ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Mechanical and Industrial Engineering (SMIE)
(Thermal and Energy Conversion Chair)

Modeling and Simulation of a Micro-Hydropower System for Rural Electrification
[A Case Study of Temcha River, Ethiopia]

By: GETNET BELIE

Advisor: - Dr. Tilahun Nigussie.

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial Fulfillment of the Requirements for the Degree of Master of Science in Thermal Engineering

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DECLARATION

This is to declare that the paper presented by Getnet Belie Endalie, titled ‘’***Modeling and Simulation of a Micro-Hydropower system for rural electrification in the case of Temecha River*** ‘’submitted to the school of Mechanical and Industrial Engineering in the partial fulfillment of the requirements for the award of the degree of Masters of Science in Thermal Engineering with the rule of the university, and meets acceptable standards with respect to quality and originality.

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Approved by Board of Examiners

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ABBREVIATIONS

MHP=Micro-hydro power
MoWIE=Ministry of Water, Irrigation and Energy
GOE's=Government of Ethiopia
KW=kilo watt
Q_f=firm flow
Q_d=design flow rate
H_g= gross head
ρ=density of water
g=acceleration due to gravity
D_p=diameter of penstock
t_p=thickness of penstock
n_p=manning roughness coefficient
Lp=length of penstock
h_t=height of the inlet entrance
V_a=allowable air velocity
Q_a=allowable air flow rate
A_a=area of air vent
D_a=diameter of air vent
L_b=length of bar for trash rack
b=spacing between two bars
H_n=net head
h_e= head losses in the entrance stage
h_r=head losses in the trash rack
h_g=head losses in the gates
h_f=head losses in the penstock
d=runner throat diameter
N_p= specific speed of turbine
N= speed of turbine in R.P.M
δ_T=the Thoma's sigma coefficient for Kaplan turbine
$^\wedge e_{nq}$=specific speed adjustment to peak efficiency
$^\wedge e_d$=runner size adjustment to peak efficiency
e_p=turbine peak efficiency
R_m=turbine manufacturer design coefficient
Q_p=peak efficiency flow
e_q=efficiency at flows above and below peak efficiency flow
$p_{avail,turbine}$=available mechanical power produced by turbine
$P_{d,turbine}$=actual power produced from the turbine
P_{avail}=available power of the MHP system
e_g=generator efficiency
$e_{t@(Qd)}$=turbine efficiency at the design flow rate
l_{trans}=transformer loss
h_{hydro}=hydraulic losses
l_{para}=parasitic electricity losses
h_{tail}=tailrace losses
$Q_{residual}$= residual flow rate in m^3/s
E_{avail}=annual available energy
Z=number of blades
ω=angular velocity
$\frac{D_h}{D_t}$=ratio of runner hub diameter to blade tip diameter
D_h=hub dimater

D_t=blade tip diamter

R_t=blade tip radius

V_{axial}=axial velocity

Φ= flow coefficient

Ґ= power coefficient

F_{axial} = axial force on the blade

H=height of draft tube

θ=taper angle of divergent portion of the draft tube

EIA=Energy Information Administration

ACKNOWLEDGMENT

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In Addition, the researcher would like to address the acknowledgment of the Ethiopian Basins Development Authority, Addis Ababa, Ethiopia, for supplying the river flow data of both Temecha and Gudla River. Last but not least, the researcher would like to acknowledge all members who stood beside me to finalize the research.

ABSTRACT

As a fact, there is an imbalance of the electricity demand and supply in Ethiopia. Since the country has the potential for a micro-hydropower (MHP) system, development of the MHP system is an important technology to solve the problem of energy scarcity in the world. Therefore, the main objective of this study is to do modeling and simulation of a micro-hydropower system for rural electrification in the case of Temecha River, Ethiopia. The methodologies followed to finalize this study are: - Firstly, literature reviews section covers the theoretical framework and related work reviews on hydropower, specifically the MHP system. Secondly, the data collection and analysis section for yearly flow data was collected from Ethiopian Basins Development Authority and used to estimate the design flow rate. Thirdly, the modeling and simulation section of the research includes the design analysis of the system components and simulation of the system using MATLAB SIMULINK. Some of the SIMULINK results are power duration curve, flow duration curve, and others are included. The gross head and design flow rates are 7m and 0.7376m^3/s, respectively considered for this research. Based on the preliminary analysis, the turbine selected for the site is a Kaplan turbine based on net head and design flow rate. As a result, the runner diameter, hub diameter, blade tip diameter, the net mechanical power output values are 354mm, 378mm, of 840mm, 82.5W respectively. The final electrical power output of the system is greater than the electricity demand amount of the selected site for 346 days of the year. In addition, the cost analysis has done via RETScreen software. The total estimated cost of the system is around $ 764,400 with that of the pay-back period is 7.2 years and the net present value is $ 1,446,858, which is positive. The value of the NPV indicates the feasibility of the system for the selected remote area to solve the scarcity of an electricity access. Finally, the overall outcomes of the study and the recommendation for future development of the system are covered.

[Keywords: - MHP, MATLAB SIMULINK, Simulation, Design Flow Rate, Kaplan Turbine, Runner Diameter, Mechanical Power.]

CHAPTER ONE

1. INTRODUCTION

This chapter introduces the research problems and the associated objectives to be achieved. The discussion includes the following aspects: Background, problem statement, research objectives, scope, significance of this study, organization of the thesis. Besides, a problem statement provided which is the description of an issue currently existing which needs to be addressed.

1.1. Background

According to (World Bank, 2020) data Ethiopia is the second highly populated country in Africa with an estimated population of 114,963,583, next to Nigeria. The country has one of the fastest-growing economies in the world. Even though the demand for electricity is dramatically increased, the generation of power has not yet increased at the same proportion.

According to (MoWIE. National electrification program 2.0:, 2019), about half of Ethiopian populations, 56% of the total population lack electricity access. In addition, to achieve the vision of Ethiopians development of transformation and prosperity requires an adequate and reliable access of electricity. And also a green energy technology plays important roles for the national development of Ethiopia. As Ethiopia is a developing country, the consumption of electricity has been increased throughout the year.

It is, therefore, necessary to use all the sources in the country for the enhancement of the access of electricity as well as to use those most economically to get and use high power. It is known that electricity provides a very important form of energy for lighting, acts as motive power for deriving various types of machines like milling machine, power for several utilization applications like for mobile charging, stoves, and the like. Sources of energy can be categorized either as renewable or non-renewable sources. Renewable energy sources are energy sources that have inexhaustible sources, whereas non-renewable energy sources have exhaustible sources. In addition to that, renewable energy can be used to reduce fuel consumption, global gas emission as well as saves money. Types of renewable energy sources are solar, wind, hydropower, and biomass energy. As known water is plentiful, cheap, clean, and will never run out makes hydropower more selectable than other classes of renewable energy like wind and the like.

Hydropower or hydroelectricity is the conversion of energy from flowing water into electricity. It is considered a renewable energy source because the water cycle is a concern with renewed by the sun. Today, hydropower plants produce electricity using a turbine and generator. The mechanical power produced by moving water spins the rotor on a turbine. This turbine is connected to an electromagnetic generator, which produces electricity on a turbine. There are two main types of hydropower production these are dams and run of rivers. Hydro dams utilize the potential energy from dam water to produce electricity. A dam is a large reservoir constructed to raise a level of water. The elevation created by the dam creates a gravitational force for turning a turbine when water is released. The second form of hydroelectricity production is run of river/river hydro. River hydro is more intermittent due to the use of natural water. There are various sizes of hydropower plant that produces electricity. These are large hydro which produces electricity greater than 30MW, small hydropower produces power between 501KW and 30MW, and Micro hydropower that produces less than 500KW. The large hydropower plant supplies many consumers with electricity whereas small and micro hydropower plants those individuals operate for their own energy needs or to sell power to utilities. Hydropower is a renewable source of energy and also from all renewable sources of energy; hydropower holds the largest share of worldwide electricity. The advantages of using hydropower as electricity production are cost-saving, reliability, flood control, and reliable water supply to the community. Hydropower generation is non-wasting, self-replenishing, and non-polluting.

This research focused on a Micro-Hydropower system to minimize the gap in the country's economy that is created by the imbalance between the demand and electricity supply. The micro-hydro power plant is a class of hydropower plant system that generates power within a range of 11 to 500KW. A micro-hydropower plant is categorized under run-of-river, small head, single purpose. The selection of the MHP system for this case is because the system is an attractive renewable energy source by reducing fuel consumption, reduction of greenhouse gas emissions, a long lasting technology, run-of-river system, more efficient than other conversion system technologies, and benefits the local communities as well as saves money(K. Kusakana et al., 2009).

Components of micro-hydropower plant

As the researcher mentioned before the research mainly focused on Micro hydropower system components that can be grouped into two sections. These are:-

1. Civil work components
2. Power house components

Civil work components

This section includes the components of micro-hydropower plant that are classed under civil work components. The major components are intake, head race canal, trash rack, penstock, surge tank, and tailrace.

- Head race canal:-it is used to convey the water from the source into the intake structure.
- Intake:-the primary component of MHP that conveys water from the intake with a required flow rate into the penstock.
- Trash rack: - it is used to capture sediments by letting the particles settle by reducing the speed of the water and clearing them out before entering into the canal.
- Penstock: - Penstock pipes are basically close conduct pipes that helps to convey the water from the intake tank to the turbine. This is the place where potential energy of water is converted into kinetic energy of flowing water.
- Tail races canal: it is similar with that of head race component, placed at the end of the civil work components. It is used to convey the water back to the source after use in the micro hydro power plant.

Powerhouse components

This is the place where potential/kinetic energy is converted into electrical energy. A power house component consists of turbine, generator, and transformers.

- Turbine: - in micro-hydro power plant, hydraulic turbine is the primary components. This turbine converts the energy of flowing water into mechanical energy.
- Generator: - generator is another component of micro-hydropower plant which converts the mechanical energy produced by the turbine into electrical energy.
- Transformer:-is an electrical device that is used to transfer electricity from one circuits to another one or multi circuits. In general, it is used as electricity distribution system.

1.2. Problem Statement

Electricity is important for the economic development of the world. In Ethiopia, the consumption of electricity increased from day to day because of the increment of population growth. Today, Ethiopia focuses on the production of electricity from cheap and renewable sources of energy that is free from environmental pollution like wind power, solar power, and hydropower systems. The current hydropower system in Ethiopia like GRD, gelgel gebie I &II are a large hydropower system that requires dams or reservoirs to produce electricity. These dams take water from rivers that flow from any direction to the reservoir/dam, but for the community that lives somehow far from the grid, there is a scarcity of electricity distribution. As we know, there are a lot of rivers in Ethiopia like the Temcha and Gudla Rivers, which are found at the boundary of East and West Gojjam. In this area, there are three kebeles namely Ebuluna-Tahisas Dar, Yemehel, and Amrin-Yewbshe averagely 400 families in each kebele, totally around 1200 family, total 7200peoples (averagely 6people/family) live in that area without the access of electric power, uses diesel and flashlights for lighting purpose. There are three junior schools from grad 1-8 in the above kebeles. Students use diesel (for Amharic word Lamba/Kuraz) and flashlights for lighting purposes to do their assignments, home works, preparation for exams, and the like rather than the use of electricity. bIn general, most of the people's lives in this area use White Gas for lighting purposes, which causes health problems. Peoples go to cities to get electricity access in addition to buying diesel and flashlights, to fulfill their living standards like charging a mobile battery, preparation of cooking materials, and the like which takes time. Also, the growth rate of the population in this area is increased from day to day with that of the consumption of electricity. Generally, the electricity distribution is not enough to the community that lives in rural areas and also the bill of electricity grows up from day to day currently. In addition, the government of Ethiopia is targeting to enhance the accesses of electricity in the country. Therefore, these types of problems enforce to use another source of electricity that is easily powered by a run of the river, which is called micro-hydropower plant. This requires a run of a river rather than that of dams to drive that of the hydropower turbine, this indicates that the micro-hydropower plant system is easily installed everywhere that have a river flow. Thus, in this work modeling and simulation of micro-hydropower system technology is intended to address the distribution of electricity to the communities that live in the Amhara Region, Macackle and Dembecha woreda, Ethiopia.

1.3. Research Objectives

General Objective

The main objective of this research is to do modeling and simulation of a Micro-Hydropower system for rural electrification in the case of Temecha River, located at the borderline of East and West Gojjam, Amhara Region, Ethiopia.

Specific Objectives

To achieve the main objective, the following specific objectives are done.

- ✓ Electricity demand analysis of the selected remote areas.
- ✓ Performing a flow duration curve /FDC of the selected river.
- ✓ Design and Simulation of the main MHP system components using Engineering software's.
- ✓ Economic Analysis of the MHP system.

1.4. Scope

The scope of the research was defined conceptually, geographically, methodologically.

Conceptually, the research covers only the procedures for modeling and simulation of a micro-hydropower system in the case study of Temecha River, Amhara Region, Ethiopia. Methodologically, this Case study also cannot proceed beyond MHP System Simulation using MATLAB SIMULINK. The research excludes the manufacturing and implementation stages due to the two reasons. These are:-

- Firstly, due to financial issues and time scope since micro-hydropower plant requires large cost for implementation and time.
- Secondly, due to geographical issues like MHP requires other construction facilities like road, deforestations and others to install the Micro-Hydropower systems.

1.5. Significance of the study

The findings from this study will help to highlight those areas where there are MHP potentials and thus will be of great benefit to the stakeholders. The stakeholders of MHP projects are the people near the plant, the general public, and investors. The result of this study would hopefully be significant in the sense that it would enable the majority of the population in Ethiopia who are living in remote areas without access to electricity. Due to this, people's use of flashlights and diesel for lighting purposes causes human health problems, will be increased. The MHP system mainly benefits households, macro industries, and others by converting the flow of water energy into electricity. More specifically:-

- The system benefits mainly the development of the nation.
- This study may be used for other researchers to go beyond to solve the electricity accesses issues.

- The results of this study initiate the governmental and non-governmental organizations for creating or developing better electricity access in the country.

1.6. Organization of the thesis

This section presents the organization of the thesis and describes the contents of the included chapters.

Chapter one: - this chapter presents the background, problem statement, objectives, scope, and significance of the research.

Chapter two: - in this section, some of the literature reviews of the research in two categories. These are the theoretical framework and related review works.

Chapter Three: - the chapter contains the research methodology section, which covers site selection, data collection, data analysis, and the like.

Chapter Four: - this section presents the modeling section of the MHP system Components.

Chapter Five: - this section introduces the simulation results and discussions of the MHP system using MATLAB Simulink.

Chapter seven: - the cost analyses of the system components has stated in this chapter.

Chapter Eight: - this is the final chapter, which covers the conclusion and recommendation parts of the research.

CHAPTER TWO

2. LITERATURE REVIEW

These section presents about theoretical frame work of hydropower development and Review of relevant works.

2.1. Theoretical frame work of hydropower development

Prior to the widespread availability of commercial electric power, hydropower was used for irrigation and operation of various machines, such as watermills, textile machines and sawmills. By using water for power generation, people have worked with nature to achieve a better lifestyle. The mechanical power of falling water is an old resource used for services and productive uses. It was used by the Greeks to turn water wheels for grinding wheat into flour more than 2,000 years ago. In the 1700s, mechanical hydropower was used extensively for milling and pumping. During the 1700s and 1800s, water turbine development continued. The first hydroelectric power plant was installed in Cragside, Rothbury, England in 1870. Industrial use of hydropower started in 1880 in Grand Rapids, Michigan, when a dynamo driven by a water turbine was used to provide theatre and storefront lighting. In 1881, a brush dynamo connected to a turbine in a flour mill provided street lighting at Niagara Falls, New York. The breakthrough came when the electric generator was coupled to the turbine and thus the world’s first hydroelectric station (of 12.5 kW capacity) was commissioned on 30 September 1882 on Fox River at the Vulcan Street Plant, Appleton, Wisconsin, USA, lighting two paper mills and a residence. Hydropower plants (HPP) today span a very large range of scales, from a few watts to several GW.

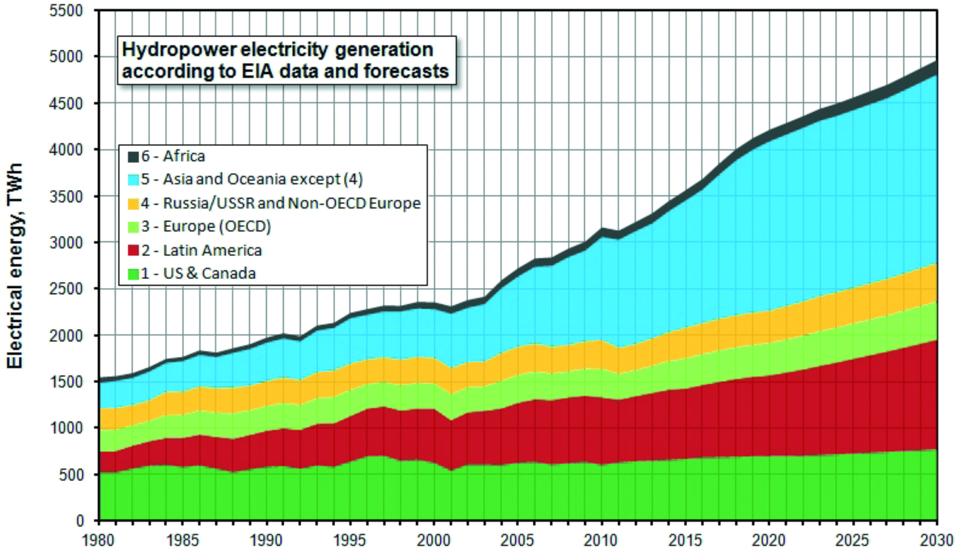


Figure 2-1:- Global hydropower electricity output, as per EIA statistical data (Steller, 2013)

Hydrology

Hydrology is system that studies about the occurrence, movement, and distribution of water on, above, and within the earth's surface. Hydrological data is represents the flow data conditions in the river being studied over the course of an average year.

A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow. The flow-duration curve is used to assess the anticipated availability of flow over time, and consequently the power and energy, at a site.

The available flow is often, a certain amount of flow must be left in the river throughout the year for environmental reasons. This residual flow is must be subtracted from all values of the flow-duration curve for the calculation of plant capacity, firm capacity and renewable energy available. The firm flow is defined as the flow being available p percent of the time, where p is a percentage specified by the user and usually equal to 95%. The firm flow is calculated from the available flow-duration curve. If necessary, a linear interpolation between 5% intervals is used to find the firm flow.

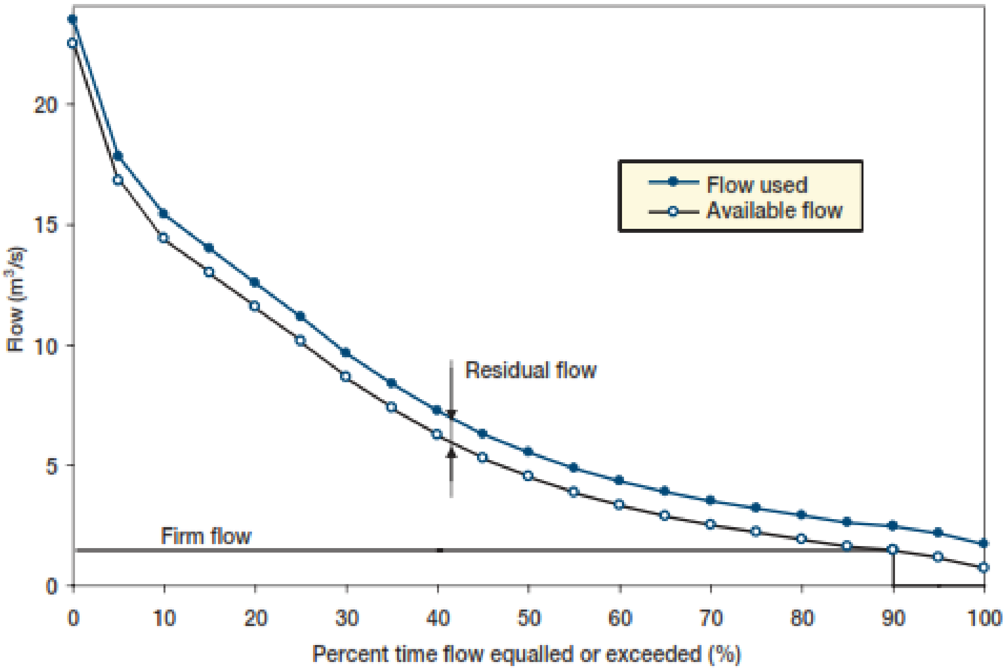


Figure 2-2:- Flow Duration Curve(RETScreen, 2004)

Energy Conversion Principle

The system converts the energy of flowing water into electricity by the aid of power house components. The hydropower turbine is a mechanical device used to transform the kinetic and potential energy of flowing water into shaft power. This shaft power is used to drive a generator to produce electricity. The system power at the design flow rate is given by

$$P_{des} = \rho\, g\, Q_{des}\, H_g\left(1 - l_{hydr}\right)\, e_{t,des}\, e_g\, (1 - l_{trans})\,(1 - l_{para})$$

Where: P_{des} is the design capacity, ρ is the density of water, g is the gravitational acceleration, Q_{des} is the design discharge, H_g is the gross head, l_{hydr} is the hydraulic loss , $e_{t,des}$ is the efficiency of turbine at the design discharge, e_g is the generator efficiency, l_{trans} is transmission loss and l_{para} is the parasitic loss.

Hydropower Turbine Selection

The selection of a turbine depends on the net head, design flow rate, and the available power of the system. Based on these three parameters the hydropower turbine is selected form figure below.

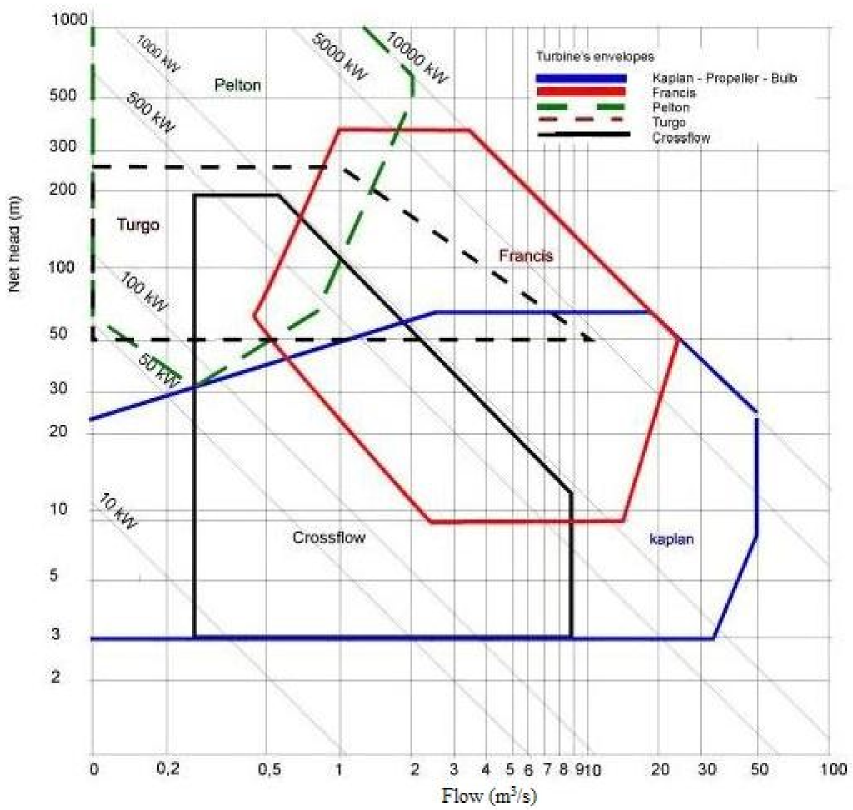


Figure 2-3:-Hydropower Turbines selection chart in terms of flow rate, net head, and power capacity (Adejumobi & Shobayo, 2015)

Working Principles of Hydropower

The flowing water has both kinetic and potential energies. The water is transferred from the river into the powerhouse component using penstock and hits the turbine blade. After the water hits the turbine blade, the turbine runner rotates and converts the energies into mechanical power. Next, the hydropower generator converts the mechanical power produced in the turbine into electricity. Both turbines and generators are the heart of the hydropower system. Finally, the generated electricity is transmitted and utilized for the consumers by using transformers and transmission lines. The amount of electricity produced highly depends on the flow rate of water, flow head. This research focused on MHP system.

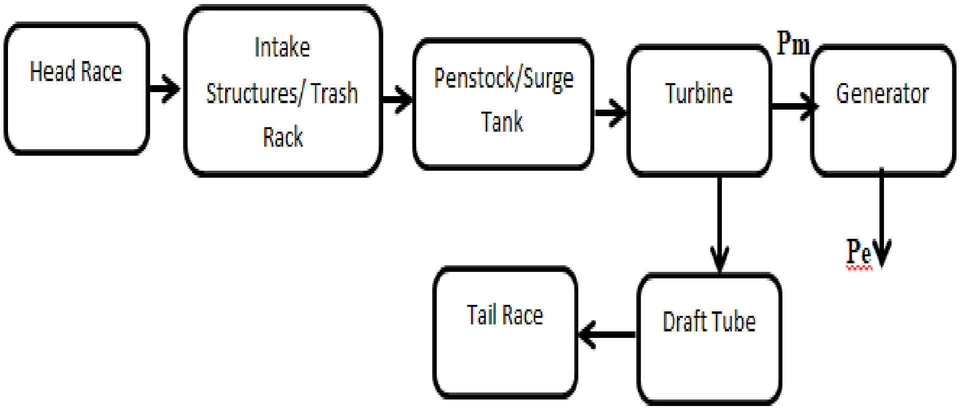


Figure 2-4:- Components and functional block diagram of MHP system

Classification of Hydropower Plants

The classification of hydropower varies from countries to countries. In Ethiopian, according to the installed capacity hydropower can be grouped into large, small, mini, micro, and Pico, according to the operational conditions hydropower can be classified as base load and peak load plant, according to the operational mode hydropower's can be classified as reservoir, run-off river, or pumped storage, according to head hydropower can be classified as low, medium, and high, lastly the classification is based on purpose single or multi-purpose hydropower's.

RETScreen Software's

RETScreen Software is available software developed by Natural Resources CAMNET Energy Technology Centre, Canada. It is excel-based software that allows predictions of renewable energy projects, including MHPs from both physical and financial perspectives. The software calculates the flow availability, potential power capacity, the capital costs, the operating costs, the amount of energy to be generated, and the payback period. The required data to be entered by the user for energy model, cost analysis, and financial analysis worksheets are given in table-2-below (Yuce & Yuce, 2016).

Table 2-1: The Required Data for Energy Model, Cost Analysis, and Financial Analysis in RETScreen Software (Yuce & Yuce, 2016).

Energy Model	Cost Analysis	Financial Analysis
• Gross Head (m) • Percent firm flow available (%) • Residual flow (m3/s) • Design flow (m3/s) • Number of turbines • Flow Duration Curve • Electricity export rate ($/MW-h)	• Feasibility study ($) • Development ($) • Engineering ($) • Hydro turbine ($/kW), • MHP system Components like Penstock. Trash Rack, and the like.	• Fuel cost escalation rate (%) • Inflation rate (%) • Project life (year) • Debt ratio (%) • Debt interest rate (%) • Effective income tax rate (%)

2.2. Related Review Works

This section of the paper reviews the various research activities that have been done before on the hydropower plant system specifically on small scale hydro power systems. Some of the review topics are simulation and implementation of micro-hydro generation for small rural loads, Analysis of Micro Hydropower Generation For Rural Electrification, Small Hydro for Rural electrification, modeling and simulation of a micro-hydropower plant using MATLAB Simulink Software, Simulation and implementation of micro-hydro generation for small rural loads, Design, Methodology of Feasibility Studies of Micro-Hydro power plants in Cameroon: Case of the Micro-hydro of KEMKEN, design of micro-hydro-electric power station, and micro-hydro-electric energy generation, an overview are included in this section of the review. Therefore, each of the above-mentioned topics shall be reviewed and presented below by giving much more attention on what has already been done before and finally the what is done in this paper to fill the gaps, which are not solved in the reviews, to find the solutions of the gap specifically in Ethiopia remote areas.

(Kilimo & Kahn, 2012) have worked a paper on “Small Hydro for Rural electrification.” This study shows the impact of electricity on living standards, health educations, and the like in developed countries. In terms of access to electricity, remote communities are highly affected due to several reasons such as insufficient supply and being economically not viable. The study aims to handle such types of problems the use of small hydropower plants being one of them. The article has highlighted the possibility of low-cost small hydropower plant that can supply power to communities which have small hydro potentials. Finally, the author proposed the use of the merits of both synchronous and induction generators to reduce the investment and maintenance cost of the plant. If implemented, the plant is expected to be of low cost hence an economically viable power source for rural electrification.

(Anaza et al., 2017) conducted research work on “micro-hydroelectric energy generation, an overview.” This study reviews that, as the human population and activities are progressively developing, it is almost certain that the demand for energy worldwide is increasing as well, and this trend is most likely to continue in the future. This article review aims to overview about micro hydro-power system by reviewing some of the basic components (like turbine and generators) including micro-hydro project planning, estimation of micro-hydropower potential which is based on head and flow rate, advantages/disadvantages of micro-hydropower. This article also overviews about three steps to make the micro-hydro projects to be successful. These are project formulation and layout, engineering design and layout optimization, and definition of project layout are considered as a must.

(Kengne Signe et al., 2017) conducted a research work on “Methodology of Feasibility Studies of Micro-Hydro power plants in Cameroon: Case of the Micro-hydro of KEMKEN,” this paper aimed to set up a methodological guide for the feasibility studies of the MHPP in Cameroon, based on the case study of the fall river of KEMKEN. The steps site visits, data collection, measurements, field surveys, meetings with local populations, and analyzes are included in this author. The inhabitants closest to the site have no electricity. The data that is gathered in this paper are KEMKEN gross head (10$\underline{+}$1) m and the average annual flow is 93m3/s. In this project 320 kW of installed power, where the Kaplan turbine is recommended, the investment cost evaluated at 212 486 656 FCFA with a payback period around 7 years is done. Finally, some technical components of MHPP like a dam with a length of 120m and a height of 4m, penstock (with a diameter of 0.84m, the thickness of 2.5mm), turbine (Kaplan Double Regulated), synchronous generator of frequency 50Hz with efficiency between 85 and 95% are selected. This study concludes that the implementation of the project can be a suitable contribution to the sustainable development of that remote area.

(Ram, 2017) worked a research study on “Analysis of Micro Hydropower Generation for Rural Electrification.” This study aimed to do the analysis of micro-hydro power generation for rural electrification in Loi Unn Village. The micro hydropower generation system is studied and discussed which is based on the consideration of a hydraulic turbine and hydroelectric generator, also the transformer and distribution system of micro-hydro power range development. Finally, the author concludes that the micro-hydropower system is installed at the Loi Unn stream to fulfill the requirements of the electrical power of villagers. The analysis results show that the fixed blade axial flow propeller turbine is one of the most cost-effective turbine options for the low head scheme, so it is selected in loi unn micro hydropower project. As the paper states that in Loi Unn micro-hydropower project, 7 turbine-generator sets are installed. The capacity of the set is 3kVA (2.4 kW). Then, the total installed capacity is 21 kVA (16.8 kW). And, the utilized power is 13.8kW. Generally, the daily operating time is from 6 p.m to 6 a.m. because Loi Unn stream is enough to generate micro-hydropower throughout the whole year. But, in the rainy season, the excess water is diverted to the other side of the Loi Unn stream.

(Bilal Abdullah, 2013) have conducted research work on the “design of micro-hydro-electric power station.” In this article review, the problems related to the energy crisis have been stated and also due to the increment of such types of difficulties, the needs of technological alternatives are recommended. This study aimed to design micro-hydro-electric power stations to generate electricity by the use of river flows as a source. The considerations that are taken in the research are the flow of water, location of the site, head of rivers are included. After the implementation of the research on MATLAB Simulink software, the results that are found in this article are that the turbine power and speed were directly proportional to the gross head, but there were specific points for maximum power and maximum speed in case of water flow variations.

(Auwal Abubakar Usman, 2018) have conducted a research on “Modeling and simulation of a micro-hydropower plant using MATLAB Simulink Software.” The author describes some problems related to energy crisis such as oil crisis, climatic change, electrical demand, and restrictions of wholesale markets a risen worldwide that leads to the increment of difficulties. This study aimed to suggest the need for technology alternatives that are used for generating electricity as near as possible of the consumption of site, using renewable and environmentally friendly energy sources such as wind, solar, and hydro-electric power plants. The system that has done on this study is supplying power common electrical three-phase parallel RLC load. Finally, models were simulated using MATLAB Simulink. The simulation results show that with the proper choice of governing system for micro-hydro power plant leads to proper load sharing, constant voltage output, and constant speed with a variety of load values.

