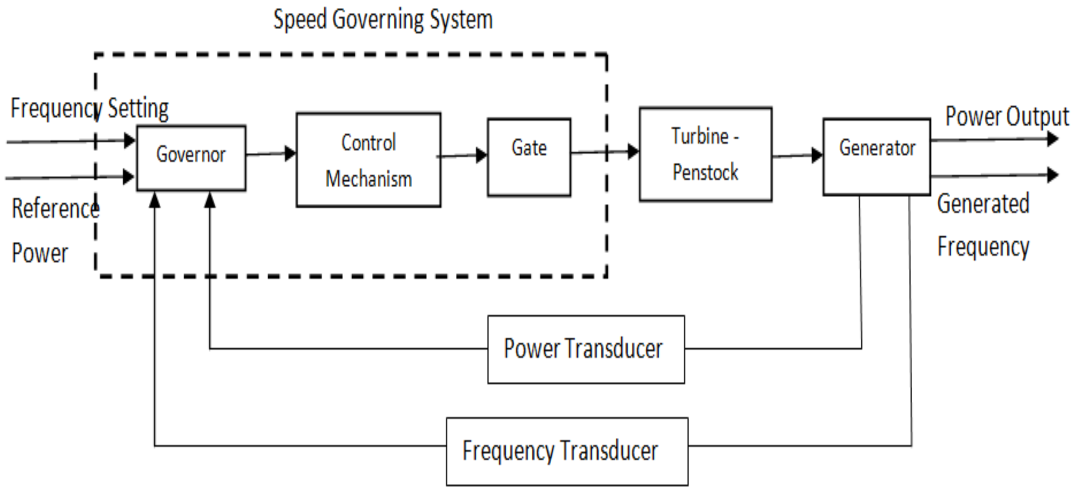


Figure 4.3 Functional Block Diagram of a Hydraulic Power Plant

The stored water at certain head contains potential energy. This energy is converted to kinetic energy. When it is allowed to pass through the penstock, this kinetic energy is converted to mechanical energy (rotational energy) which allows water to fall on the runner blades of the turbine. As the shaft of the generator is coupled to the turbine, the generator produces electrical energy by converting the mechanical energy into electrical energy. The speed governing system of turbine adjusts the generator speed based on the feedback signals of the deviations of both system frequency and power with respect to their reference settings. This ensures power generation at synchronous frequency.

4.3.1 Mathematical Model of Hydro Turbine Governor System

Due to variation of load throughout the day, the generated frequency of the system fluctuates. The hydro turbine governor is used to maintain a constant turbine speed hence the frequency and active power in response to load variation. The turbine governor regulates water input into a turbine, which in turn rotates the generator to produce electricity [3]. This section details the modeling of the mechanical-hydraulic turbine governing system. A mathematical representation of a hydraulic governing system including both the turbine-penstock and the governing system is introduced here. Hydro turbine governing systems are strongly influenced by the effects of water inertia [4, 8]. To adjust the gate opening of the wicket gate, the servomotor controls a pilot valve. The servomotor is activated by the signals generated from the turbine governor. Based on the assumption of short penstock, insignificant water hammer and incompressible flow of fluid through penstock is derived. It defines the characteristics of per unit turbine flow in terms of water time constant and head [3].

$$\frac{dq}{dt} = (Hs - H - Hl)\frac{gA}{L} \qquad (4.13)$$

Where

q = per-unit turbine flow

Hs = static head of the water column

H = head at the turbine admission

Hl = per-unit conduit head losses

L = length of conduit section

A = cross section area of the penstock

g = gravitational acceleration

The topography of the selected site is suitable for MHP plant construction; thus assume the conduit head loss negligible. Therefore, equation (4.13) rewritten as given below:

$$\frac{dq}{dt} = (Hs - H)\frac{gA}{L}) \qquad (4.14)$$

By using equation (4.14) per unit turbine flow can calculate as:

$$\frac{dq}{dt} = (Hs - H)\frac{gA}{L}) = \frac{(13-12.09)\ X\ (9.81m/s2\ X\ 0.0284m2)}{20m} = 0.0127\text{pu}$$

4.4 Modeling of Controller

The term PID is an acronym that stands for Proportional Integral Derivative. A PID controller is part of a feedback system that uses Proportional, Integral, and Derivative drive elements to control a process. These values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

Proportional Operation

- An error must be present!
- The system will try to correct the error by turning the motor in a direction that opposes the error with appropriate speed.
- The intensity of the correction is determined by proportional gain. If there is no error, there is no proportional drive.

Integral Operation

Integrating the error then provides a correction signal to the motor.

- An error must be present!

The integral section accumulates the error. A small error can become a large correction over time.
As the error is accumulated, the motor is forced to correct the error.
The integrator will overshoot the set-point. It must produce an error to counter act the input signal to discharge the capacitor.

Derivative Operation

When the motor starts to turn, the voltage measured by the resistor will be increasing or decreasing. If we have a voltage changing over a time, we have a ramp! The slope of this ramp changes with the speed of the motor. If the motor is moving quickly, the slope is high. Consequently, the output of the derivative stage will be high as well.

- The motor must be moving!

The differentiator will have a high output voltage when the motor is moving quickly and a low voltage when the motor is moving slowly.

Generally the PID controller is used as the controller. It can provide a controlled, almost-intelligent drive for systems. The error in speed is fed as input to the controller and PID controller attempts to reduce the difference between the actual speed and the reference speed by adjusting the constants of the controller [6].PID controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The output signal of the PID controller can be written in terms of the error signal as;

$$\theta(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \quad (4.16)$$

By taking Laplace transform on both sides of the equation (4.16) gives:

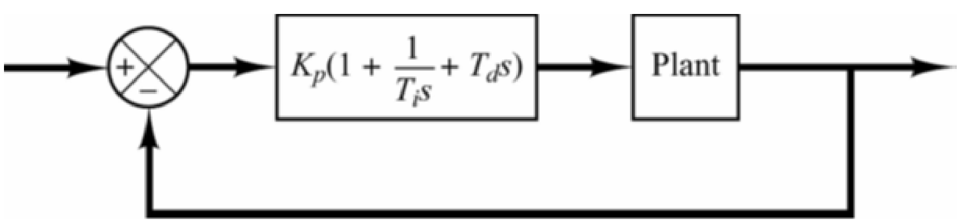
$$\theta(s) = k_p E(s) + k_i \frac{E(s)}{s} + k_d sE(s) \quad (4.17)$$

The transfer function of the PID controller is

$$C(s) = \frac{\theta(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \quad (4.18)$$

Where $\theta(s)$ the output of the PID controller represents position signal

PID can be tuned by operators without extensive background in Controls, unlike many other modern controllers (Full State Feedback) that are much more complex but often provide only slight improvement.



Where $C(s) = \frac{\theta(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s = k_p (1 + \frac{1}{T_i s} + T_d s)$

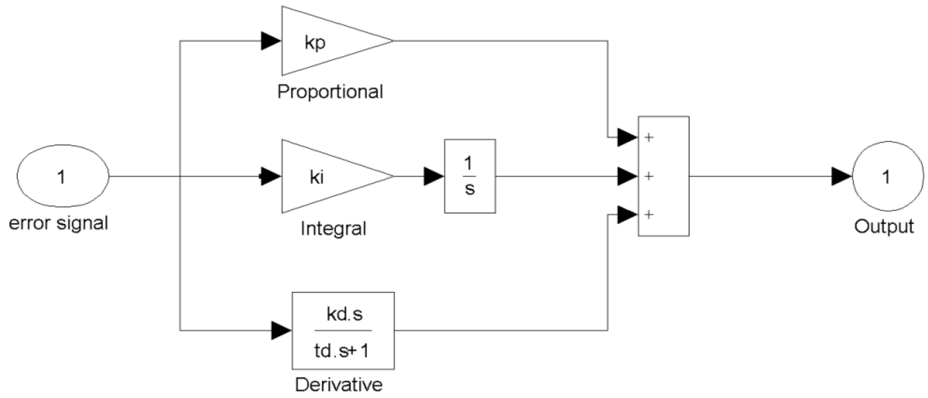


Figure 4.4 Simulink Model of a Controller

Most PID controllers are tuned on-site due to machine and process variations. The theoretical calculations for an initial setting of PID parameters can be by-passed using a few tuning rules. Using Ziegler-Nichols tuning method to determine an initial/estimated set of working PID parameters for the given system i.e. servo system. On MATLAB Simulink software, by tuning the controller parameter the values of K_p, K_i and K_d are becomes 1, 0.1 and 0.002 respectively.

