Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Mechanical and Industrial Engineering (SMIE)

Potential Assessment, Techno-Economic Feasibility Study and Modeling of a Micro Hydropower Plant to Power the Street Light Using Akaki River

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DECLARATION

This is to declare that the paper presented by Ezra Girmachew Kebede, titled ''Potential Assessment, Techno-Economic Feasibility Study and Modeling of a Micro Hydropower Plant to Power the Street Light Using Akaki 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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ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL & INDUSTRIAL ENGINEERING

(Thermal and Energy Conversion Chair)

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Approved by Board of Examiners

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ABBREVIATIONS

KW = Kilo Watt

P_{des} = Plant capacity

Q_d = design flow

$e_{t,des}$= Turbine efficiency at design flow

ρ = Density of water

g = Acceleration of gravity

H_g = Gross head

e_g = Generator efficiency

l_{trans} = Transformer losses

$lpara$ = Parasitic electricity losses

Q_f = Firm Flow Rate

D_P = Penstock diameter

t = Thickness of penstock

L = Penstock length
A = Cross-sectional area of the penstock

H_n = Net head

d = Turbine runner size

$h_{hydr} = Hydraulic\ loss$

$l_{trans} = Transformer\ loss$

l_{para} = Parasitic electricity losses

e_g = Generator efficiency

^e_{nq} = Specific Speed Adjustment to Peak Efficiency

^e_d = Runner size adjustment to peak efficiency
e_p = Turbine peak efficiency

h_{tail} = Tailrace losses

D = Runner discharge diameter

n_q = Specific speed

n = Turbine Speed

Q_p = Peak efficiency flow

P_d = Available power the MHP plant

V_{f1} = Flow velocity

U = Runner tangential velocity

$V_{\omega 1}$ = Inlet whirl velocity

D_v = The diameter of guide vane

Z = The number of guide blade

l = The length of the guide blade

Fa = correction factor

P_D = Design power
P = Transmitted power

Lp = length of the belt required

Fc = Belt pitch length correction factor

C = Center distance between the generator and turbine shaft
$e_{t@(Qd)}$ = Turbine efficiency at the design flow rate
$D_1 = Pulley\ Diameter\ of\ generator$
$D_2 = Pulley\ Diameter\ of\ turbine$
$N_1 = Speed\ of\ generator$

$N_2 = speed\ of\ turbine$

Pr = The power rating
Fd = Arc contact factor

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ABSTRACT

Ethiopia, one of the east African nations, has an abundance hydroelectric resource potential due to the abundant water resources in the country. However, in recent years, demand for electricity has grown, especially in urban areas. Therefore, it is essential to make optimum use of the national resources for the improvement of electrical energy. The main objective of this thesis is modeling, simulation, assessment of potential, and techno-economic viability of a micro-hydropower system for the electrification of street lighting in the case of Big Akaki River in Ethiopia. The approach used to achieve the objective involves understanding the fundamental operating principle and reviewing prior works, which are done as part of the literature review. The yearly flow data was collected from Ethiopia's office of water, irrigation, and energy and the head data obtained from GPS visualizer. Next based on these data modeling and selection of scheme components including techno economic viability of the system using RETScreen and MATLAB SIMULINK was done. Moreover, Flow duration curve, turbine efficiency curve, Power duration curve, from RETScreen and hydropower simulation from MATLAB SIMULINK results are included. For this research the gross head of 2.8m and design flow rates of 0.459m3/s, were considered. Based on the net head and design flow rate, Kaplan turbine was selected for this study. Consequently, the design parameters like the turbine speed, runner discharge diameter, specific speed and the net mechanical output was found to be 568.3rpm, 390mm, 515.5rpm and 7.41KW respectively. All in all, the systems water to wire efficiency of 53.13% was optimized to be greater than the demand at the selected area for street light. For the cost of the study, RETScreen software was applied also used to estimate total cost of the system to be $275,400, with a pay-back period of 15.6 years and an overall positive net present value of $30,779 overall.

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

CHAPTER ONE

1. INTRODUCTION

This chapter serves as an introduction to the research problems, describing the study area and objectives to be attained. The discussion includes the following aspects: Background, problem statement, research objectives, scope, significance of this study, organization of the thesis.

1.1. BACKGROUND

One of the most basic elements of our universe is energy. Throughout history, human population growth has always been aided by rising energy production and consumption. This ever-increasing energy demand presents significant challenges, as continued dependence on nonrenewable energy sources such as coal, natural gas, and petroleum (fossil fuels) has serious health, environmental, and climatic consequences. Renewable energy sources which are cleaner, more confident and environmentally friendly than conventional, non-renewable energy sources. Wind, solar, geothermal, biomass, and hydroelectric power are examples of renewable energy sources. Renewable energy sources replenish themselves naturally, reducing waste and global warming emissions.

The East African nation of Ethiopia has a land area of around 1.097 million km2. The estimated hydroelectric potential in Ethiopia is 45 GW, whereas wind potential is 10 GW, geothermal potential is 5 GW, and solar potential is between 4.5 and 7.5 kWh/m2/day. Despite the wealth of potential, the country has one of the lowest rates of access to sustainable energy globally. In the country, biomass is a major source of energy. In 2017, the Ethiopian ministry of water, irrigation, and electricity reported that only approximately 25% of households have connection to the electric grid. By 2014, the nation's estimated per-person power usage was 70 kWh, and by 2017, it had risen to around 100 kWh. Therefore, in order to address this issue, the Ethiopian government set strategic goals for the energy sector, including universal access to electricity, increased energy efficiency, the development of decentralized off-grid power generation, and the export of electricity to nearby nations. [1].

Ethiopia has an abundance of water resources as well as enormous hydropower potential with constitutes 20% of the total technically feasible potential in Africa [2]. Ethiopia is often referred to be the powerhouse of Africa because of this potential. But as of now, less than 10% of the nation's potential has been used. Hydropower is the main renewable energy source that can serve the country transition to more sustainable sources of energy. Considering this, government of Ethiopia has recognized hydropower as economically feasible and environmentally friendly option [1].

Addis Abeba is one of the country's fastest growing cities, with a current land area of about 540 sq. km [3]. As the population grows and new industries emerge, so does power consumption, tends to result in a power shortage. Addis Ababa, the capital city has many rivers which are the tributary of main Akaki river (Teleku or Big and Tinishu or Little). The tributaries of the Akaki River include Kebena, BancheYeketu, Kortame, Bulbula, LequSoramba and kotebe and Fincha rivers etc. The Big Akaki river flows through the eastern part of the city which rises from north-east part of Addis Ababa (Entoto Kidane Miheret) area [4].

Harvesting this renewable energy from the akaki river and generating power without damaging the environment or biodiversity would be a significant advantage to the region where electricity is a major concern for Streat lighting. Because of the rapid growth of industries and urbanization, the power shortage will persist over time. Damage is caused by the frequent power fluctuations in various places. Renewable energy technologies such as small hydro power generation can be applied to alleviate the electric energy shortage.

Hydroelectric power is a cost-effective, non-polluting, and environmentally friendly source of energy. The potential energy of water is converted to kinetic energy as it falls due to gravity. The kinetic energy of moving water is converted to mechanical energy as it turns blades or vanes in a hydraulic turbine. The turbine spins the generator rotor, converting mechanical energy to electrical energy. Micro-hydroelectric power plants are one form of renewable energy source. Hydroelectricity production form dam gives sustainable and greater power generating capacity power. A dam is a large reservoir built to elevate the level of the water in it. When water is discharged from the dam, the elevation it creates produces a gravitational force that turns a turbine. Due to the use of natural water that flows without being stored, hydroelectricity output from runoff river types is smaller than hydroelectricity production from dam to dam. Electricity is produced by hydropower plants of various sizes. These include large hydro, which generates power higher than 30 MW, small hydro, which generates power between 500 KW and 30 MW, and micro-hydro, which generates power below 500 KW. A micro-hydropower plant is categorized under run-of-river with small head. A micro hydropower plant system contains civil work and electro mechanical components. The civil work components include diversion mechanism, settling base, headrace, forebay tank penstock and tail races canal. Diversion mechanism is needed to divert the water from the source and using head race canal convey the water the settling base. Settling base is used settling of the suspended materials and also a spillway to prevent excessive water inflow into the headrace. Headrace convey water for the settling base to forebay tank. The forebay can also provide water storage. Trash rack is placed on the forebay tank and used to capture sediments before entering into the penstock. Penstock pipes, which assist get the water from the intake tank to the turbine, are essentially close conduct pipes. After being used in the micro hydro power plant, the water is transported back to the source via the tail races canal. Electro mechanical components contain turbine and generator. This turbine converts the energy of flowing water into rotational mechanical energy. Generator converts the rotational mechanical energy produced by the turbine into electrical energy.

A street light is a suggested source of light on the side of a walkway or road that is lit up at specific times. Increased safety and accident prevention are two important advantages of street lighting. Studies have shown that darkness causes a significant number of accidents and crashes, particularly those involving pedestrians; accidents involving pedestrians are 3 to 6.75 times more likely to occur at night than during the day. It has been discovered that street lighting reduces pedestrian collisions by close to 50%[5].

1.2. PROBLEM STATEMENT

Ethiopia now places a strong emphasis on producing electricity from renewable sources such solar power, wind power and specially hydropower. Because of the ongoing population expansion, there has been a rise in daily power demand. The consumption and supply of electric power are primarily unbalanced, making it difficult for governments in urban areas to meet their obligations. Electrical power will be managed by a schedule scheme in some parts of the city due to an increase in energy demand. One of the areas that is affected by the power outage is the street lighting systems. Street light are powered by electricity and while street light poles can be seen in a location of akaki river but they don't provide light due to a lack of power. The bridge around Tirunesh Beijing general hospital which is found around akaki areas have always been prone to accidents because of inadequate lighting. An open narrow bridge, with a sharp turning has caused many accidents and fatalities. In addition, lowering the amount of energy used by streetlights by isolated power system from grid-connected would be a huge benefit because the electricity coming to the street light system can be used for other purposes like for the nearby hospital and others. As a result, introducing clean energy technology in different sectors should be one of the strategies that should be introduced to mitigate such problems. Street lights are powered by electricity, and while street light poles can be seen in a location of akaki river, they do not provide light due to a lack of power.

1.3. OBJECTIVES

1.3.1. General Objectives

The general objective of this research is modeling, make potential and technoeconomic feasibility assessment of electrical power generation from big Akaki river to light bridge around Tirunesh Beijing general hospital located in Addis Ababa Ethiopia.

1.3.2. Specific objectives

The specific objectives are accomplished in order to achieve the general objective.