(Kanzumba Kusakana et al., 2012) worked a research work on “simulation and implementation of micro-hydro generation for small rural loads.” This study aims to develop a MATLAB/Simulink block of a simple run-off river micro-hydro system that can be used to simulate electricity generation at any location where the water resource and site conditions are suitable. For this article, the author selected a potential site located 40k North West of Kokstad, in the region of new Amalfi, Kwazulu-Natal from which some data’s like water head, water flow and energy demand needed as input to the developed simulation models are taken. Finally, the simulation results of the variation of the rotor angular velocity, the electromagnetic torque, and the stator voltages are included in the study. From the simulation results that are done in the article like for the selected site where the geodesic net height is 5m; the flow of water was changed at t=0.25s from 0.143m3/s to 0.2m3/sec corresponding to the turbine theoretical mechanical power of 6.313kW to 8.829kW are stated.

(Nasir, 2018) worked a research study on MATLAB simulation procedure for design of micro-hydroelectric power plant. The paper states that the researcher can do the design steps of micro-hydropower plants by the MATLAB Simulink program. It also shows that the variation of turbine type depends on the site head and the flow rate, the turbine speed, and power with that of the flow head. Finally, the researcher shows the results of turbine efficiency ranges from 80 to 95% depending on the turbine type, and also the Kaplan turbine speeds vary from 200 to 1550 r.pm. In this case the results found in this paper taken as a reference for validation.

The importance of a micro-hydropower system is to produce electricity from hydro energy/flow of water without causing environmental pollution. Even though several works of literature can be found for the micro-hydropower system, there are a lot of researches that have been done on micro-hydropower systems in the world including Ethiopia, there is a gap that is unsolved the access of electricity distribution to rural areas like in Amhara region, Ethiopia. In this perspective, this thesis aims to fill the research gap in Ethiopia by applying a micro hydropower system that produces electricity from the run of rivers.

CHAPTER THREE

3. RESEARCH METHODOLOGY

This section presents the methodologies that will be following to finalize this thesis which are the literature review, data collection and analysis, modeling and simulation, followed by cost analysis, and finally the conclusion and recommendation/future works are shown in figure 3-1 below.

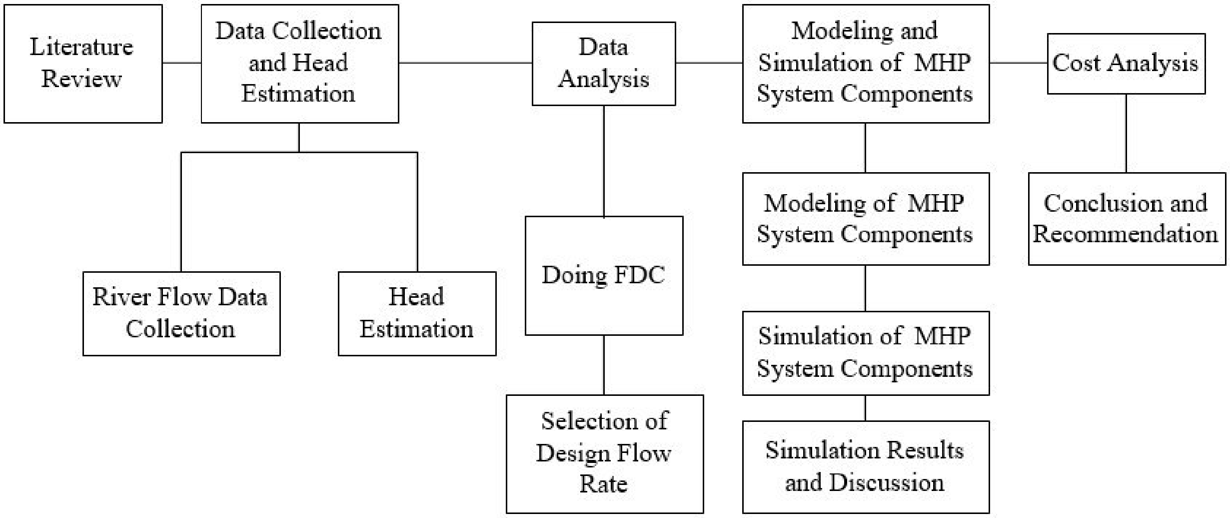


Figure 3-1:- Methodology Flow Chart

In this chapter, mainly Site selection, gathering/analyzing of the flow data, specifications of the selected site (Temecha and Gudla rivers) with the flow duration curve of the basin are included.

3.1. Site selection

A site selection is a pre-request for the development of hydropower. The site selection depends on the stream-flow, which depends on the reliability, and quantity of the water flow, the purpose of water used like for power production, plantation, animal husbandry and the like. The second selection criteria, whether the stream flow all year round or not?

Due to the above case, Temecha River is selected for this study. There also another turbitary called Gudla River, after the two rivers are mixed it's named as Temecha. The site is selected after the two rivers are mixed. The site has located 10.5150N latitude and 37.4870E longitude. It is located between Machakel Woreda (East Gojjiam) and Dembecha Woreda (West Gojjiam) in

Amhara region. It is 345km far from Addis Ababa, Ethiopia to the North West and 285km far from Bahirdar, capital city of Amhara Regional state to the South East. And also the site elevation is within the range of 950 to 2800 mean sea levels (Cherie, 2019). The site selection is due to the following two cases.

First, there is no electricity access totally in that rural area. Thus, this study states about solving rural electrification problems by using the MHP system, so this site is used for electricity production purposes.

Second, the selected site which is Temecha River has a flow rate year to year. The flow rate of a river is a seasonal one; it has more flow rate during rainy season like august because of its large catchment areas and less discharge during driest seasons like February.

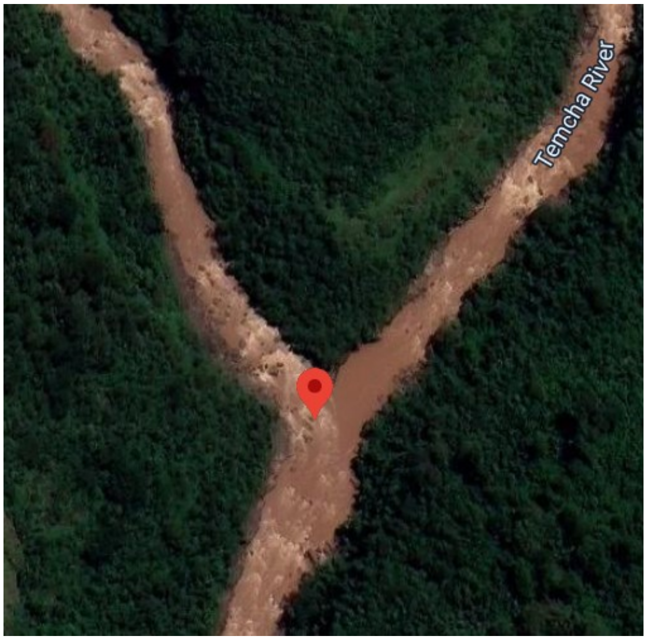


Figure 3-2:- Temcha and Gudla River (10°31'30.1"N 37°29'38.0"E)

Figure 3-3:- A MHP System site Location (10°30'52.6"N, 37°29'13.0"E)

3.2. Head estimation

(Energybc.ca, 2018) states about, in run of river system, the discharge water is diverted from the river into the turbine by using penstock. The flow water hits the turbine blade and creates rotation of turbine, converts energy of flowing water into mechanical shaft power, which drives the generator to produce electricity. This site also states about the difference between run of river and large hydropower is that run of river system have not used dam to create water reservoir, but most of run of river facilities use a small dam to ensure enough discharge enters into the penstock and have a small reservoir to store small amounts of water for same-day use. Unlike large hydro power systems, they cannot store large amount of water for future use.

(Clean Energy (online)., n.d.)This site stated that small dams can be used to generate electricity from running or falling water (called small hydropower, and micro-hydropower when it is very small). Where there is enough water from rivers or streams, micro-hydro power is the least costly way to provide electricity to rural communities.

This study states about micro-hydropower system, use run of river power has no natural head, but the site have available flow rate throughout the year. As flow head increases so that output power. The flow head is increased by constructing a dam. Therefore, based on the above two sites we can construct a small weir in micro-hydropower system to make enough flow rate enters the pipeline, which enhance the output/power production as the head increases more production of electricity generated. The value of flow head was considered in chapter 4 after table 4-3.

3.3. Data Collection

For this research case, the flow data used is taken from the Ethiopian Basins Development Authority, around 22, Addis Ababa, Ethiopia. From 1980 to 2005 E.C year flow rate of the rivers is recorded in the company.

3.4. Hydrological Data Analysis

For this research 25-years data is taken from Ethiopian Basins Development Authority Company, Addis Ababa Ethiopia and a one-year data for design purposes has taken. The averages of 25 years of data for each river are analyzed separately shown in Appendix D at the back of the paper. Finally, the combined flow rates of the two rivers are used, which is shown in figure 3-4 below.

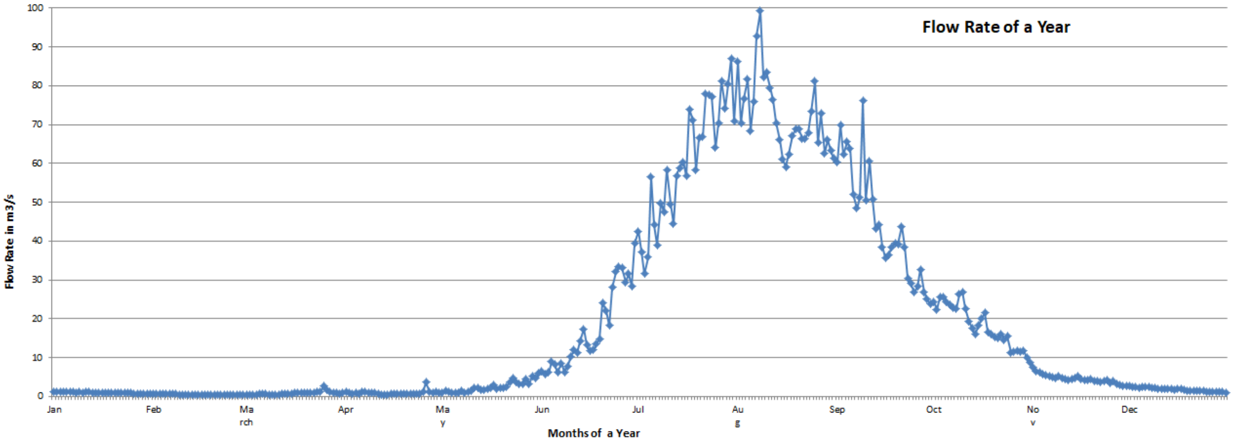


Figure 3-4:- Yearly Average Flow data's for Temecha and Gudla [Source:Ethiopian Basins Development Authority]

3.5. Flow Duration Analysis

Flow duration analysis a system of analyzing the variability of water discharge data's with time by plotting Flow Duration Curve, which is a graph of Flow rate (m^3/s) with percent of time a particular discharge can be expected to be exceeded. And also flow duration curve is used to indicate the relation between flows of data's with that of their available length of time.

There are two ways to plot the flow duration curve. These are Rank order and class interval methods. The rank order method is a technique uses a time series of flow data's with increment of time and ranks the data's based on magnitude. This technique is advised for less number of data and gives a good result.

The second way is class interval method differ from rank order in that the time series data's are categorized in class intervals. It is mainly used for huge number of data's. therefore, for this case a Rank order is selected due to that of it's simple calculate and accurate over the class interval method.

Manual FDC Analysis using Rank Order Method

The flow value ranges from the lowest value to the highest value in the time series as shown in Appendix-D table 0-3, this variation is due to the seasonal effect of the rain.

The cumulative frequency for a given flow can be divided by the total number of flow values in the data series to obtain the percent of time as shown in Appendix-D table 0-4. The value of the flow for the particular time is then plotted versus the computed percent of time.

Table 3-1:- Sample table for Flow Duration Curve Analysis taken from Appendix-D table 0-4

Flow Values in m^3/s	Frequency	Cumulative Frequency	% of time $=\frac{Cum.Frequency}{No.of\ Data}x\ 100\%$
0.4894352	1	366	100
0.57304	1	348	95.08197
0.5733838	1	347	94.80874
0.5792219	1	346	94.53552
0.6618248	1	330	90.16393
0.6632505	1	329	89.89071
0.7733714	1	312	85.2459
0.7804324	1	311	84.97268
0.9279667	1	293	80.05464
0.9283886	1	292	79.78142
1.0685571	1	275	75.13661

1.0699762	1	274	74.86339
1.16732	1	257	70.21858
1.1727048	1	256	69.94536
1.3263848	1	238	65.02732
1.3318895	1	237	64.7541
1.9080648	1	220	60.10929
1.9266505	1	219	59.83607
2.4414	1	202	55.19126
2.4533676	1	201	54.91803
3.9064238	1	183	50
4.8290362	1	165	45.08197
4.9712038	1	164	44.80874
8.3975248	1	147	40.16393
8.5841581	1	146	39.89071
14.644452	1	129	35.2459
14.931668	1	128	34.97268
22.750278	1	110	30.05464
22.801659	1	109	29.78142
29.473659	1	92	25.13661
30.428454	1	91	24.86339
39.581596	1	74	20.21858
42.612667	1	73	19.94536
58.383226	1	55	15.02732
58.848086	1	54	14.7541
66.408045	1	37	10.10929
66.49416	1	36	9.836066
74.242545	1	19	5.191257
76.029879	1	18	4.918033
99.242335	1	1	0.273224

By applying the interpolation formula table 3-1 is changed to the table 3-2 below. For example,

Flow Rate m^3/s	% of time
0.57304	94.80874
$Q_{@95\%}$ =??	95
0.5733838	94.80874

$$\frac{Q_{@95\%} - 0.57304}{0.5733838 - 0.57304} = \frac{95 - 95.08197}{94.80874 - 94.808}$$

$$Q_{@95\%} = 0.57\, m^3/s$$

Table 3-2:- Data's for Flow Duration Curve

% of time	0%	5%	10%	15%	20%	25%	30%
Flow rate Q (m3/s)	99.24	75.49	66.44	58.43	42.01	29.95	22.76

% of time	35%	40%	45%	50%	55%	60%	65%
Flow rate Q (m3/s)	17.90	8.51	4.87	3.91	2.45	1.92	1.85

% of time	70%	75%	80%	85%	90%	95%	100%
Flow rate Q (m3/s)	1.17	1.07	0.93	0.78	0.66	0.57	0.49

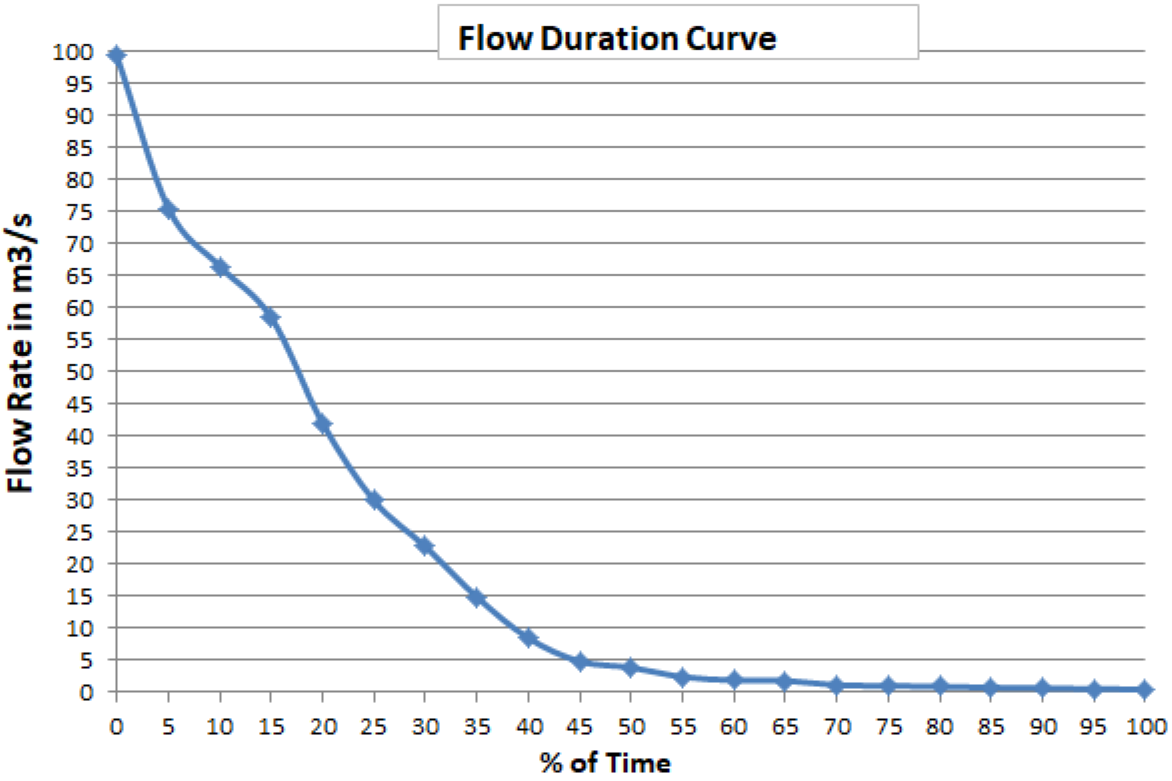


Figure 3-5: FDC of the selected site

Terminologies

Head: - the height of the water fall

Design flow rate: - the maximum flow rate of water for which the turbine is selected and designed.

The firm flow is the flow being available p% of the time, where p is a percentage specified by the user and usually between 90% and 100%(Arthur, 2014).

(Davis & Graham, 2004):- this article states that if the plant is free from any other energy backup system, the design flow should be the flow that is available 95% of the time or more.

For this case, the % of time considered for firm and design flow is 100% and 95%, respectively. Residual flow is the amount of flow left in the river due to environmental issues like evaporation, fishery, irrigations, and others. For this case the residual flow value is assumed zero due to the two reasons. Firstly, since distance between the selected site and the data collected by Ethiopian Basins Development Authority is small. Secondly, there are also other small river tributaries to the selected river, which recovers the flow left in the river due to many reasons. From the analysis done before to do the FDC the values of firm and design flow rates are

$$Firm\ Flow\ Rate\ \ Q_f = 0.49m^3/s$$

$$Design\ Flow\ Rate\ Q_{d@95\%} = 0.5731m^3/s$$

3.6. Specifications

Parameters	Symbols	Units	Values
Design Flow Rate	Q_d	m^3/s	0.5731(Justified in section 3-5)
Gross Head	H_g	m	19 (from section 3-2 and 4-5)
Density of water	ρ	Kg/m^3	1000 (Constant)
Acceleration due to gravity	g	m/s^2	9.81 (Constant)
Generator Efficiency	e_g	%	95 (Justified in section 3-5)
Parasitic Losses	l_{para}	%	3 (Justified in section 4-5)
Tailrace Losses	h_{tail}	%	7 (Justified in section 4-5)
Transformer Losses	l_{trans}	%	2 (Justified in section 4-5)
Hydraulic Losses	h_{hydr}	%	7 (Justified in section 4-5)
Design Coefficients	R_m	unit less	4.5 (Justified in section 4-5)

3.7. Electricity Demand Analysis

The table below shows the electricity demand analysis and load duration curve for the selected rural areas. As expressed in the previous pages, the rural areas had around 1200 houses without access to electricity.

Table 3-3:- Electricity Demand Analysis for Tin-Houses (900 houses)

No.	Type of load	Power Capacity(Watt)	Qty	Total Load (KW)	Running hours	Working hours/day	Energy demand/Day, KWh
1	Lighting	10	2	18	6:00PM-12:00AM 5:00AM-7:00AM	7	126
2	Mobile charging	4	2	7.2	6:00PM-12:00AM	6	43.2
3	TV, 32inches	60	1	54	12:00PM-1:00PM 6:00PM-9:00PM	4	216
	Sub Total			**79.2**			**385.2**

Table 3-4:- Electricity Demand Analysis for Grass-Houses (300 houses)

No.	Type of load	Power Capacity(Watt)	Qty	Total Load (KW)	Running hours	Working hours/day	Energy demand/Day, KWh
1	Lighting	10	1	3	6:00PM-12:00AM 5:00AM-7:00AM	7	21
2	Mobile charging	4	1	1.2	6:00PM-12:00AM	6	7.2
3	TV, 30inches	60	1	18	12:00PM-1:00PM 6:00PM-9:00PM	4	72
	Sub Total			**22.2**			**100.2**

Table 3-5:- Electricity Demand Analysis for churches (12 churches)

No.	Type of load	Power Capacity (Watt)	Qty	Total Load (KW)	Running hours	Working hours/day	Energy demand/Day, KWh
1	Lighting	10	12	1.44	6:00PM-12:00AM 5:00AM-7:00AM	7	10.08
3	Microphone	60	1	0.72	5:00AM-6:00AM 12:00PM-3:00PM 5:00PM-6:00PM	5	3.6
	Sub Total			**2.16**			**13.68**

Table 3-6:- Electricity Demand Analysis for other Utilities

No.	Type of Utility	Type of load	Power Capacity(Watt)	Qty	Total Load (KW)	Running hours	Working hours/day	Energy demand/Day, KWh
1	Mill Machines	Lighting	3000	12	36	2:00PM-6:00PM	4	144
		Sub Total			**36**			**144**

Table 3-7:- Summery of Load Demand Analysis

Time Interval	Load in Kw	Time Interval	Load in Kw
7:00AM-8:00AM	0	7:00PM-8:00PM	72
8:00AM-9:00AM	0	8:00PM-9:00PM	72
9:00AM-10:00AM	0	9:00PM-10:00PM	0
10:00AM-11:00AM	0	10:00PM-11:00PM	0
11:00AM-12:00PM	0	11:00PM-12:00AM	0
12:00PM-1:00PM	**72.72(Peak Load)**	12:00AM-1:00AM	0
1:00PM-2:00PM	0.72	1:00AM-2:00AM	0
2:00PM-3:00PM	36.72	2:00AM-3:00AM	0
3:00PM-4:00PM	36	3:00AM-4:00AM	0
4:00PM-5:00PM	36	4:00AM-5:00AM	0
5:00PM-6:00PM	36.72	5:00AM-6:00AM	23.16
6:00PM-7:00PM	72	6:00AM-7:00AM	22.44

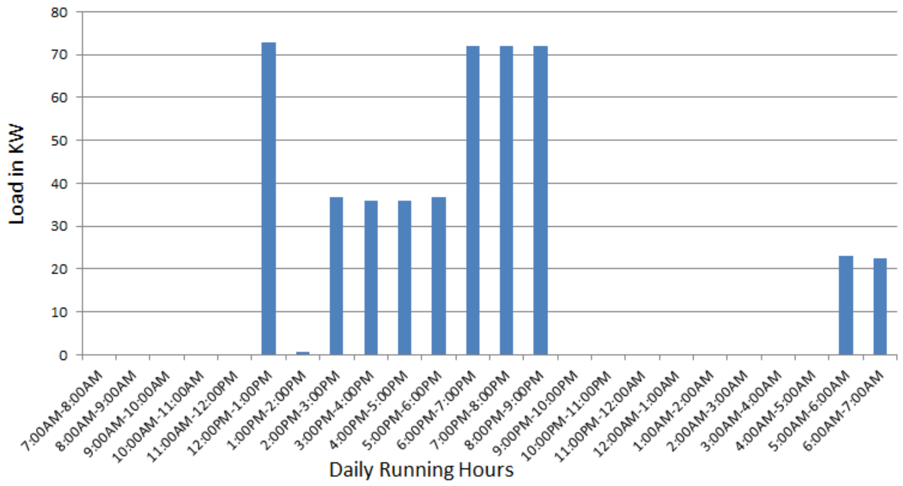


Figure 3-6:- Load Duration Curve of the Site

Figure shown above indicates about the summery of the load analysis for the selected rural areas. In this case the researcher considers Houses (either Tin or Grass), churches and other utilities like mill machines and water pumps. The purpose of the electricity are for lighting, mobile charging, TV, Microphones, and to drive machines like mill machine. As seen from the above analysis the peak load is around 72.72Kw, the average load is 20.02KW, and the minimum load is 0.72KW. In this case, the design analysis has done by the peak load value.

CHAPTER FOUR

4. MODELING OF MICRO-HYDROPOWER SYSTEM COMPONENTS

In this section of the project modeling of the MHP system components like intake penstock, structure, trash-rack, turbine, speed increaser selection, and design analysis with that of standard generator selection are mentioned. In addition, the efficiency, flow and power duration curves of the selected Kaplan turbine analysis by RETScreen Software's are included in this chapter. Figure 4-1 below shows the layout of a micro-hydropower plant for the selected site.

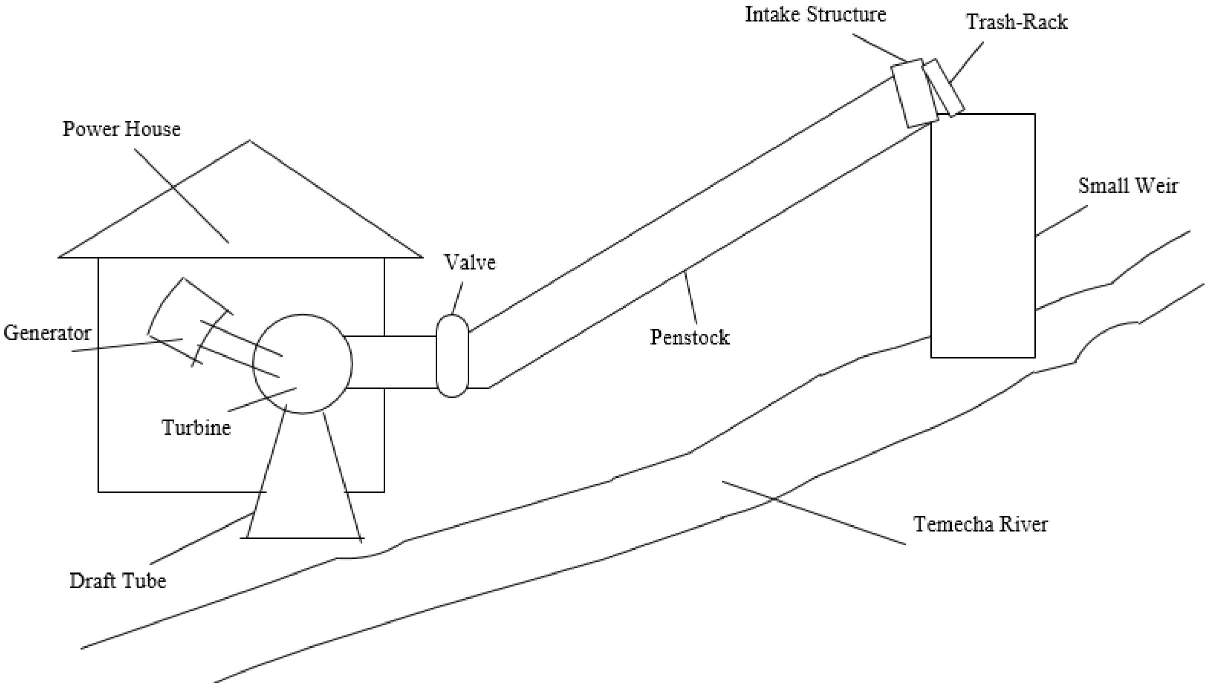


Figure 4-1:- General Layout of MHP System

4.1. Penstock design

Penstock, in Micro Hydropower system, is a longest pipe used to conveyed water from the for-bay system to turbine, the power house component. The pipe may be installed below or above the earth itself, the material type, and weather condition like temperature of the environment. During the design of this pipe the parameter that must be used are material type, length of penstock, diameter of penstock, and thickness of the pipe. The material most probably used for penstock design is that of mild-steel due to its availability, ductility behavior, and other advantages.

(Singhal M. K., 2015):- Warnick et al. (1984) developed a formula for penstock diameter (Dp) for small hydro power systems like Micro and Pico hydropower's in terms of design flow rate. This formula is expressed as

$$D_p = 0.72\sqrt{Q_d}$$

Where, $Dp = \ dimter\ of\ penstock\ in\ meter, and$

$Qd = \ design\ flow\ rate\ in\ m3/s$, which is $0.5731m^3/s$

Finally after substituting the value of design flow rate in the above relation, the diameter of the penstock

$$D_p = 0.545m$$

From Appendix C- figure 0-3, the nearest standard penstock diameter is 559mm.

$$D_p = 559mm$$

The minimum recommended thickness of the penstock is

$$t_p = \frac{D_p + 508}{400} + 1.2 \ \ (mm)$$

$$t_p \cong 3.8675mm, this\ is\ the\ minimum\ thickness\ of\ penstock$$

Depend on the type of material SCH 60s for penstock, which is steel 22.23mm thickness, is considered for this system from Appendix C-figure 0-3.

The length of penstock is calculated from the formula

$$D_p = 2.69 * ({n_p}^2\ {Q_d}^2 * \frac{L_p}{h_g})^{0.1875}$$

$Where\ n_p = \ Manning\ roughness\ coefficient, assuming\ the\ penstock\ material\ is$

$Welded\ steel\ with\ a\ Manning\ roughness\ coefficient\ of\ n_p = 0.012\ from\ table\ 4 -$

$1\ below, and$

$$Lp \ = \ length\ of\ penstock\ in\ meter$$

Table 4-1:- Manning coefficient n_p for several commercial pipes(Online:, n.d.)

Types of pipe	n_p
Welded Steel	0.012
Polyethylene(PE)	0.009
PVC	0.009

Asbestos cement	0.011
Ductile iron	0.015
Cast iron	0.014
Wood-stave(new)	0.012
Concrete (steel forms smooth finish)	0.014

Therefore, after substitution the length of penstock

$$L_p \cong 110m$$

4.2. Design of Intake structures

Intake structure is a structure which transfers water from the fore-bay to the penstock. The intake is constructed at the inlet of the penstock in which the flow rate diverted from the source like reservoirs or rivers. The advantage of the intake system is to make the flow in the penstock smooth, easy, and free from turbulent effect. Functions of intake are:-

- To control flow of water in the penstock
- To make the flow smooth, easy, and vortex or turbulence free entry of water into the penstock.
- To prevent entry of debris like trees, grass, and the like.
- To exclude heavy sediment load of river, from entering the penstock system.

Intake Selection and Design

The basic points for the selection of intake locations are

- To attain the required flow rate level, the intake must be placed sufficiently below the reservoir and high enough to prevent the entrance of sedimentation to the system.
- The location of intake is wherever possible on the concave side of the bend.
- The intake effectiveness for the prevention of sediment entry depends on the sharpness of the bend.

The design analysis of an intake is to ensure the structural stability, hydraulic efficiency, limit the inlet flow rate, and to make the operation smooth.

For this study case, the type of intake is run-off-river intake since the system is a micro hydropower system. This intake type has trash rack in front of the horizontal bell mouth inlet, which minimizes the entrance loss, traps the entry of debris, and makes the flow smooth. Trash racks in MHP system are placed at the entrance of the penstock to trap the debris in the water like grass, leaves, trees, and the like into the penstock. The acceptable size of the debris depends on the type of hydraulic turbine used for power generation.

Intake entrance

The entrance of the intake should be properly designed to minimize the entrance loss and to get the flow smooth. This should be done by using bell mouth entry, elliptical shape, governed by the equation:

$$\frac{X^2}{(0.5D_p)^2}+\frac{Y^2}{(0.15D_p)^2}=1$$

Where, $D_p = 0.545m\ is$ diameter of penstock, which is calculated before.