4.5Modelling of Electro Hydro Servo System

The Servomotor block represents a brushless motor model with closed-loop torque control. This block abstracts the torque-speed behavior of the combined motor and motor driver in order to support system-level simulation where simulation speed is important [5].

In the model of hydro turbine governor servo motor is used to control the gate valve according to the signal of the controller. The controller nullifies the error in speed signal by sending a signal to the servo motor to control the valve. The torque of the motor is the function of speed and error signal.

$$T_m = f(\dot{\theta}, e) \qquad (4.19)$$

The torque (equation (4.19)) of the servo motor can be expanded using Tylor's series as shown in equation (4.20).

$$T_m = (t_a(0) + \frac{dta}{de}(e(t) - e(0)) + \ldots + \frac{dta}{d\dot{\theta}}(\dot{\theta}(t) - \dot{\theta}(0)) + \cdots \qquad (4.20)$$

By neglecting higher order terms and considering zero initial condition, Equation (4.20) can be rewritten as

$$T_m = (k_e(t) - f\dot{\theta}(t) \quad (4.21)$$

Where $k = \frac{dT_m}{de}$ *and* $f = \frac{dT_m}{d\theta}$

We know the mechanical relations for the motor is:

$$T_m = J\,\ddot{\theta} - B\dot{\theta} \quad (4.22)$$

Where *J and B* are friction coefficient and moment of inertia respectively. From equations (4.21) and (4.22) above we can derive the equation (4.23),

$$K_e(t) - f\dot{\theta}(t) = J\,\ddot{\theta} - B\dot{\theta} \quad (4.23)$$

Taking Laplace transform on both sides, we have

$$\frac{\theta_{(s)}}{E_{(s)}} = \frac{k}{Js^2 + (B+f)s} = \frac{k}{s(Js + B + f)} = \frac{k_a}{s(t_a s + 1)} \quad (4.24)$$

Where k_a andt_a are gain and time constant respectively.

$$t_a = \frac{1}{f} = \frac{1}{50Hz} = 0.02\text{sec and } K_a \text{ taken as } 3.33 \text{ [5]}$$

Here, servo motor controls the gate opening position according to change in speed at shaft of the generator to maintain the constant speed/frequency. Here, the change in speed of the generator acts as the control signal. Equation (4.24)[4] is the required transfer function to develop the complete block diagram [7] of the hydro-electric servo system shown on figure 4.5.

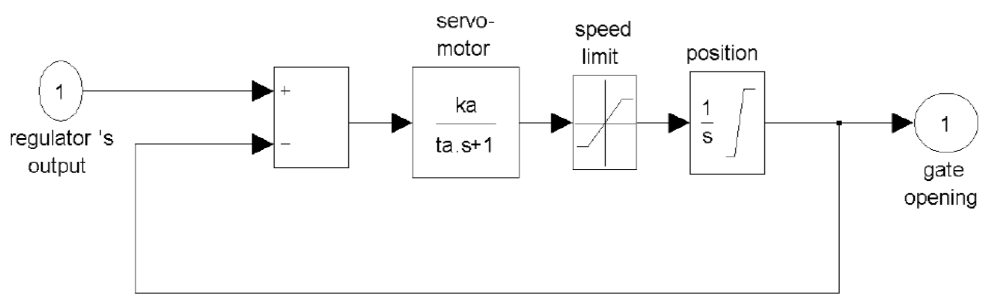


Figure 4.5 Model of Hydro-Electric Servo System

From figure 4.5 it possible to derive the equation of the system or plant. So that process (plant) servo motor becomes:

$$\text{From equation (4.24)}, \ \frac{\theta_{(s)}}{E_{(s)}} = C(s) = \frac{\mathrm{k_a}}{s(t_a s+1)} = \frac{3.33}{s(0.02s+1)} = \frac{3.33}{0.02s^2+s}$$

$$\text{Transfer function} = \frac{\text{Gate opening}}{error} = \frac{\frac{3.33}{0.02s^2+s}}{1+\frac{3.33}{0.02s^2+s}} = \frac{3.33}{0.02s^2+s+3.33} \quad (4.25)$$

4.6Modeling of Hydraulic Turbine

This section deals with the equations describing variation in flow and developed mechanical power with respect to the turbine speed, gate opening and runner blade movement of hydro turbine. Francis is used in range of application in the hydraulic industry because it performs its operation at highest efficiency comparatively other. So that Francis turbine is used in this modeling hence the pressure of the fluid will decrease during the passage of water flow through the turbine [2]. The output power of turbine is reduced due to fall of pressure across the turbine. As the developed power in the turbine varies with the flow rate, so the system operates or gains the steady state when the flow through the penstock gets constant.

The equations related to the transient performance of the hydraulic turbines are based on the following assumption [10].

- ✓ The hydraulic turbine`s blade is considered as smooth i.e. its frictional resistance is neglected.
- ✓ The water hammer on penstock is neglected.
- ✓ The fluid is considered as incompressible.
- ✓ The velocity of water in penstock varies directly with gate opening.
- ✓ The developed output power of turbine is proportional to the product of head and velocity of flow.

Equation (4.24) and (4.25) [11] represents the flow rate and the developed mechanical power at the shaft respectively in terms gate opening of the system and the net head.

$$Q = G\sqrt{H} \quad (4.26)$$

At maximum gate opening, G = 0.975rad:

$$Q = 0.975\sqrt{12.09} = 3.4\ m^3/sec \text{ and}$$

At minimum gate opening G = 0.01rad, $Q = 0.01\sqrt{12.09} = 0.035\ m^3/sec$

Where Q is flow rate in m^3/sec, G is gate opening in rad; H is net head in meter. The power developed in the turbine can be written as:

$$P_m = A_t H(Q - Q_{nl}) \tag{4.27}$$

Where, A_t is the turbine gain $A_t = \frac{1}{\overline{gFL} - \overline{gNL}}$, Qnlis the no load flow rate $\overline{gFL}$ *and* $\overline{gNL}$ the full load and no load gate opening in per-unit. Equation (4.25) is modified to describe the motion of the water in penstock to:

$$U = k_u G\sqrt{H} \tag{4.28}$$

Where, U is the velocity of the water in penstock and ku is a proportional constant.

The turbine gain, $A_t = \frac{1}{\overline{gFL} - \overline{gNL}} = \frac{1}{G\max - G\min} = \frac{1}{0.975\ pu - 0.01pu} = \frac{1}{0.965} = 1.0363pu$

Once the velocity of the water in penstock is determined, the relation of flow rate, head could be established equation (4.25) and (4.28).

$$Q = AU \tag{4.29}$$

The acceleration of the fluid in penstock is describe by equation (4.29)

$$\frac{dU}{dt} = -\frac{a_g}{L}(H - H_0) \tag{4.30}$$

Where a_g is the acceleration due gravity, L is the length of penstock.

Normalizing equation (4.25) about the rated values

$$\bar{H} = (\bar{U}/\bar{G})^2 \quad (4.31)$$

$$\frac{\bar{U}}{H - H_o} = \frac{-1}{T_w s} \quad (4.32)$$

Where, $\frac{LQ_r}{a_g A H_r}$ the water starting time at rated load. Q_r and H_r are rated water flow rate and head respectively.

$$Tws = \frac{20 \; x \; 0.158}{9.81 \; x \; 0.0713 \; x \; 12.09} = \frac{3.16}{8.46} = 0.374sec$$

The mechanical power output is given by:

$$P_m = A_t H(Q - Q_{nl}) \quad (4.33)$$

$$P_m = 1.0363 \text{ x } 12.09 \text{ x } (3.4m^3/s - 0.035m^3/s) = 42.2W$$

P_m= 42.2W which is maximum value.

The hydraulic characteristics and mechanical power output of the turbine is modeled here. The nonlinear characteristics of hydraulic turbine are neglected in this model. The complete block diagram of hydro turbine model is shown in Figure 4.6. The actuator’s (hydro-electric servo motor) output is the gate opening and it controls the valve to maintain a uniform speed by regulating the rate of water flow. The transfer function represented by Equation $\frac{-1}{T_w s}$ relates the flow rate Q and net head H. Here (H-H0) is entered as an input and the flow rate is the output signal of the transfer function. H has been assumed a static head with reference value of 1pu. Using a summation block, the signal (*H-H0*) is obtained. According to Equation $\frac{-1}{T_w s}$ is multiplied with the signal ($H-H_o$) and integrated to obtain the flow rate, Q. To find the actual water flow rate the no load flow is subtracted from Q using a sum block. Using the signal Q and 1/G and a product block, a new signal Q/G is produced, the square root of which gives the actual value of head, H according to Equation (4.25). Turbine frictional factor is neglected in this modeling. To get the value of P_m, Equation (4.26) is used. Equation (4.26) establish the relation between the develop power at turbine, actual water flow rate and the Head.