- To assess the potential by perform flow duration curve of the site
- To select the optimum routing and size of main component
- To model and simulate the system using engineering softwires
- To make techno-economic feasibility of the system using commercial software.

1.4. SCOPE

In this thesis, the Big Akaki River in Addis Ababa, Ethiopia, was used as a case study to model and simulate a micro-hydropower system. Additionally, a MATLAB SIMULINK simulation of the system and a technoeconomic feasibility analysis of the hydropower were performed. Due to budget and timing constraints, the manufacturing and implementation phases of the micro-hydropower plant were not included in the research.

1.5. LIMITATIONS

Civil, geographical survey, and water-treatment systems are not included in this study.

1.6. SIGNIFICANCE

One of the most significant benefits is that it can assist in the powering of street lights, as well as supporting the grid by allowing the use of street light power for other purposes. The generated power will brighten the streets and reduce the chances of accidents by providing a healthy environment for all vehicles and pedestrians passing by. The other most significant feature of this research is that it will draw attention to this issue and launch a study on Ethiopian small-scale river power generation. The findings of this study will lead to the development of a key strategy. The development of the country is the major advantage of the micro hydropower system, which supports a variety of minor sectors including homes, macro companies, and others. Governmental and non-governmental groups will get started on building up this system to provide power access throughout the nation by showcasing how much energy the Big Akaki river offers. This study will inspire additional research into this system and efforts to address the electrical problems.

1.7. ORGANIZATION OF THE THESIS

This section outlines the thesis' structure and provides summarizes an overview of the chapters' contents.

In **Chapter one** background, problem statement, research question, both general and specific objectives, scope, limitation and significance of the study are all included.

In **Chapter two** literature reviews of related works is presented.

In **Chapter Three** research methodology section, which include site selection, data collection for both head and flow rate, flow rate data analysis are included.

In **Chapter Four** modeling and selection of a micro hydropower components like selecting flow diversion mechanism, design penstock and turbine are included.

In **Chapter Five** Covers Software analysis using RETScreen Clean Energy Management and MATLAB SIMULINK simulation results and discussions.

In **Chapter Six** the conclusion and recommendation are covered.

CHAPTER TWO

2. LITERATURE REVIEW

In this chapter some of the relevant literature that are currently available has been presented to gain an understanding of the prior research on the topic. It will pay attention to theoretical reviews and review earlier research on the issue to show how prior studies relate to the current one.

2.1. Theoretical Review of Hydropower

Using a water wheel or a turbine, hydropower is generated by converting the kinetic energy of moving water into useful mechanical energy. This energy can then be converted into electricity by means of an electric generator. The idea behind hydropower is that water in motion, whether it's flowing or falling, has a certain amount of potential kinetic energy attached to it. Hydro powers can be classified according to plant capacity and available Head at the turbine inlet.

Table 2-1 Hydro power classification based on plant capacity [6][7]

Type	Capacity
Pico hydro power plants	<5kW
Micro hydro power plants	< 100 kW
Mini hydro power plants	100kW to 1MW
Small hydro power plants	1 MW to 25MW
Medium hydro power plants	25 MW to 1000 MW
Big hydro power plants	More than 1000 MW

According to the available Head at the turbine inlet, the hydropower are classified as low, medium, high and very high head power plants. [6]

Table 2-2 Hydropower classification based on head [6]

Type	Head
Low head power plants	< 15 m
Medium head power plants	15 – 70 m
High head power plants	70 – 250 m
Very high head power plants	More than 250 m

A Run of river hydropower plants draws the energy for electricity production mainly from the available flow of the river. A hydroelectric plant of this type typically has some short-term storage (hourly, daily, or weekly), allowing for some adaptations to the demand profile. The majority of the time, run-of-river hydropower plants are used as base-load power plants. The river water will be diverted to a channel, pipe line (penstock) to convey the water to hydraulic turbine which is connected to an electricity generator [8].

Runoff River plants are of two types; Runoff River plant without pondage and runoff River plant with pondage. In Runoff River plant without pondage, since there is no control over the flow water is lost during high flooding or low loads, and the utility of these plants is much lower than that of other forms during low runoff. When the system's flow is strong, these plants can handle the system's base load; when the flow drops, they can handle the peak demands. This creates fluctuation in power production. In contrast, a pondage plant in the Runoff River Pondage is the term used to describe the storage of water behind a dam at a plant to maximize stream capacity for a limited period of time. Storage plants may be used as base load and peak load plants [7].

The turbine is an assembly made up of a nozzle, stator, runner, and shaft that together convert water flow energy and pressure into rotating mechanical work. The nozzle or stator, which may be a series of vanes or an opening that produces a high-speed jet, directs the flow to the runner. The runner is a mechanism that converts the hydraulic energy into mechanical power by redirecting fluid flow. The runner is typically equipped with cups or blades that interact with the moving water and cause the runner to rotate, the mechanical work is transferred by the shaft to a generator [9].

Turbines can be crudely classified as high head, medium head or low head machines, as shown in Table 2-3.

Table 2-3 Head and Specific Speed Range for different types of Turbine [10]

Turbine type	Head range (meter)	Specific speed range
Kaplan and propeller	2 <Hn< 40	200 ≤Ns≤ 1550
Francis	10 <Hn< 350	50 ≤Ns≤ 350
Pelton (four nozzles)	50 <Hn< 1300	7≤Ns≤ 35
Cross-flow (Banki-Michell)	3 <Hn< 200	20≤Ns≤ 200

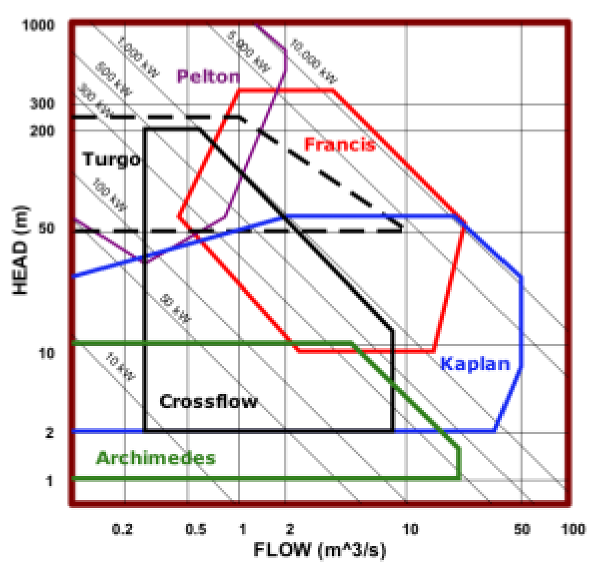


Figure 2-1 Head vs flow ranges of micro-hydro turbines

Impulse and reaction turbines are the two main categories of turbines based on how they operate. The reaction turbine's rotor is completely submerged in water and is covered by a pressure casing. The runner rotates because of the wings that are imposed by pressure variations across the blades of the runner. In contrast, a water jet (or jets) driving an impulse turbine runner maintains atmospheric pressure both before and after the water makes contact with the runner blades.

Reaction turbines exploit the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades. They are distinguished from the impulse type by having a runner that always functions within a completely water-filled casing. All reaction turbines have a diffuser known as a 'draft tube' below the runner through which the water discharges. The draft tube slows the discharged water and reduces the static pressure below the runner and thereby increases the effective head
Propeller-type turbines are similar in principle to the propeller of a ship, but operating in reversed mode. Various configurations of propeller turbine exist; a key feature is that for good efficiency the water needs to be given some swirl before entering the turbine runner. With good design the swirl is absorbed by the runner and the water that emerges flows straight into the draft tube with little residual angular momentum. When guide vanes are used, these are often adjustable so as to vary the flow admitted to the runner. In some cases, the blades of the runner can also be adjusted, in which case the turbine is called a Kaplan. The mechanics for adjusting turbine blades and guide vanes can be costly and tend to be more affordable for large systems. [11]
Reaction turbines can perform well even in the low head range (less than 10 m), making them more desirable since low head water sources are more accessible and closer to end-use locations [9].

The basic principle of hydropower converting the flowing water into electricity by the help of hydropower turbine and generator. The hydropower turbine is a device used to convert the potential and kinetic energy of moving water into rotational power and generators convert the rotational power to electrical energy. Plant capacity of small hydro at the design flow value is given by the following equation, in which the flow-dependent hydraulic losses is taken into account: [12]

$$P_{des} = \rho g Q_d H_g (1 - h_{hydr}) e_{t,des} e_g (1 - h_{trans})(1 - lpara)$$

where P_{des} is the plant capacity, Q_d design flow, $e_{t,des}$ the turbine efficiency at design flow, ρ is the density of water (1,000 kg/m3), g the acceleration of gravity (9.81 m/s^2), H_g the gross head, l_{hydr} the hydraulic losses, e_g is the generator efficiency, h_{trans} the transformer losses, and $lpara$ the parasitic electricity losses.

RETScreen was created by Canada's Natural Resources CAMNET Energy Technology Centre and is accessible to the general public. It is an Excel-based program that enables preliminary financial and physical estimates of renewable energy projects. The flow availability, the payback period, potential power capacity, the amount of energy to be generated, The operating costs, the capital costs and the payback period are all calculated by the software. The results of the software's potential calculation are shown in Table 2-4 [13].

Table 2-4 The required data for energy model, cost analysis

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

2.2. Reviewing related works

Y. R. Pasalli and A. B. Rehiara, design planning of micro-hydro in Hink River found in Manokwari, Indonesia [14]. The hydraulic potential of the site have 29.4 kW with the flow rate 0.3 m3/s and head height 10 m. With the efficiency of turbine, generator and penstock were known about 76%, 92% and 98 % respectively while effective head after installation the equipment's was approximately 8.6 m. Therefore, overall efficiency becomes 68.52% and generated power was 17.32KW. The turbine used in this micro hydro power was cross flow type Flow T-14 D-300 is chosen to be coupled with 3 phase synchronous generator. Utilizing overhead distribution lines, the energy can be submitted to a few villages in the Hink District approximately 4 kilometers from the power plant. It is intended to transfer electrical energy from the micro-hydro power plant to five villages, each of which will consume 335567 Wh per day. About 80113 Wh of energy was saved from the power plant each day, which would be used for nearby homes or other public buildings.

I. Loots, M. Van Dijk, B. Barta, S. J. Van Vuuren, and J. N. Bhagwan, review of available low head hydropower technologies, followed by the identification of sites where the technologies can be implemented, applied specifically to a South African context [15]. A low head hydropower as an electricity generation device conveying sustainable volumes of water at relatively low-pressure heads (up to 30 m). Different turbine manufacturers are manufacturing low head turbines. The manufacturers whose head and flow rate are similar to this research area's specifications are described in the table 2-5.