Therefore $10.46X^2 + 116.22Y^2 = 1$

The location of the intake h_t is given by

$$h_t = D_p + 2Y_{\omega(x=0)}, Y_{\omega(x=0)} = 0.082m$$

$$Where, \quad h_t = \ the\ height\ of\ inlet\ entrance$$

$$D_p = \ diameter\ of\ penstock\ .$$

$$h_t = 0.709m \cong 709mm$$

Intake aeration

The use of an air vent is always recommended just downstream of a control gate. The main advantages of using an air vent are to avoid vacuum effect, which might be created after the control gate is closed causes the drained of the penstock and to avoid the air in the conduit

Capacity of air vent (Q_a) is 25% of the design flow rate and allowable air velocity in air vent is between (40-90) m/s (TALARGEW MEKONEN, n.d.). Take allowable air velocity (V_a) is 65m/s fort his paper.

$$V_a = 65m/s$$

$$Q_a = 0.25 * Q_d$$

$$Q_a = 0.25 * 0.5371\,{}^{m^3}\!/_{s}$$

$$Q_a = 0.1343\,{}^{m^3}\!/_{s}$$

The area of the air vent (A_a) is found from capacity of air and the allowable air velocity, which is shown in the form

$$A_a = \frac{Q_a}{V_a} = 2.07 * 10^{-3} m^2$$

Therefore, the diameter of the air vent (D_a) is

$$A_a = \frac{\pi {D_a}^2}{4}$$

$$D_a = 0.051m = 51mm$$

4.3. Design of Trash Rack

The trash racks usually placed vertically or near vertically say (0^0 to 25^0) from the vertical axis. Which is usually across the water flow in the power channel keeping the trash rack inclined is always a better practice. For this case, take $\varphi = 25^0$ for easy cleaning. The following are recommended limiting entrance velocities. (TALARGEW MEKONEN, n.d.)

i. Mooneye's formula to eliminate eddies and vortices

$$V = 0.075\sqrt{2}gH$$

$$Where: g - acceleration\ due\ to\ gravity, and$$

$$H = net\ head$$

ii. U.S.B.R's criterion: permissible velocity in the range of 0.6-1.5m/s. For this project, the trash rack is designed so that the approach velocity (Va) is in between 0.6 to1.5 m/s. For this case let's take the velocity of 0.6m/s.

Racks

According to the site(TALARGEW MEKONEN, n.d.) : - The thickness of bars is usually from 6mm to 25mm. For this research case take bare thickness of $t = 20mm$.

The maximum length of rack bars is limited by the bar thickness and the approach velocity through the bars. The following table shows the maximum length of bar using bar thickness and velocity approaching the bar.

Table 4-2:- Unsupported length of bar in cm for velocity (m/s) (TALARGEW MEKONEN, n.d.)

Thickness	Velocity in (m/s)

of bar in mm	0.6	1	1.5	2	3
6	50	42	32	29	24
10	75	60	47	40	35
12	100	80	63	55	45
20	150	115	100	82	65
25	175	145	125	112	88

Therefore, for thickness of 20mm and velocity of 0.6m/s, the length of bar from table 2 above is $L_b = 150cm$.

The spacing of trash rack is in the range of 100 to 500mm. the experimental recommendation is

$$\frac{b}{L_b} \leq 0.7$$

Where, $L_b = length\ of\ bar\ in\ cm$

$$b = spacing\ between\ two\ bars\ in\ mm$$

After substitution the value of spacing between two bars is $b \leq 105mm$, take $b = 105mm$.

Checkup for vibration using the criteria below

$$\frac{b}{10} \leq t$$

$$10.5mm \leq 25mm, \dots \dots which\ is\ \boldsymbol{safe}!$$

Net Head

Net head is the head available for power generation, the difference of the gross head and hydraulic loss.

$$H_n = H_g - \sum H_{loss}$$

Where, $H_n = Net\ Head$

$H_g = Gross\ Head = 7m\ for\ this\ case$

$\sum H_{loss} = totall\ hydraulic\ and\ Tail\ race\ loss$

$$H_n = H_g\ (1 - (h_{hydr} + h_{tail})$$

Hydraulic losses

Hydraulic losses are losses created on the entrance, trash rack, gate, penstock, and surge tank/tunnel stages.

$$Where, Hydraulic\ losses\ h\_hydr = 7\%, and\ tailrace\ losses\ h_{tail} = 7\%\ are\ assumed\ for\ this\ case.$$

$$H_n = H_g\ (1 - (0.07 + 0.07)$$

The relation between gross head and net head was defined in chapter four. As the gross head varies it has an effect on the net head, type of turbine, power and others.

4.4. Design of Surge Tank

A surge tank is a structure which is an essential component of the conveying pressure conduit systems used to minimize the sudden water surge, develop damage or increase the stress level on the system. If the system is long the surge tank may be placed close to the power house components. The main advantages of surge tank is that of preventing of long pressure tunnel in medium and high head plants against high water hammer pressure arising from sudden rejection or acceptance of load and act as a safety value to relive the penstock pipe for water hammer pressure. The design aspects of surge tank concerns on its own height and the cross section. Due to an economical point of view the surge tank is not reccommended for MHP system. Therfore, the design analysis part is not included in the case of this research.

4.5. Turbine selection and Design Analysis

This section presents about the Selection of turbine, analysis of the system both manually and using RETScreen Software with the validation of both results. Selection of turbine depends on the design flow rate, flow head, and cost. In this case the hydropower turbine is selected from the standard chart based on the net head and design flow rate. The parameters values design flow rate, Q_d=0.5731m^3/s and net head up to 16.34m as shown in figure 4-2 below, the type of turbines may be Cross flow, Kaplan, and Propeller. For this case Kaplan turbine is selected, an axial flow reaction turbine suitable for low heads. The selection of the Kaplan turbine is due to the reasons, first, it handles the variation of flow efficiently and secondly, it is more efficient than propeller and bulb turbines.

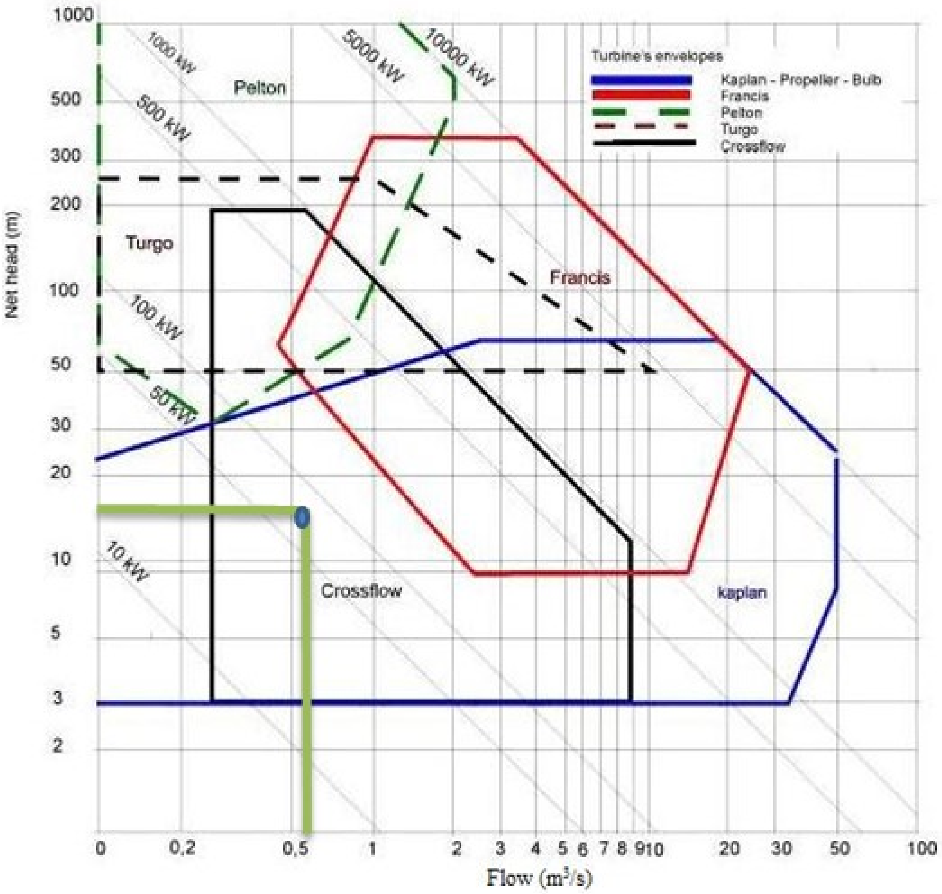


Figure 4-2:- Turbine Selection Chart based on net head and flow rate(Sangal et al., 2013)

Manual Analysis

In this section, the turbine parameters like the turbine runner size, specific speed, efficiency, and power are solved manually.

Determination of the Turbine parameters

- **Reaction turbine runner size (d)** given by

$$d = kQ_d{}^{0.473}$$

$$Where, d\ =\ runner\ throte\ diameter\ in\ m$$

$$K = 0.46\ \ for\ d < 1.8m, used\ for\ this\ case$$

$$K = 0.41\ \ for\ d \geq 1.8m$$

The diameter of turbine runner throat is $d = 0.354m$.

$$d = 354mm$$

- **Specific speed (n_q)** :- is a dimensionless parameter given by

$$n_q = k(h_{net})^{-0.5}$$

$$Where, \qquad n_q = specific\ speed\ based\ on\ flow$$

$$K = \ 800\ for\ propeller\ and\ Kaplan\ turbines$$

- **Turbine speed (n)**

The turbine speed and specific speed are related in the following formula

$$n_q = \frac{n * \sqrt{P_{d,turbine}}}{{H_n}^{5/4}}$$

Rearranging, the formula to find turbine speed is

$$n = \frac{n_q * {H_n}^{5/4}}{\sqrt{P_{d,turbine}}}$$

$$where, n = turbine\ speed\ in(r.p.m), Hn = net\ head\ in\ (m), Pd$$
$$= turbine\ power\ in(Kw), n_q = turbine\ specific\ speed$$

The specific speed used as criteria for the selection of turbine type and dimensions, whereas the turbine speed can be used to select speed increaser ratio generator type. In the case of speed increasers between the hydropower turbine and generator, the synthetic belts (flat, toothed and V-belts) are recommended. Gearboxes are recommended under for high gearing ratio. High quality flat belts are recommended for the turbine power ranges of (5–100) Kw. Standard V-belts are recommended for outputs below 30KW.

Calculation of the Turbine Efficiency at Each Flow

- The specific speed adjustment to peak efficiency ($\hat{}e_{nq}$) is

$$\hat{}e_{nq} \ = (\frac{n_q - 170}{700})^2$$

- Runner size adjustment to peak efficiency ($\hat{}e_d$) is

$$\hat{}e_d \quad = (0.095 \quad + \ \hat{}e_{nq})(1 - 0.789 * d^{-0.2})$$

- Turbine peak efficiency (e_p) is

$$e_p = 0.905 - \ \hat{}e_{nq} \quad + \ \hat{}e_d \quad - \ 0.0305 \ + 0.005R_m$$

$$where, R_m = turbine\ manfacturer\ /\ design\ \ coefficent\ (2.8\ to\ 6.1, 4.5\ is\ used\ by\ defult)$$

- Peak efficiency flow (Q_p)

$$Q_p = 0.75Q_d$$

- Efficiency at flows above and below peak efficiency flow (e_q)

$$e_q = [1 - 3.5(\frac{Q_p - Q}{Q_p})^6]\ e_p$$

- The available mechanical power produced by the turbine is given by

$$P_{avail} = \rho g Q(h_g - (h_{hydr} + h_{tail}))e_{t,Qd}$$

The actual power from the turbine (P_{design}) as a function of design flow rate is given by

$$P_{d,turbine} = \rho g Q_d h_g(1 - (h_{hydr} + h_{tail}))e_{t,Qd}$$

- Available power the MHP plant

The power available and the flow rate are related with the equation below

$$P_{avail} = \rho g Q(h_g - (h_{hydr} + h_{tail}))e_{t,Qd}e_g(1 - l_{trans})(1 - l_{para})$$

The actual power from this micro hydropower system of (P_{design}) as a function of design flow rate by assuming generator efficiency of 95% is expressed as

$$P_d = \rho g Q_d h_g\ (1 - (h_{hydr} + h_{tail}))e_{t,Qd}e_g(1 - l_{trans})(1 - l_{para})$$

Where, $e_{t@(Qd)} = turbine\ efficiency\ at\ the\ design\ flow\ rate = 86.23\%$

$e_g = generator\ efficiecny = 95\%\ , Hydraulic\ losses\ h\_hydr = 7\%, Transformer\ losses\ l_{trans} = 2\%, Parasitic\ electricity\ losses\ l_{para} = 3\%, and\ tailrace\ losses\ h_{tail} = 7\%\ are\ assumed\ for\ this\ case.$

Table below shows the summary of the turbine parameters as the gross head varies. The analysis was done to estimate the gross head for the selected river to satisfy the peak load required by the area.

Table 4-3:-Turbine parameter analysis as variable gross head

Gross head, H_g (m)	Net head, H_n (m)	turbine runner size, d (m)	Specific speed, n_q	Turbine Speed, n (r.p.m)	specific speed adjustment to peak efficiency ($\hat{}e_{nq}$)	Runner size adjustment to peak efficiency ($\hat{}e_d$)	Turbine peak efficiency (e_p)	Peak efficiency flow (Q_p) (m^3/s)	Available power at the design flow rate, P_d (Kw)	MHP System Available Power in KW
10	8.6	0.354	273	616	0.0216	0.0033	0.879	0.403	42.5	38.4
12	10.32	0.354	249	642	0.0127	0.0031	0.887	0.403	51.5	46.5
14	12.04	0.354	231	665	0.0075	0.0029	0.892	0.403	60.4	54.6
16	13.76	0.354	216	687	0.0043	0.0028	0.896	0.403	69.3	62.6
18	15.48	0.354	203	706	0.0023	0.0028	0.898	0.403	78.1	70.5
19	**16.34**	**0.354**	**198**	**716**	**0.0016**	**0.0028**	**0.898**	**0.403**	**82.5**	**74.5**
20	17.2	0.354	193	725	0.0011	0.0027	0.899	0.403	86.9	78.5

As expressed in the demand analysis the peak load is 72.72KW. and also as seen in table 4-4 above the researcher gets the amount of power that satisfies the peak load requirement at 19m gross head, net head is 16.34m, and 0.5731m3/s design flow rate. Therefore, based on the above analysis and justifications in section 3-2, 19m gross head is considered for this case with a net head value of 16.34m.

Cavitation Phenomenon

The formation process of bubbles during the hydro-dynamic pressure in a flow water falls below the vapor pressure of the liquid water and their subsequent collapse is called cavitation. To avoid cavitation, the next criteria should be satisfied in the micro-hydropower system design:

$$\frac{n_q}{995} \leq 0.686 * (\delta_T)^{0.5882}$$

Where, $\delta_T = the\ Thoma'ssigma\ coefficient\ for\ Kaplan\ turbine\ which\ is\ given\ by$

$$\delta_T = 6.4 * 10^{-5} * (n_q)^{1.46}$$

$$\frac{198}{995} \leq 0.686 * (6.4 * 10^{-5} * (198)^{1.46})^{0.5882}$$

$$0.199 \leq 0.22 \ldots\ldots\ldots \quad \boldsymbol{satisfied.}$$

The above checkup indicates that no cavitation is created on the selected Kaplan turbine. The main components of Kaplan Turbine are the runner blade, spiral casing, and draft tube with guide vane or without it. The next section shows the analysis of these parts.

Design of Turbine runner blade

The input parameters are

Flow rate, $Q_d = 0.5731\text{m}^3/s$

Net head, $H_n = 16.34m$

Turbine speed, $N = 716r.p.m$, and Specific Speed of turbine=198.

There are other parameters like the number of blades, and diameter ratio of runner hub: tip is identified by the designer. The values on the graph are for guidance, for this project the blade number and diameter runner hub: tip ratio $(\frac{D_h}{D_t})$ are taken at the specific speed values of the chart below.

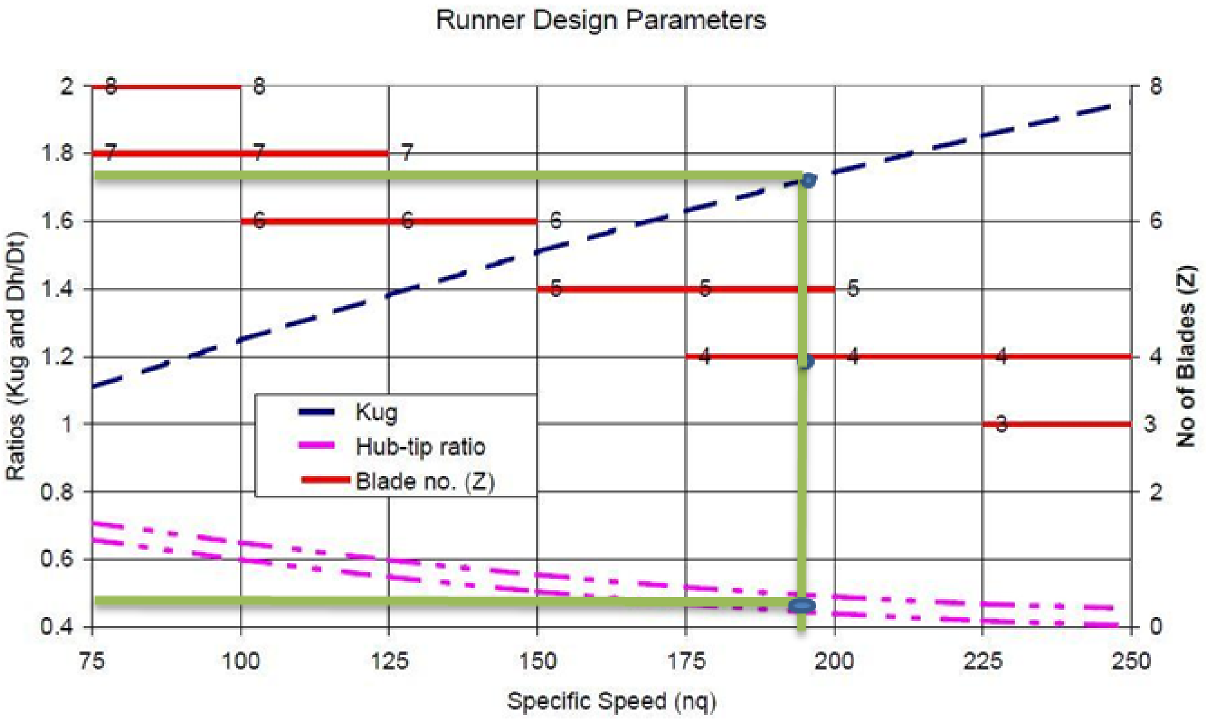


Figure 4-3: Number of Blades, Diameter Ratio, and Kug versus Specific Speed of Turbine chart (Adhikari et al., 2014)

The other input data's used for this project are

$$Number\ of\ Blade, Z = 4$$

$$\frac{D_h}{D_t} = 0.45, and\ Kug = 1.75$$

- Velocity, $u = Kug\sqrt{2gH_n} = 1.75\sqrt{2 * 9.81 * 16.34}$

$$u = 31.3m/s$$

- The angular velocity of the turbine runner , $\omega = \frac{2\pi N}{60},\ N = 716\ r.p.m$

$$\omega = 74.98rad/second$$

- The blade tip radius,

$$r_t = \frac{u}{\omega}, \qquad r_t = 0.42m\ \cong 420mm$$

- The blade tip diameter, D_t

$$D_t = 2r_t, \qquad D_t = 0.84m \cong 840mm$$

- The hub diameter, D_h

$$\frac{D_h}{D_t} = 0.45, \quad D_h = 0.378m \cong 378mm$$

- Cross sectional area, A

$$A = \frac{\pi}{4}\left(D_t{}^2 - D_h{}^2\right), \qquad A = 0.442m^2$$

- Axial velocity, V_{axial}

$$V_{axial} = \frac{Q_d}{A} = \frac{0.5731m^3}{0.442m^2}, \qquad V_{axial} = 1.3m/s$$

Design of Turbine Scroll Case

Scroll case protects the turbine blades from damage and also used to direct the water from the penstock to the runner. The advantages of spiral casing are:-

- Achieve the turbine long life time
- To get good reliability of the system, and
- Protects the runner from harmful damages

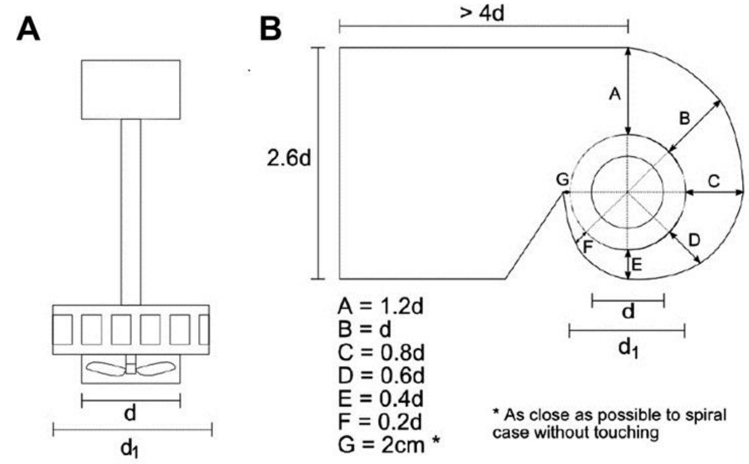


Figure 4-4: Spiral Casing Shape (d=runner diameter=0.343m)(Susanto & Stamp, 2012)

The spiral/scroll casing parameters/dimensions are:-

A	**0.424m**
B	0.354m
C	0.283m

D	0.212m
E	0.141m
F	0.071m

G	0.020m
4d	1.414m
2.6d	0.919m

Draft tube

In the hydropower system, the draft tube is one component of reaction turbines. The geometrical shape of the draft tube increased from the top to the bottom. In this case study, the draft tube connects the Kaplan turbine runner exit to the tailrace. One end of the draft tube is connected to below the water level in the tailrace, while the other end to the outlet port. The main advantage of the draft tube is to allow the turbine installation above the tailrace without causing a head loss and to transfer the flow rate from the turbine runner exit into the tailrace of the Micro hydropower system by converting the kinetic energy produced by the turbine runner into pressure energy. Draft tube also used to increase the efficiency of the system. The conversion has done by increasing the pressure from the low-pressure exit of the runner into the atmospheric pressure, in which the fluid is exhausted.

Types of draft tube

There are four types of draft tube. These are:-

- Conical diffuse/ Divergent Draft tube
- Simple elbow draft tube
- Elbow with the varying cross-section
- Moody spreading draft tube

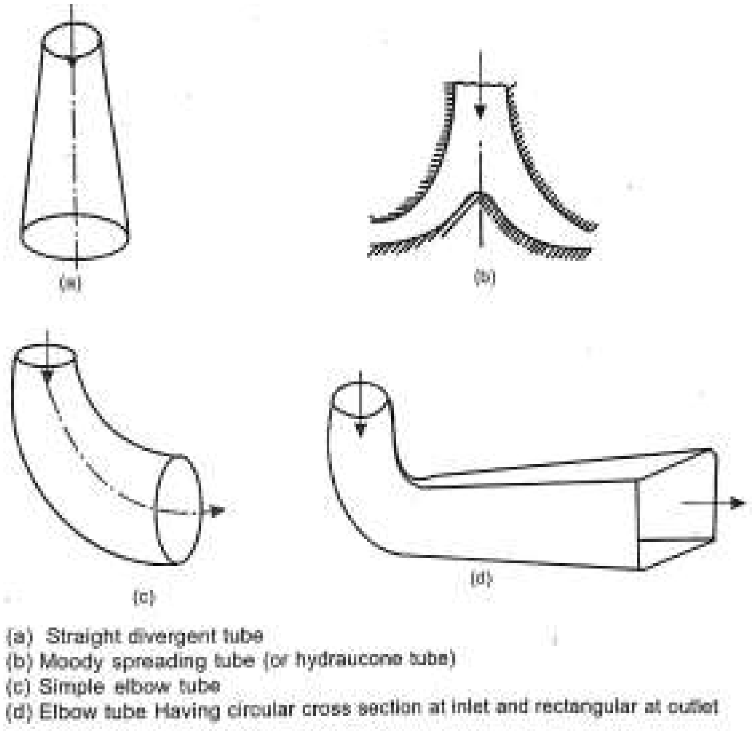


Figure 4-5:- Types of Draft tubes (Krushna et al., 2019)

Divergent draft tube is made of mild steel plates and also the simplest of draft tubes with good hydraulic feature. The conical draft tube has efficiency about 90 percent.

Simple elbow draft tube is used for low head. The efficiency is about 60 percent which is medium. The area of the inlet and outlet are the same but there is some change in the outlet.

Elbow with varying cross section has three parts. These are cone, elbow, and diffuser. In this tube the upper section is circular and the outlet is a rectangular section.

Moody spreading draft tube helps the system by reducing the whirling speed of the water with an efficiency of around 88 percent, which is good. And also this type of draft tube has one inlet and 2 outlets with a centroid core, the place where two parts of an outlet are distributed.

For this research the conical type of draft tube is selected. This is due to that the conical type is simple and efficient than others.

The design analysis of the conical draft tube type is shown below.

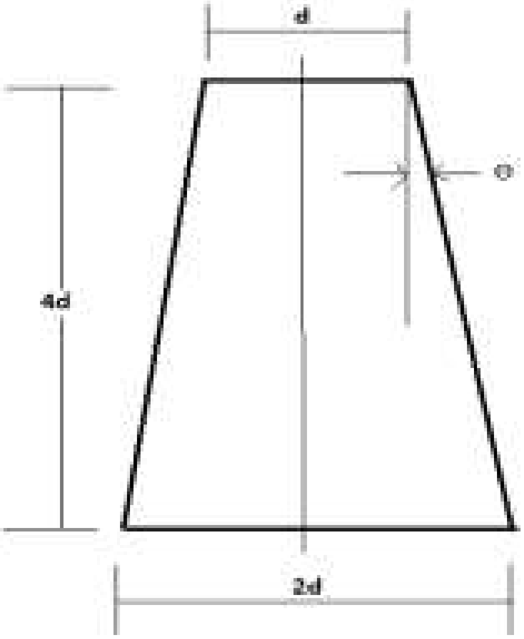


Figure 4-6:- Conical draft tube (Krushna et al., 2019)

As shown in figure 2 above, the one end of the draft tube connected to the turbine runner side has the same dimension as that of the runner diameter, and the other end, which is sub-merged below the level of water in the tailrace has dimension twice that of the runner diameter. Finally, the height of the draft tube is four times the diameter of the runner.

The height of the draft tube is

$$H = 4d$$

Where, H= height of draft tube

d= diameter of turbine runner.

The angle θ is always less than or equal to 10^0 (Krushna et al., 2019).

$$\theta = \tan^{-1} \frac{d/2}{4d} = 7.125^0 \leq 10^0 \ldots\ldots\ldots\ldots.\boldsymbol{Safe}!$$

$$\theta = Taper\ angle\ of\ divergent\ portion\ of\ tube$$

4.6. Generator Selection

Generator in hydropower system is a device used to convert the mechanical energy produced by the hydraulic turbine into electrical energy/electricity. There are two types of generators used for hydropower systems. These are synchronous and asynchronous generators. Synchronous generators are used for large hydropower system capacities more than 10Mw, whereas Induction generators are used for low power capacities less than 10Mw. The advantages of asynchronous/Induction Generators over the synchronous generators are:-

- Induction generators requires less maintenance
- They are available cheaply
- they are simple to built
- they less susceptible for damage and very reliable, and
- They can operate at variable speed and constant frequency

(Srpčič, 2012):- this article states that ‘’In Hydropower system either the induction or synchronous generators are used. In small hydro power systems like MHP plant, induction generators are recommended and the size of the generator is determined by the output power of the turbine’’. Based on the above advantages and MHP system has capacity power less than 10MW induction generator type is selected for this project case. Based on the numerical output power of the system, which is 74.5KW, the standard induction type generator selected for this system specifications are shown in table:

Table 4-4:- Induction Generator specifications

- **Prime Power/Stand by Power: 93KVA/75kw**
- **Voltage type 50Hz, 380/220V, 3 phases and 4 wires**
- **Speed 1500 RPM**
- **W: 760/1100**
- **Dimension (mm): 2800*1100*1650**
- **Weights (kg): 1820**

Figure 4-7:-93kVA/75kw Power Generator Diesel Engine Genset Diesel Generator Set SET (Selected Generator Image)

4.7. Selection of Speed Increaser and Design Analysis

This section presents some of the speed increaser/ power transmission mechanisms, selections, and design analysis of the system.

4.7.1. Selection of Speed Increaser

Some of the speed increaser mechanisms are Gear, belt with pulley, and chain with sprockets systems. Based on the speed of generator selected, the hydraulic turbines in MHP system are connected to the generator either directly or using gearbox, belts with pulleys, chain with sprockets.

Gear system

Gears are mechanism mushed together to transmit power, speed, and torque. Gear drive is a mechanical system used to transmit power, when the distance between the driver and the driven is small. Figure 4-8 shows the gear mechanism.

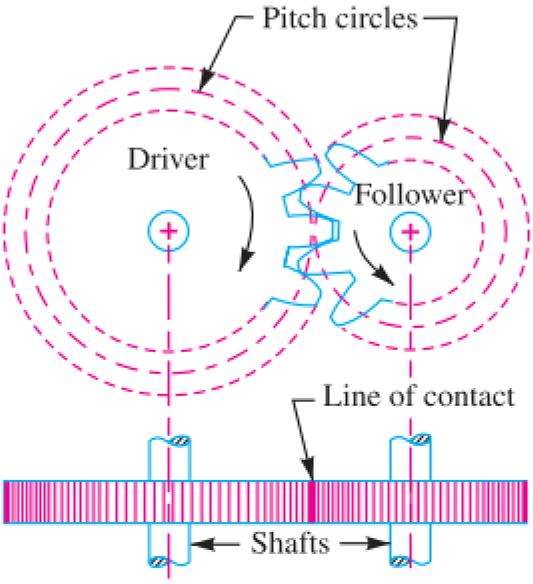


Figure 4-8:- Gear System (Khurmi & Gupta, 2005)

Belt and pulley systems

Belt is a mechanical element used for the transmission of power from one element to another by the use of pulleys which rotates at the same or different speed with the element the belt system is used for a longest distance. The factors that affect the amount of power transmitted are the velocity of the belt, the arc of contact between the belt and the smaller pulley, and the tension under which the belt is placed on the pulleys. (Khurmi & Gupta, 2005)

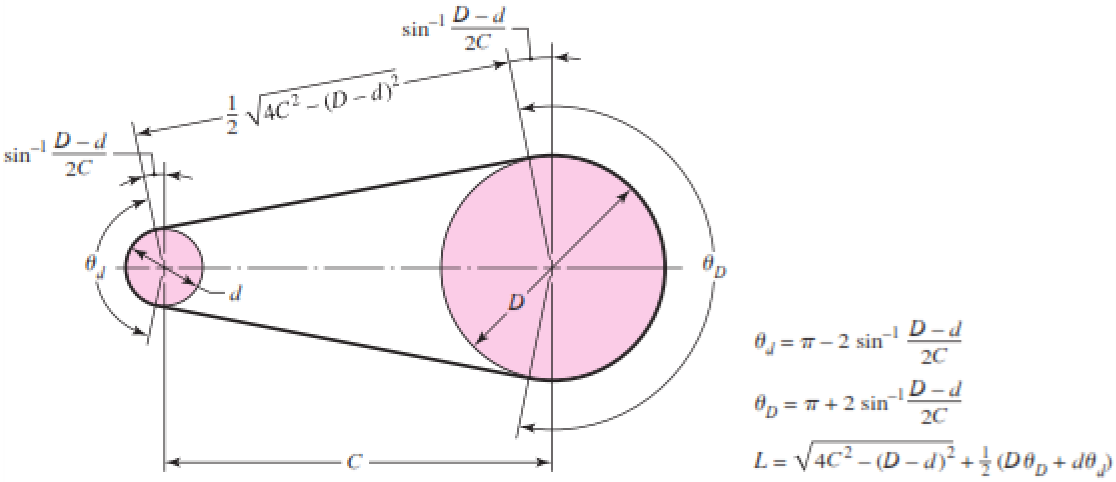


Figure 4-9:- Flat Belt (Nisbett, 2011)

Chain and sprocket systems

Chain and sprocket systems are also a mechanical device used for the transmission of power. Sprocket is a rotating mechanical element that has teeth and can be used with a chain to transmit power. Chain and sprockets are used to change the speed, torque and direction of a system. Sprockets and chains must have the same thickness and pitch. This system is rarely used due to that of the strength and noisiness of the system during operation.

Figure 4-10:- Chain and Sprockets (*Gears and Sprockets*, 2016)

Selection of the system

Belt and pulley systems are selected for this case due to the following advantages of belt and pulley drive over others like silent, smooth, easily installed, reliable, flexible, cheap, minimizes the requirement of lubricant, easy to assemble and disassemble, can use more than one belt at a time, and parallel shafts are not as a must. There are also different types of Belt systems. These are flat belt, V- belt, and timing belts. These belt systems are used to transmit power. Among these types, flat belt is selected due to the following advantages compared to others.

- ✓ Simple to design
- ✓ Cheap
- ✓ Smooth
- ✓ Used for long distances, and
- ✓ Very flexibility makes flat belts better than others.