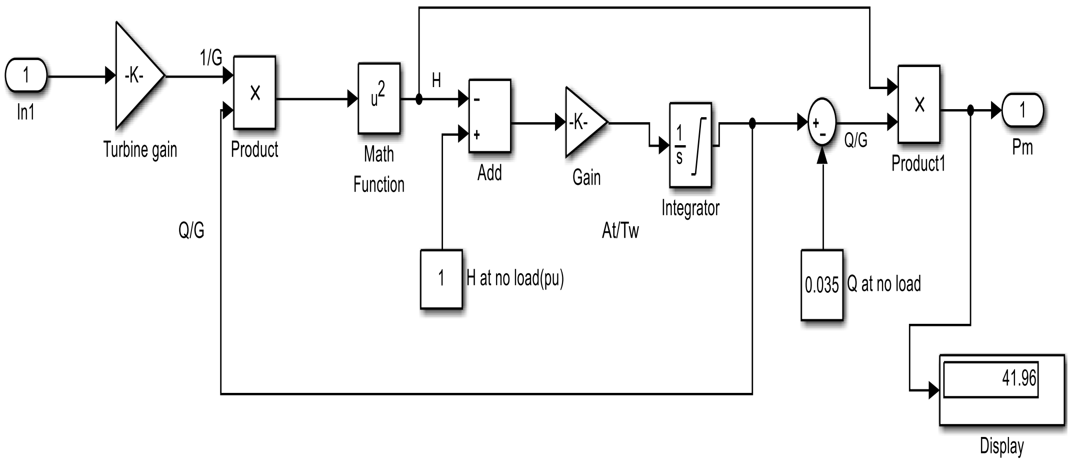


Figure 4.6 MATLAB/Simulink Model of Hydro Turbine

4.7 MATLAB/Simulink Model of Hydro Turbine Governor

Hydro turbine governor is a major part of hydro power plant. It is basically used for two purposes - firstly, it develops mechanical power at the shaft of the generator which is fed to the generator for production of electricity. And secondly, it controls the variation of speed of the generator such that the generated frequency remains constant. The PID controller, hydroelectric servo system and hydraulic turbine are the main components of the hydro turbine governor. The mathematical modeling and block formation has been done in the previous section of this chapter. These block model of components are connected in such a manner that the generated frequency remains constant. The block diagram of hydro turbine governor is shown in Figure 4.7. The first element of the governor is PID controller. The error in speed and deviation of power is entered as input to the controller, which generate the position signal at the input of the hydro-electric servo motor. Further the servo motor response by controlling the valve according to input signal to the servo mechanism. The valve is used to control the flow rate such that the generated frequency of the system remains constant.

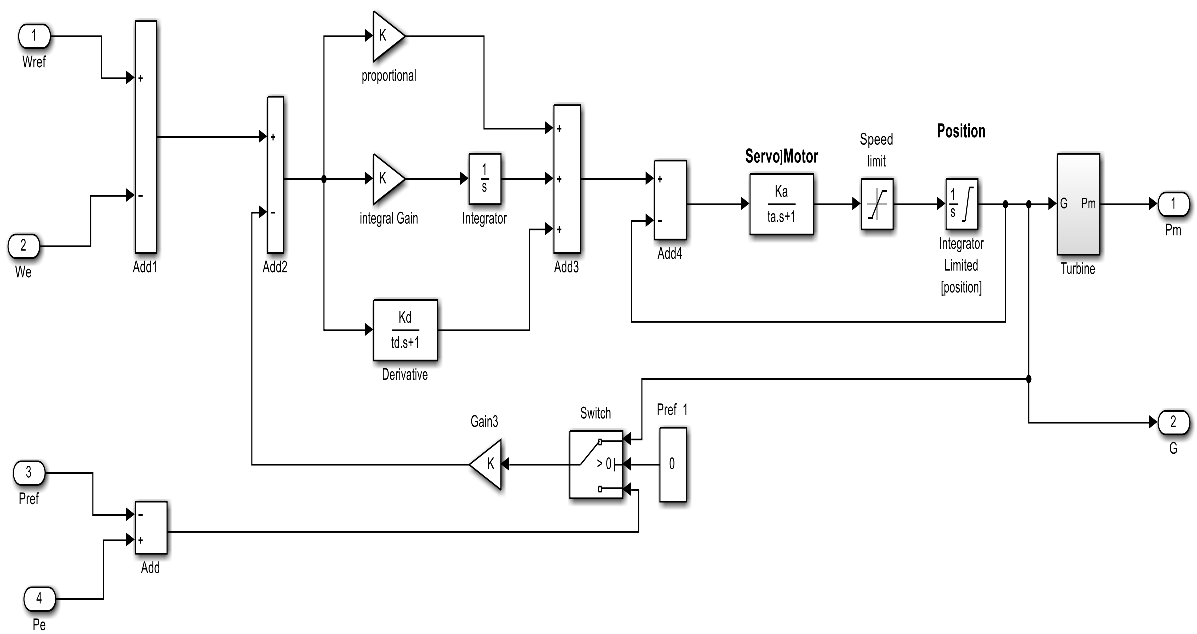


Figure 4.7 Block Model of Hydro Turbine Governor

4.8 Synchronous Generator Models

The rotor in a synchronous machine rotates in normal steady state with an angular velocity that corresponds to the electrical power frequency of the system. In modern synchronous machines, the field winding, in which the field current flows that generate the field flux, is on the rotor. This rotating flux, which is constant in steady state, induces through its rotation voltages in the three stator windings, one for each phase. The stator voltages, or generator terminal voltages, give rise to currents that then are transformed to power in the loads of the system. The voltages and currents in the stator windings give rise to a torque through the air gap flux that booms to retard the rotor. In steady state this torque must be compensated for by the mechanical torque from the prime mover of the generator. The prime movers, i.e. gas, hydro or steam turbines, drive the rotor through the turbine shaft so the rotor rotates with synchronous speed. By the definition, synchronous generators produce electricity whose frequency is synchronized with the mechanical rotational speed.

$$f_e = \frac{p}{120}\mathrm{N} \qquad (4.34)$$

Where fe is the electrical frequency, Hz;

N is the rotor speed of the machine, rpm;

p is the number of poles.

4.8.1 Model of Mechanical System

If the electrical frequency of the system is ω_e, the mechanical angular velocity ω_m of the rotor is:

$$\omega_m = \frac{\omega_e}{p/2} \tag{4.35}$$

Where P: Number of poles of the machine.

If there is a gear box in the system, it is of course difficult to define one mechanical angular velocity. In such a case inertia is calculated as the ratio between total stored kinetic energy and the MVA rating of the machine. The inertia constant states how long time it would take to bring the machine from synchronous speed to standstill if rated power is extracted from it while no mechanical power is fed into it. Table 4.2 shows typical values of inertia for different types of synchronous machines [21].Inertia constant of synchronous machine changes depending on size of machine which is huge or small. The inertia constant (H) is obtained as:

$$H = \frac{0.5 * J * \omega_{mo}^2}{S} \tag{4.36}$$

Where;

J is total inertia of rotor and turbine,

ω_{mo} is mechanical angular velocity,

S is total power (MVA) of machine

Table 4.2. Typical values of inertia, H for different types of synchronous machines [21].

Type of Synchronous Machine	Inertia Constant H (s)
Thermal Power: • Steam Turbine • Gas Turbine	4 – 9 7 – 10
Hydro Power: • Slow (< 200 rpm) • Fast (≥ 200 rpm)	2– 3 2 – 4

4.8.2 Model of Electrical System

The standard way to model synchronous machines is to transform the three physical phase quantities to two new components called direct and quadrature components, or d- and q-components, respectively by Park's transformation. It is also important to know that the reactance's in d-axis and q-axis are different, and are in steady state denoted as X_d and X_q, respectively.

4.8.3 Park's Model of Synchronous Machine

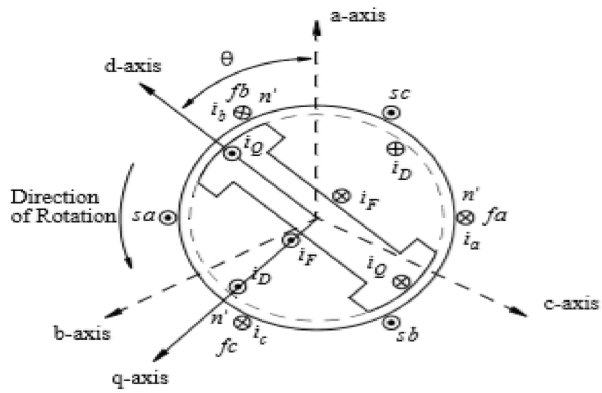


Figure 4.8 Schematic picture of a synchronous machine with salient poles is shown.