Table 2-5 Reaction and Impulse turbines suitable for low head hydropower.

Type	Turbine Type	Suppliers	Flow range (m3/s)	Head range (m)	Power output (KW)
Reaction Turbines	Kaplan (propeller and bulb included)	Mavel	0.3-150	1.5-35	30-20,000
		Gugler	0.2-50	1-100	3-10,000
Impulse Turbines	Cross-flow (Banki)	Ossberger	0.04-13	2.5-200	15-3000

H. M. Aung, N. A. San, and W. P. P. Myo, design and sturdy the performance of a Low Head Propeller Turbine [16]. In this research article the guide vane, runner, casing, and draft tube are the most significant components of a propeller turbine. It can be used at sites with a 3m head and a 0.94m^3/s flow rate. The turbine speed is 565 rpm, with a specific speed of 673 rpm to provide the required output power of 15 kW. The detailed design of a blade separated into five cylindrical pieces is provided in this study. The blade profile is then drawn using SolidWorks software. SolidWorks software is used to simulate the velocity and pressure distributions operating on the propeller turbine. According to reaction turbine theory, the input velocity is lower than the output velocity, and the outlet pressure rejected from the draft tube falls to about atmospheric pressure.

The feasibility of hydraulic turbines, theory of propeller turbine and detailed design calculation of 10 kW propeller turbine were described in reference [17]. This study looked into the practicality of hydraulic turbines, the theory of propeller turbines, and the precise design calculation of a 10kW propeller turbine. It can be used at sites with a head of 2.5 meters and a flow rate of 0.75 m^3/sec. The needed head and flow rate data are obtained from the Kula micro-hydropower plant in Mandalay Division's Kyaukse Township. The propeller turbine is a reaction turbine which is particularly suited for low head. The propeller turbine's blade profile is sufficient to generate the required 10kW of power. The propeller turbine is intended to generate electricity from water as a natural resource. In this thesis, the runner blade profile is primarily redesigned, and other major components such as the guiding vane, spiral casing, and draft tube are constructed. NACA 2412 is the chosen profile for the runner blade. The spiral casing and conical draft tube were chosen for this thesis for a variety of reasons, including cost, portability, and ease of construction.

Z. M. Chan and Z. N. Aung, presents the runner of a low head Kaplan turbine [18]. The Kaplan turbine may or may not brave adjustable guide vanes. It is referred to as double-regulated if both the blades and the guide-vanes can be adjusted. The system was single-regulated if the guide-vanes are fixed. When both flow and head stay essentially constant, an unregulated propeller turbine was used. In this article the runner of a low head Kaplan turbine having the net head of 2.4m and rated 0.8 m3/s. A single regulated Kaplan turbine is used and produce net power capacity of 15 kW. The spiral casing, guide vane mechanism, and runner are designed in this work as the main components of the Kaplan turbine. Kaplan turbines work well in situations with high discharge rates and low heads.

M. I. Abid, M. S. Khalid, M. Kamran, M. Arshad, M. F. Masood, and T. Murtaza design a micro hydropower system in Pakistan using Retscreen based modeling [19]. RETScreen based modeling and optimization of the project The system generates 107 kW for a lifetime of 20 years with the design flow rate of 2m3/s and gross head of 10m. The intended micro-hydro energy system's viability was confirmed by a RETScreen optimization study based on the COE and NPV. Based on the Net Present Value of 139,280 $, Cost of Energy of 0.049 kWh/$, Cumulative Cash Flows of 400,000 $, and a Payback Period of 3.1 years, the proposed micro hydropower project is both technically and financially feasible.

N. A. Fadhil, M. Elmnifi, O. D. H. Abdulrazig, and L. J. Habeeb investigate In Al-Marj road, which is roughly 100 km from Benghazi, the viability of a small hybrid electrical Micro-hydro Photovoltaic battery supply system for road lighting [20], was d. The elevation deference (slope) measurement is obtained from GPS (Geographical Positioning System) and flow data obtained from the Ministry of Water and Irrigation. The flow rate was 0.46 m/s on average. To model and analyze data for a hybrid power generation system, HOMER software has been used. The electrical load for lighting the road with 100 solar-powered poles holding LED lamps was considered in the analysis. From the output of the HOMER software result that at the time, 30KW PV and 0.9 KW Hydro power. Its startup energy cost of $0.032 per kilowatt-hour is significantly lower than the capital cost of the network system for that specific site. The government network cannot employ lighting over a distance of three kilometers.

G. Subhashini, D. Munandy, and R. Abdulla, design and develop LED based lighting system by using Pico hydro-power [21]. The system was designed in a small scale which was capable of lighting up a LED light. Reaction turbine was selected in this system for Pico Hydro System. By experimenting with different blade materials, the system's performance is evaluated, and the optimal number of blades for the system to operate at peak efficiency is determined. At a head height of 0.65 meters and a flow rate of 5.51 liters per minute, it was noted that the system could produce a maximum voltage of 5.46 volts. This number was calculated theoretically to have a net electrical power output of 4.62 watts.

A micro-hydropower system uses the flow of water to generate electricity without polluting the environment, and the electricity generated is used for various purposes in the designated area. A lot of research has been done on micro-hydropower systems around the world, including in Ethiopia, and despite the existence of a number of works of literature on the subject, there is still remains an imbalance in the supply and demand of electricity in Ethiopia's capital, Addis Ababa. Thus, the goal of this thesis is to minimize Addis Ababa's electricity scarcity for street lighting by implementing a micro hydropower system that generated electricity.

CHAPTER THREE

3. RESEARCH METHODOLOGY

This chapter provide research methodology techniques that have been applied to achieve the study's objectives. Additionally, topics related to method of data collection, data and energy analysis were included.

3.1. Research design approach

The first step in the research design approaches was to getting deep understanding of the selected topic area from the literature review. Reviewing related works helps how the system addresses related issues and how those issues were resolved. After assessing relevant work, choosing an appropriate location for setting up the system is the next step. Data collection follows site selection. The hydraulic head data (difference in elevation) and river flow rate are the two key pieces of information for hydropower projects. The head data was taken from the site elevation difference and the flow rate data was gathered from Ethiopia's office of water, irrigation, and energy. The flow rate data is shown in Appendix A.

The next phase is data analysis, which was done after data collection for the selected site called akaki river. The percentage of days in a year where the mean daily flow is equal to or greater than that is shown by the flow duration analysis. This will make choosing the design flow rate easier. The power required to illuminate the street was determined using the standard street lighting guidelines in the case of energy analysis. Choosing the percentage of time and the design flow rate from the flow duration curve in order to provide the necessary power with the available head.

Component modeling and selecting was the following next phase. This step involves choosing the flow diverter mechanism, designing the penstock, choosing and designing the turbine, calculating the output power, and choosing the generator and connection mechanisms with the turbine based on the turbine speed and output power. Calculations up to this point were done manually. When the power output was less than what was required, the researcher repeat the computation using a greater value of flow from the flow duration curve. The generator was selected based on output power. The connection between the generator and turbine was completed after that, and Appended B shows the connection data that was used for this part.

The final step was to perform software analysis to validate the manual labor. This part makes use of Matlab Simulink and RETScreen expert analysis. Matlab Simulink simulation shows the result of each month's separate analysis for power generation form the system along with other parameters and a remark based on the findings. In RETScreen energy, emission, cost and economic feasibility analysis of the system have been investigated.

3.2. Site selection

The big Akaki river is chosen for this study, and the chosen location is 8.87°N latitude and 38.78°E longitude. It's near Tirunesh Beijing General Hospital in Addis Ababa's Akaki sub-city and it can be seen on figure 3-1.

The hydropower plant's proximity to the bridge will decrease power transmission losses, and there is also an open land on this site that might be used to build a micro hydropower plant.

3.3. Data Collection

In hydropower, the two primary data are the flow rate and head data.

3.3.1. Flow Rate Data

The flow rate data in the table 3-1 comes from Ethiopia's Office of Water, Irrigation, and Energy around 22, Addis Ababa, Ethiopia. The listed flow rate is in Cumecs (m^3/s).

Table 3-1 Average monthly flow (m3/s) for river Akaki

Month	Year				
	2012	2013	2014	2015	2016
Jan	0.014	0.000	0.000	0.120	0.061
Feb	0.000	0.000	0.088	0.128	0.023
Mar	0.379	2.772	1.887	0.135	0.050
Apr	0.422	1.694	0.758	0.032	13.536
May	1.062	4.068	0.504	2.705	0.150
Jun	0.664	2.454	0.060	4.425	2.797
Jul	18.910	31.622	11.874	38.991	55.066
Aug	35.731	37.912	48.714	56.820	53.446
Sep	37.059	34.131	22.068	16.762	33.741
Oct	0.267	4.455	0.607	4.167	1.371
Nov	0.000	1.336	0.150	0.809	0.000
Dec	0.006	0.705	0.126	0.472	0.000

3.3.2. Head Data

The head data is obtained using google map and GPS visualizer. A GPS is a web tool that generates maps and profiles Using geographic information [35].

Steps in finding the elevation difference (head)

I. After downloading and installing the google map software zoom to the desired location

II. Add a route by giving it a unique name and color. In our case, the “Path” is the name of the location where the hydropower is located, and the color is red; the river is green, and the bridge is yellow located in the map shown in the figure 3-1. The yellow and green colors are only used to indicate the location of the bridge and the river's path. After that, save the path to a file in .kmz format.