In addition, flat belt is selected based on justification shown in section 4-5.

4.7.2. Design analysis of flat belt and pulley

Flat belts are made of urethane and also of rubber-impregnated fabric reinforced with steel wire or nylon cords to take the tension load (Nisbett, 2011).

Design specifications:-

Driver puller speed (N) =turbine speed =716r.p.m

Driven speed (n) =generator speed=1500r.p.m

Driver pulley diameter (D) =600mm, which is greater that turbine hub diameter (assumed)

Rated (transmitted) power, $P_R = 82.5KW$

$Center\ distance(C)\ \geq (\frac{diamter\ of\ driven\ pulley(d)+dimater\ of\ driver\ pulley(D)}{2})$

The speed and diameter ratio are related by the formula

$$\frac{N}{n} = \frac{d}{D}$$

$$\frac{716}{1500} = \frac{d}{600}, \ldots..d = 286mm$$

The center distance will be greater or equal to 443mm. $let's\ take\ C = 2000mm\ for\ this\ case.$

$Ks = 1.2$, from Appendix-C figure 0-1.

Design factor $nd = 1.05$……..assumed

Let's select Polyamaide A-3 material for flat belt from Appendix-C-Figure 0-2.

Thickness t=0.13in=0.003302m

$$C_v = 1$$

$$\gamma = 0.042lbf/in3\ = 11.401KN/m$$

$$f = 0.8$$

$$F_a = 100lbf/in = 17.5127KN/m\ at\ 600rev/min$$

$$C_p = 0.87$$

$$(F1)_a = bF_aC_p \ldots.where\ b\ is\ belt\ width$$

$$(F1)_a = 15.24b\ KN$$

The design power is calculated by using the formula

$$P_d = P_R * K_s n_d$$

$$P_d = 82.5 * 1.2 * 1.05 = 103.95KW$$

Power is the product of torque and angular speed. So to get the torque transferred, use the formula

$$P_d = T * n$$

$$T = \frac{P_d * 60}{n * 2\pi} = 662N.m$$

The estimate value of (fϕ) for full friction development is

$$\phi = \theta_d = \pi - 2\sin^{-1}\left(\frac{D-d}{2C}\right)$$

$$\phi = \theta_d = \pi - 2\sin^{-1}\left(\frac{600-315.2}{2*2000}\right) = 171^0 \cong 3rad$$

$$exp(f\phi) = 11$$

The estimated value of the centrifugal tension F_c in terms of belt width b is given by

$$w = \gamma bt = \frac{11.41KN}{m3} * b * 0.003302m$$

$$w = 37.65b\ N/m$$

The speed of belt is given by

$$V = \frac{n*2}{d} = \frac{1500*2\pi}{60} * \frac{286}{2*1000}$$

$$V = 22.5m/s$$

The centrifugal force is

$$F_c = \frac{w}{g}(V)^2$$

$$F_c = \frac{37.65b}{9.81}(22.5)^2$$

$$F_c = 1943b\ N$$

For design condition that is at the design power level, using the equation

$$(F1)_a - F_2 = \frac{2T}{d} = \frac{2*662}{0.286}$$

$$(F1)_a - F_2 = 4629.4N$$

$$F_{2=}(F1)_a - [(F1)_a - F_2] = (15240b - 4629.4)N$$

$$F_i = \frac{(F1)_a + F_2}{2} - F_c, after\ substitution$$

$$F_i = (13297b - 2314.7)N$$

Let’s assume the frictional development is at its highest level for this research case

$$exp(f\phi) = \frac{(F1)_a - F_c}{F_2 - F_c}$$

$$11 = \frac{15240b - 1943b}{15240b - 4629.4 - 1943b}$$

Finally, the minimum width of flat belt is $b = 0.383m = 383mm \cong 15.1in$

The total length of flat belt is $L = \sqrt{}(4C\text{^}2 - (D-d)\text{^}2\ ) + \frac{1}{2}(D\theta_D + d\theta_d)$

$$\theta_D = \pi + 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 189^0 = 3.3rad$$

$$L = \sqrt{4C^2 - (D-d)^2} + \frac{1}{2}(D\theta_D + d\theta_d)$$

$$L = 5407mm \cong 5.407m$$

The width of pulley is found by adding some extra dimensions to that of the belt width.

$$b_{pulley} = b + 25mm \cong 408mm$$

4.8. RETScreen Analysis

This section covers the analysis of the flow duration, efficiency and power curves of the system with the help of RETScreen Software's.

Site Information

The study site for this research is located 10.514614 degree North and longitude of 37.486939 degree east. The closest climate data location is in Debre Markos, located in the East Gojjam Zone of the Amhara Administrative Region; it has a latitude and longitude of 10.3°′N 37.7°′E, and an elevation of 2,446 meters. The site metrological data is presented below in figure below.

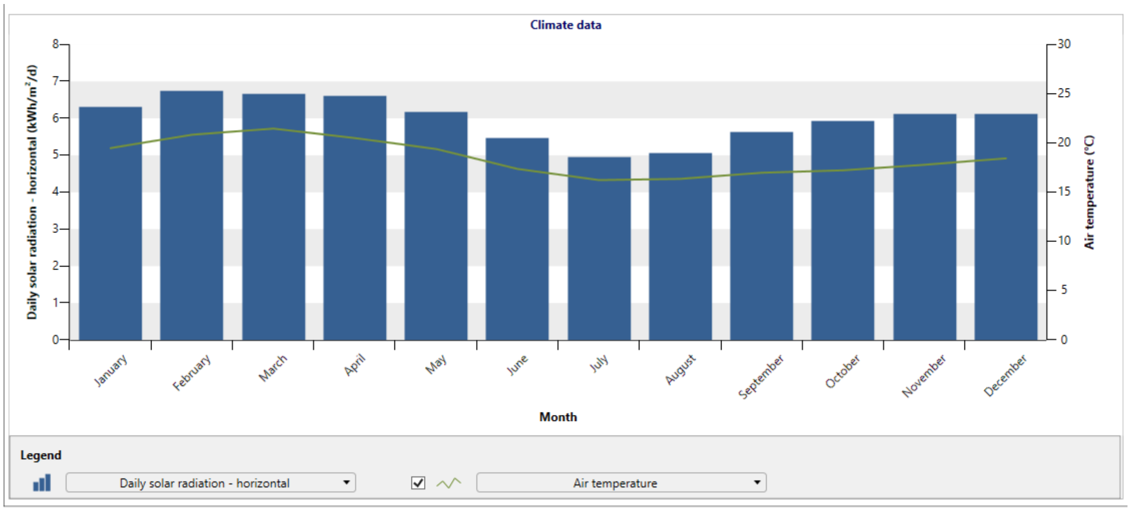


Figure 4-11:- Metrological data of the Reference site

RETScreen Facility Information

Table 4-5:- RETScreen Facility Information

Facility Type	Power Plant
Type	Hydro Turbine
Description	A Micro-Hydro Power System Analysis

RETScreen Energy Model

The energy model is used to get the annual energy production for a micro-hydropower system up on local site conditions and system features. In this case study, the residual flow, which is the minimal flow left over due to some environmental cases like for drinking and evaporation issues, is assumed 0.01m^3/s. Since Level 2 is more detail than level 1, tables below show the detail data.

Table 4-6:- RETScreen Energy Model Resource assessment and Hydro Turbine Data's

Hydro Turbine	**Level**
Description:- Hydro Turbine	Level 2
Note:- A Micro-Hydro Power System Analysis	
Hydro Turbine- Level 2	
Resource assessment	
Proposed Project	Run-of- River
Hydrology method	User-Defined
Gross head	19m(From Section 4-5 Table 4-4)
Maximum tail water effect	1.33m (7% of gross head)
Residual flow	0(Assumed from Justification in section 3.5)
Percent time firm flow available	100%
Firm Flow	0.49
Hydro Turbine	
Design flow	0.5731m3/s (95% of availability)
Type	Kaplan
Turbine efficiency	Standard
Number of turbine	1
Manufacturer	Canadian Hydro Components
Model	Kaplan
Design Coefficient	4.5
Efficiency adjustment	0.35%
Turbine peak efficiency,%	89.9%
Flow at peak efficiency , m3/s	0.43
Turbine efficiency at design flow, %	89.8%

Table 4-7:- Flow Duration and Turbine Efficiency Curve Data

% of Time	Flow rate,m3/s	Turbine Efficiency	Number of Turbines	Combined efficiency
0%	99.24	0.00	0	0.00
5%	75.49	0.00	1	0.00
10%	66.44	0.00	1	0.00
15%	58.43	0.07	1	0.07
20%	42.01	0.41	1	0.41
25%	29.95	0.62	1	0.62
30%	22.76	0.75	1	0.75
35%	17.90	0.83	1	0.83
40%	8.51	0.87	1	0.87
45%	4.87	0.88	1	0.88
50%	3.91	0.89	1	0.89
55%	2.45	0.90	1	0.90
60%	1.92	0.90	1	0.90
65%	1.85	0.90	1	0.90
70%	1.17	0.90	1	0.90
75%	1.07	0.90	1	0.90
80%	0.93	0.90	1	0.90
85%	0.78	0.90	1	0.90
90%	0.66	0.90	1	0.90
95%	0.57	0.90	1	0.90
100%	0.49	0.89	1	0.89

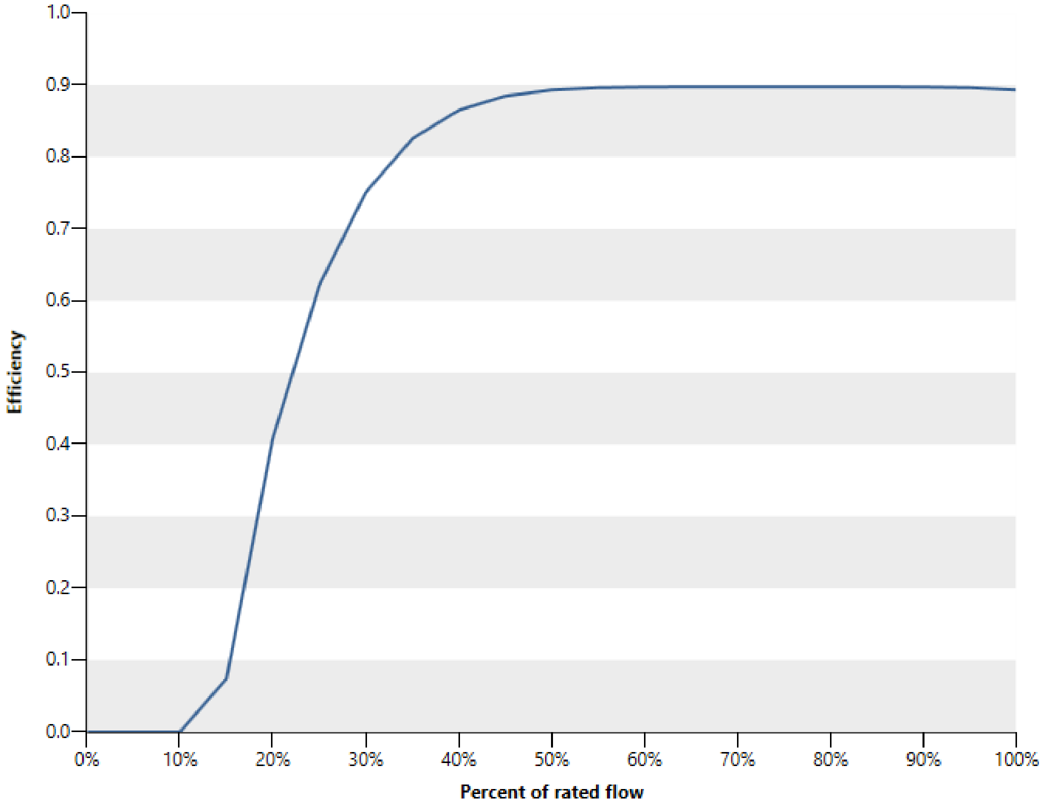


Figure 4-12:- RETScreen Result of Turbine Efficiency Curve

Figure 4-12above shows the combined efficiency of the selected number of turbines over the full flow range from 0 to 95% of the design flow.

Figure 4-13 below shows the flow and power duration curve of a Micro-Hydro power plant in the case of Temecha River.

Table 4-8:- System Losses and Summary of Energy Model Results

Losses	
Maximume Hydraulic Losses, %	7%
Miscellaneous Losses, %	12%
Generator efficiency, %	95%
Availability, %	100%
Summary	
Power Capcity, KW	74.6KW
Availability flow adjustment factor	1
Capcity factor, %	93.2%

Electricity Export rate	Electricity exported to grid- annually
	$/KW= 0.23
Electricity Exported to grid, MWh	643
Electricity export revenue	$ 147,973

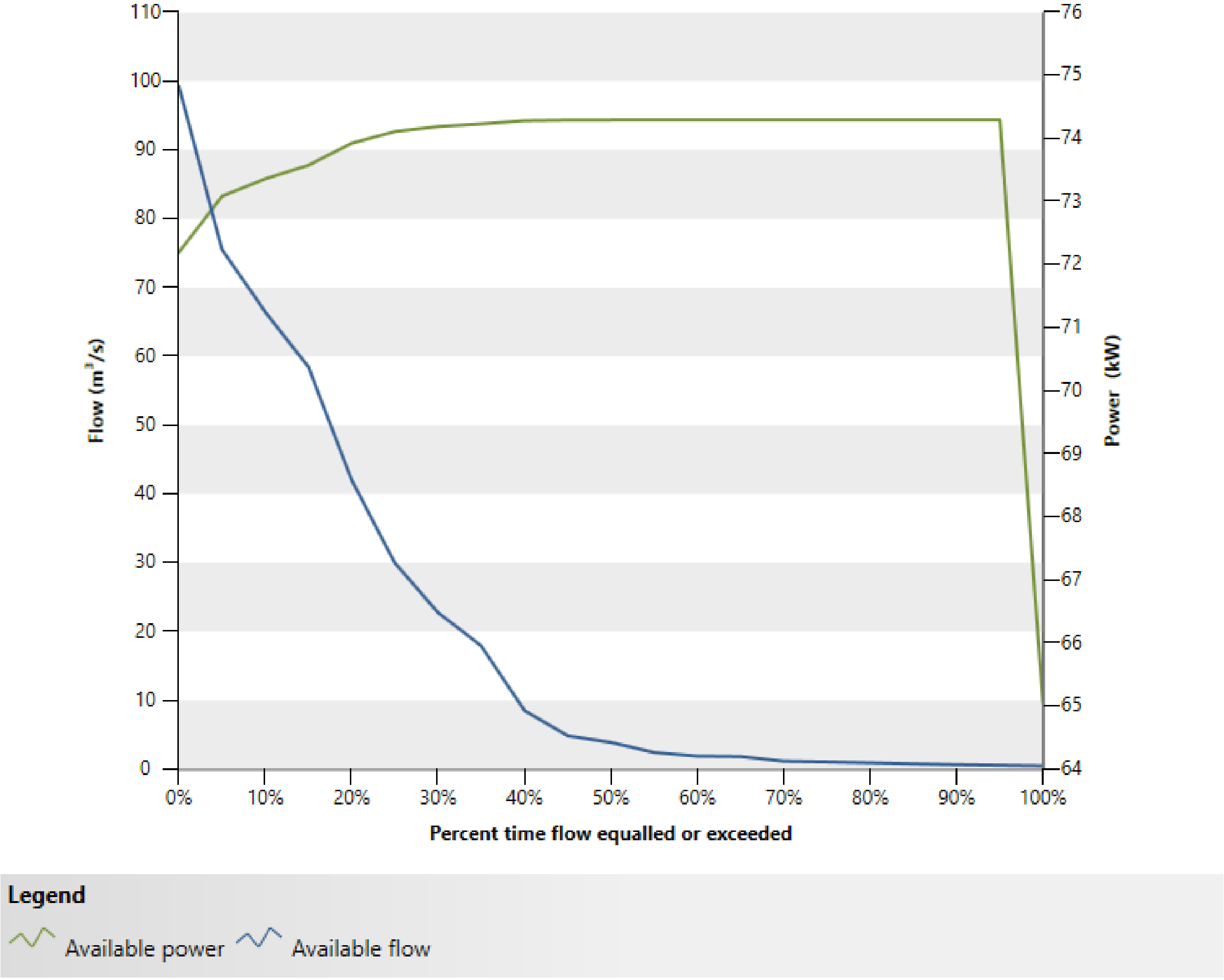


Figure 4-13:- RETScreen Results of Flow and Power Duration Curve

The result shown in figure 4-13 is both the flow and power duration curves. This result has done with the help of RETScreen software. The power curve shows some increments, constant and decrement values. This is due to that of the effect of both the flow rate and the tail water. The output result of the Capacity Power is 74.6 Kw. The model calculates the capacity factor, which represents the ratio of the average power produced by the hydro plant over a year to its rated power capacity. Typical values for hydro plant capacity factor range from 40 to 95%. In this case the calculated capacity factor is 93.2%, which is within a range of 40 to 95%.

CHAPTER FIVE

5. SIMULATION RESULTS AND DISCUSSIONS

This section presents the modeling and simulation analysis of the system components using MATLAB SIMULINK Software. SIMULINK is a system in MATLAB used to simplify the modeling and simulation analysis resource usages. And also, the simulation results with discussions like flow duration curve, efficiency curve, power duration curve, and the like for the 12 months of the year separately are shown at the end of the analysis. The MATLAB code has stated in appendix-A at the back. In addition, the validation of the results with other previous works is stated at the end of this section. As shown in the y-axis, there are different values of flow rates for different months.

5.1. Intake Structure

This section includes the case study input data's of Temecha River. The data's are imported from the excel data into the MATLAB workspace by generating a MATLAB code, which is attached in the appendix part. Figure 5-1 below contains the average yearly flow data's of 12 months of the year. As shown in figure 5-1below, the y-axis have different values of flow rates for different months.

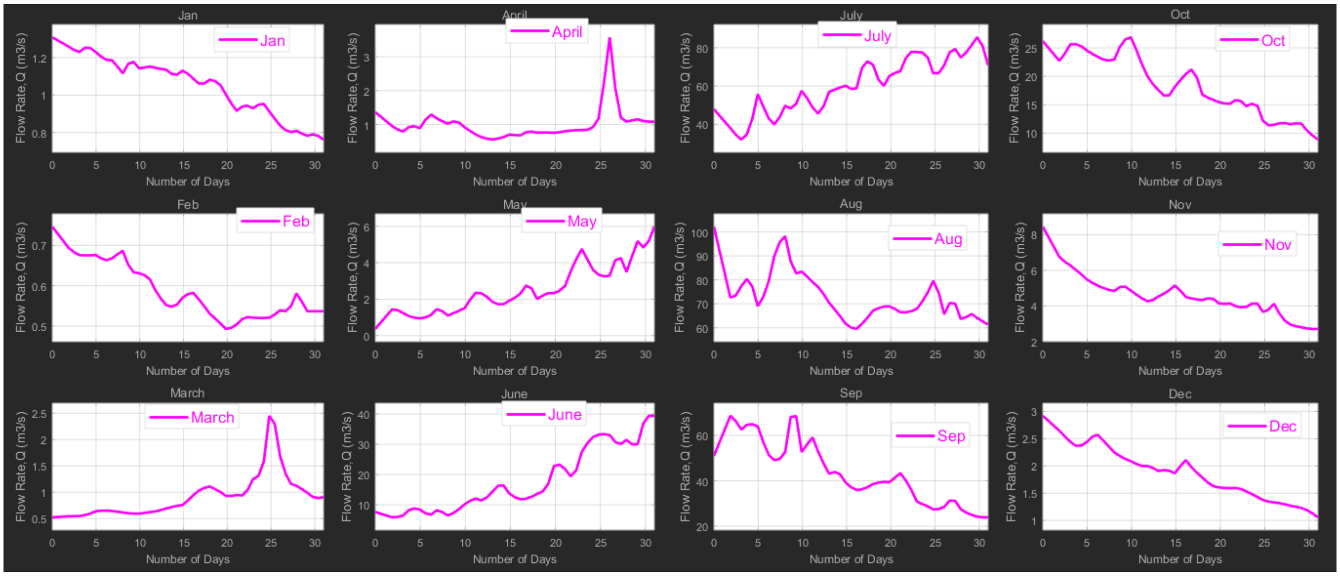


Figure 5-1:- River flow data in m3/s of each month

5.2. Penstock

This section presents about the model and simulation results of penstock flow data using MATLAB SIMULINK. As shown in the figure 5-2 below, the simulation results shows that the flow capacity of the penstock is less than or equal to the design flow rate value 0.5731m^3/s due to that of the system has 95% time of flow. The detail is shown in the appendix-B.

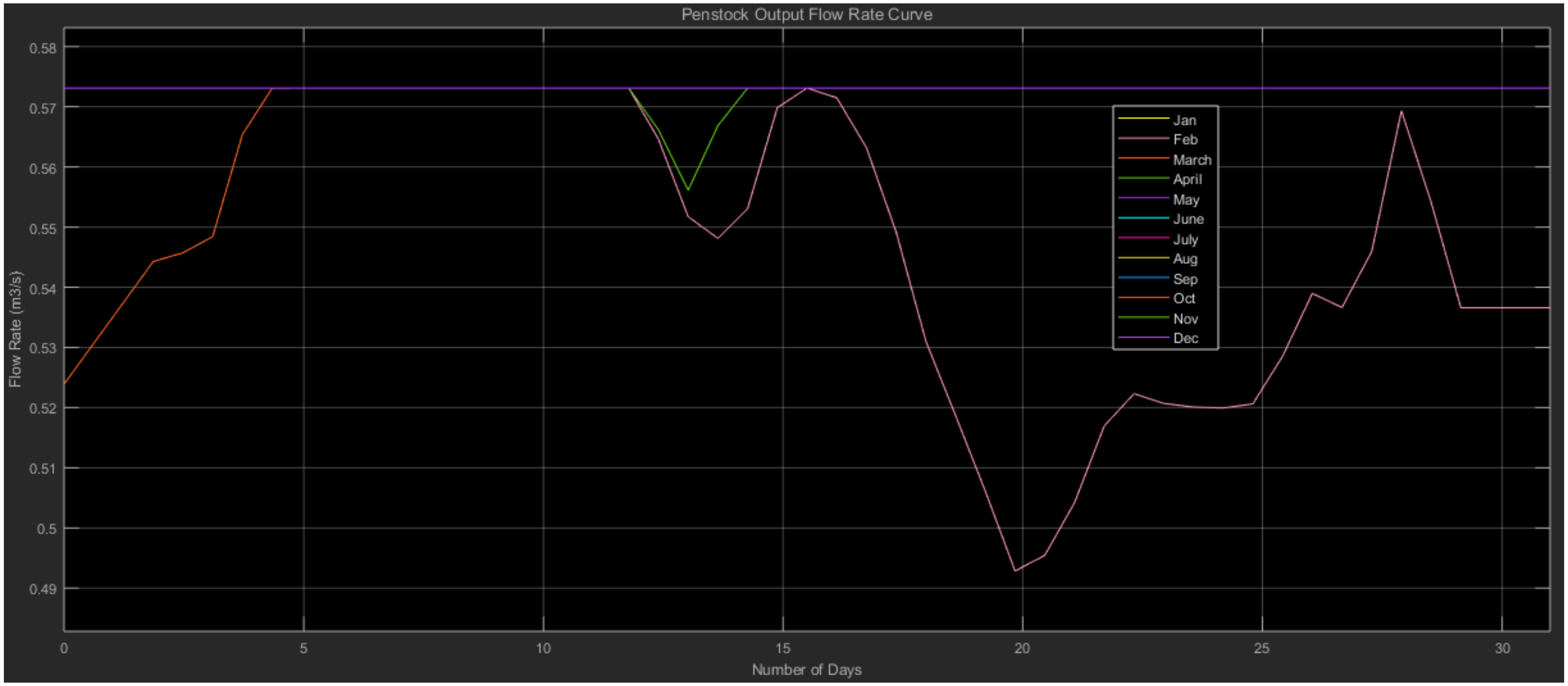


Figure 5-2:- Flow duration curve in the penstock (Flow rate in m3/s vs number of days)

The above figure is developed on MATLAB SIMULINK software'. It contains the 12 month flow rate of the site, which is less than or equal to the design flow rate. As shown in the figure the flow rate of 11 months of the year is equivalent to that of the design flow rate. And also the flow rate of February is less than that of the design flow rate for 16 days of a month. The flow rate of March is less than the design flow rate for 3 days of the month. The flow rat of April is less than that of the design flow rate for 1 day. For the flow rats equal to the design flow rate the system gets enough flow rate for that days without the interruption.

5.3. Power house

The powerhouse components include turbine, generator, and transformers. The turbine model using MATLAB SIMULINK and simulation results like mechanical power output curve/power duration curve, turbine speed, and MHP system power curve of the twelve months are shown clearly in figure 5-3, figure 5-5, and figure 5-7 below, respectively. As seen in the figure, the power output is constant for the 9 months and covers the electricity demand required by the community. The detail result is found in the appendix.

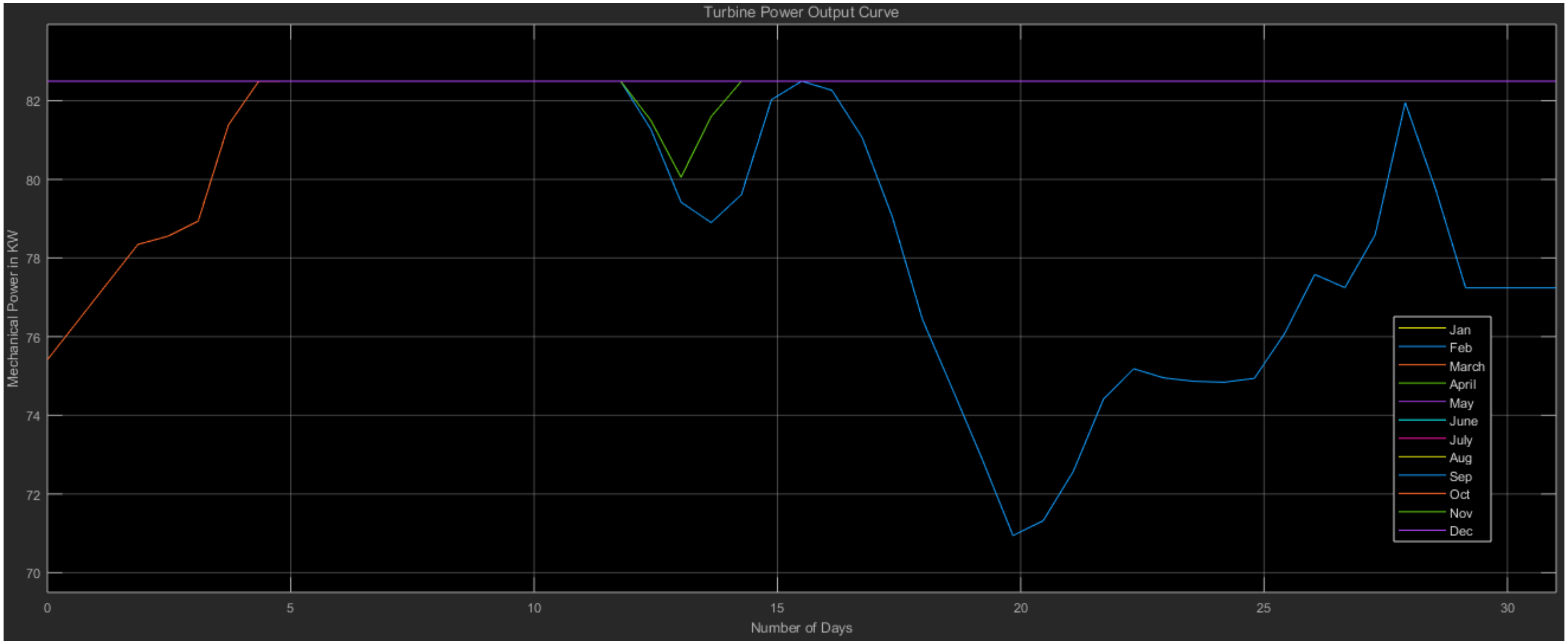


Figure 5-3:- Turbine mechanical power output curve (mechanical power in Watt vs. number of days)

The above figure has done on MATLAB SIMULINK Software's. The figure is represented by Mechanical power vs. number of days for each months of the year. As shown above, the mechanical power output from the Kaplan turbine is around 82.5kw and below it for around 20days of the year. For example, the mechanical power produced during February month is less than the maximum one for 16days, this is due to the flow rate of the month is less than that of the design flow rate. For March, the mechanical power produced is around 82.5kw for 27 days and less than that for the other 3 days. For April, the turbine output power is 82.5Kw for 29 days and less than that for 1 day of the month. Generally, the above variation of the turbine output power is caused due to the flow rate variation of the year.

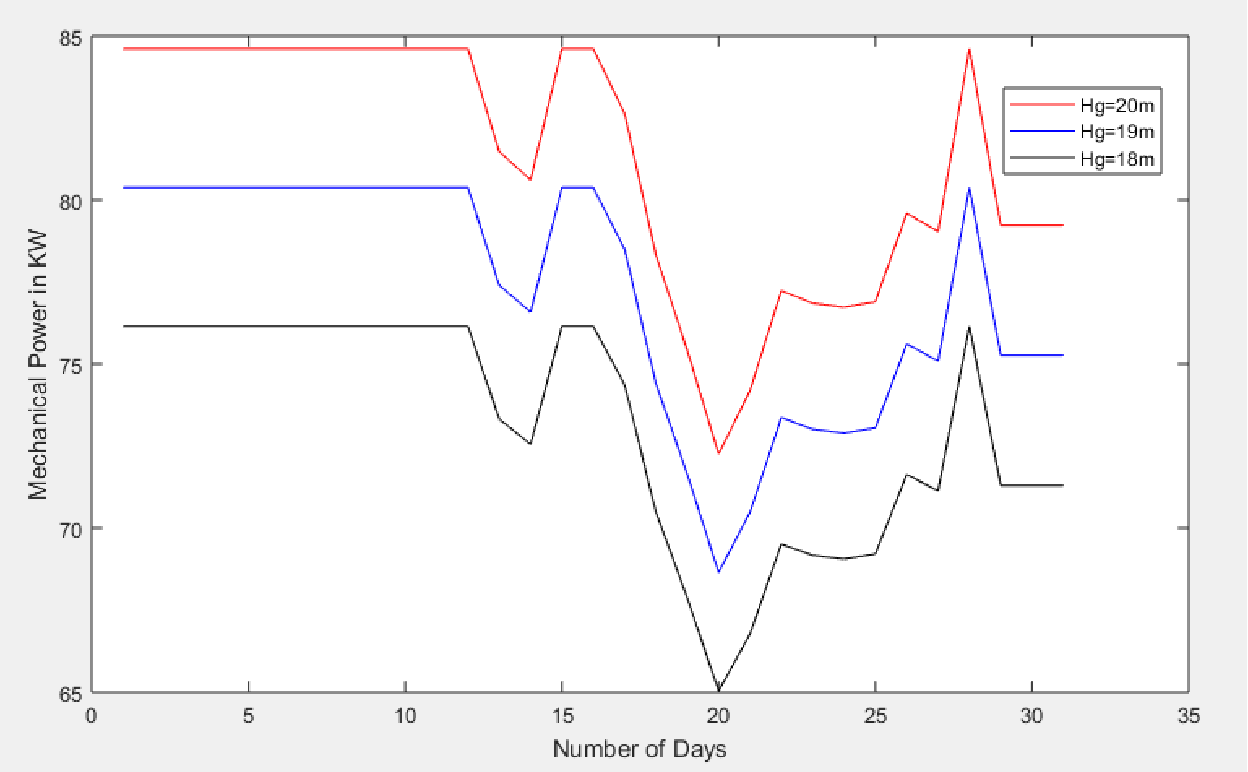


Figure 5-4:- Mechanical power vs Number of Days at variable gross head (February month)

The figure shows the variation of mechanical power with the number of days at different values of the gross head. As shown above, as the flow head increases, the mechanical power also increased. From this figure, we can conclude that if the flow head increases, the mechanical power also increases. In general, the output mechanical power has increased by increasing the flow head of the river.