It is always the case that $X_d \geq X_q$ for machines with non-salient poles, i.e. most thermal units, $X_d \approx X_q$, while for salient pole machines, i.e. hydro units, the difference between X_d and X_q can be significant, see Table 4.3 [21].

Table 4.3. Typical values of reactance's for synchronous machines [21]

	Non Salient Poles	Salient Poles
X_d(p.u.)	1.0 – 2.3	0.6 – 1.5
Xq(p.u.)	1.0 – 2.3	0.4 – 1.0
X'_d(p.u.) (p.u.)	0.15 – 0.4	0.2 – 0.5

The synchronous machine model is simulated in MATLAB/Simulink software shown on Figure 4.9. This model is available as a single block with various terminals in MATLAB/Simulink library. The model takes into account the dynamics of the stator, field, and damper windings.

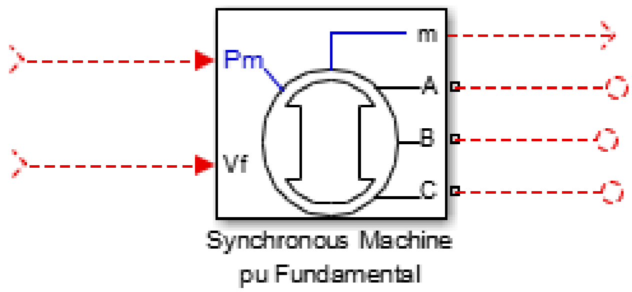


Figure 4.9 Block Diagram of Synchronous Machine

4.9. MATLAB/Simulink Model of Micro Hydro Power Plant

The individual sub-models like hydro turbine governor, synchronous generator, excitation system and 3-phase RLC load are now connected together to form the complete block diagram of micro hydro power plant shown in figure 4.10.

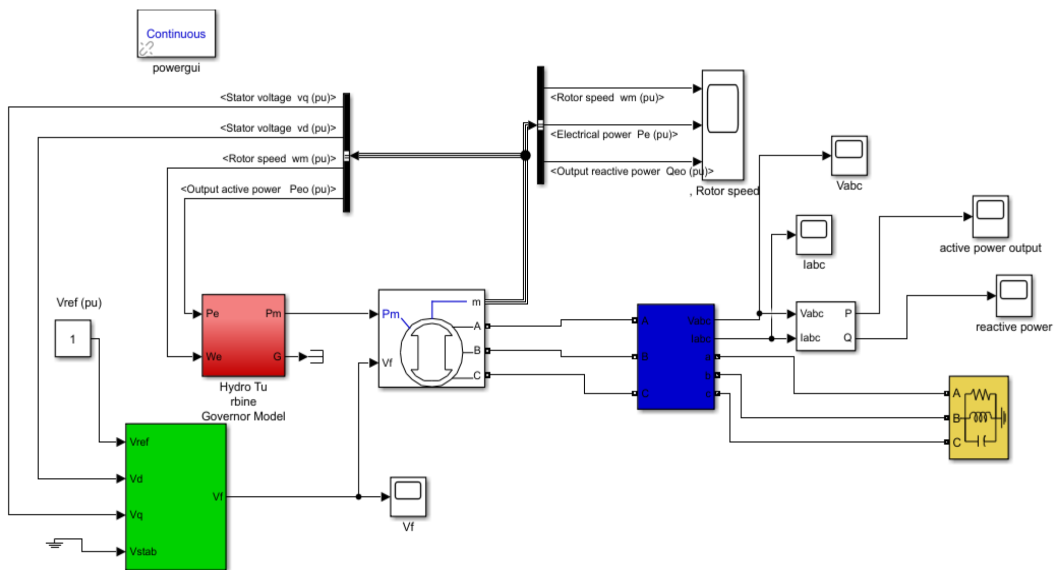


Figure 4.10 MATLAB/Simulink Model of a Hydro Power Plant

4.10Simulation Results of Micro Hydro Power Plant Model

The simulation results shows that with proper choice of governing system for micro hydro power plant leads to proper load sharing, constant voltage output and constant speed with variation of load values. In this thesis the simulation result shown from figures 4.11 up 4.15shown below.

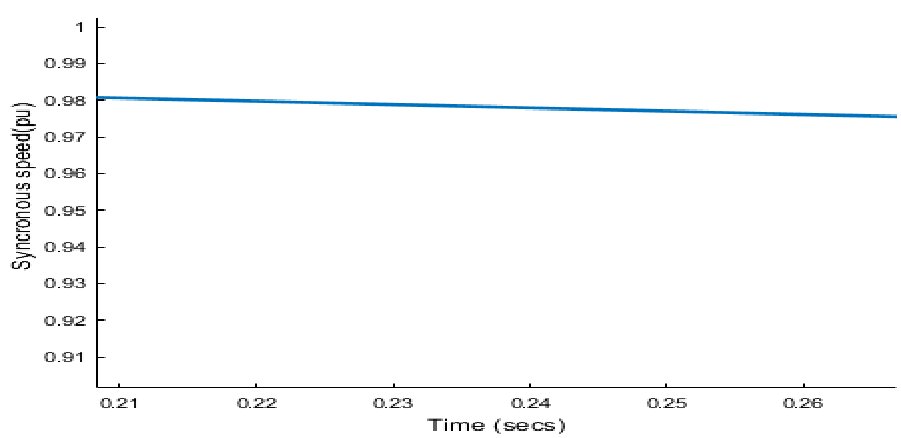


Figure 4.11 Synchronous Generator Speed Characteristics

The under damped rotor speed characteristic of hydro (synchronous) generator is shown in Figure 4.11. From the characteristics, it is saw that the transient time is less than 0.21sand its speed 0.98pu i.e.1470rpm reaches steady state at synchronous speed. With sudden application of mechanical torque input to the shaft of alternator, the load angle settles to a steady state value after few oscillations owing to system damping following the swing equation and power angle characteristics. Moreover, the governor setting K_p= 1 K_i = 0.1 and K_d= 0.002 chosen by trial and error method helps to keep the speed near synchronous speed (1500rpm).

But when derivative gain (K_d) increases, there is excessive oscillation of electrical power, mechanical power, rotor speed and gate opening for the constant proportional gain (K_p =1.0) and integral gain (K_i=0.1). This will possibly cause instability to the generating units. Therefore, a low value of derivative gain (K_d) is recommended.

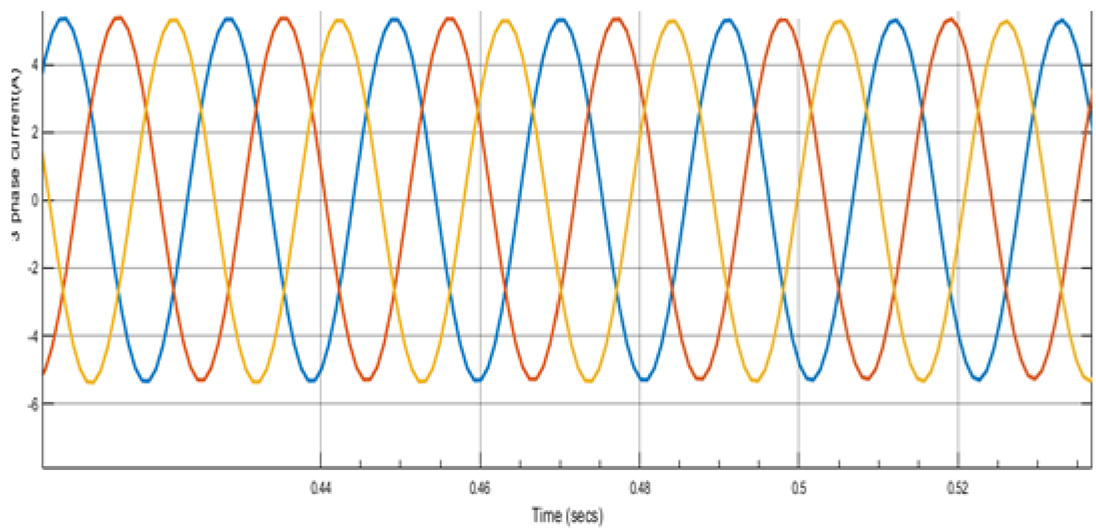


Figure 4.12 Stator Three Phase Current Characteristics for 0.02sec at Steady State

Figure 4.12 shows the stator current characteristics of the generator. When the load is changed, due to the presence of the transient and sub-transient reactance, envelop of three phase current shows under damped response at initial stage. After that it gains the steady state characteristics. It is observed from the plot that the transient period is very few seconds for three phase stator current.