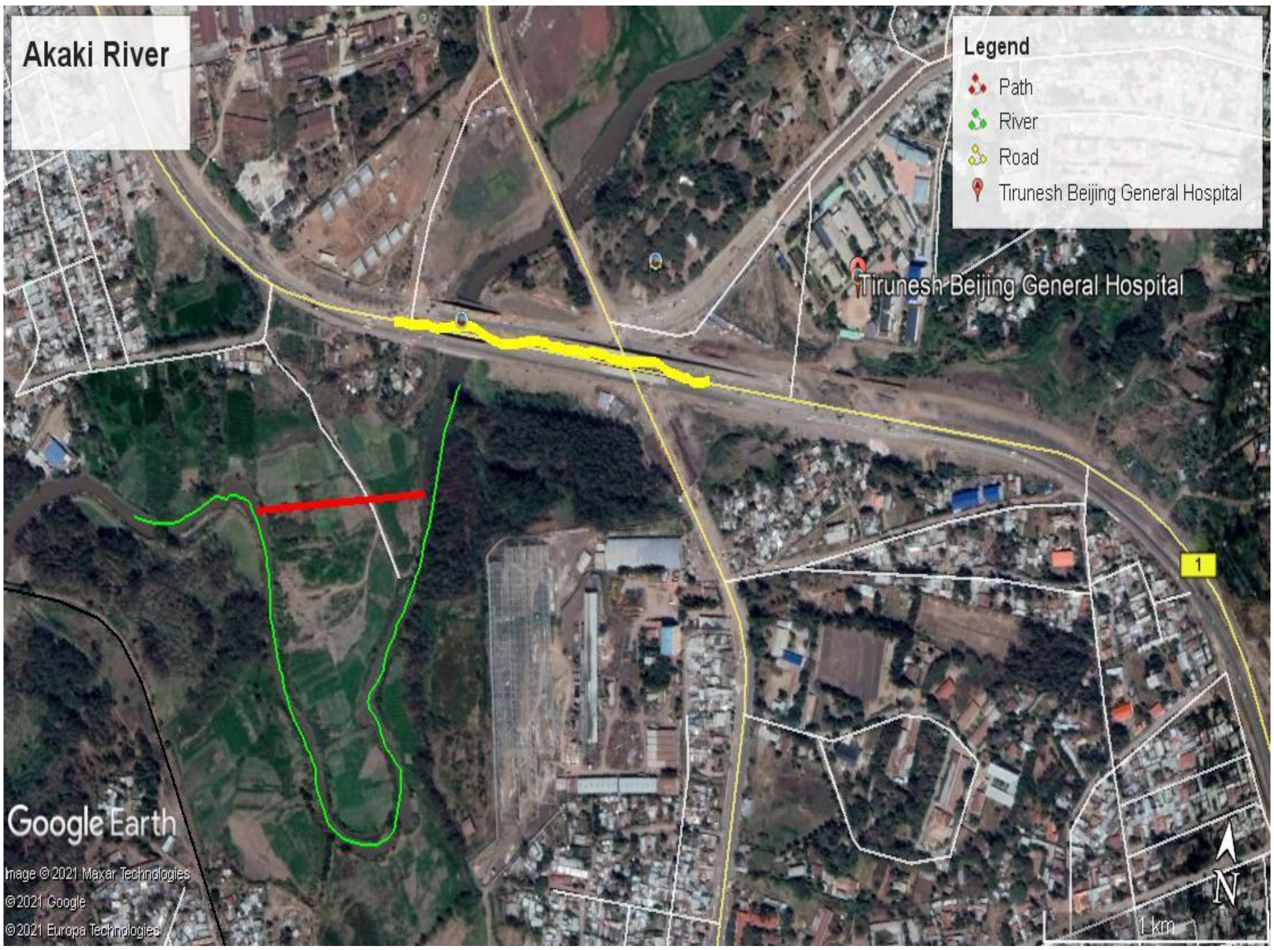


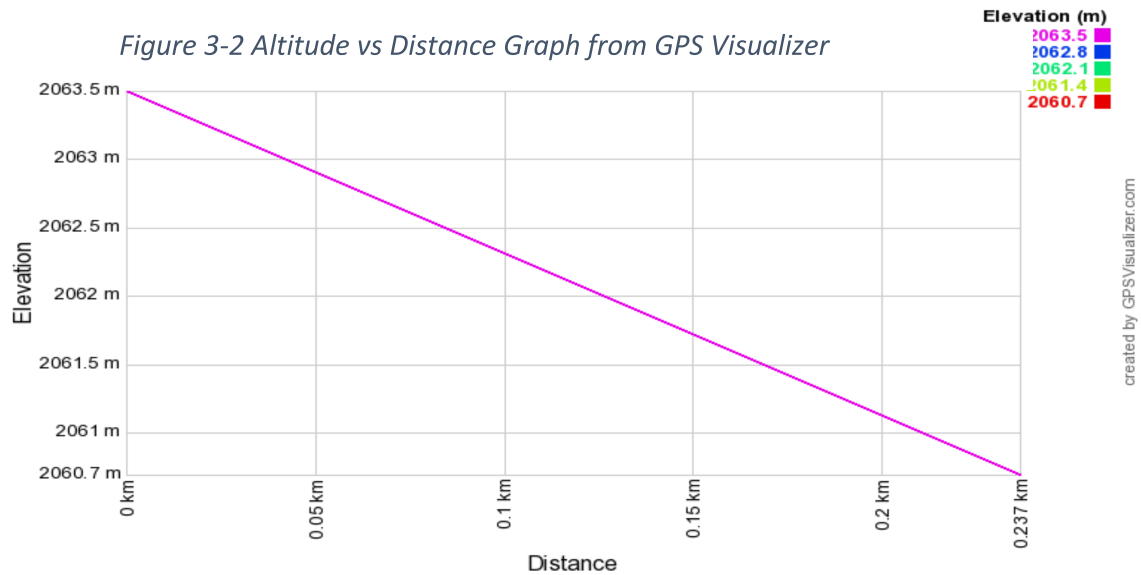
Figure 3-1 Akaki River on Google Map Photo

III. Open GPS visualizer website and on the DEM (Digital elevation model) database choose the previously saved kmz file, then change the output format .txt to get the elevation difference in txt file and change the unit to metric to get the elevation vs distance graph. The elicitation differences are given in the table and figure below.

Table 3-2 GPS Visualizer Result

type	latitude	Longitude	altitude (m)	color	opacity	width	name	desc
T	8.8744	38.7824	2063.5	#ff0000	1	5	Path	
T	8.8748	38.7846	2060.7					

Figure 3-2 Altitude vs Distance Graph from GPS Visualizer



For the result the research gets for the GPS visualizer website subtracting the altitude difference will give the head.

$$head = 2063.5m - 2060.7m = 2.8m$$

- From the altitude difference, the head was found to be 2.8m.

3.2. Data Analysis

The head data was calculated from the altitude difference in the data collection section. In this section basically the flow duration analysis was done from the yearly collected flow data that was gathered from Ethiopia's Office of Water, Irrigation, and Energy.

3.2.1. Flow duration analysis

Flow duration analysis is a method of examining the variability of water flow rate data over time. The flow duration Curve, shows the flow rate in cubic meter per second versus the percent of time in a graph. A flow duration curve is also used to show the relationship between flow data and the amount of time they have available. The flow duration curve can be plotted in two ways, class interval and Rank order methods.

The rank order method is a methodology that orders flow data based on magnitude using a time series of flow data with increments of time. This method is recommended for small amounts of data and produces acceptable results. The second approach is the class interval method, in this method time series data is divided into class intervals. It is mostly utilized for large amounts of data.

As a result, a Rank order was chosen in this study due to its ease of calculation and accuracy over the class interval approach.

Steps in calculating flow duration curve

I. Calculating the automatic mean of five-year flow rate
II. Using the rank-ordered technique, rank the flow rates. The complete time series of flows, such as mean daily, weekly, or monthly flows, that indicate equal time increments for each measurement value and order the flows by magnitude.
III. According to the rank rearrange the months and calculate exceedance percentage.
IV. Draw the flow rate verses exceedance percentage graph.

All the above are summarized in tables 3-3 and figure 3-4.

Table 3-3 Average Flow Rate and Ranking of Each Month

Month	Year					Average Discharge (m/s)	Rank
	2012	2013	2014	2015	2016		
Jan	0.014	0.000	0.000	0.120	0.061	0.0390	12
Feb	0.000	0.000	0.088	0.128	0.023	0.0478	11
Mar	0.379	2.772	1.887	0.135	0.050	1.0446	8
Apr	0.422	1.694	0.758	0.032	13.536	3.2884	4
May	1.062	4.068	0.504	2.705	0.150	1.6978	7
Jun	0.664	2.454	0.060	4.425	2.797	2.0800	6
Jul	18.910	31.622	11.874	38.991	55.066	31.2926	2
Aug	35.731	37.912	48.714	56.820	53.446	46.5246	1
Sep	37.059	34.131	22.068	16.762	33.741	28.7522	3
Oct	0.267	4.455	0.607	4.167	1.371	2.1734	5
Nov	0.000	1.336	0.150	0.809	0.000	0.4590	9
Dec	0.006	0.705	0.126	0.472	0.000	0.2618	10

Using Microsoft Excel, a flow duration curve for the scheme was created, as shown in figure 4, which is a plot of the re-arranged flow rate on the vertical axis against duration on the horizontal axis. The scheme's design flow was chosen to be 90 percent equal to or greater than the flow rate. This flow rate is accessible for at least 90% of the year, making it dependable for power generation.

Table 3-4 Exceedance Percentage and Rank

Month	Flow rate	Rank	Exceedance %
Aug	46.5246	1	8.33
Jul	31.2926	2	16.66
Sep	28.7522	3	25
Apr	3.2884	4	33.33
Oct	2.1734	5	41.66
Jun	2.08	6	50
May	1.6978	7	58.33
Mar	1.0446	8	66.66
Nov	0.459	9	75
Dec	0.2618	10	83.33
Feb	0.0478	11	91.66
Jan	0.039	12	100

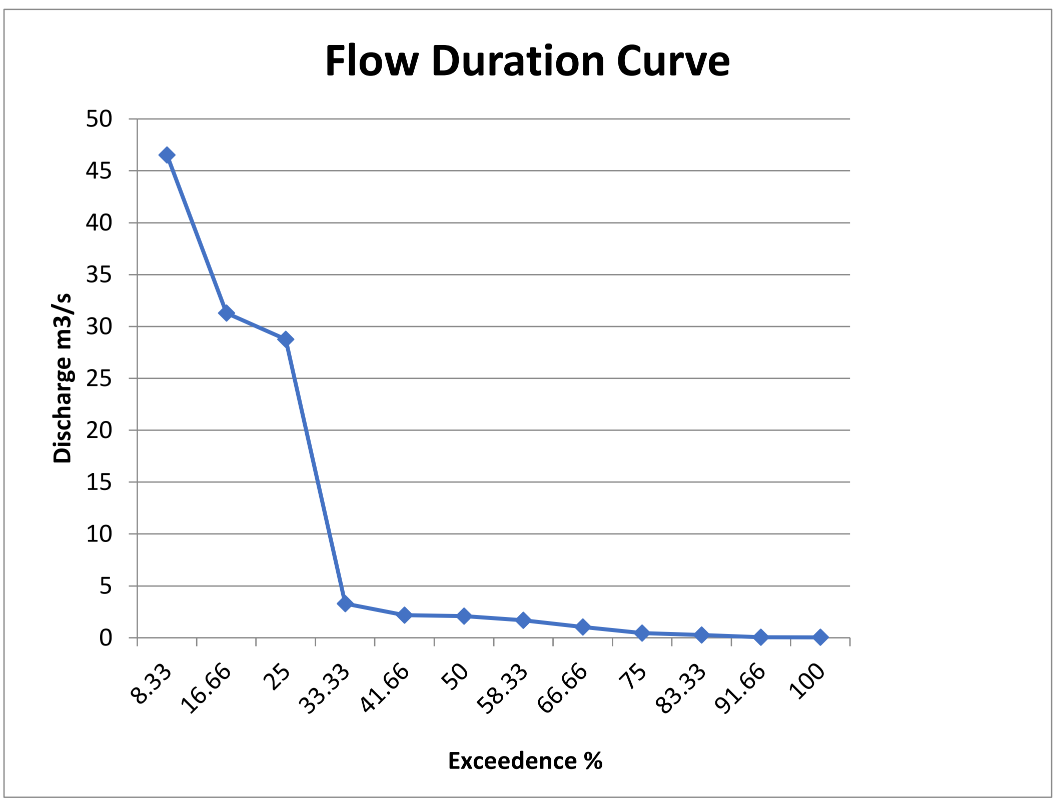


Figure 3-3 Flow Duration Curve

3.3. Potential Assessment of the Selected Site

The potential power of a hydropower site is evaluated by the following formula [22].

$$P = \rho Q_d g H_g$$

$Where,$ $\rho = density\ of\ water\ (KN/m^3), Q_d = Design\ Flow\ rate\ (m^3/s),$
$g = Gravity\ (m/s^2), H_g = Gross\ head\ (m),$

The available potential of the site for each month of the flow rate and a gross head of 2.8 m is shown in the table 3-5.