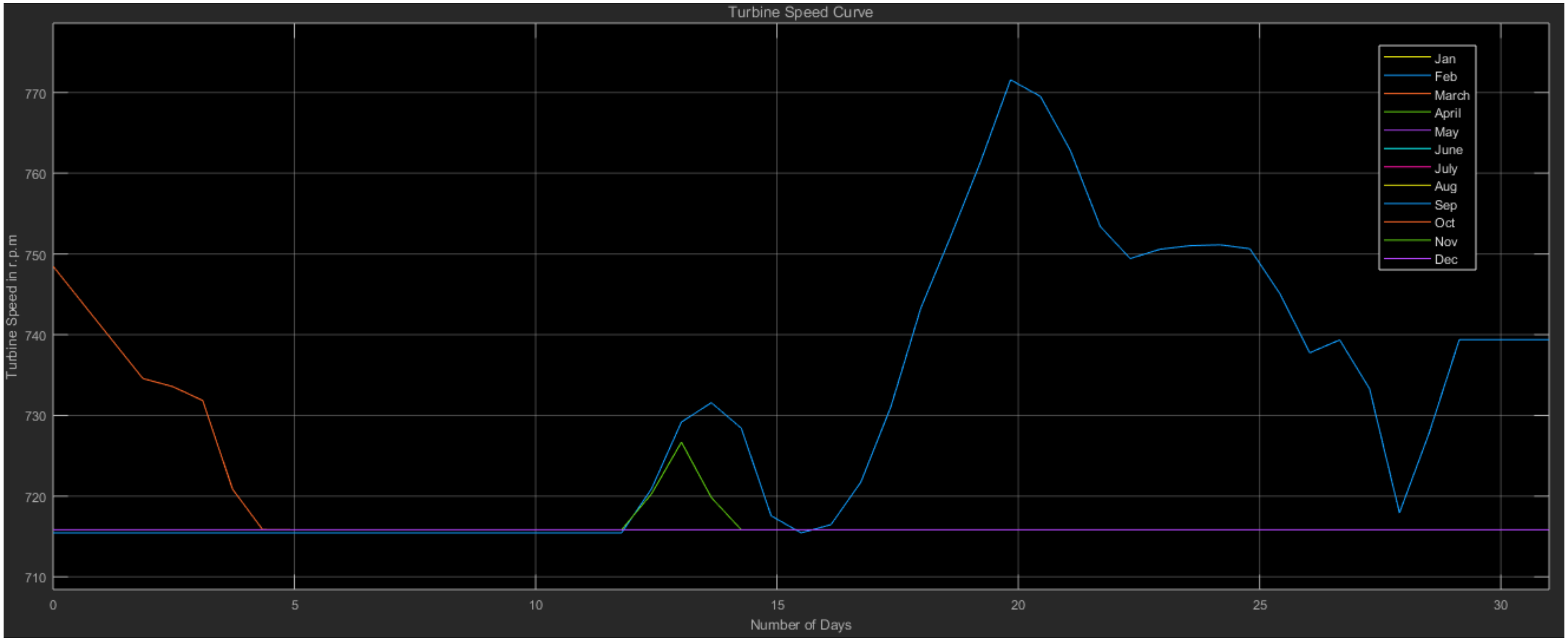


Figure 5-5:- Turbine speed in r.p.m. vs number of days for each month

The figure shows the turbine speed versus the number of days of the year for each month. As shown in the previous analysis, the turbine speed depends on the flow rate of the site. If the flow rate of the site increases, the turbine speed decrease. Therefore, for the minimum amount of flow rates like February, March, and April, the turbine speed is above the others, which is 716 r.p.m. The main reason for this case is that, as the flow rate value increases, the pressure too. Pressure and speed have inversely related, due to this reason why the turbine speed is inversely related to that of the flow rate value.

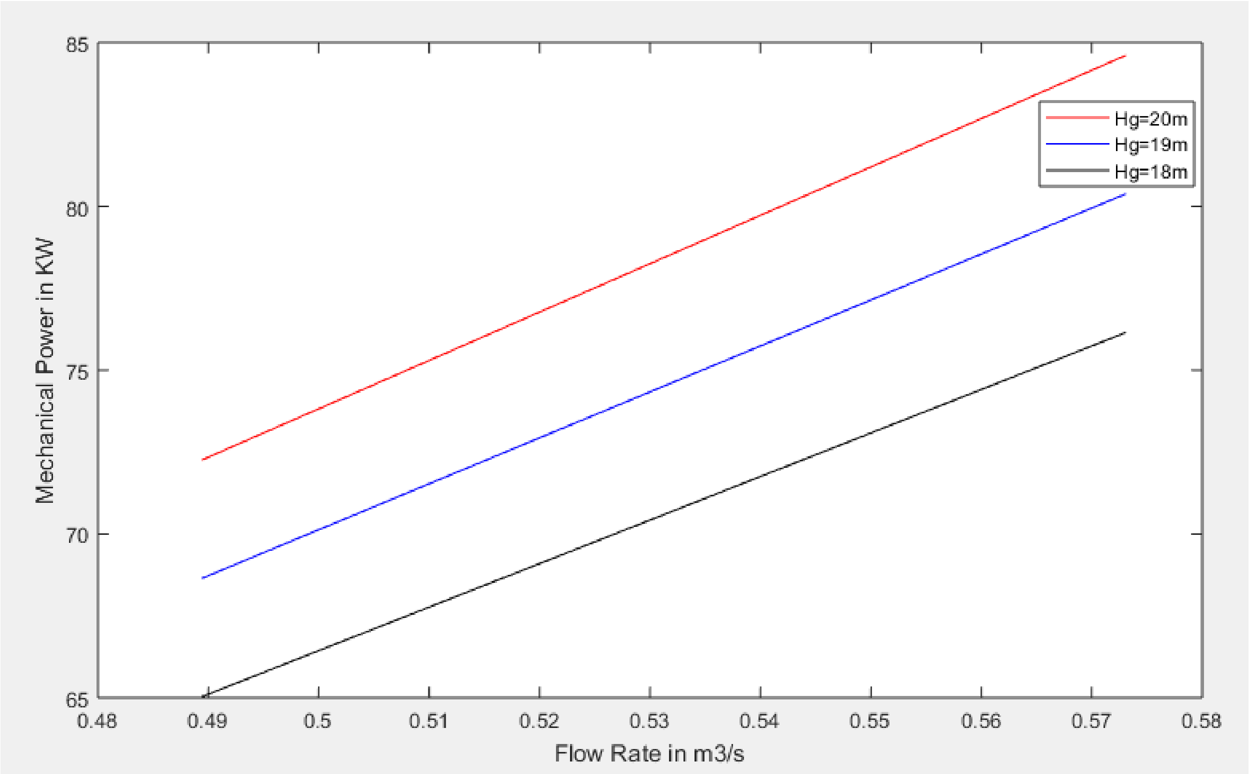


Figure 5-6:- Mechanical power versus Flow rate at variable gross head

The above figure shows the mechanical power output versus flow rate at different flow head values of the site. The figure shows that as the flow rate increases, the power output also. And also, as the flow head value increases, the power output also. Therefore, mechanical power, flow rate, and flow head have a direct relationship with each other. The reason is that, as one of them is varied, it affects the others directly.

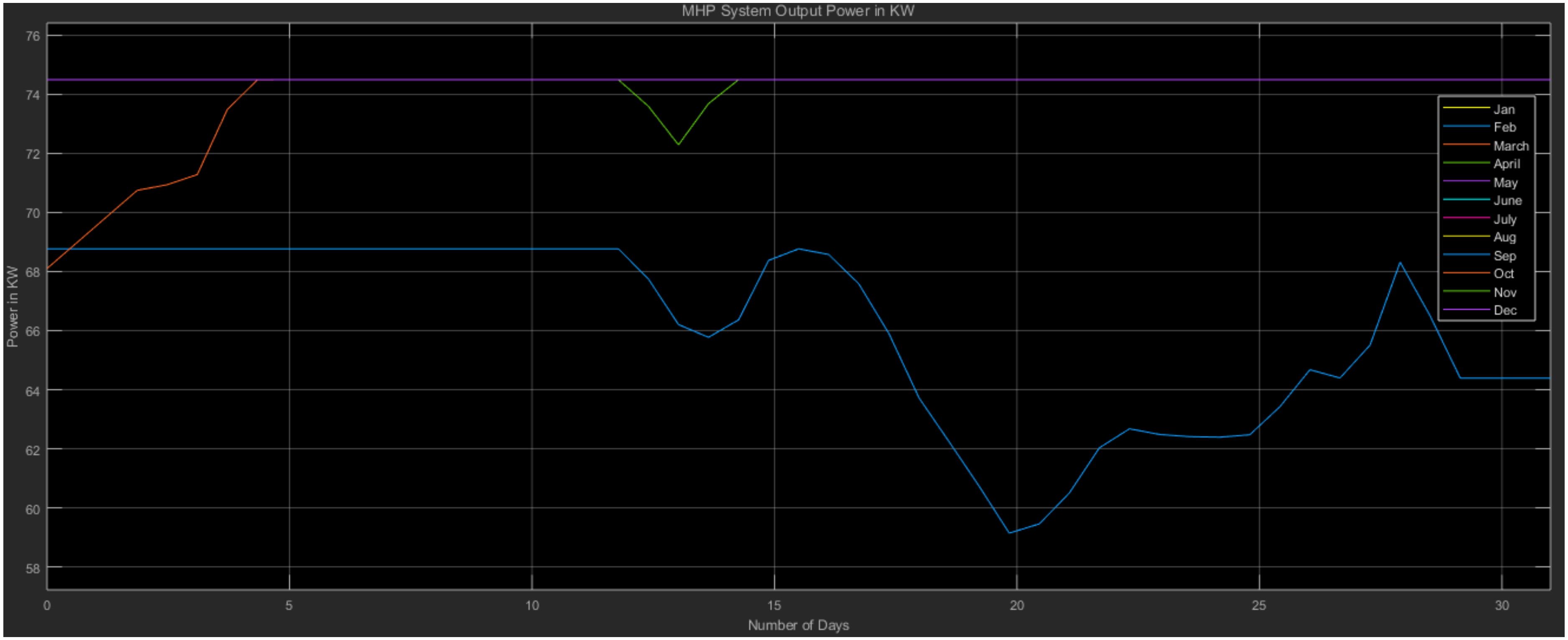


Figure 5-7:- MHP system output power

The figure shows that the MHP system output power versus the number of days of the year for each month. As seen in the figure, the maximum power output of the system is 74.5kw. This numerical value is constant for 11 months of the year. For February, the output power is below the maximum one for 16 days. For March, the output power is less than the maximum value for around 3 days. For April, the output power is less than the maximum one for 1 day of the month. The reason that makes the output power produced below the maximum value is due to the flow rate of the site less than the design flow rate value. Generally, the system satisfies the demand amount for 346 days of the year.

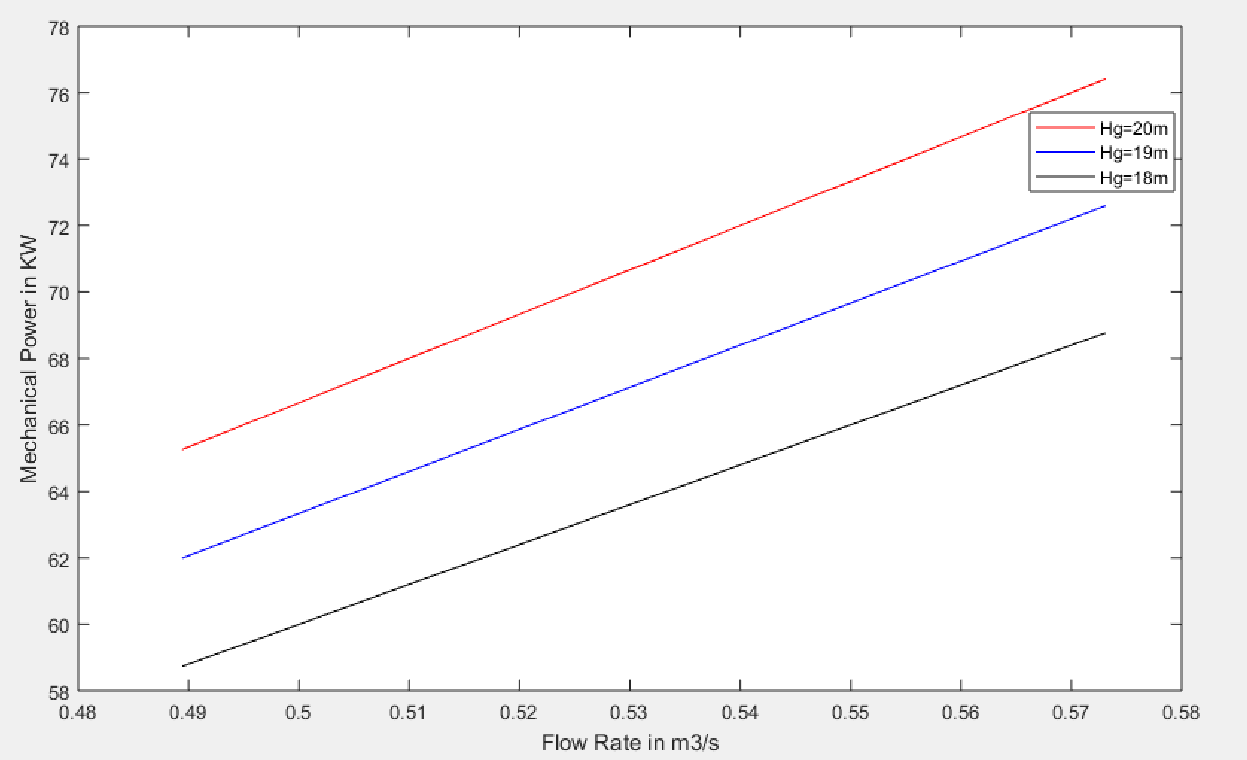


Figure 5-8:- Final system output power vs flow rate at different values of Gross Head

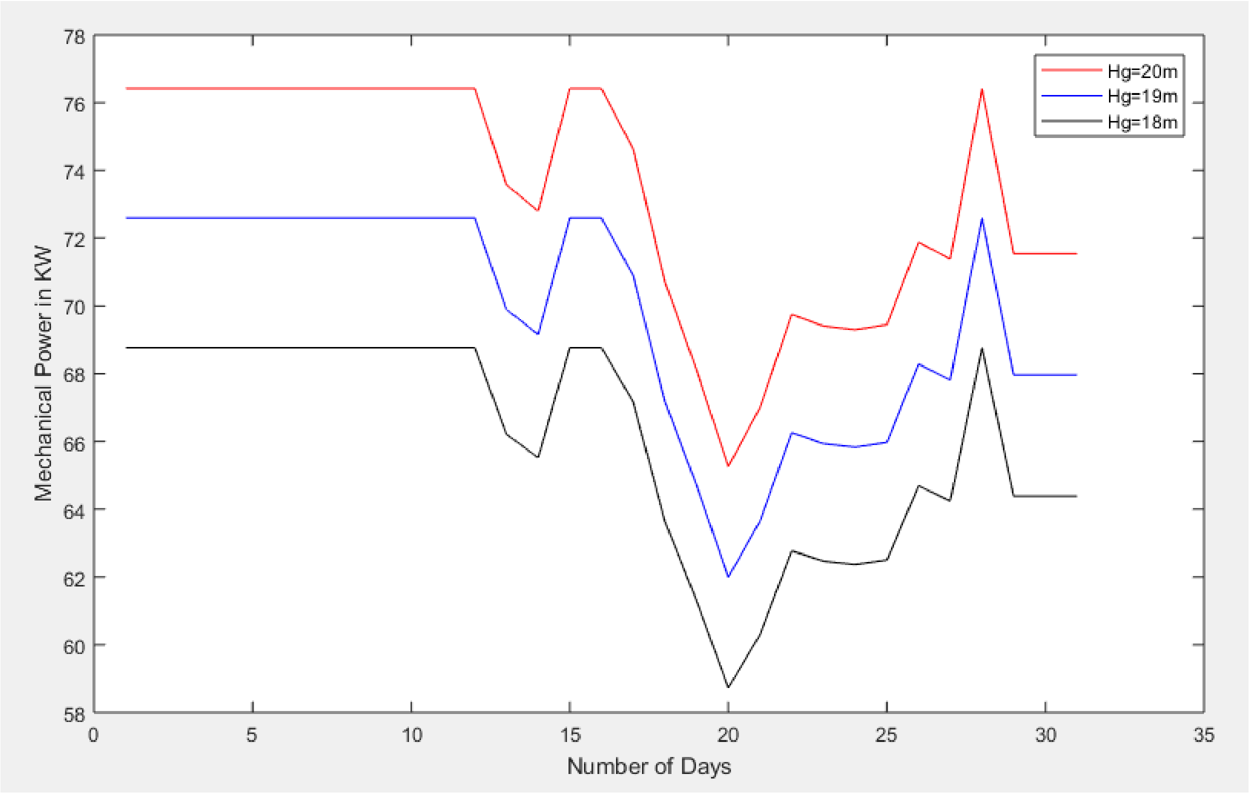


Figure 5-9:- MHP System Power in KW vs Number of days for February month at different values of gross head

CHAPTER SIX

6. ECONOMIC ANALYSIS OF MHP SYSTEM

In this section, the researcher uses the RETScreen Software for the cost and financial analysis of the system. RETScreen software is engineering software used to estimate the cost of renewable energy sources like solar PV, wind, and hydropower. For this case, the researcher uses the RETScreen software for purpose of micro-hydropower System cost estimation.

6.1. RETScreen Cost Analysis

The cost analysis of this MHP system was done by the use of RETScreen Software's. RETScreen software's has two levels of cost analysis. The first one is detail cost estimation methods that have estimated quantity and unit cost, which is carried out in the cost analysis sheet. This estimation method has three levels in which the user can select one of them considering the level of detail available for cost calculation. More detailed cost estimations can be made with the level 3. The second cost estimation method in level 3 offered by RETScreen is "hydro formula costing method". The hydro formula costing method tool estimates the project costs using the empirical formulae derived from the costs of numerous completed small hydro projects. This research used level 3 cost estimation methods in combined with hydro formula costing method. The hydro formula costing method uses the following relationships.

The researcher enters the relative cost of construction equipment in the country as compared to Canadian costs. This value is entered as the decimal ratio relative to Canadian cost. (Note that costs must be expressed in the same currency when calculating the ratios.) This value is used in the model to estimate the cost of projects outside Canada by adjusting the calculated costs for the local components of the work. For this case study the value of local vs. Canadian equipment cost ratio is 1.2.

The researcher enters the relative cost of fuel in the country as compared to Canadian costs. This value is entered as the decimal ratio relative to Canadian cost. (Note that costs must be expressed in the same currency when calculating the ratios.) This value is used in the model to estimate the cost of projects outside Canada by adjusting the calculated costs for the local components of the work. The Local vs. Canadian fuel cost ratio is 1.

The researcher enters the relative cost of labor in the country as compared to Canadian costs. This value is entered as the decimal ratio relative to Canadian cost. (Note that costs must be expressed in the same currency when calculating the ratios.) This value is used in the model to estimate the cost of projects outside Canada by adjusting the calculated costs for the local components of the work. The Local vs. Canadian Labor cost ratio is 0.5.

The researcher enters an adjustment factor to allow for the relative cost of manufacturing the equipment in the country as compared to in Canada. This value is entered as a decimal ratio that expresses the cost of equipment manufacturing relative to Canadian costs. This value is used in the model to adjust the cost of the foreign (i.e. imported) components (e.g. hydro turbine, substation and transformer, penstock, civil works and also engineering). The equipment manufacture cost ratio is 1.1.

The researcher enters the exchange rate to convert the calculated Canadian dollar costs into the currency in which the project costs are reported as selected in the file worksheet. The rate entered must be the value of one Canadian dollar expressed in the currency in which the project costs are reported, 0.794 $/CAD.

The researcher indicates by selecting from the drop-down list whether or not the small hydro project is located in a cold climate. Projects that are located in cold climates will cost more due to the increased difficulty of construction (i.e. due to increased transportation costs, shorter construction season, higher cost of equipment, material and labor, etc.). For the purposes of RETScreen, sites are located in a cold climate if, on average, they are situated in locations that experience at least 180 days with frost (temperatures below 0ºC) per year. The project site does not locate in a cold climate.

The researcher enters the design flow, which is defined as the maximum flow that can be used by the turbine(s). The selection of the design flow depends, primarily, on the available flow (hydrology) at the site. For central-grid connected run-of-river projects the optimum design flow is usually close to the flow that is equaled or exceeded about 30% of the time. For isolated-grid and off-grid applications, the flow required to meet the peak load may be the deciding factor for selecting the design flow, provided that this flow is available. The design flow considered for this study is at 95% of time, 0.5731m^3/s.

Maximum hydraulic and miscellaneous losses

The researcher enters a value that represents the estimated equivalent hydraulic losses (%) in the water passages. In a small hydro system, energy is lost as water flows through the water passages. A value of 5% is appropriate for most small hydro plants. For plants with very short water passages, a value of 2% is appropriate. For low-head small hydro plants with long water passages, the factor can be increased to 7%. Since the system has low head, the hydraulic loss is 7%.

The researcher enters a value to account for the allowable intake and miscellaneous losses in the water conveyance structures. This value accounts for hydraulic losses other than in a tunnel, canal or penstock, which are accounted for separately. The user enters the allowable penstock head loss factor. It is the ratio of the allowable head loss in the penstock(s) compared to the available gross head and is expressed as a percentage. For this case, a miscellaneous loss of 12% is assumed.

Road Construction

The researcher indicates by ticking the box whether or not an access road is required to be built to the small hydro project site. An access road to the site is required during construction to transport equipment and construction materials and for maintenance after the project is complete. The estimated length of road is around 6km. To estimate the cost of a required access road, the user specifies the road length, whether or not it is to be constructed as a tote road only and the difficulty of terrain through which the road is to be built. The road is constructed not only for construction purpose but also for others. The user enters a value between 1 and 4 representing the difficulty of the terrain through which the access road will be built. From table below the value of difficulty of the terrain is 1.

Table 6-1:- RETScreen Guide to Selecting Access Road Difficulty of Terrain Factors

Type of terrain	Difficulty of terrain
Flat, gently undulating terrain, no rock outcrops	1
Hilly terrain, some rock outcrops	2
Hilly terrain with rock outcrops	3
Hilly terrain with many rock outcrops	4

The researcher indicates by ticking the box whether or not a tunnel is required for the small hydro project. This value is not applicable for micro hydro projects. It is assumed that any tunnel required for a micro hydro project would make the project financially unviable. As shown in Table 6-2 below, the total initial cost of the MHP system is $ 764,400

Table 6-2:- RETScreen Cost Analysis

Initial cost (Credit)	**Amount in USD**	**Adjustment factor**	**Total Amount**	**Percentage**
Feasibility Study	$ 19,000	1	$ 19,000	3%
Development	$ 24,000	1	$ 24,000	3.8%
Engineering	$ 6,000	1	$ 6,000	0.94%
Power system				
Hydro Turbine	$ 253,000	1	$ 253,000	39.7%
Road Construction(length 6km)	$ 87,000	1	$ 87,000	13.7%
Transmission line(length 3km)	$ 55,000	1	$ 55,000	8.6%
Substation	$ 2,000	1	$ 2,000	0.31%
Balance of System & Miscellaneous Hydro turbine				
Penstock	$ 63,000	1	$ 63,000	9.9%
Others	$ 128,000	1	$ 128,000	20.1%
Sub Total	$ 637,000		$ 637,000	100%
Contingency 20%	$ 127,400		$ 127,400	
Total Initial Cost	$ 764,400		$ 764,400	

6.2. RETScreen Financial Analysis

In this section, there are two levels of financial analysis. In this Case study, Level 2 is selected. The analysis section contains financial input parameters like inflation rate, discount rate, project life, debt ratio, debt interest rate, debt term, and electricity export escalation rate. The financial viability outputs of the analysis are shown in table below.

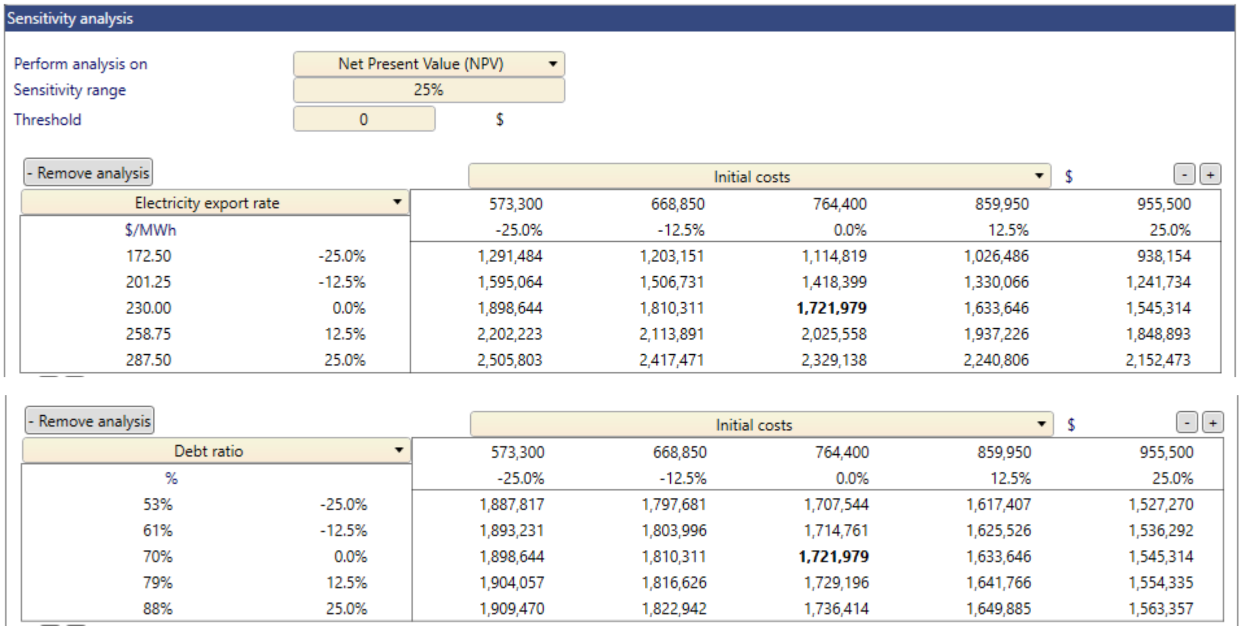
Table 6-3:- Financial Result of the system

Economic Indicators	**Result**
Pay-back period	5.2 yr
Net present value (NPV)	$ 1,721,979
Annual life cycle savings	$/yr 190,450

As shown in table 6-3 above, the pay-back period is 5.2 year. The NPV, which is the variation of the present values of the cash inflows and outflows as per a period of time, is $ 1,721,979.

6.3. RETScreen Sensitivity and Risk Analysis

The sensitivity and risk analysis worksheet can help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In this study, the effect of the following parameter is investigated: initial investment, electricity export rate, dept-ratio, debt interest rate, debt rate, annual O&M cost on the net present value of the project.



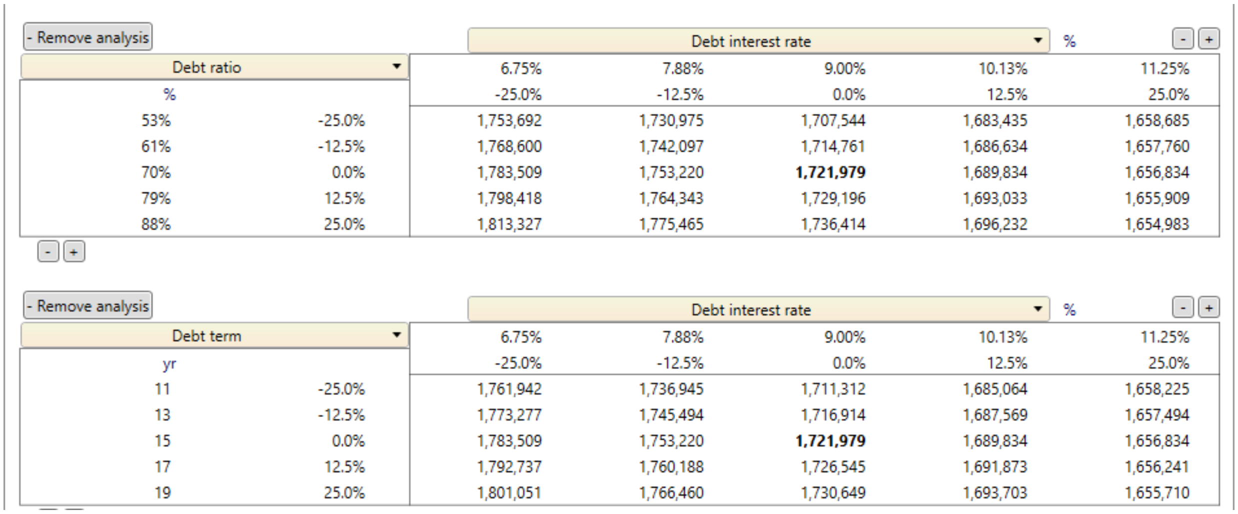
Perform analysis on: Net Present Value (NPV)
Sensitivity range: 25%
Threshold: 0 $

Initial costs $

Electricity export rate		573,300	668,850	764,400	859,950	955,500
$/MWh		-25.0%	-12.5%	0.0%	12.5%	25.0%
172.50	-25.0%	1,291,484	1,203,151	1,114,819	1,026,486	938,154
201.25	-12.5%	1,595,064	1,506,731	1,418,399	1,330,066	1,241,734
230.00	0.0%	1,898,644	1,810,311	**1,721,979**	1,633,646	1,545,314
258.75	12.5%	2,202,223	2,113,891	2,025,558	1,937,226	1,848,893
287.50	25.0%	2,505,803	2,417,471	2,329,138	2,240,806	2,152,473

Initial costs $

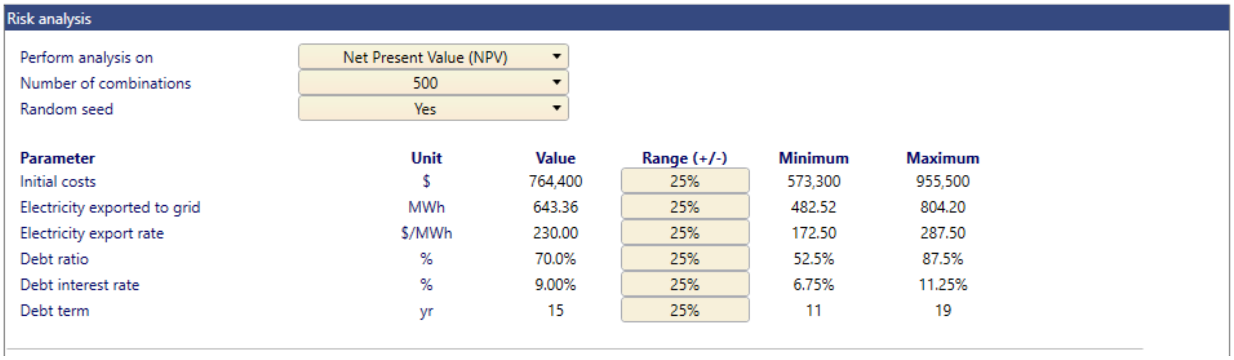
Debt ratio		573,300	668,850	764,400	859,950	955,500
%		-25.0%	-12.5%	0.0%	12.5%	25.0%
53%	-25.0%	1,887,817	1,797,681	1,707,544	1,617,407	1,527,270
61%	-12.5%	1,893,231	1,803,996	1,714,761	1,625,526	1,536,292
70%	0.0%	1,898,644	1,810,311	**1,721,979**	1,633,646	1,545,314
79%	12.5%	1,904,057	1,816,626	1,729,196	1,641,766	1,554,335
88%	25.0%	1,909,470	1,822,942	1,736,414	1,649,885	1,563,357



		Debt interest rate %				
Debt ratio		6.75%	7.88%	9.00%	10.13%	11.25%
%		-25.0%	-12.5%	0.0%	12.5%	25.0%
53%	-25.0%	1,753,692	1,730,975	1,707,544	1,683,435	1,658,685
61%	-12.5%	1,768,600	1,742,097	1,714,761	1,686,634	1,657,760
70%	0.0%	1,783,509	1,753,220	**1,721,979**	1,689,834	1,656,834
79%	12.5%	1,798,418	1,764,343	1,729,196	1,693,033	1,655,909
88%	25.0%	1,813,327	1,775,465	1,736,414	1,696,232	1,654,983

		Debt interest rate %				
Debt term		6.75%	7.88%	9.00%	10.13%	11.25%
yr		-25.0%	-12.5%	0.0%	12.5%	25.0%
11	-25.0%	1,761,942	1,736,945	1,711,312	1,685,064	1,658,225
13	-12.5%	1,773,277	1,745,494	1,716,914	1,687,569	1,657,494
15	0.0%	1,783,509	1,753,220	**1,721,979**	1,689,834	1,656,834
17	12.5%	1,792,737	1,760,188	1,726,545	1,691,873	1,656,241
19	25.0%	1,801,051	1,766,460	1,730,649	1,693,703	1,655,710