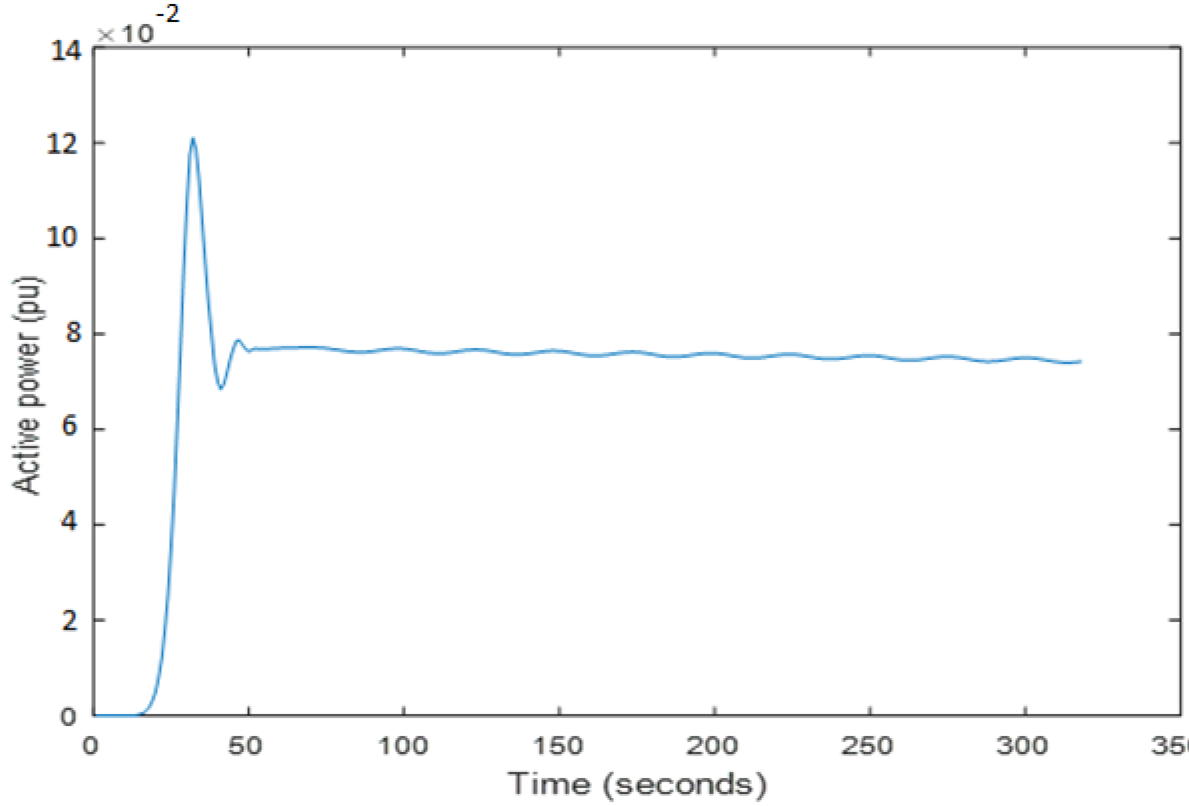


Figure 4.13 Active Power Characteristics of Hydro Power Plant

Active power characteristics figure 4.13 of synchronous generator, which shows a steady state value of 80kW is nothing but the average (actual) load connected to the plant. It is observed that the steady state is obtained around 40sec. To reach the stable operating point on power - angle characteristics, few oscillations around this point occurs. This leads to initial overshoots and undershoots of the power characteristics.

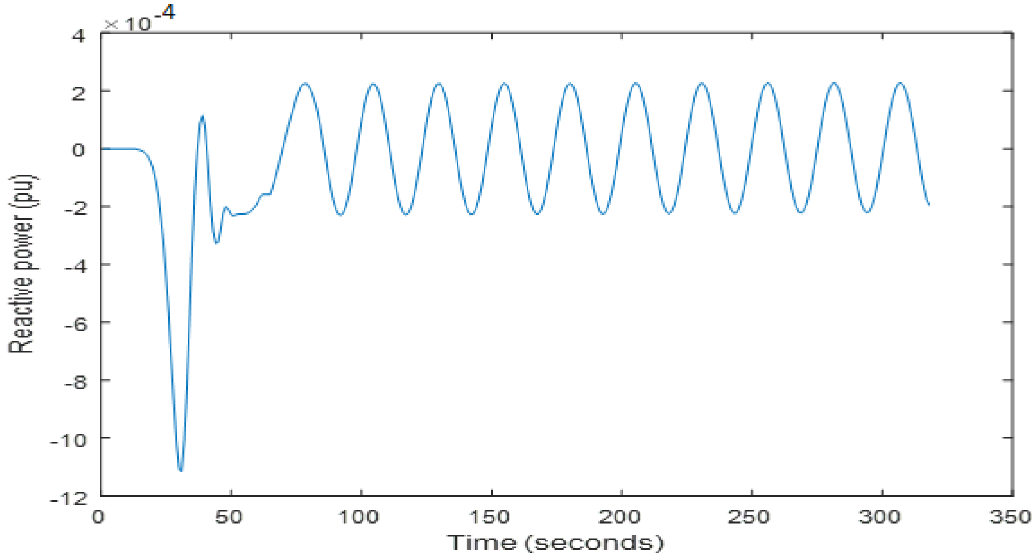


Figure 4.14 Reactive Power Characteristics of Hydro Power Plant

Figure 4.14 shows that the reactive power characteristics complete its transient period in 50 seconds and steady state value achieved is 0.209pu is obtained which matches the actual reactive load connected.

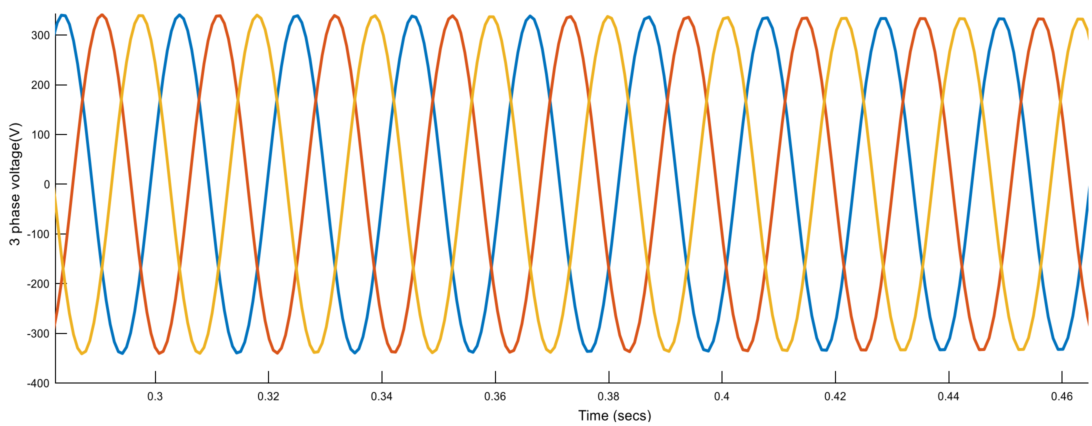


Figure4.15 Phase Voltage Characteristics of Stator

The stator phase voltages plot is shown in Figure 4.15. The magnitude of phase voltage observed is 0.95pu i.e. 380 Volt which is the rated voltage (Phase) output of the generator. It reaches steady state very quickly and follows a sinusoidal pattern during steady state. Three phase voltages lag each other by 120 degree.

CHAPTER 5

COST ANALYSIS

5.1 Cost Evaluation of Micro-Hydro Power Generation

5.1.1 Cost Calculation of Penstock [9]

The cost of penstock is determined after determining its weight. Cost of the penstock is Birr 18.00. Which means the total cost of the penstock becomes multiplication of a weight and cost per weight. The standard length of penstock is 2m and 12 joints are needed. Cost of flanges and bolts for each joint is estimated Birr 540.57 or US $ 20.02 per joint, and then total costs for all links will be Birr6, 486.84 or US $ 240.253. Hence, the total penstock cost for Meribo River micro hydro power generation roughly estimated reaches to approximately Birr 24,486.84or US $ 906.92.

5.1.2 Turbine (Cross Flow) Cost

The cost of a number of types of turbine is given in references [9] which are given in range with respect to the shaft power and the shaft power is calculated as 10kW.Hence, it is possible to get the cost of turbine for shaft power which is (US $ 5,000). Considering the inflation rate, transportation cost and taxation, the total cost rises to US $ 8250.00 or Birr 222,750.