Table 3-5 Available Potential of Akaki River

Rank	Exceedance %	Flow rate	Gross head Hg	Available Potential Power in KW
1	8.3	46.52	2.8	1277.94
2	16.7	31.29	2.8	859.55
3	25.0	28.75	2.8	789.77
4	33.3	3.29	2.8	90.33
5	41.7	2.17	2.8	59.70
6	50.0	2.08	2.8	57.13
7	58.3	1.70	2.8	46.64
8	66.7	1.04	2.8	28.69
9	75.0	0.46	2.8	12.61
10	83.3	0.26	2.8	7.19
11	91.7	0.05	2.8	1.31
12	100.0	0.04	2.8	1.07

3.4. Street Light Energy Analysis

This section analyzes the energy required for the street light by taking the rod type and street light configuration into account.

The type of road that cover the lighting systems used to illuminate classified as follows: [23]

I. Expressways; These are roads that are only open to motor vehicles, have no grade crossings, and can only be reached from interchanges.
II. Major Roads: - These roads are a part of the roadway system that acts as the main conduit for through traffic. The routes link key traffic-generating areas in various cities or municipalities.
III. Collector Road: - These are collector and distribution roads that handle traffic between major and minor roadways. In urban areas, they are primarily used for traffic movements within residential, commercial, and industrial centers.
IV. Minor Roads: - These roads include subdivision roads and local routes that are typically used mainly as access roads to residential areas, businesses, and industrial facilities, with minor through traffic.
V. Rural Highways: - These are the main roadways in the rural areas, which are provincial roads.

The selected area, which is around the bridge area road, is classified as a collector road from the list of different types of roads above. The lighting setups make up the second criterion. The lighting configurations are displayed in figure 3-4 [23].

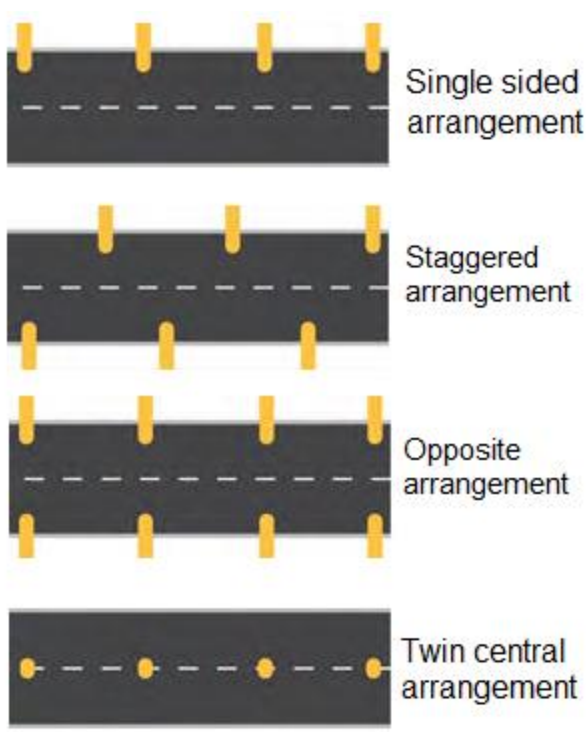


Figure 3-4 Different type of lighting arrangements [23]

i. Single sided arrangement: - when the road width is less than or equal to the mounting height and all of the luminaires are situated on one side of the road.
ii. Staggered arrangement: - When the road width is equal to one to one and a half times the mounting height, a "zig-zag" or staggered arrangement in which the luminaires are placed alternately on each side of the road must be used.
iii. Opposite arrangement: - When the road width is greater than 1.5 times the mounting height, a configuration in which the luminaires are put opposite one another and pointing each other along the road, must be used.
iv. Twin central arrangement: - When the road width is less than or equal to the mounting height, the luminaires must be mounted on T-shaped like masts in the middle of the central island of the road.

The placement of the road lights is based on the width of the road and the height of the street light poles. The installation of a single-sided street light for each lane on the six-meter-wide road surrounding the bridge will enhance lighting effect.

Table 3-6 Placement Guide for Roadway Lighting [23]

Road	Road Width, meters	Arrangement	Lamp Wattage, Watts	Luminaire Spacing, Meters	Mounting Height, meters	Mast Arm Length, meters
Expressway	10	Twin Central	250	25-35	12	1.5
	15		250	20-35	12	3.0
	20	Opposite	250	20-45	12	1.5
	25		250	20-40	12	1.5
	30		250	20-30	12	1.5
	36		250	20-25	12	1.5
	40		250	20-22	12	1.5
Major	10	One-side	250	10-40	10	1.5
	15		250	10-45	12	3.0
	10	Twin Central	150	20-37	10	1.5
	15		250	20-43	12	3.0
	20	Opposite	150	20-40	10	3.0
	25		250	20-45	10	1.5
	30		250	20-45	10	1.5
	36		250	20-45	12	3.0
	40		250	20-45	12	3.0
Collector	10	One-side	150	10-40	10	1.5
	15		250	10 50	12	3.0
	10	Twin Central	150	20-40	10	1.5
	15		150	20-37	12	3.0

Table 3-6 determine the characteristics of roadway illumination for uniformity and safety. With a lamp wattage of 150W, luminaire spacing of 10 to 40 meters, a pole height of 10 meters, and a mast arm length of 1.5 meters, choose one side of the configuration from table 3-6 from collector road.

There are eight lanes surrounding the 100-meter-long bridge near the Tirunesh Beijing General Hospital, which includes two under it, two on top, two on either side, and two next to it. Lighting the 8 lanes for 150 meter makes the overall length of the road 1200 meter and all the roads have 6m width. As shown in Table 3-6, the recommended street light pole luminaire spacing is between 10 and 40 meters, and choosing the street light spacing to be 30 meters. In order to illuminate the 1.2 kilometers of road, 40 street light poles with 150w street lights need to be placed every with 30 meters spacing, making the total wattage 6KW. Finally, the Street light Energy analysis was done with 6KW lode value.

CHAPTER FOUR

4. MODELING AND SELECTION OF MICRO-HYDRO COMPONENTS

In this section modeling of micro-hydro components; penstock, turbine, and turbine to generator connection mechanism also selection of civil works structure like intake structure are covered in this portion.

4.1. Flow Diversion Mechanism and Intake Structure

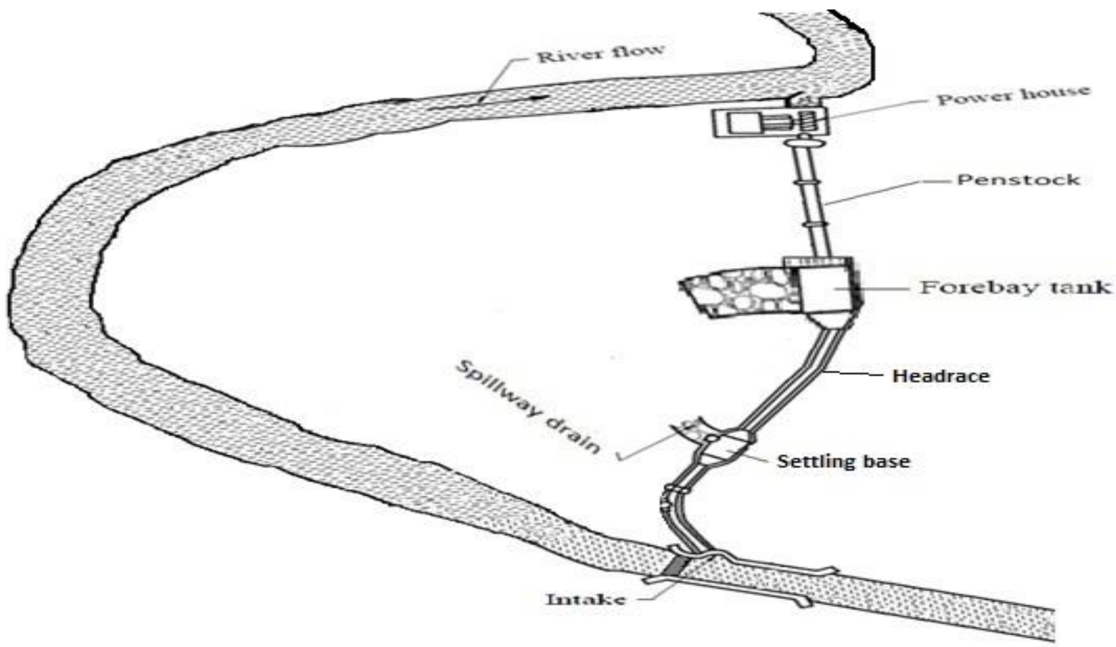


Figure 4-1 General Layout of MICRO HYDROPOWER System

The proposed diversion mechanism works for a micro-hydropower system for controlling the flow of water from the source river into the settling base as shown in figure 4-1. The water level at the point of diversion must be maintained constant at a certain stage because the water source's available discharge may vary due to seasonal changes. As a result, a weir or other control mechanism is required at the intake. A weir is a structure that is placed across a river to direct some of the runoff into a channel. To maintain a constant minimum depth of water upstream of the weir, the weir can be constructed to raise the water level. As long as there is enough water in the river, this enables the necessary flow to be diverted to the headrace. Additionally, the intake structure needs to be able to handle the bed load that the river carries. Silt and sand make up the majority of the river's bed load during the low water season, but during the flood season, the river may carry large boulders. The two most common types of intakes are side and bottom intakes.