Figure 6-1:- Results of sensitivity Analysis



Risk analysis

Perform analysis on: Net Present Value (NPV)
Number of combinations: 500
Random seed: Yes

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	764,400	25%	573,300	955,500
Electricity exported to grid	MWh	643.36	25%	482.52	804.20
Electricity export rate	$/MWh	230.00	25%	172.50	287.50
Debt ratio	%	70.0%	25%	52.5%	87.5%
Debt interest rate	%	9.00%	25%	6.75%	11.25%
Debt term	yr	15	25%	11	19

Figure 6-2:- Risk Analysis

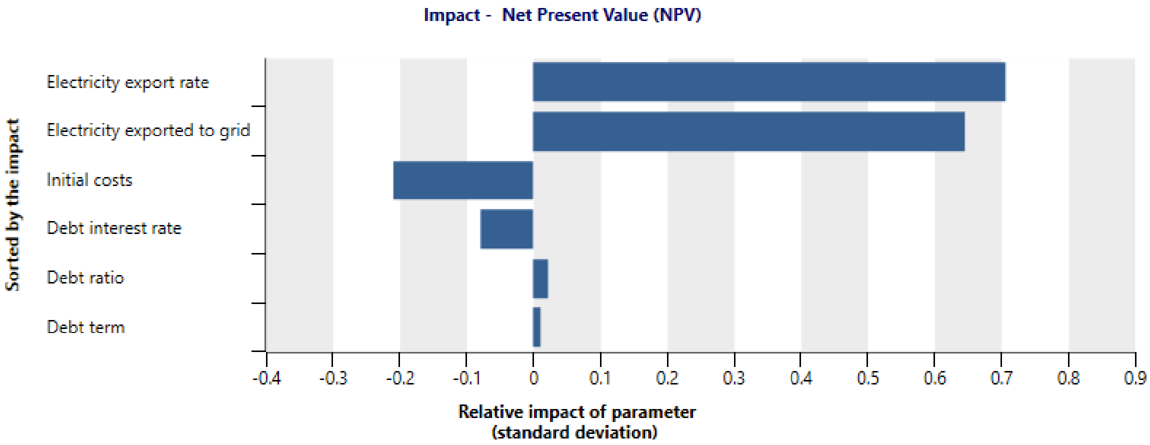
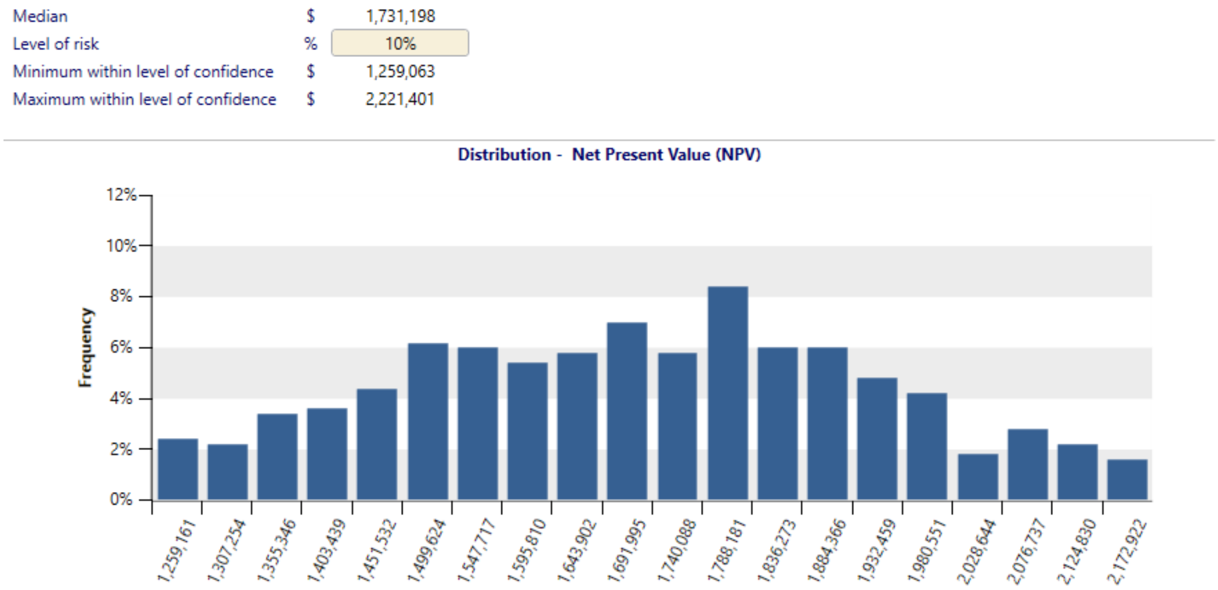


Figure 6-3:- Impact graph of the risk analysis result



Median	$	1,731,198
Level of risk	%	10%
Minimum within level of confidence	$	1,259,063
Maximum within level of confidence	$	2,221,401

Figure 6-4:- Distribution graph of the risk analysis result

Figure6-4 above shows the distribution graph of the risk analysis result, a distribution of the possible values for the financial indicators. The values in the y-axis represent the frequency (%) of values that fall in the range defined by the width of each bar. The value corresponding to the middle of each range is plotted on the x-axis. As depicted in the figure, the distribution graph is relatively narrow, which indicate that the NPV in this case has a relatively low standard error. The median of NPV is 1,731,198 USD, when the level of risk takes 10%, the minimum level of confidence for NPV is 1,259,063 USD, and the maximum level of confidence for NPV is 2,221,401 USD.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

This chapter presents the overall outcomes of the thesis and indicates the problem is solved or not, like is that the result solves the problem stated in the problem statement. And also, the future development of the study is included in this section.

7.1. Conclusion

In conclusion, MHP system is a good solution than other green-energy technologies in order to solve rural electrification problems in remote areas that are far from the national grid system. The main objective of this research is to model and simulate the MHP system in the case of the Temecha River. Some specific tasks are covered here to satisfy the main task. These are a collection of data performing a flow duration curve, the selection and design of Kaplan turbines, the standard selection of generators, and the like. The uniqueness of this research from previous works is:-

- This case study states to solve the problem of rural electrification for the selected remote area.
- The design flow rate is 0.5731m^3/s. The design flow is available 95% of the time or more.
- The simulation results are flow duration, turbine efficiency, power duration curves, and turbine speed.
- As seen in the simulation result, figure-5-8 shows that with a 16.34m net head and 0.5731m^3/s design flow rate, the electricity produced is up to 74.5KW of power, which is enough to be more than our requirement 72.72KW of electricity.
- From these results, we can conclude that by implementing this MHP system shows that 74.5KW electricity has produced by the system for around 11 months of the year. And also the remote area can access electricity fully for around 346 days of the year. The result indicates that the numerical value is higher than that of the electricity demand analysis of the selected remote area for around 346 days of a year.

- In general, by implementing such an MHP system, around 1200 families can get electricity access only for lighting, mill machine and mobile charging purposes without power interruptions for 346 days of a year.

7.2. Recommendation

This section states some of the future works of the research. Since the river has MHP potential, the system will be manufacture to access electricity to the remote areas. MHP system is recommended for other areas of the country if the site has enough flow rates. The system benefits the community by addressing electricity access to the community for households, industries, and others. For the other 20 days, the researcher will recommend using additional sources of electricity in February month. In addition, the other researchers will develop a system like the solar system and the like. The reason for these recommendations is that in those days, a solar system is available. And also another solution, the researcher can further work on this research to get the electricity demand through the year without destruction by increasing the flow head of the river.

References

[1] Adejumobi, I., & Shobayo, D. (2015). Optimal Selection of Hydraulic Turbines for Small Hydro Electric Power Generation – A Case Study of Opeki River, South Western Nigeria. *Nigerian Journal of Technology*, *34*(3), 530. https://doi.org/10.4314/njt.v34i3.15

[2] Adhikari, P., Budhathoki, U., Timilsina, S. R., Manandhar, S., & Bajracharya, T. R. (2014). A Study on Developing Pico Propeller Turbine for Low Head Micro Hydropower Plants in Nepal. *Journal of the Institute of Engineering*, *9*(1), 36–53. https://doi.org/10.3126/jie.v9i1.10669

[3] Anaza, S. O., Abdulazeez, M. S., Yisah, Y. A., Yusuf, Y. O., Salawu, B. U., & Momoh, S. U. (2017). Open Access Micro Hydro-Electric Energy Generation- An Overview American Journal of Engineering Research (AJER). *American Journal of Engineering Research (AJER)*, *6*(2), 5–12. WWW.AJER.OTG

[4] Arthur, J. K. (2014). Assessment of a typical small hydropower site for rural electrification in the western region of Gana. *Master of Science in Renewable Energy Technologies, KNUST*.

[5] Auwal Abubakar Usman, R. A. A. (2018). *Modelling and Simulation of Micro Hydro Power Plant Using MATLAB Simlulink*. *January*, 260–272.

[6] Bilal Abdullah, N. (2013). Design of Micro - Hydro - Electric Power Station. *International Journal of Engineering and Advanced Technology (IJEAT)*, *ISSN: 2249*(February).

[7] Cherie, W. D. (2019). *Assessing the Impacts of Land use / cover Change on the Hydrological Response of Temcha watershed , upper Blue Nile basin , Ethiopia*. *2*(November 2018), 10–19.

[8] Clean Energy (online). (n.d.). *http://en.hesperian.org/hhg/A-Community-Guide-to-Environmental-Health:Small-Dams*.

[9] Davis, S., & Graham, S. (2004). *Micro-Hydropower System's A Buyer's Guide*.

[10] Energybc.ca, [Online] &. (2018). *"Run of River Power - Energy BC."*

[11] *Gears and sprockets*. (2016). *33*(0).

[12] Kengne Signe, E. B., Hamandjoda, O., & Nganhou, J. (2017). Methodology of Feasibility Studies of Micro-Hydro power plants in Cameroon: Case of the Micro-hydro of KEMKEN. *Energy Procedia*, *119*(July), 17–28.

https://doi.org/10.1016/j.egypro.2017.07.042

[13] Khurmi, R. S., & Gupta, J. K. (2005). A Textbook of Machine Design. *Garden*, *I*, 14.

[14] Kilimo, A. S. G., & Kahn, M. T. E. (2012). *Small Hydro for Rural Electrification*.

[15] Krushna, S., Mit, P., Nilesh, W., Jejurkar, A., Pre, S., Nasik, S. V. I. T., Pre, S., & Nasik, S. V. I. T. (2019). *Introduction and Design of Conical Type Draft Tube*. 172–173.

[16] Kusakana, K., Munda, J. L., & Jimoh, A. A. (2009). A survey of technologies increasing the viability of micro-hydropower as a cost-effective energy source for remote communities in South Africa. *IEEE AFRICON Conference*, *September*, 5–9. https://doi.org/10.1109/AFRCON.2009.5308182

[17] Kusakana, Kanzumba, Vermaak, H., & Yuma, G. P. (2012). *Simulation and Implementation of Micro Hydro Generation for Small Rural Loads*. *April*. https://doi.org/10.2316/p.2012.768-013

[18] MoWIE. National electrification program 2.0: (2019). National Electrification Program 2.0. Integrated planning for universal access. Technical report, Ethiopian Ministry of Water, Irrigation and Electricity, 201. *Thematic Program Document*, *October*, 49. https://www.east-africa-summit.com/sites/default/files/clarion_www_poweringafricatanzania_com/pdfs/nep_2.0_ethiopia.pdf%0Awww.ens.dk/en

[19] Nasir, B. A. (2018). Mat lab Simulation Procedure for Design of Micro -Hydro- Electric Power Plant. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, *13*(4), 36–50. https://doi.org/10.9790/1676-1304013145

[20] Nisbett, R. G. B. and J. K. (2011). *Shigley's Mechanical Engineering Design, Ninth Edition*.

[21] Online: (n.d.). Manning coefficient np for several commercial pipes. *Http://Indmicrohydro.Blogspot.Com/2010/05/Manning-Coefficient-Nfor-Several.Html*.

[22] Ram, S. (2017). Analysis of Micro Hydropower Generation For Rural Electrification. *Mandalay Technological University*.

[23] RETScreen. (2004). *Clean Energy Project Analysis:RETScreen® engineering & cases textbook-small hydro project analysis chapter*. http://www.retscreen.net/download.php/ang/109/0/Textbook_HYDRO.pdf

[24] Sangal, S., Garg, A., & Kumar, D. (2013). Review of Optimal Selection of Turbines for

Hydroelectric Projects. *Review of Optimal Selection of Turbines for Hydroelectric Projects*, *3*(3), 424–430.

[25] Singhal M. K., A. K. (2015). Optimum Design of Penstock for Hydro Projects. *International Journal of Energy and Power Engineering*, *4*(4), 216. https://doi.org/10.11648/j.ijepe.20150404.14

[26] Srpčič, G. (2012). *Selection of induction generator for a small hydropower plant " Sušica ", XIV International PhD Workshop*. *October*, 20–23.

[27] Steller, J. (2013). Hydropower and its development. *Acta Energetica*, *3*(16), 7–20. https://doi.org/10.12736/issn.2300-3022.2013301

[28] Susanto, J., & Stamp, S. (2012). Local installation methods for low head pico-hydropower in the Lao PDR. *Renewable Energy*, *44*(August 2012), 439–447. https://doi.org/10.1016/j.renene.2012.01.089

[29] TALARGEW MEKONEN. (n.d.). *CERTIFICATION "GILGEL-ABBAY MEDIUM HYDROPOWER PROJECT" AND HEREBY RECOMMEND FOR ACCEPTANCE BY ARBA MINCH UNIVERSITY DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING*.

[30] World Bank. (2020). *https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ET*.

[31] Yuce, M. I., & Yuce, S. (2016). Pre-feasibility assessment of small hydropowen projects in Turkey by RETScreen. *Journal - American Water Works Association*, *108*(5), E269–E275. https://doi.org/10.5942/jawwa.2016.108.0046

Appendix- A: - Generated MATLAB Code for Simulink simulation

```
%% Intake Structure
% insertion the flow data of 12 months of the year
%...............
days=1:1:31;
x=days';
jan=xlsread('Jan');
%%sima=[x,jan]
feb=xlsread('Feb');
%%sima=[x,feb]
march=xlsread('March');
%%sima=[x,march]
april=xlsread('April');
%%sima=[x,april]
may=xlsread('May');
%%sima=[x,may]
june=xlsread('June');
%%sima=[x,june]
july=xlsread('July');
%%sima=[x,july]
aug=xlsread('Aug');
%%sima=[x,aug]
sep=xlsread('Sep');
%%sima=[x,sep]
oct=xlsread('Oct');
%%sima=[x,oct]
nov=xlsread('Nov');
%%sima=[x,nov]
dec=xlsread('Dec');
%%sima=[x,dec]
```

```
%%......................................................................
%% penstock flow modeling analysis using MATLAB SIMULINK
%%%%.........................
Qd=0.5731; % Design flow rate in m3/s
Dp=0.559; % diameter of penstock in meter from standard
Lp=110; %length of penstock in meter
tp=22.23; % thickness of penstock in mm from standard table

%..............
%%%% for january month
for i=1:length(jan)
    jan(i);
    if jan(i)>=Qd
      pjan(i)=Qd;
      %sima=[i pjan(i)]
    elseif jan(i)<Qd
      pjan(i)=jan(i);
      %sima=[i pjan(i)]
    end
end
%..................
%% for february month
for i=1:length(feb)
    feb(i);
    if feb(i)>=Qd
      pfeb(i)=Qd;
      %sima=[i pfeb(i)]
    elseif feb(i)<Qd
      pfeb(i)=feb(i);
      %sima=[i pfeb(i)]
    end
```

```
end
%%............................
%% for march month
for i=1:length(march)
    march(i);
    if march(i)>=Qd
      pmarch(i)=Qd;
      %sima=[i pmarch(i)]
    elseif march(i)<Qd
      pmarch(i)=march(i);
      %sima=[i pmarch(i)]
    end
end
%%......................
% for April month
for i=1:length(april)
    april(i);
    if april(i)>=Qd
      papril(i)=Qd;
      %sima=[i papril(i)]
    elseif april(i)<Qd
      papril(i)=april(i);
      %sima=[i papril(i)]
    end
end
%%..........................
% for May month
for i=1:length(may)
    may(i);
    if may(i)>=Qd
      pmay(i)=Qd;
```

```
      %sima=[i pmay(i)]
    elseif may(i)<Qd
      pmay(i)=may(i);
      %sima=[i pmay(i)]
    end
end
%%......................
% for June month
for i=1:length(june)
    june(i);
    if june(i)>=Qd
      pjune(i)=Qd;
      %sima=[i pjune(i)]
    elseif june(i)<Qd
      pjune(i)=june(i);
      %sima=[i pjune(i)]
    end
end
%%...........................
% for July month
for i=1:length(july)
    july(i);
    if july(i)>=Qd
      pjuly(i)=Qd;
      %sima=[i pjuly(i)]
    elseif july(i)<Qd
      pjuly(i)=july(i);
      %sima=[i pjuly(i)]
    end
end
%%.....................
```

```
% for Augest month
for i=1:length(aug)
    aug(i);
    if aug(i)>=Qd
      paug(i)=Qd;
      %sima=[i paug(i)]
    elseif aug(i)<Qd
      paug(i)=aug(i);
      %sima=[i paug(i)]
    end
end
%%...................
% for September month
for i=1:length(sep)
    sep(i);
    if sep(i)>=Qd
      psep(i)=Qd;
      %sima=[i psep(i)]
    elseif sep(i)<Qd
      psep(i)=sep(i);
      %sima=[i psep(i)]
    end
end
%%....................
% for October Month
for i=1:length(oct)
    oct(i);
    if oct(i)>=Qd
      poct(i)=Qd;
      %sima=[i poct(i)]
    elseif oct(i)<Qd
```

```
      poct(i)=oct(i);
      %sima=[i poct(i)]
    end
end
%%.................
% for November month
for i=1:length(nov)
    nov(i);
    if nov(i)>=Qd
      pnov(i)=Qd;
      %sima=[i pnov(i)]
    elseif nov(i)<Qd
      pnov(i)=nov(i);
      %sima=[i pnov(i)]
    end
end
%%......................
% for December month
for i=1:length(dec)
    dec(i);
    if dec(i)>=Qd
      pdec(i)=Qd;
      %sima=[i pdec(i)]
    elseif dec(i)<Qd
      pdec(i)=dec(i);
      %sima=[i pdec(i)]
    end
end
%%....................................
%% Modeling of MHP system turbine using MATLAB Simulink
%...........
```

```
rho=1000; % density of water in kg/m3.
g=9.81; % accelaration due to gravity in m/s2
Hg=19; % Gross head of the system in meter
hhydr=0.07; % hydraulic losses
eg=0.95; % assumed generator efficiency  for this case study
ltrans=0.02; % transformer losses
lpara=0.03; % parasaitic electricity losses
htail=0.07; % taile race losses
etd=0.898; % turbine efficiency at design flow rate
kt=0.3; % for bell mouth entry
Hn=Hg*(1-( hhydr + htail); % net head in meter
kd=0.46; %constant factor which relates dimater of turbine with that of design flow rate
ks=800; % constant factor for propelloer and kaplan turbines which relates net head and specific speed of turbine
Rm=4.5; % turbine manufacturer/design coefficent
d=kd*(Qd^0.473); % formula used to calculate the diamter of reaction turbine runner using design flow rate
nq=ks*(Hn^-0.5); % specific speed of the turbine
pd=rho*g*Qd*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara); % maximume power capacity of the turbine at the design flow rate
n=(nq*(Hn^(5/4)))/sqrt(pd/1000); % turbine speed n in R.P.M
%..................
%%%%specific speed adjustment to peak efficiency
enq=((nq-170)/700)^2;
%.................
%%Runner size adjustment to peak efficiency
ed=(0.095+enq)*(1-(0.789*(d^(-0.2))));
%...........
%% turbine peak efficiency
ep=0.905-enq+ed-0.0305+0.005*Rm;
%..........
```

```
%% peak efficency flow
Qp=0.75*Qd;
%%%..............
%% for January
%%..............
%% avaliable power
TPjan=rho*g*pjan*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%...........................
%% Efficiency at flows above and below peak efficiency flow
janeq=(1-(((Qp-pjan)/Qp).^6))*ep;
%................
%% Turbine speed
njan=(nq*(Hn^(5/4)))./sqrt(TPjan); % turbine speed n in R.P.M
%%...........................
%% for Feburary
%%..............
%% avaliable power
TPfeb=rho*g*pfeb*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%...........................
%% Efficiency at flows above and below peak efficiency flow
febeq=(1-(((Qp-pfeb)/Qp).^6))*ep;
%................
%% Turbine speed
nfeb=(nq*(Hn^(5/4)))./sqrt(TPfeb); % turbine speed n in R.P.M
%%...........................
%% for March
%%..............
%% avaliable power
```

```
TPmarch=rho*g*pmarch*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the
turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
marcheq=(1-(((Qp-pmarch)/Qp).^6))*ep;
%...............
%% Turbine speed
nmarch=(nq*(Hn^(5/4)))./sqrt(TPmarch); % turbine speed n in R.P.M
%%..........................
%% for April
%%.............
%% avaliable power
TPapril=rho*g*papril*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine
at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
aprileq=(1-(((Qp-papril)/Qp).^6))*ep;
%...............
%% Turbine speed
napril=(nq*(Hn^(5/4)))./sqrt(TPapril); % turbine speed n in R.P.M
%%..........................
%% for May
%%.............
%% avaliable power
TPmay=rho*g*pmay*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine
at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
mayeq=(1-(((Qp-pmay)/Qp).^6))*ep;
%...............
%% Turbine speed
```

```
nmay=(nq*(Hn^(5/4)))./sqrt(TPmay); % turbine speed n in R.P.M
%%..........................
%% for June
%%.............
%% avaliable power
TPjune=rho*g*pjune*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
juneeq=(1-(((Qp-pjune)/Qp).^6))*ep;
%...............
%% Turbine speed
njune=(nq*(Hn^(5/4)))./sqrt(TPjune); % turbine speed n in R.P.M
%%..........................
%% for July
%%.............
%% avaliable power
TPjuly=rho*g*pjuly*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
julyeq=(1-(((Qp-pjuly)/Qp).^6))*ep;
%...............
%% Turbine speed
njuly=(nq*(Hn^(5/4)))./sqrt(TPjuly); % turbine speed n in R.P.M
%%..........................
%% for Augest
%%.............
%% avaliable power
TPaug=rho*g*paug*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
```

```
%..........................
%% Efficiency at flows above and below peak efficiency flow
augeq=(1-(((Qp-paug)/Qp).^6))*ep;
%...............
%% Turbine speed
naug=(nq*(Hn^(5/4)))./sqrt(TPaug); % turbine speed n in R.P.M
%%..........................
%% for Septemeber
%%.............
%% avaliable power
TPsep=rho*g*psep*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
sepeq=(1-(((Qp-psep)/Qp).^6))*ep;
%...............
%% Turbine speed
nsep=(nq*(Hn^(5/4)))./sqrt(TPsep); % turbine speed n in R.P.M
%%..........................
%% for October
%%.............
%% avaliable power
TPoct=rho*g*poct*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
octeq=(1-(((Qp-poct)/Qp).^6))*ep;
%...............
%% Turbine speed
noct=(nq*(Hn^(5/4)))./sqrt(TPoct); % turbine speed n in R.P.M
%%..........................
```

```
%% for Novemebr
%%.............
%% avaliable power
TPnov=rho*g*pnov*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
noveq=(1-(((Qp-pnov)/Qp).^6))*ep;
%...............
%% Turbine speed
nnov=(nq*(Hn^(5/4)))./sqrt(TPnov); % turbine speed n in R.P.M
%%..........................
%% for Decemebr
%%.............
%% avaliable power
TPdec=rho*g*pdec*Hg*(1-(hhydr+htail))*etd/1000; % avaliable power capacity of the turbine at each flow rate
%..........................
%% Efficiency at flows above and below peak efficiency flow
deceq=(1-(((Qp-pdec)/Qp).^6))*ep;
%...............
%% Turbine speed
ndec=(nq*(Hn^(5/4)))./sqrt(TPdec); % turbine speed n in R.P.M
%.............
................
%%% Modeling of the net power of the MHP System using MATLAB SIMULINK
%%%.............
%% for January
%..............
%% avaliable power
```

```
janpower=rho*g*pjan*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable
power capacity of the system at each flow rate
%%..........................
%% for Feburary
%%...............
%% avaliable power
febpower=rho*g*pfeb*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable
power capacity of the system at each flow rate
%%..........................
%% for March
%...............
%% avaliable power
marchpower=rho*g*pmarch*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; %
avaliable power capacity of the system at each flow rate
%%..........................
%% for April
%...............
%% avaliable power
aprilpower=rho*g*papril*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable
power capacity of the system at each flow rate
%%..........................
%% for May
%...............
%% avaliable power
maypower=rho*g*pmay*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable
power capacity of the system at each flow rate
%%..........................
%% for June
%...............
%% avaliable power
```

```
junepower=rho*g*pjune*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for July
%...............
%% avaliable power
julypower=rho*g*pjuly*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for Augest
%...............
%% avaliable power
augpower=rho*g*paug*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for Septemeber
%...............
%% avaliable power
seppower=rho*g*psep*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for October
%...............
%% avaliable power
octpower=rho*g*poct*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for Novemebr
%...............
%% avaliable power
```

```
novpower=rho*g*pnov*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
%%..........................
%% for Decemebr
%...............
%% avaliable power
decpower=rho*g*pdec*Hg*(1-(hhydr+htail))*etd*eg*(1-ltrans)*(1-lpara)/1000; % avaliable power capacity of the system at each flow rate
```