5.1.3 Cost Generator

The design decision is compromise between trying to minimize capital costs and maximize efficiency and the number of generating units to ensure the best availability. Cost of synchronous generator depends size (rate). Accordingly the cost of synchronous generator /alternator is USD 556/kW [9]. The power demand is 43,289kWh/day; from this, it is possible to get the generator size that is sufficient for this power. After that consider, there is power loss in the transmission line, transformer, and generators itself, so, the generator rating will be 43,289kWconsidering by diversity factor and the power should be more than32, 466.75kW. So that the size of the synchronous generator will be between 32,466.75kW and 43,289kW.Thus the required generator cost calculated become approximately USD63, 384 but it is better, using updated cost information [5].The approximate cost must including inflation rate (25%), transportation cost (10%) and taxation (30%), respectively.

5.1.4 Civil Work cost

The cost of civil works varies depending on the general layout of the scheme, and it includes channel work, fore-bay tank, tail race, and power house. In calculation:

- Intake Facilities = 1,400 x H x L = 1400 x 1m x10m = 14,000
- Concrete Diversion canal = 11,300 x H x L = 11,300 x 1m x10m = 113,000

Where H: Height of canal = 1 meter

L: Length of Diversion = 10 meters

- Settling Basin = 372,600 x $Q^{0.504}$ x372,600 x $0.158^{0.504}$ = 147,016.5

  Where Q is Turbine Discharge = 0.158m^3/sec
- Penstock Civil Works = 5,300 x $\varphi^{0.571}$x L = 5,300 x0.426 x20 =45156

Where φ: Diameter of Penstock = 0.426m

L: Length of Penstock = 20m

- Power house Foundation (include tailrace) = 33,600 x $P^{0.456}$ = 33,600 x $9.866^{0.456}$ = 95,426.2 and
- Power house building = 16,900 x P + 139,900 = 16,900 x 9.866 +139,900 = 306635.4

  Where P: Maximum Output (kW) = 9.866kW

  Therefore, the total civil cost becomes 721,234.10 Birr.

5.1.5 Transmission Line cost

The finest approximate cost of transmission line including poles and cables will be [8]:-

$$\text{Transmission line cost} = 0.0011 \text{ x D x P x } L_t^{0.95} \text{ x Vx } 10^6 \qquad (5.1)$$

Where: D: Transmission line installation difficulty 1 to 2;

P: Reflect cost of wood vs. steel tower construction 0.85 if v < 69, 1.0 if v≥69;

V: Transmission line voltage (kV) which is V (0.38kV);

$L_{t:}$ Length of transmission line in (km).

By using equation (5.1) the transmission line cost calculated as:

Transmission line cost = 0.0011 x 1 x 0.85 x $(2)^{0.95}$ x 0.38kV x 10^6 = Birr 686,394.4Where the distance of load center 2km equal with Length of transmission line, L_t. Inflation, transportation and taxation cost should be into consideration.

If the Transmission line is extended from the main grid the total cost becomes:

$$\text{Cost} = 0.0011 \text{ x } D \text{ x } P \text{ x } L_t^{0.95} \text{ x } V\text{x } 10^6 = 0.0011 \text{ x } 1 \text{ x } 0.85 \text{ x } (15)^{0.95} \text{ x } 15\text{kv x}10^3$$

$$= \text{Birr } 4{,}960{,}818.412.$$

High difference of cost is visible; which is uneconomical. The recent cost of medium voltage transmission line is 2.802 US $/km which shows the expensiveness of long transmission line extension. Again the voltage drop also very high on long transmission line extension.

The voltage drop, Vd calculation for 3-phase transmission line is as follow

$$Vd = \sqrt{3} x I x R x \, {}^{L}/_{CM} (\text{volts}) \qquad (5.2)$$

Where R = (12.9 Ω for copper wire) or (21.2 Ω for aluminum wire) resistance constant

L = length of the line from the micro-hydro power station to the load site which is 6561.68ft or 2km

I = load current in amperes

CM = conductor wire size in Circular-Mills. Mostly EEP uses 95mm^2 size of wire for 15kV voltage level. Where the circular mil or CM is a unit of area that's used when denoting the cross sectional size of something circular in shape — such as a wire. Assume #1 AWG THHN aluminum conductor with cmil = 83,690 cmil will be used [26].

Therefore; $V_d = \sqrt{3} x I x R x \, {}^{L}/_{CM} = \sqrt{3} x 0.5A x \; 21.2 \; \Omega x \; {}^{6,561.68ft}/_{83,690}$ = 1.44Volt

But if the electric line is extended from the grid; the voltage drop becomes:

$V_d = \sqrt{3} x I x R x \, {}^{L}/_{CM} = \sqrt{3} x 0.5A x \; 21.2 \; \Omega x \; {}^{51,181.1ft}/_{83,690}$ = 11.215Volt

The high difference is visible on voltage drop. So that it is better to use the indicated micro hydropower on Meribo River.

5.1.6 Installation Cost

Installation cost of the micro hydro power generation is approximated as 20% of the total cost of the equipment [8]. Hence, it becomes US Dollar 327.8284 or Birr 8,851.367

Table 5.1 Total cost estimation for the micro hydro power generation

<table>
<tr><th>No.</th><th colspan="2">Component Description</th><th>Unit price [Birr]</th><th>Total Price [Birr]</th></tr>
<tr><td>1</td><td colspan="2">Penstock</td><td>24,486.84</td><td>24,486.84</td></tr>
<tr><td>2</td><td colspan="2">Cross Flow Turbine</td><td>222,750.00</td><td>222,750.00</td></tr>
<tr><td>3</td><td colspan="2">Motor as generator</td><td>8500.00</td><td>8500.00</td></tr>
<tr><td>4</td><td colspan="2">Transmission Line</td><td>44,256.83</td><td>44,256.83</td></tr>
<tr><td>5</td><td colspan="2">Controller /frequency and voltage/</td><td>32,600.00</td><td>32,600.00</td></tr>
<tr><td colspan="4">Total cost of equipment</td><td>332,593.67</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Civil cost</td><td>Intake Facilities &Settling Basin</td><td>161016.5</td><td rowspan="2">721,234.10</td></tr>
<tr><td>Concrete Diversion canal and Penstock Civil Works</td><td>158156</td></tr>
</table>

	Power house Foundation (include tailrace)	95,426.2	
	Power house building	306635.4	
7	Installation cost [20% of total equipment cost]	66,518.73	66,518.73
8	Compacted type fluorescent 45lamps for school and 2lamps for clinic [11W]	120	5,640.00
9	Lamps cost 3per house hold	75	18,375.00
10	Miscellaneous cost [8% of total cost of equipment]	26,607.49	26,607.49
Subtotal			117,176.22
Total Cost of the System			1,136,003.99

So that for individual household, the total cost for this micro hydro power generation will be total cost of the system divide to number of households 4636.75 Birr.

5.2 Financial Evaluation

The economy feasibility of the different option of rural electrification having different life span cannot be compared using common feasibility indicators such as internal rate of return, net present value and pay-back . Hence, the method used in this study the different option is using the electricity service cost either in monthly or unit energy basis. The monthly energy cost which hast to be beard by the customer is calculated from the annual cost of the investment and annual operating cost which is mainly maintenance cost. Similarly, the unit energy cost can be calculated by dividing the total annual cost by the energy generated per annum.

$$C_A = \frac{C_I}{\frac{(1+i)^n - 1}{i(1+i)^n}} + C_m \qquad (5.2)$$

Where:

C_A = Annual payment

C_l= Capital cost

n = life span

C_m = maintenance cost

i = interest rate

The unit energy cost (price) is determined by dividing the total annual cost by the total of electrical energy generated per year.

5.2.1Micro Hydro Power Generation capital cost

The initial capital cost of Meribo River micro hydro power generation system is Birr 1,136,003.99. The annual maintenance cost of micro hydro power generation is usually taken as2% of the initial investment cost of the system [5]. Hence, annual maintenance cost will be Birr 22,720.08. Then depending on equation (5.2) total annual payment cost of plant is:-

$$C_A = \frac{C_l}{\frac{(1+i)^n - 1}{i(1+i)^n}} + C_m = \frac{1,136,003.99}{\frac{(1+0.1)^{25} - 1}{0.1(1+0.1)^{25}}} + 22,720.08 = 147,872.00\text{Birr}$$

Annual payment cost per household = $\frac{147,872.00}{245}$= 603.56Birr or

Monthly payment cost per household = 50.30 Birr.