Side intakes are simpler as well as less costly than other types of intakes. Building, operating, and maintaining them is easy. They are favorable for low and high gradient water flow and also, they are good in any path of the river. Side intake is suitable for suspended sediment concentrations of both high and low levels combination with very efficient settling basin.

The bottom intake, which is sometimes referred to as a Tyrolean or trench intake, is a grille-like hole that collects water from the riverbed and discharges it into the headrace. The flow typically exits the intake structure through an aperture in a wing wall and moves away from the river. Favorable for very high gradient but they are not good for high gradient flow. They are good for only straight path of the river and they are not good for high suspended sediment concentration. Form the above comparison and description for this project side intakes are suitable [24].

Depending on the features of the river, the geology of the catchment region, and the discharge, the majority of rivers carry a significant amount of sediment in the form of gravel, sand, or finer particles. Given the high flow velocity at the runner, suspended silt can seriously damage the seals, bearings, and turbine runner. The turbine's efficiency decreases as a result of this wear, which finally results in total failure. To solve this problem settling base is required. A settling basin has a much greater cross-sectional area, which is helpful in lowering the flow velocity and enabling the settling of suspended debris. It also features a spillway to stop too much water from entering the headrace [24].

In order to spill overflow during the monsoon and in the event of an obstacle before approaching the canals, spillways are necessary in the settling base. Similar to this, the forebay also needs spillways to release the whole design flow in the event of a sudden closure of the valve at the powerhouse [24].

To convey water for the settling base to forebay tank headrace is needed. The headrace for a small-scale hydropower plant essentially adopts an exposed construction due to the often-small volume of water transportation. In general, level to slightly sloping terrain should be used for the headrace alignment. The headrace can be either open channel or a covered channel [25].

From table 4-1 open channel is selected due to low contraction cost and the sediments fallen is separated in the forebay tank.

A micro-hydro system's forebay serves the following tasks: [25]

- It serves as the transition for the flow of water to pressure flow conditions from open channel.

- It controls the flow into the penstock, especially by dumping extra water into a spillway.
- As the wave exits the penstock pipe, the surge pressure is released.
- Additionally, it can act as the headrace's secondary or final settling basin and catch certain particles that passes the settling basin.
- The forebay can also offer water storage for usage during peak power demand periods, though it is quite uncommon in micro-hydro projects.

Table 4-1 Types of headraces for small-scale hydropower plants [25]

Type	Advantages and Problems	Typical Structure
Open channel	Advantages • Relatively inexpensive • Easy construction Problems • Possible inflow of sediment from the slope above • High incursion rate of fallen leaves, etc.	• Simple earth channel • Lined channel (dry or wet masonry lining; concrete lining) • Fenced channel (made of wood, concrete or copper) • Sheet-lined channel • Half-tube channel (corrugated piping, etc
Closed conduit / Covered channel	Advantages • Generally large earth work volume • Low incursion rate of sediment and fallen leaves, etc. into the channel Problems • Less easy channel inspection, maintenance work, including sediment removal, and repair	• Buried tube (Hume, PVC or FRPM) • Box culvert • Fenced channel with cover

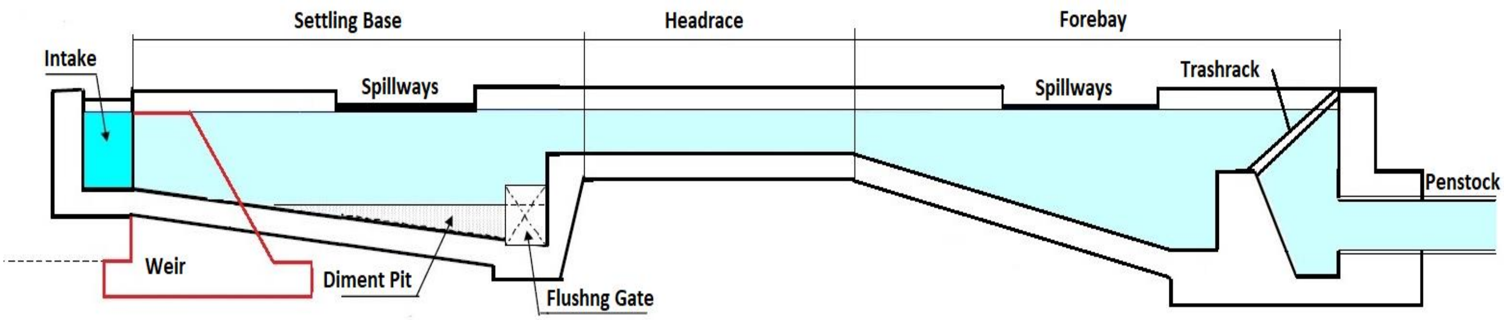


Figure 4-2 Flow Diversion Mechanism and Intake structure components

4.2. Penstock Design

The penstock is a crucial part of micro hydro power since it is utilized to transport water from its source to the turbine, converting potential energy into kinetic energy as it does so. Penstock may be exposed or buried in the earth, depending on a variety of factors, such as the material of the penstock, the local climate, and environmental concerns. When constructing penstock, a number of elements are taken into consideration, such as thickness, diameter, cross-sectional area and water velocity.

Mild steel was shown to be the best material for penstock when compared to polyvinyl chloride, high-density polyethylene and glass reinforced plastic based on yield strength, material life, thickness, material cost, and installation cost[26].

4.2.1. Diameter of the penstock

For small (micro and Pico) hydropower plants, Warnick et al. (1984) suggested an empirical relationship between penstock diameter and design flow rate (Q_d) [27].

$$D_P = 0.72Q_d^{0.5}$$

Where D_P= Penstock diameter and Q_d= Design flow rate. (design flow rate is selected in section 4.4.1)

Replacing the design flow rate in the above formula, the diameter of the penstock will be

$$D_P = 0.488\ m$$

The standard pipe diameter From Appendix B- table 0-9, the nearest value is D_P=0.508m

4.2.2. Thickness of the penstock

The penstock's wall thickness is affected by the diameter, operating pressure, material, and tensile strength. Based on its diameter, the penstock's minimum thickness may be determined using the formula below [10].

$$t = \frac{D_p + 508}{400} + 1.2$$

Where t is the minimum thickness in mm of the penstock and D_P is the diameter of the penstock.

$$t = 3.74mm$$

For the standard pipe diameter list for Dp 0.508m (20in) selecting the standard schedule 20 having a thickness of 9.53mm.

4.2.3. Length of the penstock

The length of the penstock is calculated using this formula [28].

$$D = 2.69x(n^2 \ x \ Q_d^2 \ x \ \frac{L}{H_g})^{0.1875}$$

Where D is diameter of the penstock, n is manning roughness coefficient for mild steel is 0.012 as shown in table 4-2, Q_d is design flow, L is penstock length and H_g is gross head.

$$L = 12.72m$$

Table 4-2 Manning coefficient n for commercial pipes [36]

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

4.2.4. Penstock cross-sectional area

Using this formula, the penstock's cross-sectional area is calculated from its diameter.

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

Where D is the penstock's diameter, and A is the penstock's cross-sectional area.

$$A = 0.2m^2$$

4.3. Losses and Net head Calculation

By deducting hydraulic loss from the gross head, one can determine the net head needed for power generated.

$$H_n = H_g - \sum H_{loss}$$
$$H_n = Net\ head$$
$$H_g = Gross\ head$$
$$\sum H_{loss} = sumation\ of\ losses$$

The summation of losses are hydraulic and tail race losses.

$$\sum H_{loss} = Hydraulic\ loss + Tail\ race\ loss$$

Under hydraulic losses, penstock, garbage rack, gate, entrance and surge tank/tunnel stages are all categorized.

For this case assuming hydraulic loss 7% and trail race loss 7% the above equation becomes

$$\sum H_{loss} = 0.07H_g\ + 0.07H_g = 0.14H_g$$

$$H_n = H_g - 0.14H_g$$
$$H_n = 0.86H_g = 2.408m$$

4.4. Hydropower Turbines Selection and Analysis

In this section selection and analysis of turbine is caried out. The main selection criteria for selecting a turbine are design flow rate, operating head and specific speed of the turbine. From the standard turbine selection chart in figure 4-3 Cross-flow, Kaplan and Propeller turbines can be used, according to the net head (Hn = 2.408m) and design flow rate (Qd = 0.459 m3/s). Specific speed is the other parameter to select form the three turbines. The specific speed range and operating head of turbines shown in table 2-3.

- ✓ For Cross-flow turbine, the range of specific speed is 20≤Ns≤200 [29].

$$n_q\ = \frac{513.55}{H^{0.505}}$$

$$n_q\ = \frac{513.55}{H^{0.505}} = \frac{513.55}{2.408^{0.505}} = 329.14\ rpm$$

The calculated specific speed is not within the specified specific speed range.

- ✓ For Kaplan and Propeller turbine the specific speed the range is 200≤Ns≤1550 can be calculated as follows [18].

$$n_q\ = \frac{800}{H^{0.5}}$$

$$n_q = \frac{800}{H^{0.5}} = \frac{800}{2.408^{0.5}} = 515.5\ rpm$$

The calculated specific speed is within the specified specific speed range.

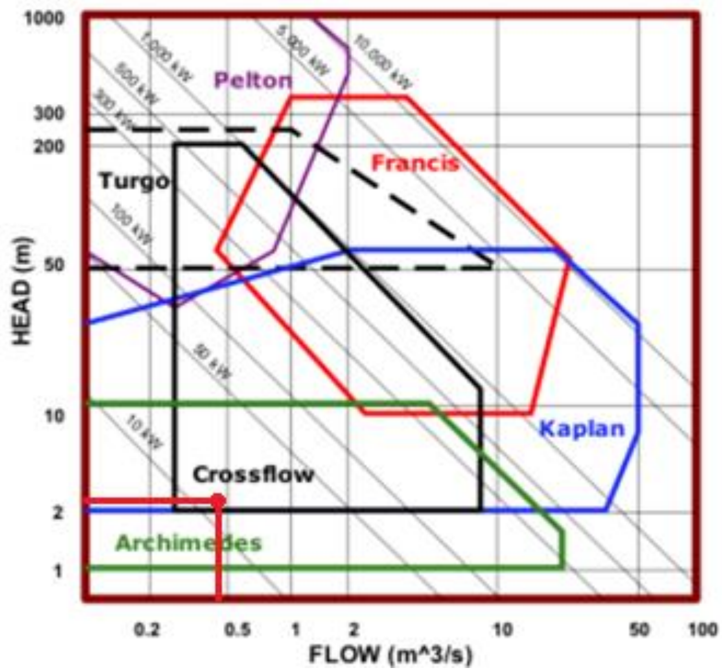


Figure 4-3 Turbine selection chart based on Head vs flow

- ❖ Based on the above calculation, cross flow turbine specific speed result value is not within the specified specific speed range and for Kaplan and propeller turbines the calculated specific speed is within the specified range. Therefore, the Kaplan and propeller turbines are suitable for this case. From Kaplan and propeller turbines, Kaplan turbine is selected for this thesis since Kaplan turbine is more efficient than propeller turbines and can manage varying flows well due to its movable runner blades.