Appendix –B: - MATLAB Simulink Results

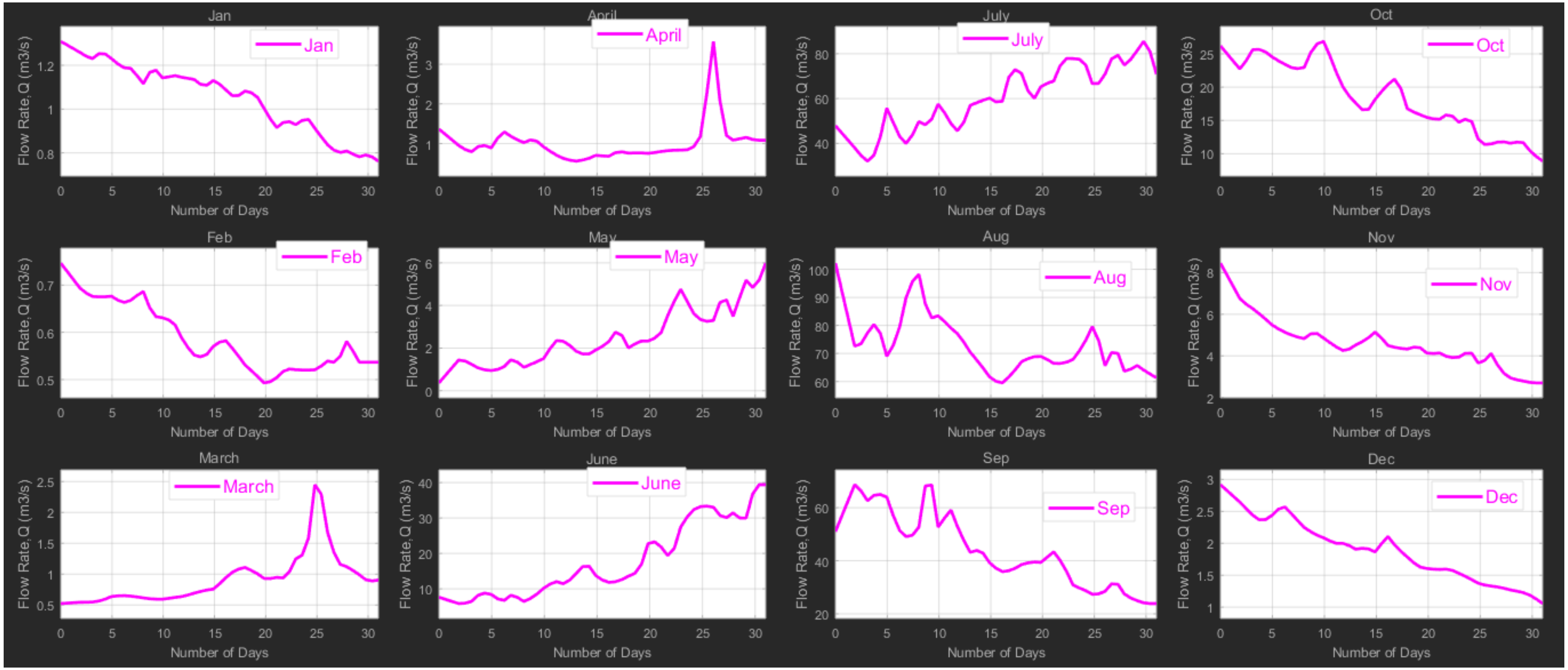


Figure 0-1:- Input Yearly flow data of the river in m^3/s

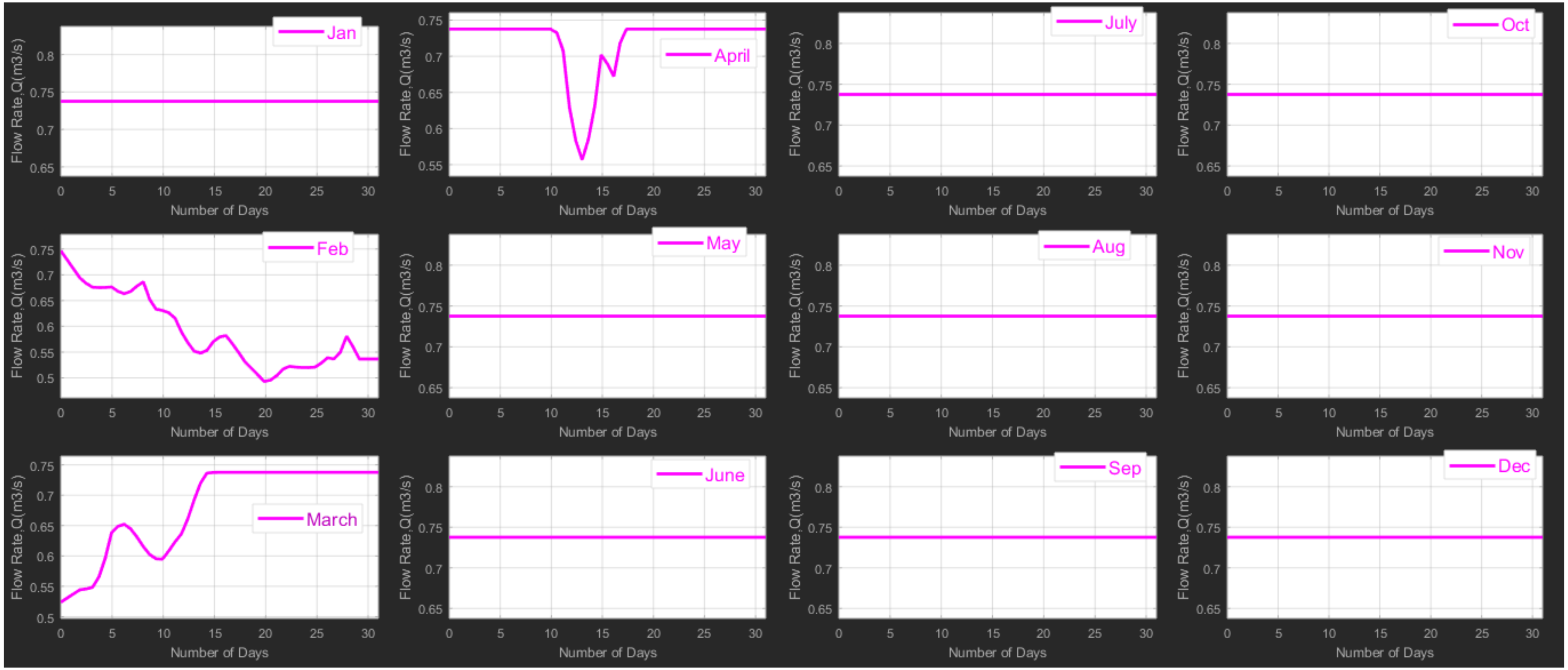


Figure 0-2:- Detail Flow duration Curve of the river

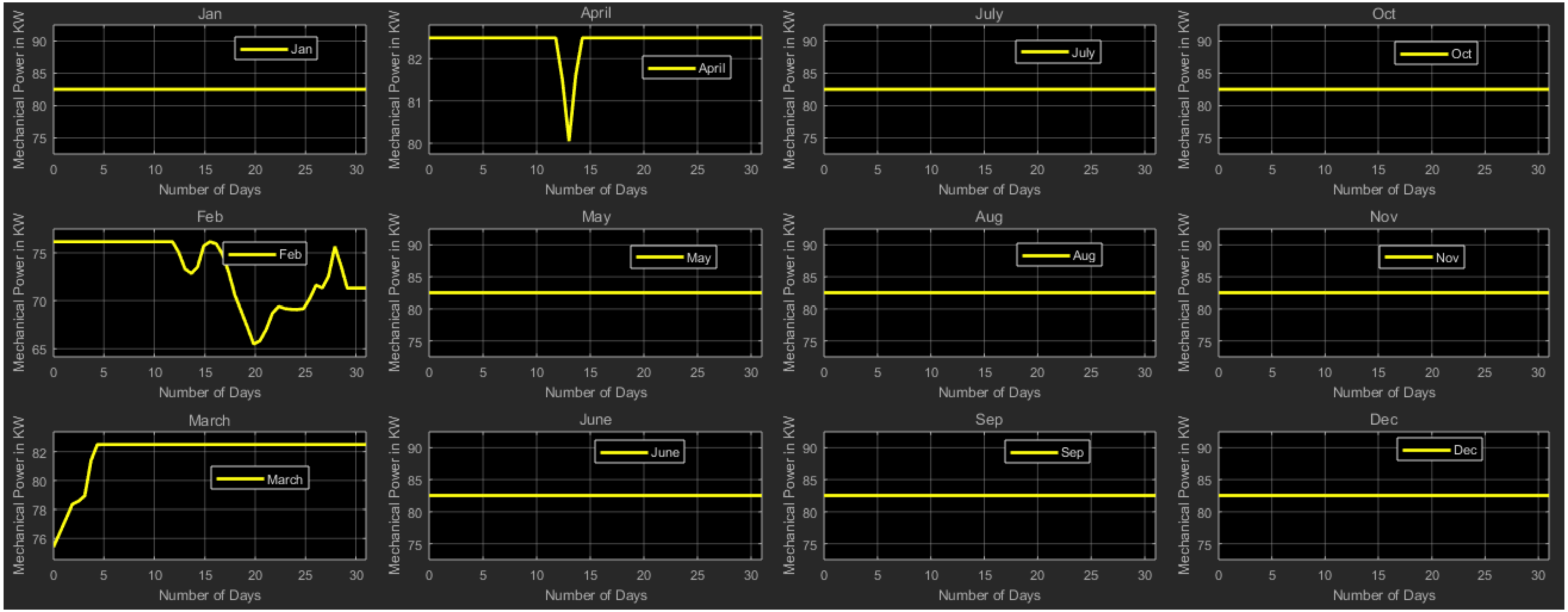


Figure 0-3:- Detail Turbine mechanical power output of the 12 months

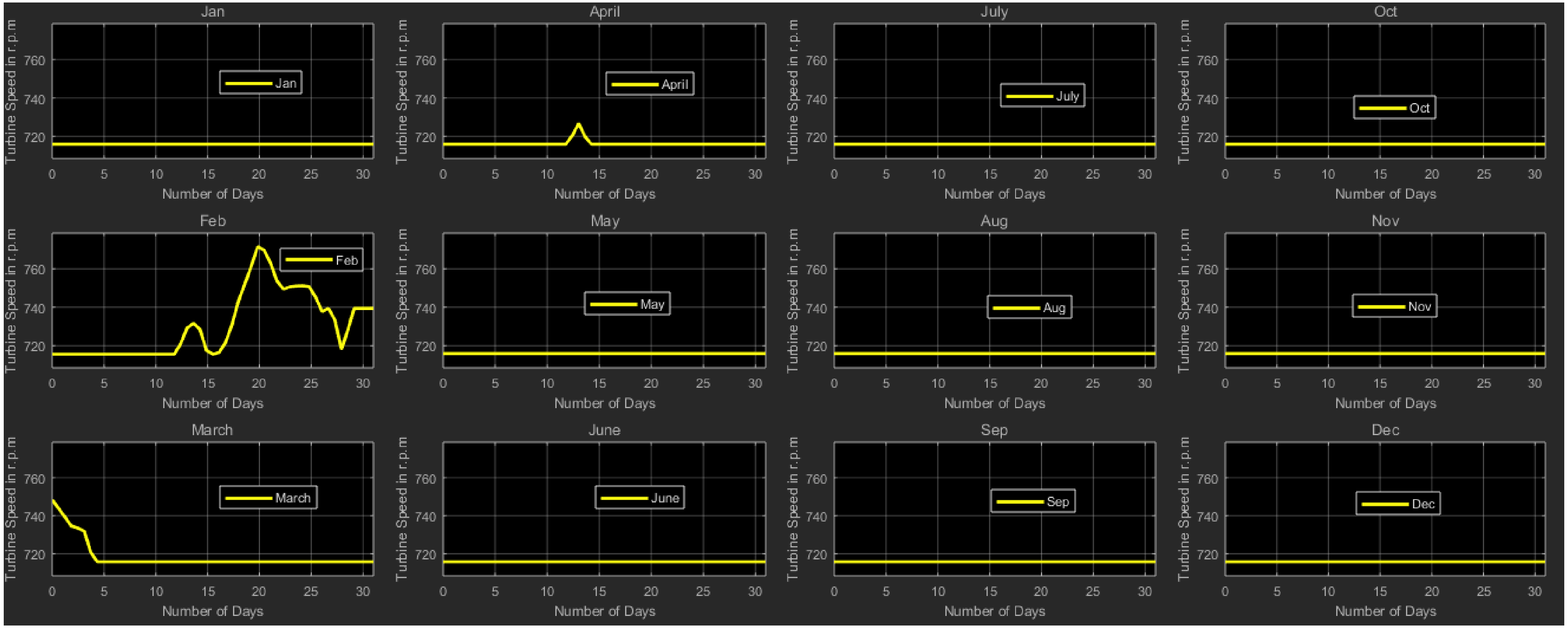


Figure 0-4:- Detail Turbine speed in r.p.m vs number of days for each month

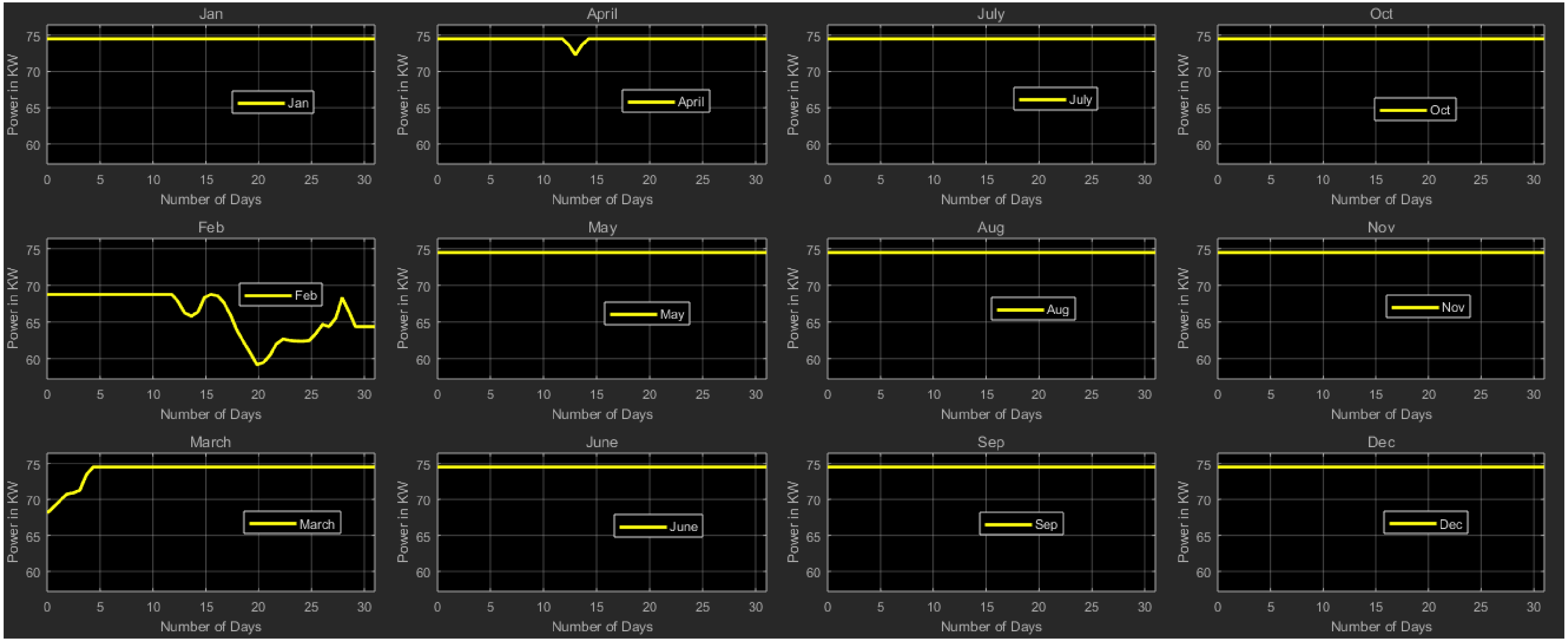
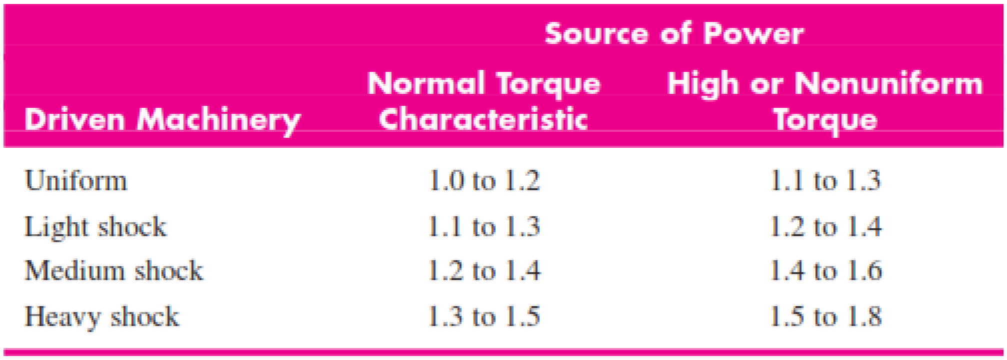


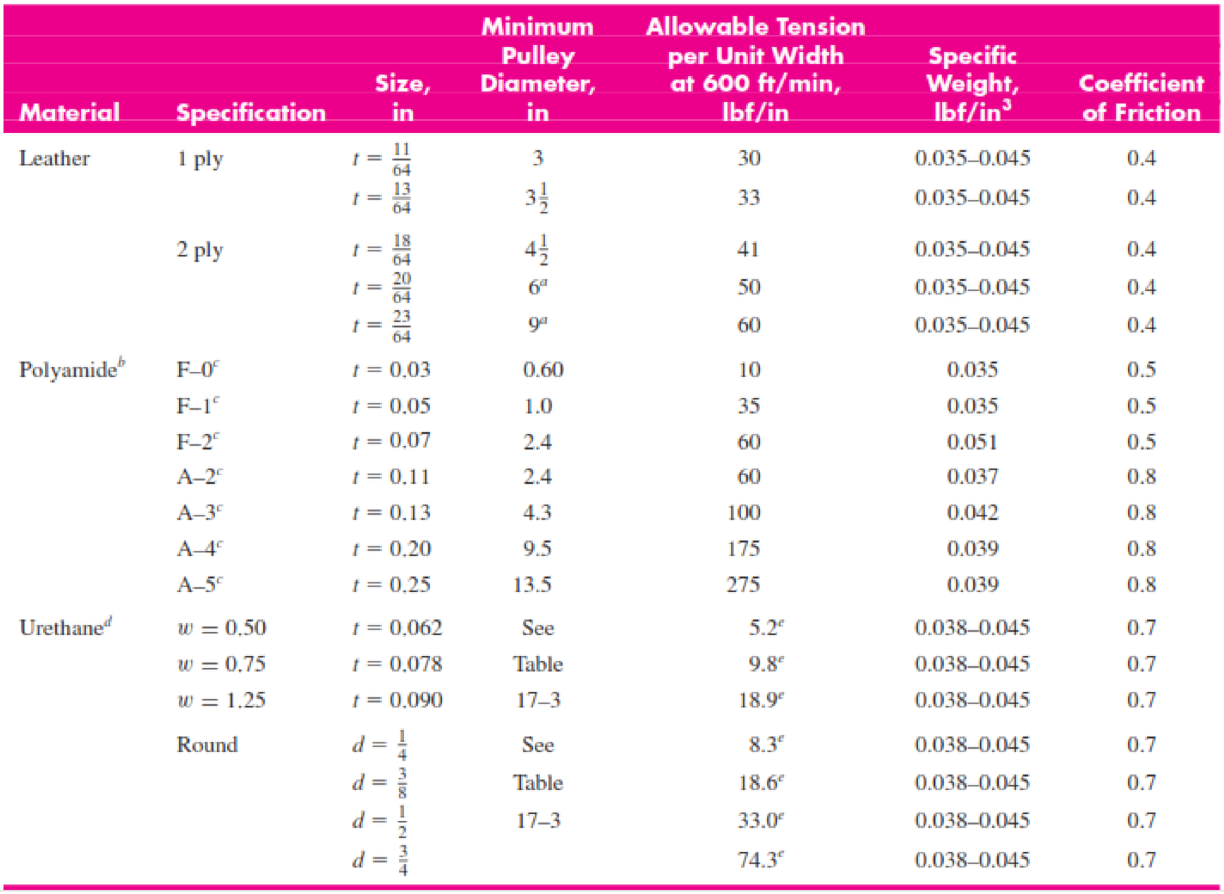
Figure 0-5:- Detail MHP system output power curve

Appendix C



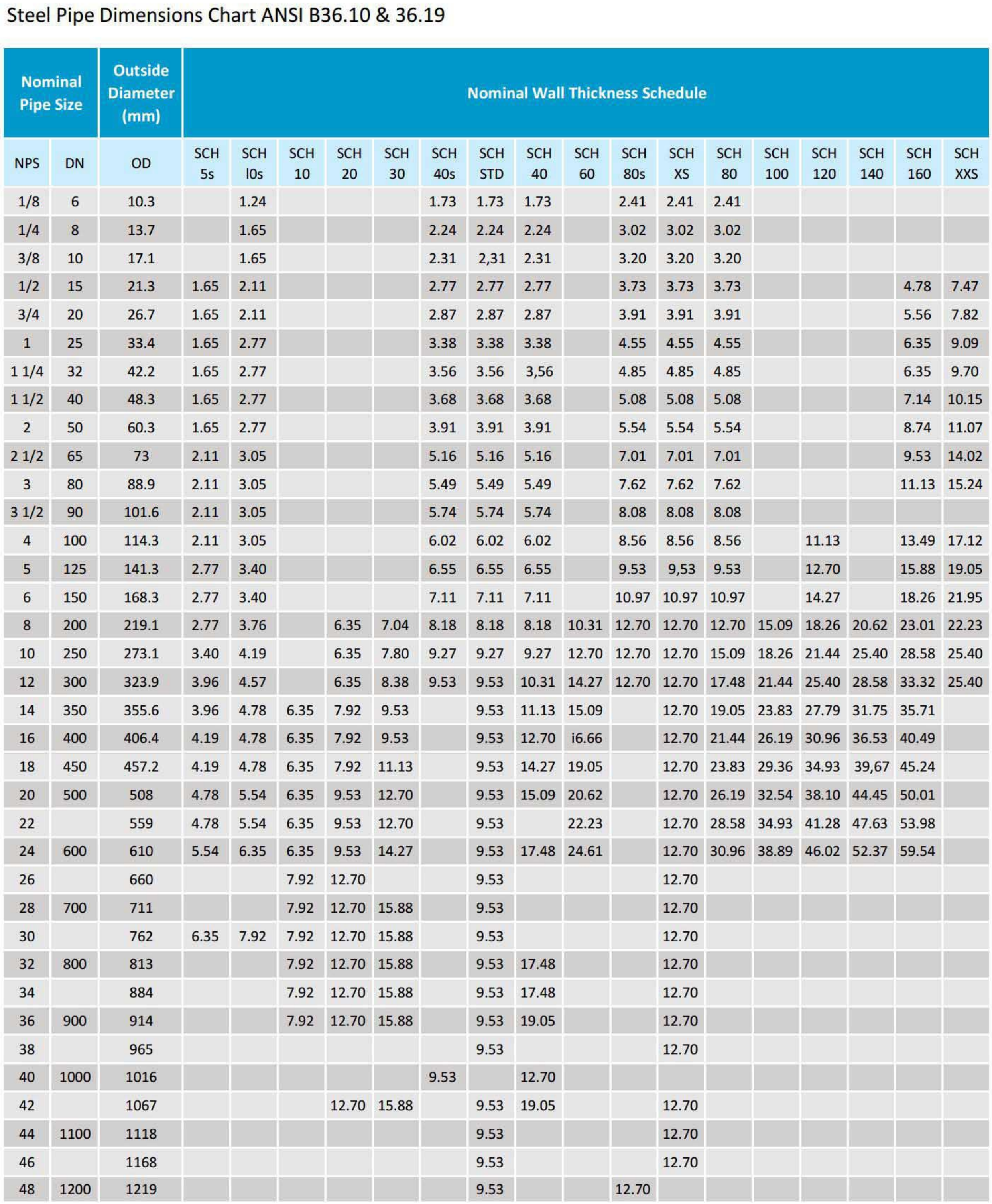
	Source of Power	
Driven Machinery	Normal Torque Characteristic	High or Nonuniform Torque
Uniform	1.0 to 1.2	1.1 to 1.3
Light shock	1.1 to 1.3	1.2 to 1.4
Medium shock	1.2 to 1.4	1.4 to 1.6
Heavy shock	1.3 to 1.5	1.5 to 1.8

Figure 0-1:- Suggested Service Factor, Ks for Belt drives(Nisbett, 2011)



Material	Specification	Size, in	Minimum Pulley Diameter, in	Allowable Tension per Unit Width at 600 ft/min, lbf/in	Specific Weight, lbf/in^3	Coefficient of Friction
Leather	1 ply	$t = \frac{11}{64}$	3	30	0.035–0.045	0.4
		$t = \frac{13}{64}$	$3\frac{1}{2}$	33	0.035–0.045	0.4
	2 ply	$t = \frac{18}{64}$	$4\frac{1}{2}$	41	0.035–0.045	0.4
		$t = \frac{20}{64}$	6[a]	50	0.035–0.045	0.4
		$t = \frac{23}{64}$	9[a]	60	0.035–0.045	0.4
Polyamide[b]	F–0[c]	$t = 0.03$	0.60	10	0.035	0.5
	F–1[c]	$t = 0.05$	1.0	35	0.035	0.5
	F–2[c]	$t = 0.07$	2.4	60	0.051	0.5
	A–2[c]	$t = 0.11$	2.4	60	0.037	0.8
	A–3[c]	$t = 0.13$	4.3	100	0.042	0.8
	A–4[c]	$t = 0.20$	9.5	175	0.039	0.8
	A–5[c]	$t = 0.25$	13.5	275	0.039	0.8
Urethane[d]	$w = 0.50$	$t = 0.062$	See	5.2[e]	0.038–0.045	0.7
	$w = 0.75$	$t = 0.078$	Table	9.8[e]	0.038–0.045	0.7
	$w = 1.25$	$t = 0.090$	17–3	18.9[e]	0.038–0.045	0.7
	Round	$d = \frac{1}{4}$	See	8.3[e]	0.038–0.045	0.7
		$d = \frac{3}{8}$	Table	18.6[e]	0.038–0.045	0.7
		$d = \frac{1}{2}$	17–3	33.0[e]	0.038–0.045	0.7
		$d = \frac{3}{4}$		74.3[e]	0.038–0.045	0.7

Figure 0-2:- Standard Flat Belt Materials(Nisbett, 2011)



Steel Pipe Dimensions Chart ANSI B36.10 & 36.19

Nominal Pipe Size		Outside Diameter (mm)	Nominal Wall Thickness Schedule																
NPS	DN	OD	SCH 5s	SCH l0s	SCH 10	SCH 20	SCH 30	SCH 40s	SCH STD	SCH 40	SCH 60	SCH 80s	SCH XS	SCH 80	SCH 100	SCH 120	SCH 140	SCH 160	SCH XXS
1/8	6	10.3		1.24				1.73	1.73	1.73		2.41	2.41	2.41					
1/4	8	13.7		1.65				2.24	2.24	2.24		3.02	3.02	3.02					
3/8	10	17.1		1.65				2.31	2,31	2.31		3.20	3.20	3.20					
1/2	15	21.3	1.65	2.11				2.77	2.77	2.77		3.73	3.73	3.73				4.78	7.47
3/4	20	26.7	1.65	2.11				2.87	2.87	2.87		3.91	3.91	3.91				5.56	7.82
1	25	33.4	1.65	2.77				3.38	3.38	3.38		4.55	4.55	4.55				6.35	9.09
1 1/4	32	42.2	1.65	2.77				3.56	3.56	3,56		4.85	4.85	4.85				6.35	9.70
1 1/2	40	48.3	1.65	2.77				3.68	3.68	3.68		5.08	5.08	5.08				7.14	10.15
2	50	60.3	1.65	2.77				3.91	3.91	3.91		5.54	5.54	5.54				8.74	11.07
2 1/2	65	73	2.11	3.05				5.16	5.16	5.16		7.01	7.01	7.01				9.53	14.02
3	80	88.9	2.11	3.05				5.49	5.49	5.49		7.62	7.62	7.62				11.13	15.24
3 1/2	90	101.6	2.11	3.05				5.74	5.74	5.74		8.08	8.08	8.08					
4	100	114.3	2.11	3.05				6.02	6.02	6.02		8.56	8.56	8.56		11.13		13.49	17.12
5	125	141.3	2.77	3.40				6.55	6.55	6.55		9.53	9,53	9.53		12.70		15.88	19.05
6	150	168.3	2.77	3.40				7.11	7.11	7.11		10.97	10.97	10.97		14.27		18.26	21.95
8	200	219.1	2.77	3.76		6.35	7.04	8.18	8.18	8.18	10.31	12.70	12.70	12.70	15.09	18.26	20.62	23.01	22.23
10	250	273.1	3.40	4.19		6.35	7.80	9.27	9.27	9.27	12.70	12.70	12.70	15.09	18.26	21.44	25.40	28.58	25.40
12	300	323.9	3.96	4.57		6.35	8.38	9.53	9.53	10.31	14.27	12.70	12.70	17.48	21.44	25.40	28.58	33.32	25.40
14	350	355.6	3.96	4.78	6.35	7.92	9.53		9.53	11.13	15.09		12.70	19.05	23.83	27.79	31.75	35.71	
16	400	406.4	4.19	4.78	6.35	7.92	9.53		9.53	12.70	i6.66		12.70	21.44	26.19	30.96	36.53	40.49	
18	450	457.2	4.19	4.78	6.35	7.92	11.13		9.53	14.27	19.05		12.70	23.83	29.36	34.93	39,67	45.24	
20	500	508	4.78	5.54	6.35	9.53	12.70		9.53	15.09	20.62		12.70	26.19	32.54	38.10	44.45	50.01	
22		559	4.78	5.54	6.35	9.53	12.70		9.53		22.23		12.70	28.58	34.93	41.28	47.63	53.98	
24	600	610	5.54	6.35	6.35	9.53	14.27		9.53	17.48	24.61		12.70	30.96	38.89	46.02	52.37	59.54	
26		660			7.92	12.70			9.53				12.70						
28	700	711			7.92	12.70	15.88		9.53				12.70						
30		762	6.35	7.92	7.92	12.70	15.88		9.53				12.70						
32	800	813			7.92	12.70	15.88		9.53	17.48			12.70						
34		884			7.92	12.70	15.88		9.53	17.48			12.70						
36	900	914			7.92	12.70	15.88		9.53	19.05			12.70						
38		965							9.53				12.70						
40	1000	1016						9.53		12.70									
42		1067				12.70	15.88		9.53	19.05			12.70						
44	1100	1118							9.53				12.70						
46		1168							9.53				12.70						
48	1200	1219							9.53			12.70							

Figure 0-3:-Steel Pipe Dimensions Chart [Source:- http://m.cnspipes.com/info/steel-pipe-dimensions-sizes-chart-schedule-54227183.html]

Appendix-D:- Data Analysis Table

Table 0-1: yearly Average flow data’s for Gudla River in m^3/s jan,1-Dec,31

Flow Rate (m3/s)
0.54145
0.53714
0.52133
0.52245
0.52941
0.50598
0.46936
0.44886
0.52574
0.47348
0.49012
0.47057
0.45357
0.48802
0.49014
0.47679
0.45833
0.50817
0.47398
0.42929
0.39674
0.39421
0.40917
0.38621
0.35562
0.34314
0.33938
0.34205
0.32195
0.33019
0.31014
0.27695
0.27343
0.26571
0.26676
0.26876
0.24891
0.24886
0.27295
0.25314
0.2521
0.24014
0.21876
0.20829
0.19781
0.20352
0.20686
0.20257
0.18971
0.17919
0.1641
0.16738
0.1831
0.18905
0.17924
0.17291
0.18129
0.18152
0.19195
0.20314
0.20705
0.21814
0.21862
0.216
0.20981
0.21086
0.20386
0.19857
0.18262
0.20533
0.20157
0.20895
0.20348
0.20795
0.23257
0.35743
0.42043
0.45981
0.39005
0.30119
0.32119
0.28848
0.64676
0.57924
1.06133
0.51467
0.406
0.42271
0.42705
0.33819
0.364
0.60619
0.428
0.28257
0.39829
0.30343
0.65091
0.32452
0.2501
0.36438
0.3111
0.22748
0.16436
0.15533
0.21974
0.31998
0.24719
0.23602
0.25686
0.23983
0.20898
0.29245
0.30919
0.3451
0.33124
0.664
2.93755
0.67426
0.53486
0.4985
0.38967
0.33069
0.72536
0.57988
0.30924
0.27695
0.2566
0.31245
0.39643
0.57731
0.55743
0.78445
0.88381
0.88531
0.74291
0.99695
1.00114
1.16067
0.88302
1.32007
1.51317
1.14029
2.41241
3.68371
2.15219
1.6325
1.27333
1.18591
1.60098
2.80743
1.64579
2.14852
3.98264
2.42071
2.91971
4.78367
5.23241
3.5071
5.58824
3.88193
5.33581
7.14693
7.63605
5.10305
8.71431
10.5251
7.65026
7.61505

5.86474	44.9266	30.531	11.1157	1.79367
7.46524	34.4182	30.4786	11.9056	2.11019
8.05755	37.4071	31.3994	12.0292	2.33452
15.0486	48.0864	31.4125	12.4749	2.32114
13.9232	40.4529	35.3661	13.1528	2.01848
8.79548	42.3411	41.4861	12.4252	1.88819
17.4044	43.2681	34.2135	9.18252	1.76224
17.7565	38.5254	23.4683	8.46329	1.75938
18.9697	51.1545	22.9675	6.84419	1.78091
16.732	43.3781	24.9071	6.99505	2.00438
16.6966	43.9243	25.6039	8.22205	1.71752
18.8176	46.8785	23.4401	12.4067	1.78971
16.005	37.7749	23.6749	7.63967	2.43286
25.1179	39.9596	22.2867	6.82052	1.66643
29.3257	43.2498	21.5847	7.01043	1.38295
21.3301	51.3091	24.1234	7.84305	1.50714
18.852	46.695	19.6697	8.90943	1.32181
21.2656	48.3607	19.0375	5.27495	1.24752
34.4471	43.8001	18.6683	8.09852	1.22514
25.4739	39.7641	19.5967	4.35562	1.22971
21.8929	38.214	19.8565	5.06024	1.13967
33.9338	34.1181	19.1146	5.99386	1.05105
31.2683	32.0554	16.6627	5.79038	1.00157
27.3963	26.8164	18.0396	5.87795	1.072
25.7574	32.7051	14.5597	4.04086	1.07414
25.228	37.1211	14.4186	3.51833	1.02014
36.9716	39.2693	13.3377	3.12929	0.96952
36.7423	36.5751	13.4024	2.83148	0.92076
35.9232	32.164	16.5198	2.75205	0.86948
34.4516	32.5769	11.5584	2.40186	0.827
46.6216	35.6427	10.6271	2.22419	0.821
40.6696	36.467	10.4989	2.08771	0.82891
32.4574	40.1104	12.5317	2.06352	0.8791
41.5412	32.9728	10.0627	1.942	0.86848
38.4381	39.4973	13.3867	2.24643	1.15371
50.1991	34.5599	12.7377	2.05648	0.98519
47.0087	35.2476	13.0285	1.88448	0.80814

0.73129
0.70719
0.69133
0.70729
0.65338
0.60248
0.57
0.54481
0.51595
0.51619
0.50014
0.49391
0.47333

Table 0-2:- Yearly Average flow data's for Temecha River in m^3/s jan,1-Dec,31

Flow Rate (m3/s)
0.74096
0.71844
0.70552
0.74124
0.69916
0.68372
0.71612
0.66248
0.6684
0.66476
0.66472
0.67268
0.68264
0.61224
0.6448
0.6156
0.5922
0.57468
0.596
0.5614
0.51592
0.55576
0.5188
0.5784
0.54372
0.49556
0.46008
0.46756
0.45848
0.46364
0.4522
0.44144
0.41668
0.41032
0.40812
0.40768
0.41292
0.42016
0.41666
0.38118
0.37842
0.38248
0.36046
0.34356
0.34822
0.36986
0.3782
0.35712
0.34072
0.3316
0.32534
0.33516
0.34004
0.3315
0.3405
0.34794
0.35784
0.35384
0.39392
0.33346
0.3278
0.32766
0.32704
0.35704
0.43112
0.44372
0.43854
0.41794
0.41298
0.38926
0.41846
0.4322
0.48802
0.5279
0.52848
0.57096
0.64552
0.65104
0.63878
0.61088
0.62804
0.64644
0.6223
0.75964
1.66664
1.18488
0.76992
0.69262
0.58098
0.54198
0.54136
0.53908
0.49676
0.4908
0.58494
0.58352
0.67548
0.8298
0.7688
0.76084
0.59064
0.50042
0.43674
0.40044
0.3824
0.39552
0.41606
0.5715
0.50242
0.52828
0.54244
0.50528
0.52232
0.49104
0.52116
0.59498
0.7339
0.58302
0.5337
0.66882
0.69346
0.61228
0.79188
0.67856
0.69088
0.6692
0.78026
1.22798
0.69386
0.71976
0.96448
1.57624
1.42768
0.97008
0.90728
0.9522
1.21792
1.77516
1.1092
1.0108
0.816
1.4892
1.48968
1.12844
1.5392
1.6274
1.9718
3.41916
1.76832
2.46032
3.06248
3.83888
2.66944
3.27444
3.2538
4.18744
3.16512
2.75324
2.99592
2.44196
2.4062
3.18868
4.54096
6.114
5.54652
6.91336
5.56712
4.16328
6.19436
6.14852
6.87412
9.193

8.19428
9.46216
10.6646
14.369
14.5212
16.4644
12.777
12.8646
12.4502
14.2918
13.287
15.9661
12.8076
14.6695
22.1212
18.6867
17.1794
15.9819
16.3294
30.9869
23.8876
19.2574
19.9393
22.1058
24.4359
22.2782
27.3352
30.4585
25.8141
25.1239
28.5466
27.7131
30.8169
32.392
29.6354
33.1028
33.2583
33.7896
38.1777
43.8033
32.3656

35.1329
26.9889
32.9028
34.7896
30.7059
36.0703
49.6132
47.9332
35.6067
35.1532
35.7451
36.5838
32.3198
31.9712
29.0258
32.2946
29.7864
30.0334
29.5646
32.3689
34.3302
33.8311
32.3061
36.8747
41.027
32.3871
33.3972
28.0931
30.8136
32.9564
30.8733
29.0724
38.5715
26.917
24.0569
29.67
28.6971
25.4543
26.2788
50.5685
27.1893

37.0427
28.409
21.551
20.2015
18.902
16.7767
17.6978
19.0012
19.7251
20.2041
27.1057
20.5223
15.8687
14.7118
13.5553
14.9209
16.2541
15.3164
14.4849
13.3563
11.8089
12.4147
12.2235
12.9456
11.4758
12.4531
10.896
10.721
13.8361
13.7649
10.3092
10.1163
9.16936
9.19688
11.4437
12.0164
9.12546
9.03664
9.16848
8.35814
7.25262