The annual cost calculated above is not difficult for the user /customer/.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Micro-hydro-electric power is both an efficient and reliable form of clean source of renewable energy. It can be an excellent method of harnessing renewable energy from small rivers and streams. The micro-hydro power have designed to be a run -off-river type within small diversion, because it requires very little or no reservoir in order to power the turbine. The water will run straight through the turbine and back into the river or stream to use it for the usual purposes. The modeling of micro hydro power plant is done in this thesis by using MATLAB/Simulink. Introduction of micro hydro power plant reduces a lot of burden without any adverse effect on environment while meeting the localized power requirement. The simulation results shows that with proper choice of governing system for micro hydro power plant leads to constant voltage output and constant speed with variation of load values. This leads to an economical operation of the system.

Hence, the above result visualizes feasibility of electric generating potential of the river and micro hydro power generation at Meribo River has good flow rate or discharge which can use for excess electric energy production for the electrification of Chumlugo Village and it is preferable to construct micro hydro power generation at the specified site. There is always a maximum useful power output available from a given hydro power site, which limits the level of expansion of activities which make use of the power. When micro hydro power generation is considered at the given site within magnitude of 9.37kW concluded that it has capacity to electrifying the given village.

6.2 Recommendation

Besides this research work, it has seen that Ethiopia has a huge potential for rural electrification through the off grid system. There are, however, formidable challenges like unfavorable public attitude towards the private sector and unfair regulations that work against growth and distribution of renewable energy technologies. It is thus recommended that the government, non-governmental organizations and the public make mutual efforts to overcome these challenges by using more flexible approaches to improve the current awful state of rural electrification in Ethiopia. Since the government cannot simply afford to electrify rural areas of Ethiopia, such like Meribo River which can help to generate good and enough energy to electrify the village round it, has living without giving an expected energy.

Therefore the maximum effort must be exerted to change the prevailing attitude towards the private investors and help the private sector in all possible ways beyond designing policies. This study shows only the selected sites of Ethiopia and it doesn't represent all areas of the country. So, the future researchers should expand this research work in other sites and make the rural people beneficial. Finally, it recommended that this research work can be changing in to project and will be doing by another researcher or organization.

REFERENCES

[1] Aklilu Dalelo, *Rural Electrification in Ethiopia*: opportunities and bottlenecks, Addis Ababa University, College of Education

[2] Dilip Singh, Micro Hydro Power Resource Assessment Handbook. 2009.

[3] Delson Josel, Lini Varghese, Renjini G., Design of Small Hydro Electric Project Using Tailrace Extension Scheme, *International Journal of Advanced Research in Electrical and Electronics Engineering, Volume 3,* (2014).

[4] Agbeko, E.K, *MSc thesis on Small Scale Wind Turbines*, University of Strathclyde, Department of Mechanical Engineering, 2005

[5] Bilal Abdullah Nasir, Design of Micro - Hydro -Electric Power Station, International Journal of Engineering and Advanced Technology, Volume 2, (2013),

[6] Berhanu Adane, Eyasu chirko (1997): *Report on small hydro power sites Investigation in East And West Gojjam*, May 1997, Addis ababa

[7] Benaim Abate, MSc Thesis on "*Design of Micro-Hydro Turbine Suitable for Most Ethiopian Sites",* June 2004

[8] Canadian Energy Research Institute Electricity Generation Technologies: *Performance and Cost Characteristics*, Prepared for the Ontario Power Authority, August 2005

[9] CRES, K., *Guide book on the Renewable Energy System Power Generation Technology***,**

August2001, Athens

[10] Ethiopian energy access: Baseline survey monitoring and Evaluation frame work Hydro Market development strategy. Part II, Final Report, may 2003

[11] Harvey, A., Brown, A., Hettiarachi, P., A (1998): *Micro Hydro design manual, a Guide to small Scale water power schemes,* Intermediate Technology Publications

[12] Oliver, P. (2002): Micro-hydro Power status and prospect UNCC, Addis Ababa, 21-22 March 2002 (figure of efficiency of turbines) [Online] www.greenliving.co.uk

[13] *Role of mini and micro hydro power plant for rural Ethiopia*; A case study, Jan 31, 1992.

[14] Somaraki, M., *MSc thesis on A Feasibility Study of a Combined Wind – Hydro Power Station in Greece*,University of Strathclyde, Department of Mechanical Engineer, October 2003

[15] Ermias Tenkir, "Financial and Economic Analysis of Small Hydropower in Ethiopia," August 2014.

[16] KENENI, "Potential Assessment of Micro Hydropower for rural electrification in Some selected Sites of Genale-dawa basin, Ethiopia," August 2007.

[17] Melessaw Shanko, "Ethiopia‟s Small Hydro Energy Market Target Market Analysis Author," December 2009.

[18] CSA Federal Democratic Republic of Ethiopia Central statistical agency, "Population projection of Ethiopia for all regions at woreda level from, 2014-2017.," 2013.

[19] Ethiopian Electric Agency (EEA), "The Electricity Proclamation No. 86/1997 That Ethiopian

Electric Agency (EEA) Established in," Ethiopian, June 1997.

[20] Zelalem, Micro-hydropower under Ethiopian condition, 1992.

[21] U. Stephen D, Fitzgerald & Kingsley's electric machinery, New York: McGraw-Hill, 2014.

[22] 2007 Population and Housing Census of Ethiopia: Results for Oromia Region, Vol.1 Archived 2011.

[23] https://www.google.com/search?q=US+Army+corps+of+engineers+manual 19881, Sept. 2018

[24] An international hydropower industry guide as compiled by The International Journal of Hydropower and Dams – mainly oriented towards larger companies and Projects. http://www.hydropower-dams.com

[25] Http // practicalaction.org/education/ sustainable_design_technology, September 20, 2018.

[26] Http//file:///G:/Users/DELL/Desktop/december%20freq/Voltage-Drop.pdf

APPENDIX-A: - Annual report of daily flow rate data of Meribo River

Station Number: 061002 Year: 2009 G.C[source: - **Ministry of water, irrigation and energy]**

Station Name: Meribo nr. Adaba

Time-Series Type: Flow (cumecs = cubic meter per second)

Latitude: 7: 0: 0 N   Longitude: 39:20: 0 E   Area: 185.0 sq. km

Table A-1 Daily flow rate of Meribo River

Date	**Year 2009**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.419	0.308	0.265	0.265	1.636	3.178	3.632	13.32	11.593	9.979	1.554	0.717
2	0.414	0.299	0.236	0.248	1.997	3.493	3.697	12.92	11.012	11.489	1.464	0.743
3	0.384	0.278	0.209	0.329	2.079	2.601	4.021	9.802	10.778	9.901	1.554	0.743
4	0.374	0.304	0.205	0.577	2.259	2.113	5.084	9.089	10.876	7.527	1.554	0.704
5	0.345	0.336	0.213	0.724	1.991	1.587	10.96	8.743	8.092	5.522	1.446	0.698
6	0.345	0.35	0.261	0.667	2.756	1.455	9.539	9.855	7.384	4.647	1.502	0.691
7	0.369	0.415	0.269	0.433	3.208	1.429	7.881	8.012	6.429	4.064	2.087	0.653
8	0.376	0.451	0.265	0.291	2.987	1.394	6.217	6.909	5.641	3.553	2.837	0.641
9	0.602	0.42	0.244	0.299	3.284	1.177	5.158	5.996	5.559	3.221	2.136	0.604
10	0.875	0.379	0.273	0.318	5.046	1.066	4.516	6.203	8.077	2.939	1.818	0.598
11	0.909	0.345	0.322	0.432	6.858	1.266	3.981	8.487	9.032	2.704	1.852	0.592
12	0.859	0.341	0.278	0.656	5.577	2.221	3.618	10.1	8.06	2.334	2.581	0.563
13	0.784	0.331	0.257	1.109	4.36	3.599	3.36	12.67	7.403	2.258	2.554	0.592
14	0.611	0.278	0.187	2.147	3.177	5.286	3.999	16.34	6.444	2.487	2.366	0.592
15	0.506	0.265	0.179	1.352	2.105	5.34	4.945	14.8	6.493	2.398	2.141	0.557
16	0.435	0.24	0.201	1.394	1.137	5.484	4.898	15.23	6.345	2.365	2.048	0.545
17	0.462	0.232	0.197	1.338	1.369	4.419	4.177	13.19	5.206	2.3	2.037	0.511
18	0.505	0.216	0.162	0.816	1.292	3.887	3.489	11.4	4.573	2.51	1.997	0.505
19	0.539	0.256	0.197	0.641	1.16	3.138	3.184	10.1	4.413	4.377	1.723	0.505
20	0.505	0.244	0.201	0.523	1.066	2.672	2.856	8.029	4.371	7.495	1.456	0.505