4.4.1. Manual Hydro Power Analysis

This section assesses the site's potential using the flow rate analysis from section 3.2.1 table 3-4 Exceedance Percentage and the net head analysis, which came out at 2.408 meters. Form hydropower turbines selection, Kaplan turbine is suitable for this study. The turbine parameters like the turbine runner size, specific speed, efficiency, and power output form the micro hydro power are manually solved using the formulas provided below [12].

- ❖ Reaction turbine runner size (d) given by

$$d = KQ_d^{0.473}$$

$$Where\ d = runner\ throte\ diameter\ in\ metter$$

$$\mathrm{K = 0.46\ for\ d < 1.8m}$$

- Specific speed (n_q): -

$$n_q = \frac{800}{H^{0.5}}\ (r.p.m)$$

- Turbine speed (n): -

$$n = \frac{n_q x H_n^{5/4}}{\sqrt{P_{d,turbine}}}(r.p.m)$$

$$Where\ , H_n = net\ head\ (m) \quad P_d = turbine\ power\ in\ (Kw)$$

$$n_q = turbine\ specific\ speed$$

Calculation of the Turbine Efficiency at Each Flow

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

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

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

$$(\hat{}e_d\ ) = (0.09 + \ \hat{}e_{nq})(1 - 0.789xd^{-0.2})$$

- Turbine peak efficiency (e_p): -

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

$$Where, \qquad R_m = Turbine\ manfacturer\ design\ coefficent\ (2.8\ to\ 6.1)$$

$$4.5\ is\ used\ by\ defult$$

- Peak efficiency flow (Qp): -

$$Q_p = 0.75Q_d\ \left(\frac{m^3}{s}\right)$$

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

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

- The actual power from the turbine ($P_{d,\ turbine}$): -

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

- The available power from the micro hydro power plant

$$P_d = \rho g Q h_g (1 - (h_{hydr} + h_{tail})) e_t \, e_g (1 - l_{hydr})(1 - l_{para})$$

Were these values are assumed for this case.

$e_{t@(Qd)} = Turbine\ efficency\ at\ the\ design\ flow\ rate = 68.3\%$

$e_g = Generator\ efficiency = 95\%$

$h_{hydr} = Hydraulic\ loss = 7\%$

$l_{trans} = Transformer\ loss = 2\%$

$l_{para} = Parasitic\ electricity\ losses = 3\%$

$h_{tail} = tailrace\ losses = 7\%$

Table below shows the summary of the turbine parameters as the flow rate varies. The analysis was done to estimate the flow rate for the selected river to satisfy the peak load required by the area found form the energy analysis of street light which is 6Kw.

Table 4-3 Turbine parameter analysis as variable flow rate

Rank	Exceedance %	Flow rate	Gross head Hg	Net head Hn	Turbine runner size d	Specific speed, nq	Turbine speed n	Specific speed adjustment to peak efficiency	Runner size adjustment to peak efficiency	Turbine peak efficiency	Peak efficiency flow	Actual power from the turbine, $P_{dturbine}$	MHP System Available Power in KW
1	8.3	46.52	2.8	2.408	2.83	515.5	52.9	0.244	0.122	0.779	34.89	856.14	773.16
2	16.7	31.29	2.8	2.408	2.34	515.5	64.8	0.244	0.113	0.771	23.47	569.93	514.69
3	25.0	28.75	2.8	2.408	2.25	515.5	67.7	0.244	0.112	0.769	21.56	522.30	471.68
4	33.3	3.29	2.8	2.408	0.81	515.5	206.1	0.244	0.060	0.725	2.47	56.32	50.86
5	41.7	2.17	2.8	2.408	0.66	515.5	255.4	0.244	0.049	0.714	1.63	36.66	33.10
6	50.0	2.08	2.8	2.408	0.65	515.5	261.3	0.244	0.047	0.713	1.56	35.03	31.64
7	58.3	1.70	2.8	2.408	0.59	515.5	290.2	0.244	0.042	0.708	1.27	28.40	25.64
8	66.7	1.04	2.8	2.408	0.47	515.5	373.7	0.244	0.028	0.694	0.78	17.13	15.47
9	75.0	0.459	2.8	2.408	0.32	515.5	568.3	0.244	0.003	0.683	0.34	7.41	6.69
10	83.3	0.26	2.8	2.408	0.24	515.5	769.5	0.244	-0.016	0.653	0.20	4.04	3.65
11	91.7	0.048	2.8	2.408	0.11	515.5	1889.9	0.244	-0.077	0.593	0.04	0.67	0.60
12	100.0	0.039	2.8	2.408	0.10	515.5	2104.7	0.244	-0.086	0.586	0.03	0.54	0.49

As expressed in the demand analysis for street light the energy needed to power the street light was 6Kw and as seen form table 4-3 above the amount of power that satisfies the requirement at 2.8m gross head is 0.459m3/s flow rate. For this study 75% of the time which is 0.459m3/s is selected as a design flow rate. The specific speed, turbine speed, output power from the turbine, output power from the micro hydro power is 515.5 rpm, 568.3rpm, 7.4KW, 6.7KW respectively.

$$The\ Firm\ Flow\ Rate\ is\ Q_f = 0.039\, {m^3}/{s}$$
$$The\ Design\ Flow\ Rate\ is\ Q_{d@75\%} = 0.459\, {m^3}/{s}$$

The systems water to wire efficiency can be calculated by

$$\eta = \frac{Hydro\ power\ out\ put\ power}{\text{Potential power of a hydropower}} x100$$

$$\eta = \frac{6.7KW}{12.61KW}$$

$$\eta = 53.13\%$$

4.4.2. Kaplan Runner blade design

1. The runner discharge diameter can be calculated from the following equation.

$$D = \frac{85.4\ x\ \emptyset\ x\ \sqrt{H}}{n},$$
$$where\ \ \emptyset = \ periphery\ coefficient = 0.0242\ x\ \ {N_s}^{2/3}$$
$$\emptyset = 1.555$$
$$D = \frac{85.4\ x\ \emptyset\ x\ \sqrt{H}}{n} = 0.39\ m$$

2. Based on the specific speed, the number of blade and the ratio of hub and outer diameter of Kaplan turbine can be read from figure 4-4 [30].

- The ratio of hub and outer diameter is d/D =0.465
- The number of blades from the figure 4-4 is 5.
- Hub diameter can be calculated from d/D ratio

$$\frac{D_d}{D} = 0.465\,,$$

$$D_d = 0.179m$$

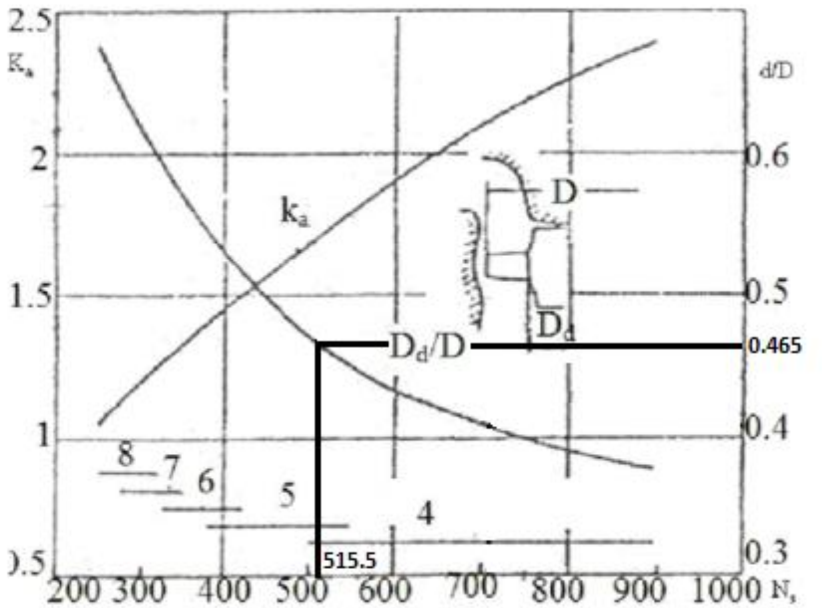


Figure 4-4 Inlet and Outlet Velocity Triangle of Kaplan Turbine [18]

3. Flow velocity can be calculated from the flow rate of the water

$$Discharge \quad Q = A\,x\,V_{f1}$$

$$Flow\ velocity\ V_{f1} = \frac{Q}{A},\ \ where \quad A = \frac{\pi}{4}(D_{run}^2 - d_{hub}^2) = 0.095m^2$$

$$V_{f1} = \frac{Q}{A} = 5.14\,{}^{m}/{}_{s}$$

4. Guide vane

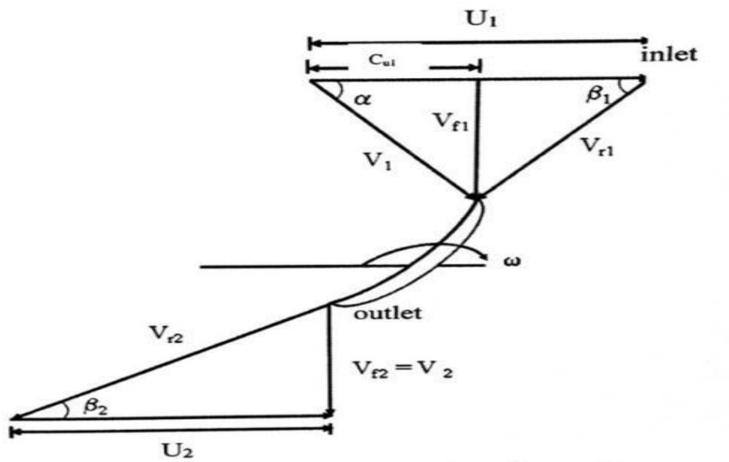


Figure 4-5 Relationship between Speed Ratio and specific speed [30]

- The runner tangential velocity (Peripheral velocity at inlet and outlet are equal) (U)

$$U = \frac{\pi D n}{60} = 11.63\, {}^{m}/_{s}$$

- Inlet whirl velocity ($V_{\omega 1}$)

$$V_{\omega 1} = \frac{\eta_h . g . h}{U} = 2.2\, {}^{m}/_{s}$$

- Guide vane angle (α)

$$\alpha = tan^{-1}\frac{V_{f1}}{V_{\omega 1}} = 67°$$

- The diameter of guide vane can be calculated (D_v)

$$D_v = 1.5D = 0.587m$$

- The number of guide blade (Z) can be evaluated as follow

$$Z = \frac{1}{4}\sqrt{D} + 5 = 5.15 \approx 5$$

- The length of the guide blade (l)

$$l = \frac{1.5D - D}{2sin\alpha} = 0.09m$$

5. Design of turbine scroll case

The scroll case is used to evenly distribute water around the turbine, allowing it to operate smoothly and with high system reliability [31].