7.21
9.3695
7.4891
6.99102
6.3999
5.88288
5.74856
6.04862
5.98528
5.36392
4.41718
3.80394
3.55998
3.5155
3.24568
3.08464
2.90768
2.8669
2.93136
2.77256
2.5867
2.40462
2.41024
2.4357
2.86952
2.49806
2.49002
2.5634
2.7204
2.29324
2.15288
2.1889
2.15384
1.82854
1.84084
2.76594
1.75512
1.58216
1.55624
1.47692
1.5422

1.48624
1.40232
1.33536
1.3694
1.5294
1.41352
1.28508
1.22892
1.2108
1.17286
1.1788
1.07916
1.05122
0.98862
0.978
0.94146
0.97442
0.90484
0.89272
0.89914
0.89054
0.87378
0.84534
0.78772
0.78708
0.79272
0.74986
0.73678
0.6788

Table 0-3: yearly Average Flow data's for the combination of Temecha and Gudla Rivers in m^3/s by increasing order

0.4894352	0.6690171	0.9429705	1.1941381	1.99986	4.3256381	11.538941	26.310997	50.695674	70.891001
0.50254	0.674881	0.946152	1.226853	2.080276	4.378210	11.77832	26.87478	51.18593	71.128103
0.5107905	0.6760343	0.9492305	1.2285648	2.1317143	4.4711762	11.876737	26.893054	52.165413	72.894553
0.519738	0.676441	0.949974	1.236922	2.149681	4.47978	11.92657	26.9176	56.56827	73.341652
0.5205476	0.6896124	0.9646143	1.2555829	2.2190629	4.5165362	12.059098	28.069029	56.729859	73.956788
0.520844	0.690108	0.983225	1.257281	2.254603	4.520430	12.17700	28.32324	56.91089	74.242545
0.5231352	0.6914962	0.9906857	1.258441	2.3114895	4.6050648	13.217382	28.455264	58.271501	76.029879
0.530434	0.715496	1.000118	1.2589	2.329166	4.708265	13.61375	29.13045	58.38322	76.172377
0.5348476	0.7183924	1.0080276	1.2636924	2.3308714	4.7702238	14.26083	29.473659	58.848086	76.347875
0.535363	0.727896	1.018895	1.266050	2.336931	4.808	14.64445	30.42845	59.11102	76.827126
0.5366029	0.7358524	1.0288276	1.2690619	2.3606924	4.8121543	14.931668	31.659536	60.35905	77.318619
0.539125	0.751416	1.036855	1.282412	2.433662	4.829036	15.09566	31.68213	60.47174	77.825567
0.5456559	0.7592771	1.0505333	1.2970695	2.4414	4.9712038	15.368569	32.125436	60.717597	77.912215
0.545802	0.761051	1.056761	1.308672	2.453367	5.172354	15.58762	32.77384	61.08114	79.545171
0.5460295	0.7623429	1.0659486	1.3263848	2.6035429	5.1777886	15.989004	33.196336	61.351871	80.518883
0.551845	0.768113	1.068557	1.331889	2.625906	5.190662	16.0410	33.4909	62.28311	81.137421
0.5557733	0.7733714	1.0699762	1.3388781	2.6294857	5.2677486	16.119429	35.814176	62.491583	81.344749
0.559691	0.780432	1.082846	1.3577	2.702062	5.469870	16.67630	35.93516	62.65304	81.668116
0.57304	0.7938305	1.0831267	1.4478162	2.7279733	5.6951543	17.438431	36.366113	63.487332	82.301692
0.573383	0.797732	1.090288	1.517237	2.771914	5.917357	17.63264	37.29623	63.88356	83.513867
0.5792219	0.799461	1.0923857	1.5219086	2.8037638	5.9874038	18.257636	38.561831	64.053658	86.287416
0.585057	0.807523	1.100263	1.52716	2.903969	6.173514	18.43870	38.57170	65.35984	87.071395
0.5858724	0.8096076	1.1108495	1.5404324	2.9358267	6.2603352	19.298784	38.597887	65.542988	92.863006
0.594593	0.831510	1.111337	1.590473	3.245133	6.312027	20.23842	39.07224	66.06125	99.242335
0.5955599	0.8361352	1.1153343	1.5978257	3.2599	6.3238886	21.532127	39.318719	66.089295	
0.601097	0.838702	1.12522	1.599910	3.262262	6.635416	22.11751	39.40964	66.408045	
0.6021381	0.8523981	1.1349429	1.6361257	3.3692962	6.6520829	22.477347	39.581596	66.49416	
0.616511	0.880170	1.136211	1.650184	3.507268	7.546465	22.73441	42.61266	66.665178	
0.6200314	0.8869486	1.1382362	1.6995467	3.6714476	7.7420095	22.750278	43.135627	66.984631	
0.622622	0.89933	1.143251	1.782562	3.691390	8.397524	22.80165	43.76832	67.154475	
0.6305152	0.9017352	1.1452705	1.8553895	3.9020848	8.5841581	23.56881	44.160565	67.948814	
0.634322	0.9053	1.154323	1.857096	3.906423	8.882253	23.85519	44.32492	68.480785	
0.6409295	0.9120705	1.154839	1.9080648	3.9435543	8.9711067	24.241548	44.485444	68.833886	
0.641152	0.912658	1.1673	1.926650	4.074144	10.02613	24.34056	47.59768	68.943948	
0.6423971	0.92476	1.1727048	1.9303152	4.1488924	10.335609	24.504236	48.421736	69.983936	
0.654577	0.927966	1.1759	1.949152	4.15726	11.21704	25.11197	49.64499	70.366999	
0.6618248	0.9283886	1.1854771	1.9922238	4.1982867	11.346639	25.610214	49.91571	70.509848	
0.663250	0.934916	1.189696	1.999	4.261397	11.46013	25.68335	50.62946	70.53378	

Table 0-4:- % of Time Analysis table for the 366 number of data's

Flow Value	Frequency	Cum.Frequency	% of time
0.4894352	1	366	100
0.502541	1	365	99.72678
0.5107905	1	364	99.45355
0.5197381	1	363	99.18033
0.5205476	1	362	98.9071
0.5208448	1	361	98.63388
0.5231352	1	360	98.36066
0.5304343	1	359	98.08743
0.5348476	1	358	97.81421
0.5353638	1	357	97.54098
0.5366029	1	356	97.26776
0.5391257	1	355	96.99454
0.545659	1	354	96.72131
0.5458029	1	353	96.44809
0.5460295	1	352	96.17486
0.5518457	1	351	95.90164
0.5557733	1	350	95.62842
0.5596914	1	349	95.35519
0.57304	1	348	95.08197
0.5733838	1	347	94.80874
0.5792219	1	346	94.53552
0.5850571	1	345	94.2623
0.5858724	1	344	93.98907
0.5945933	1	343	93.71585
0.595599	1	342	93.44262
0.6010971	1	341	93.1694
0.6021381	1	340	92.89617
0.6165114	1	339	92.62295
0.6200314	1	338	92.34973
0.6226229	1	337	92.0765
0.6305152	1	336	91.80328
0.6343229	1	335	91.53005
0.6409295	1	334	91.25683
0.6411524	1	333	90.98361
0.6423971	1	332	90.71038
0.6545771	1	331	90.43716
0.6618248	1	330	90.16393
0.6632505	1	329	89.89071
0.6690171	1	328	89.61749
0.6748819	1	327	89.34426
0.6760343	1	326	89.07104
0.6764419	1	325	88.79781
0.6896124	1	324	88.52459
0.6901086	1	323	88.25137
0.6914962	1	322	87.97814
0.7154962	1	321	87.70492
0.7183924	1	320	87.43169
0.7278962	1	319	87.15847
0.7358524	1	318	86.88525
0.7514162	1	317	86.61202
0.7592771	1	316	86.3388
0.7610514	1	315	86.06557
0.7623429	1	314	85.79235
0.7681133	1	313	85.51913
0.7733714	1	312	85.2459
0.7804324	1	311	84.97268
0.7938305	1	310	84.69945
0.7977324	1	309	84.42623
0.799461	1	308	84.15301
0.8075238	1	307	83.87978
0.8096076	1	306	83.60656
0.8315105	1	305	83.33333
0.8361352	1	304	83.06011
0.8387029	1	303	82.78689
0.8523981	1	302	82.51366
0.8801705	1	301	82.24044
0.8869486	1	300	81.96721
0.899339	1	299	81.69399
0.9017352	1	298	81.42077
0.90536	1	297	81.14754
0.9120705	1	296	80.87432
0.9126581	1	295	80.60109
0.92476	1	294	80.32787
0.9279667	1	293	80.05464
0.9283886	1	292	79.78142
0.9349162	1	291	79.5082
0.9429705	1	290	79.23497
0.9461524	1	289	78.96175
0.9492305	1	288	78.68852
0.9499743	1	287	78.4153
0.9646143	1	286	78.14208
0.9832257	1	285	77.86885
0.9906857	1	284	77.59563
1.0001181	1	283	77.3224
1.0080276	1	282	77.04918
1.0188952	1	281	76.77596
1.0288276	1	280	76.50273
1.0368552	1	279	76.22951
1.0505333	1	278	75.95628
1.0567619	1	277	75.68306
1.0659486	1	276	75.40984
1.0685571	1	275	75.13661
1.0699762	1	274	74.86339
1.0828467	1	273	74.59016
1.0831267	1	272	74.31694
1.0902886	1	271	74.04372
1.0923857	1	270	73.77049
1.1002638	1	269	73.49727
1.1108495	1	268	73.22404
1.1113371	1	267	72.95082
1.1153343	1	266	72.6776
1.125221	1	265	72.40437
1.1349429	1	264	72.13115
1.1362114	1	263	71.85792
1.1382362	1	262	71.5847
1.1432514	1	261	71.31148
1.1452705	1	260	71.03825
1.1543238	1	259	70.76503
1.154839	1	258	70.4918
1.16732	1	257	70.21858
1.1727048	1	256	69.94536
1.17592	1	255	69.67213
1.1854771	1	254	69.39891
1.1896962	1	253	69.12568
1.1941381	1	252	68.85246
1.2268533	1	251	68.57923
1.2285648	1	250	68.30601
1.2369229	1	249	68.03279
1.2555829	1	248	67.75956
1.2572819	1	247	67.48634
1.258441	1	246	67.21311
1.25898	1	245	66.93989
1.2636924	1	244	66.66667
1.2660505	1	243	66.39344
1.2690619	1	242	66.12022
1.2824124	1	241	65.84699
1.2970695	1	240	65.57377
1.3086724	1	239	65.30055
1.3263848	1	238	65.02732
1.3318895	1	237	64.7541
1.3388781	1	236	64.48087
1.35772	1	235	64.20765
1.4478162	1	234	63.93443
1.5172371	1	233	63.6612
1.5219086	1	232	63.38798
1.527161	1	231	63.11475
1.5404324	1	230	62.84153
1.5904733	1	229	62.56831
1.5978257	1	228	62.29508
1.5999105	1	227	62.02186
1.6361257	1	226	61.74863
1.6501848	1	225	61.47541
1.6995467	1	224	61.20219
1.7825629	1	223	60.92896
1.8553895	1	222	60.65574
1.8570962	1	221	60.38251
1.9080648	1	220	60.10929
1.9266505	1	219	59.83607
1.9303152	1	218	59.56284
1.9491524	1	217	59.28962
1.9922238	1	216	59.01639
1.9998	1	215	58.74317
1.99986	1	214	58.46995
2.0802762	1	213	58.19672
2.1317143	1	212	57.9235
2.1496819	1	211	57.65027
2.2190629	1	210	57.37705
2.2546038	1	209	57.10383
2.3114895	1	208	56.8306
2.3291667	1	207	56.55738
2.3308714	1	206	56.28415
2.3369314	1	205	56.01093
2.3606924	1	204	55.7377
2.4336629	1	203	55.46448
2.4414	1	202	55.19126
2.4533676	1	201	54.91803
2.6035429	1	200	54.64481
2.6259067	1	199	54.37158
2.6294857	1	198	54.09836
2.7020629	1	197	53.82514
2.7279733	1	196	53.55191
2.7719143	1	195	53.27869
2.8037638	1	194	53.00546
2.9039695	1	193	52.73224
2.9358267	1	192	52.45902
3.2451333	1	191	52.18579
3.2599	1	190	51.91257
3.2622629	1	189	51.63934
3.3692962	1	188	51.36612
3.5072686	1	187	51.0929
3.6714476	1	186	50.81967
3.6913905	1	185	50.54645
3.9020848	1	184	50.27322
3.9064238	1	183	50
3.9435543	1	182	49.72678
4.0741448	1	181	49.45355
4.1488924	1	180	49.18033
4.157261	1	179	48.9071
4.1982867	1	178	48.63388
4.2613971	1	177	48.36066
4.3256381	1	176	48.08743
4.3782105	1	175	47.81421
4.4711762	1	174	47.54098

4.479781	1	173	47.26776
4.5165362	1	172	46.99454
4.5204305	1	171	46.72131
4.6050648	1	170	46.44809
4.7082657	1	169	46.17486
4.7702238	1	168	45.90164
4.8089	1	167	45.62842
4.8121543	1	166	45.35519
4.8290362	1	165	45.08197
4.9712038	1	164	44.80874
5.1723543	1	163	44.53552
5.1777886	1	162	44.2623
5.1906629	1	161	43.98907
5.2677486	1	160	43.71585
5.4698705	1	159	43.44262
5.6951543	1	158	43.1694
5.9173571	1	157	42.89617
5.9874038	1	156	42.62295
6.1735143	1	155	42.34973
6.2603352	1	154	42.0765
6.3120276	1	153	41.80328
6.3238886	1	152	41.53005
6.6354162	1	151	41.25683
6.6520829	1	150	40.98361
7.5464657	1	149	40.71038
7.7420095	1	148	40.43716
8.3975248	1	147	40.16393
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8.8822533	1	145	39.61749
8.9711067	1	144	39.34426
10.026137	1	143	39.07104
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14.644452	1	129	35.2459
14.931668	1	128	34.97268
15.095668	1	127	34.69945
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19.298784	1	116	31.69399
20.238428	1	115	31.42077
21.532127	1	114	31.14754
22.117518	1	113	30.87432
22.477347	1	112	30.60109
22.734418	1	111	30.32787
22.750278	1	110	30.05464
22.801659	1	109	29.78142
23.56881	1	108	29.5082
23.855197	1	107	29.23497
24.241548	1	106	28.96175
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24.504236	1	104	28.4153
25.111975	1	103	28.14208
25.610214	1	102	27.86885
25.683354	1	101	27.59563
26.310997	1	100	27.3224
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26.893054	1	98	26.77596
26.91769	1	97	26.50273
28.069029	1	96	26.22951
28.323241	1	95	25.95628
28.455264	1	94	25.68306
29.130459	1	93	25.40984
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30.428454	1	91	24.86339
31.659536	1	90	24.59016
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32.125436	1	88	24.04372
32.773842	1	87	23.77049
33.196336	1	86	23.49727
33.49093	1	85	23.22404
35.814176	1	84	22.95082
35.935163	1	83	22.6776
36.366113	1	82	22.40437
37.296239	1	81	22.13115
38.561831	1	80	21.85792
38.571707	1	79	21.5847
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42.612667	1	73	19.94536
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56.568279	1	59	16.12022
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56.910895	1	57	15.57377
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58.383226	1	55	15.02732
58.848086	1	54	14.7541
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60.35905	1	52	14.20765
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61.351871	1	48	13.11475
62.283119	1	47	12.84153
62.491583	1	46	12.56831
62.653045	1	45	12.29508
63.487332	1	44	12.02186
63.883564	1	43	11.74863
64.053658	1	42	11.47541
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65.542988	1	40	10.92896
66.061259	1	39	10.65574
66.089295	1	38	10.38251
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66.49416	1	36	9.836066
66.665178	1	35	9.562842
66.984631	1	34	9.289617
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67.948814	1	32	8.743169
68.480785	1	31	8.469945
68.833886	1	30	8.196721
68.943948	1	29	7.923497
69.983936	1	28	7.650273
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70.509848	1	26	7.103825
70.53378	1	25	6.830601
70.891001	1	24	6.557377
71.128103	1	23	6.284153
72.894553	1	22	6.010929
73.341652	1	21	5.737705
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74.242545	1	19	5.191257
76.029879	1	18	4.918033
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76.347875	1	16	4.371585
76.827126	1	15	4.098361
77.318619	1	14	3.825137
77.825567	1	13	3.551913
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79.545171	1	11	3.005464
80.518883	1	10	2.73224
81.137421	1	9	2.459016
81.344749	1	8	2.185792
81.668116	1	7	1.912568
82.301692	1	6	1.639344
83.513867	1	5	1.36612
86.287416	1	4	1.092896
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92.863006	1	2	0.546448
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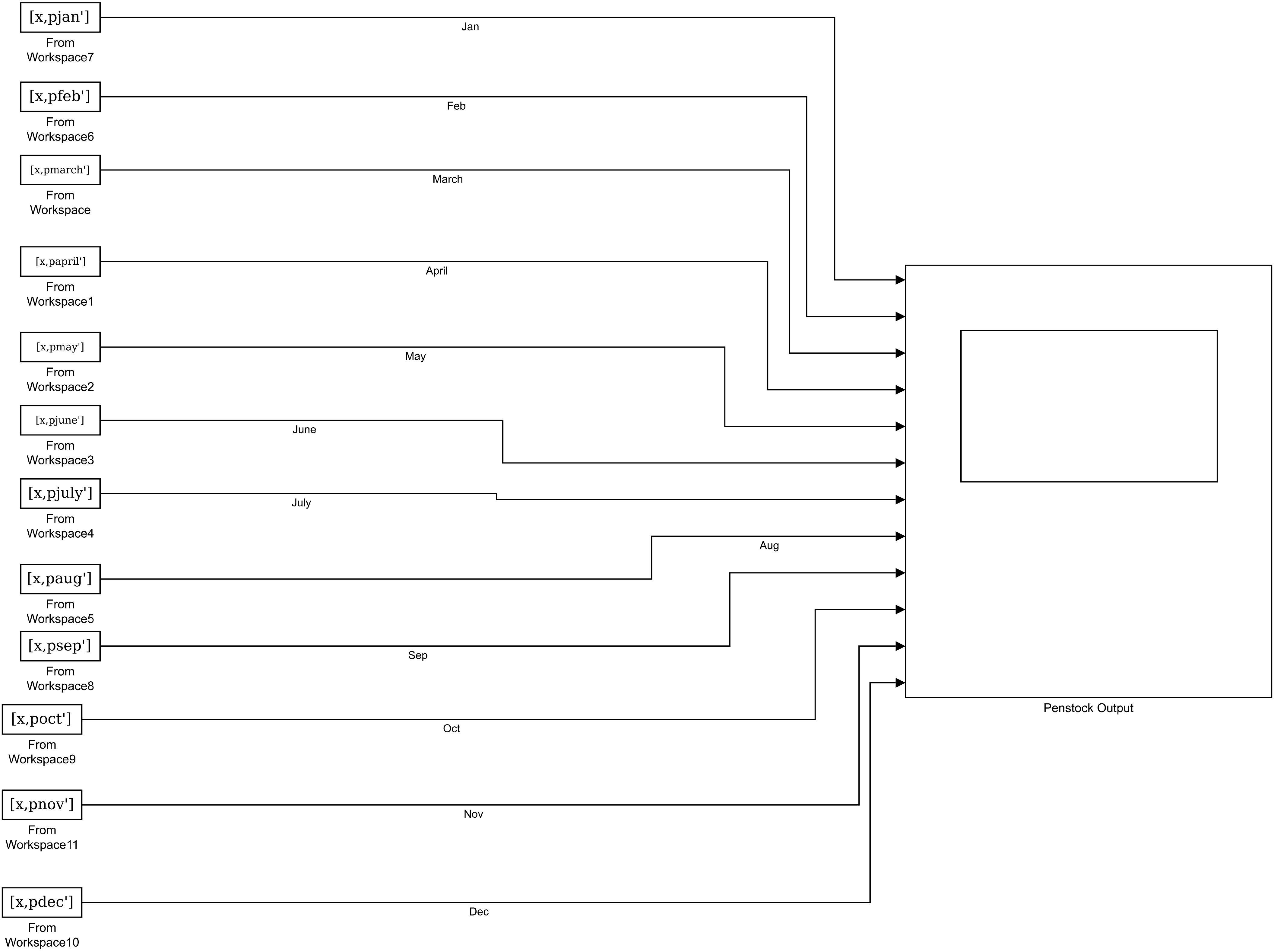
MATLAB-SIMULINK Model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From Workspace6
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From Workspace
March
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April
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From Workspace2
May
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From Workspace3
June
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From Workspace4
July
Aug
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From Workspace8
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Nov
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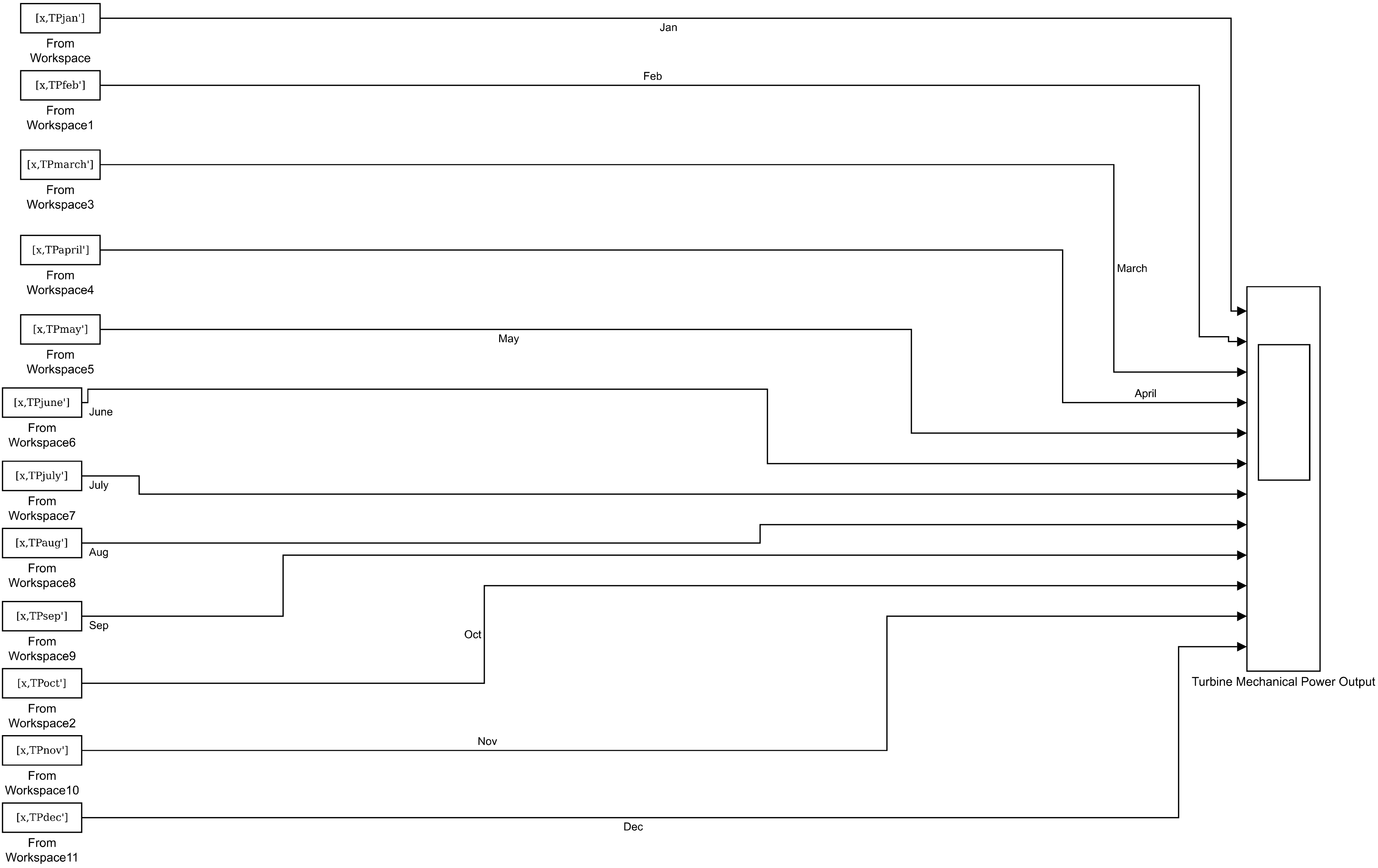
Dec
Penstock Output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From Workspace10
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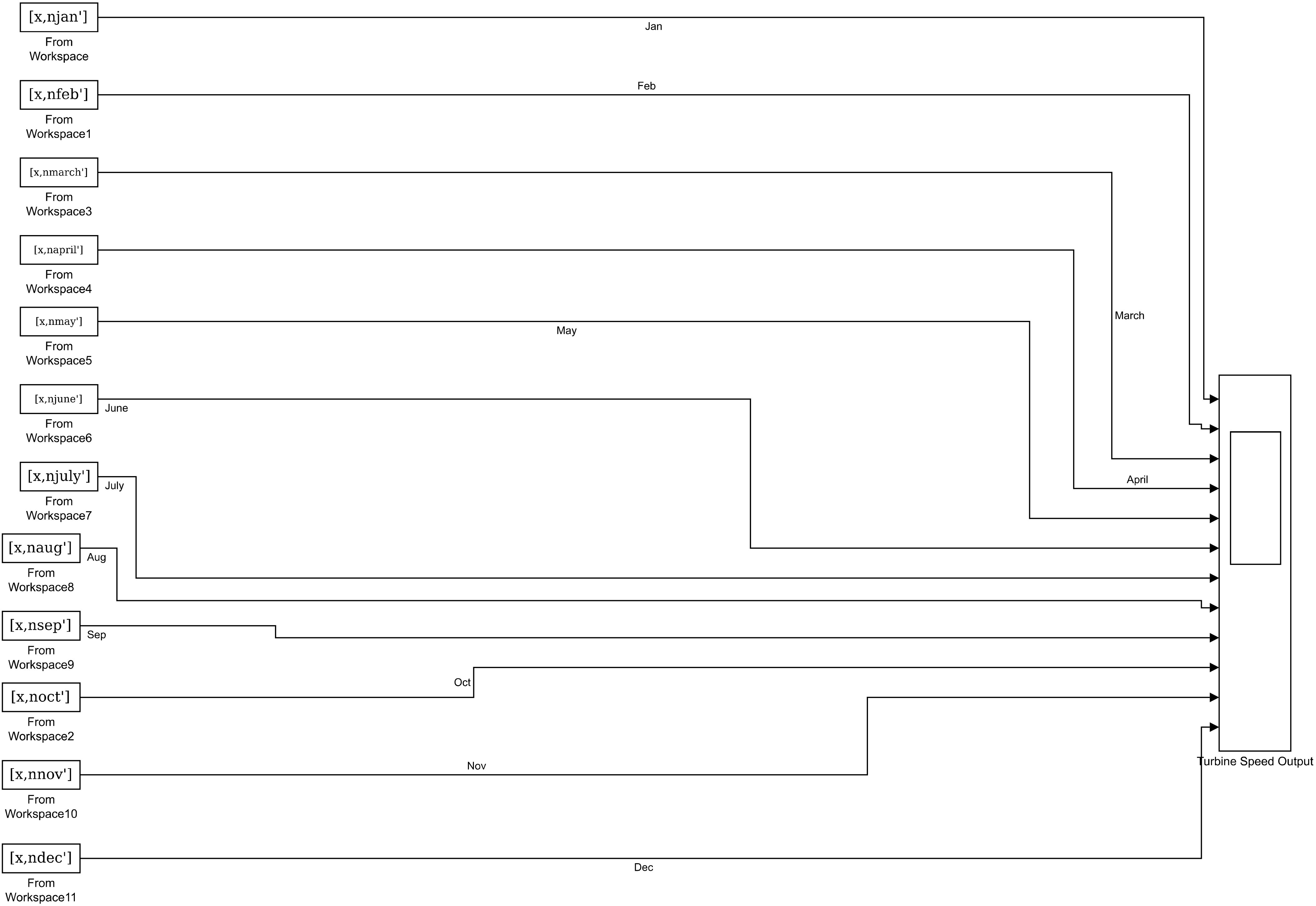
Dec
From Workspace11
Turbine Mechanical Power Output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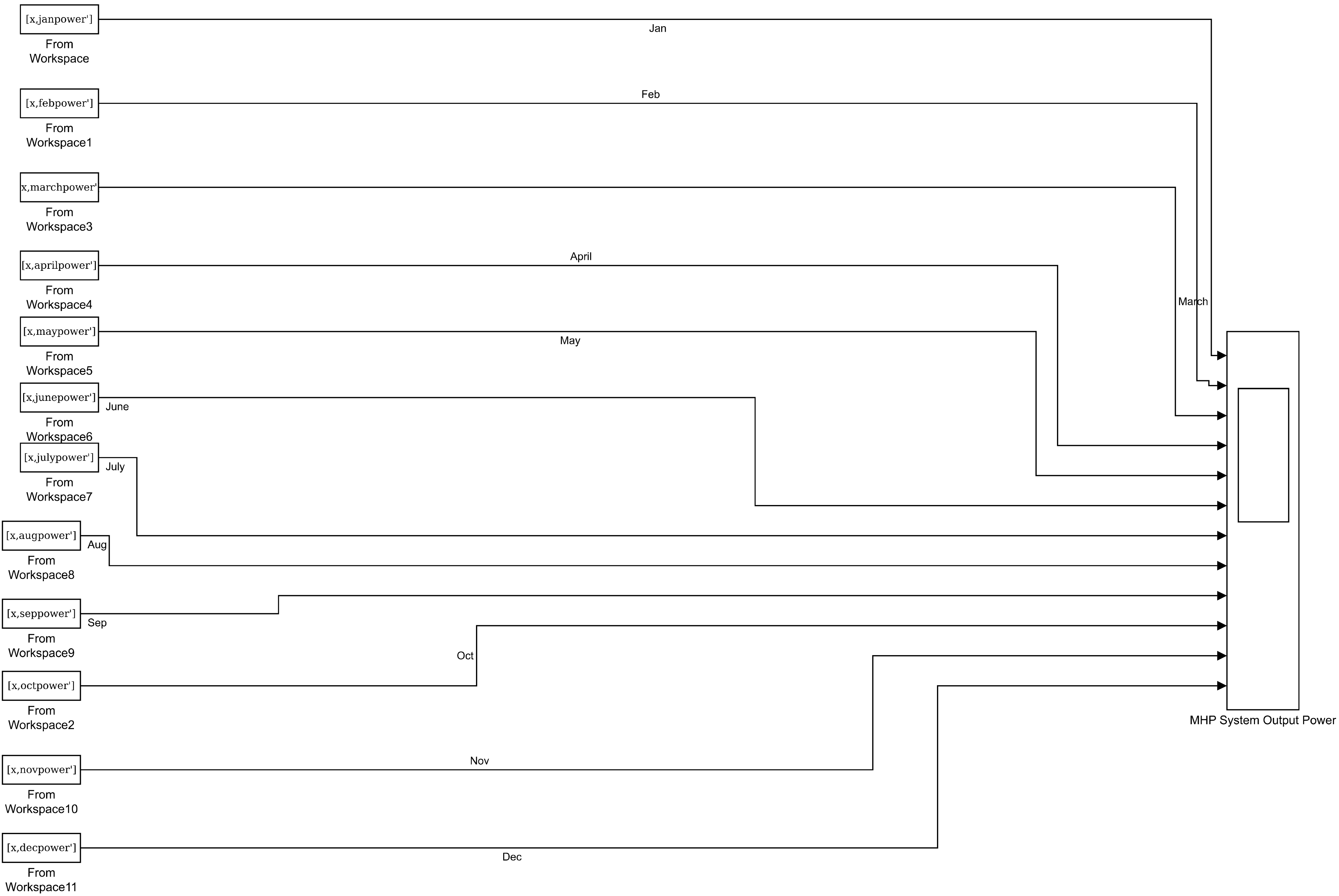
Dec
Turbine Speed Output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From Workspace
Jan
[x,febpower']
From Workspace1
Feb
x,marchpower'
From Workspace3
March
[x,aprilpower']
From Workspace4
April
[x,maypower']
From Workspace5
May
[x,junepower']
From Workspace6
June
[x,julypower']
From Workspace7
July
[x,augpower']
From Workspace8
Aug
[x,seppower']
From Workspace9
Sep
[x,octpower']
From Workspace2
Oct
[x,novpower']
From Workspace10
Nov
[x,decpower']
From Workspace11
Dec
MHP System Output Power