21	0.462	0.265	0.186	0.505	1.113	3.592	3.383	7.328	5.144	7.69	1.343	0.505
22	0.425	0.265	0.224	0.529	0.932	5.024	4.756	7.436	11.951	8.061	1.177	0.505
23	0.414	0.244	0.205	0.78	0.831	5.278	4.386	8.633	15.242	6.773	1.105	0.5
24	0.384	0.265	0.183	1.625	0.902	4.898	4.299	17.25	12.564	5.804	1.089	0.467
25	0.374	0.269	0.197	2.316	1.053	4.545	4.8	15.59	10.151	4.57	1.028	0.462
26	0.35	0.269	0.176	1.717	2.053	3.819	7.663	15.33	7.699	3.178	0.931	0.456
27	0.374	0.265	0.158	1.353	2.652	3.578	9.111	15.68	7.819	2.727	0.902	0.425
28	0.374	0.244	0.201	1.045	1.769	3.657	8.378	18.08	7.264	2.388	0.831	0.419
29	0.345		0.228	0.832	1.438	3.334	9.216	21.06	8.842	2.111	0.888	0.419
30	0.341		0.216	0.909	1.3	3.124	11.41	16.37	11.867	1.809	1.012	0.419
31	0.336		0.261		1.51		11.52	11.41		1.721		0.388
Mean	0.477	0.298	0.221	0.872	1.609	3.298	5.476	11.82	8.226	4.763	1.653	0.569
Flow (MCM)	1.279	0.746	0.592	2.261	4.31	8.549	14.67	31.65	21.323	12.757	4.285	1.524
Maximum	0.909	0.451	0.322	2.316	2.861	5.484	11.41	21.06	15.242	11.489	2.837	0.804
Minimum	0.336	0.216	0.158	0.248	0.831	1.066	2.856	5.996	4.371	1.809	0.831	0.419
Runoff (mm)	6.912	4.034	3.202	12.223	23.295	46.21	79.28	171.1	115.26	68.959	23.16	8.239

MCM = *Million Cubic Meters, flow (MCM) = mean*60sec *60min *24hrs *number of days in a month*

Mean = sum of daily flow rate divide to number of days in a month.

Table A-2 Annualmonthly average flow rate of Meribo River since 2007 to 2009

Annual Report of Monthly Data: Instantaneous Monthly Flow												
Station Number : 061002												
Mean	0.424	0.26	0.903	2.117	7.73	1.395	5.783	10.46	6.946	5.259	1.219	0.437
Flow (MCM)	1.137	0.629	2.419	5.488	20.704	3.615	15.488	28.01	18.004	14.086	3.159	1.169
Maximum	0.283	0.176	0.304	0.205	3.133	0.866	1.495	6.461	3.574	1.263	0.647	0.304
Minimum	0.336	0.216	0.158	0.248	0.831	1.066	2.856	5.996	4.371	1.809	0.831	0.419
Mean	0.243	0.397	0.818	4.593	5.134	2.33	6.738	10.83	7.038	6.735	2.3	1.607

Flow (MCM)	0.652	0.96	2.19	11.91	13.75	6.04	18.047	29.01	18.243	18.04	5.962	4.305
Maximum	0.304	1.111	2.132	9.382	14.089	5.916	15.875	17.03	10.633	18.463	6.298	4.544
Minimum	0.205	0.148	0.19	1.581	1.209	1.035	1.857	5.438	3.423	3.482	1.144	0.604
Mean	0.477	0.299	0.221	0.872	1.609	3.298	5.476	11.82	8.226	4.763	1.653	0.569
Flow (MCM)	1.279	0.746	0.592	2.261	4.31	8.549	14.667	31.65	21.323	12.757	4.285	1.524
Maximum	0.909	0.451	0.322	2.316	2.861	5.484	11.406	21.06	15.242	11.489	2.837	0.804
Minimum	0.336	0.216	0.158	0.248	0.831	1.066	2.856	5.996	4.371	1.809	0.831	0.419
Mean	0.381	0.319	0.647	2.527	4.824	2.341	5.999	11.04	7.403	5.586	1.724	0.871
Flow (MCM)	1.023	0.778	1.734	6.551	12.921	6.068	16.067	29.56	19.19	14.961	4.469	2.333
Maximum	0.807	0.687	1.614	7.043	11.342	4.82	15.521	19.01	12.997	15.123	3.961	2.005
Minimum	0.275	0.18	0.217	0.678	1.724	0.989	2.069	5.965	3.789	2.185	0.874	0.442

APPENDIX-B: - Population Data

Table B-1 Population data from Statistical agency of Ethiopia

የክልል የዞን ና የወረዳ የሕዝብ ብዛት ትንበያ በጾታ በገጠርና ከተማ ሐምሌ 2006

Populaion projection values of 2014 at zonal and wereda levels by urban and rural residence and by sex.

TABLE-1 (Cont'd)

ክልል/ዞን/ወረዳ	ጠቅላላ የሕዝብ ብዛት በጾታ			የከተማ ሕዝብ ብዛት በጾታ			የገጠር ሕዝብ ብዛ	
	ወንድ	ሴት	ድምር	ወንድ	ሴት	ድምር	ወንድ	ሴት
Guji-Zone								
Zone Total	**847,424**	**833,435**	**1,680,859**	**93,934**	**87,916**	181,850	**753,492**	**745,5**
Uraga-Wereda	105,651	105,642	211,293	5,495	5,213	10,708	100,156	100,4
Bore-Wereda	126,540	125,683	252,223	7,400	6,966	14,366	119,140	118,7
Adola-Wereda	66,381	64,528	130,909	-	-	-	66,381	64,5
Wadera-Wereda	30,956	30,187	61,143	3,386	3,237	6,623	27,570	26,9
Odo Shakiso-Wereda	130,896	121,695	252,591	25,074	22,028	47,102	105,822	99,6
Kercha-Wereda	136,157	136,435	272,592	6,979	6,866	13,845	129,178	129,5
Liben-Wereda	83,352	82,091	165,443	907	1,034	1,941	82,445	81,0
Dima-Wereda	33,549	34,449	67,998	978	1,038	2,016	32,571	33,4
Hambela Wamena-Wereda	62,176	63,072	125,248	1,239	1,126	2,365	60,937	61,9
Girja-Wereda	30,005	29,901	59,906	714	654	1,368	29,291	29,2
Negele/Town/- Wereda	25,497	23,888	49,385	25,497	23,888	49,385	-	
Adola/Town/- Wereda	16,264	15,864	32,128	16,264	15,864	32,128	-	
Adama Special- Zone	**151,266**	**157,260**	**308,526**	**151,266**	**157,260**	308,526	-	
Adama wereda	151266	157260	308,526	151,266	157,260	308,526	-	
Jima Special - Zone	**84,508**	**84,938**	**169,446**	**84,508**	**84,938**	169,446	-	
Jima/Town/wereda	84,508	84,938	169,446	84,508	84,938	169,446	-	
West Arsi-Zone								
Zone Total	**1,183,540**	**1,210,670**	**2,394,210**	**192,186**	**188,927**	381,113	**991,354**	**1,021,7**
Siraro-Wereda	85,536	88,851	174,387	3,587	3,658	7,245	81,949	85,1
Shala-Wereda	89,742	90,108	179,850	5,658	5,096	10,754	84,084	85,0
Arsi Negele-Wereda	158,131	162,253	320,384	35,563	36,637	72,200	122,568	125,6
Kofele-Wereda	108,156	108,003	216,159	11,504	10,124	21,628	96,652	97,8
Kore Wereda	61,751	62,805	124,556	4,068	3,482	7,550	57,683	59,3
Gedeb Asasa-Wereda	111,853	114,890	226,743	14,541	14,408	28,949	97,312	100,4
Dodola-Wereda	116,375	121,430	237,805	24,435	23,396	47,831	91,940	98,0
Kokosa-Wereda	83,453	89,219	172,672	2,476	2,037	4,513	80,977	87,1
Nensebo-Wereda	68,242	69,339	137,581	4,320	4,179	8,499	63,922	65,1
Adaba-wereda	**82,844**	**84,755**	**167,599**	**8,442**	**8,507**	**16,949**	**74,402**	**76,2**
Shashemene /Town/-Wereda	70,378	70,339	140,717	70,378	70,339	140,717	-	
Shashemene Zuria-Wereda	147,079	148,678	295,757	7,214	7,064	14,278	139,865	141,6