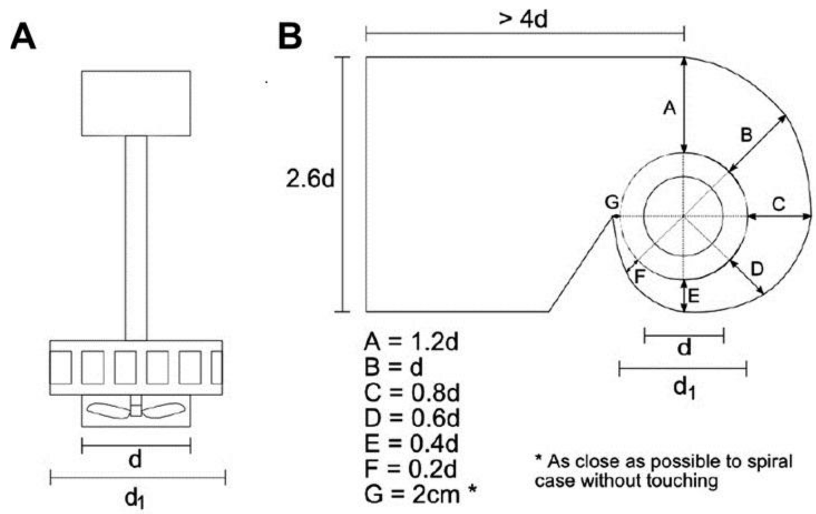


Figure 4-6 Spiral casing shape [31]

d= runner diameter=0.39m

A = 1.2d = 0.586x1.2 = 0.47

B = d = 0.39

C =0.8d = 0.586x0.8 = 0.31

D =0.6d = 0.6x0.586 = 0.235

E =0.4d = 0.4x0.586= 0.156

F =0.2d = 0.2x0.38 = 0.078

G = 0.035m

2.6d = 2.6x0.37 =1.02

>4d = 4x0.37 = 1.55

4.4.3. Draft Tube

A draft tube is essentially a tube with a steadily expanding area that connects the turbine runner's output to the tail race, where the water is going to be expelled from the turbine. As a result, water will be discharged to the tail race from the turbine's outlet via a draft tube. A draft tube's main purpose is to essentially provide a channel for the water discharge from the turbine. Draft tubes will slow the speed of released water, which will decrease the amount of kinetic energy lost at the exit. A draft tube can help by producing a negative head at the runner's exit, in order to assist in raising the net head on the turbine. With a draft tube, a turbine may be positioned above the tail race without any net head loss [32].

The following draft tube types are typically utilized in turbine operation:

1. Conical draft tubes
2. Simple elbow draft tubes
3. Moody spreading draft tubes
4. Elbow draft tubes with circular inlet and rectangular outlet

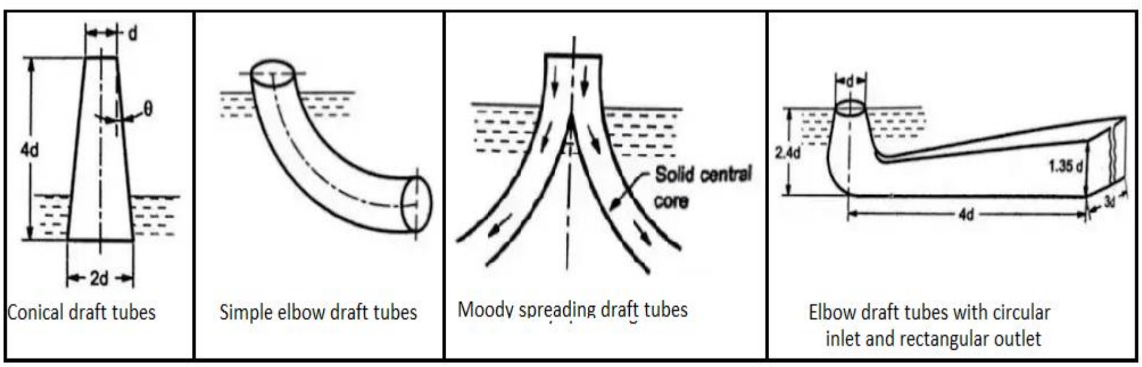


Figure 4-7 Different types of draft tube [32]

Circular inlets and outlets will be featured on a conical draft tube. It can be viewed as a conventional taper tube. Taper angles range from 4 to 7 degrees, as seen in the figure 4-7. Mild steel plates will be used to create the conical draft tube. Conical draft tubes will have up to 90% efficiency [32].

From the draft tube's inlet to its exit, simple elbow draft tubes will have a circular cross-section. Simple draft tubes, as their name implies, are simply tubes with uniform cross sections that have been twisted 90 degrees. To decrease the impact of cavitation, a simple elbow draft tube built of concrete with a steel liner at its intake will be constructed. Simple elbow draft tubes will operate at up to 60% efficiency.

Moody spreading draft tubes are used with vertical shaft turbines and are nearly equivalent to conical draft tubes. Moody spreading draft tubes will operate at up to 85% efficiency. To minimize spinning, a Moody spreading draft tube will have a solid central core at the center, as seen in the figure 4-7.

As implied by the name, elbow draft tubes will have a circular inlet and a rectangular exit, as seen in figure 4-7. In order to lessen the impact of cavitation, concrete elbow draft tubes with a circular inlet and a rectangular output will be constructed. The efficiency of these draft tubes will range from 60% to 80%. Conical draft tubes and Moody spreading draft tubes are the most effective of draft tubes.

The above-mentioned draft tube types with the highest efficiency are conical and Moody spreading. For this research, conical draft tubes have been selected. Conical draft tube is easy and simple to manufacture and efficient than moody spreading draft tube. The design for the conical draft tube type is based on the turbine runner diameter.

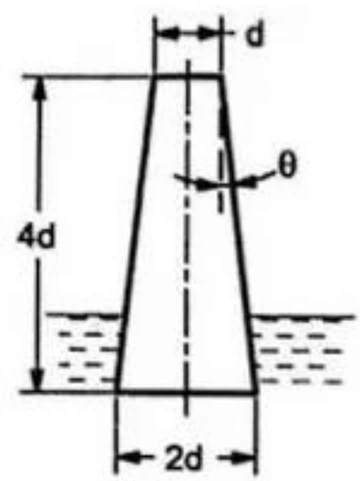


Figure 4-8 Conical draft tube [32]

Form the above figure

D = 0.39m

2D = 0.78

4D = 1.56

θ = 7°

4.5. Generator selection

The hydraulic turbine's mechanical energy is converted into electrical energy by means of a generator. Asynchronous or synchronous generators are the two primary types of generators used in the hydropower sector. In large-scale energy generation, synchronous generators are the primary generator types used. Asynchronous generators are also favored in the manufacture of generators because they can run at a variety of speeds while maintaining a consistent frequency, are less expensive, and need less maintenance than synchronous generators. As a source of isolated power, the proposed asynchronous generator provides a number of benefits over the conventional synchronous generator. The major benefits of asynchronous generators are a decrease in prices per unit, durability, reduced size, absence of a separate DC power supply, ease of maintenance, and self-protection against extreme overloads and short circuits. The mass and cost advantages of asynchronous machines are most noticeable in the power range of a few kW to 100 kW [33].

The main parameter for Generator selection the output power, turbine speed and the generator type. For this thesis the power produced by the Kaplan turbine is 7.41Kw, turbine speed is 568.3 and based on the above discussion, for micro hydro power less than 100KW asynchronous generator is applicable. The speed difference can be managed in generator to turbine connection method. From Appendix-B Table 0-9 From the generator ANR132S4 is selected based on the power output of the turbine. The specifications are mentioned below.

Power: -	7.5 KW
Voltage: -	3Phase 380V
Frequency: -	50Hz
Speed: -	1500rpm
Water resistant: -	IP54

Figure 4-9 Selected 7.5 Kw Generator

4.6. Generator turbine connection

In this section Generator to turbine connection method is selected and designed. There are different mechanism used to connect two rotating components (one driving one driven). Since the generator and the turbine have different speed, it cannot connect using coupling method. A mechanical drive is a device that transmits mechanical power across a predetermined distance, typically requiring a change in speed and torque. Depending on how they function, mechanical drives are divided into two classes. Mechanical drives include those that convey power by friction, such as belt and rope drives, as well as those that transmit power through engagement, such as chain and gear drives.

A chain drive consists of two sprockets and a never-ending chain. Both long and short center distances can be employed with chain drives. Shaft alignment needs to be exact for chain drives. Chain drives need slack correction, such as a tensioning tool. Chain drives need more maintenance, especially lubrication than belt drives do. Chain drives produce sound.

Gears are toothed wheels that transmit power and motion from one shaft to another by engaging their teeth one after the other. Drives using gears have a very high efficiency. Compact construction is achieved by the very close center distance between the shafts. However, gear drives are expensive, and they also cost more to maintain. Gear production is a highly specialized and complex operation. Gear drives need to be lubricated and kept clean with great care. They also need the shafts to be precisely aligned.

Belts are used to transmit power between two shafts by means of friction. Three components make up a belt drive: driving and driven pulleys, as well as an endless belt that surrounds them. Between the axes of the driving and driven shafts, belt drives have the ability to convey power across a significant distance. Belt drives operate quietly and smoothly. They have the capacity to dampen vibration and absorb shocks. They are easily designed. Their initial cost is low. Belts are divided into flat belts and V-belts based on the shape of the cross-section. V-belt have trapezoidal shape, whereas flat belt has narrow rectangular cross-section. The power transmitting capacity of flat-belt drive is low. Flat-belt drives have large dimensions and occupy more space compared to V-belt drives. Flat belts generate more noise than V-belts.

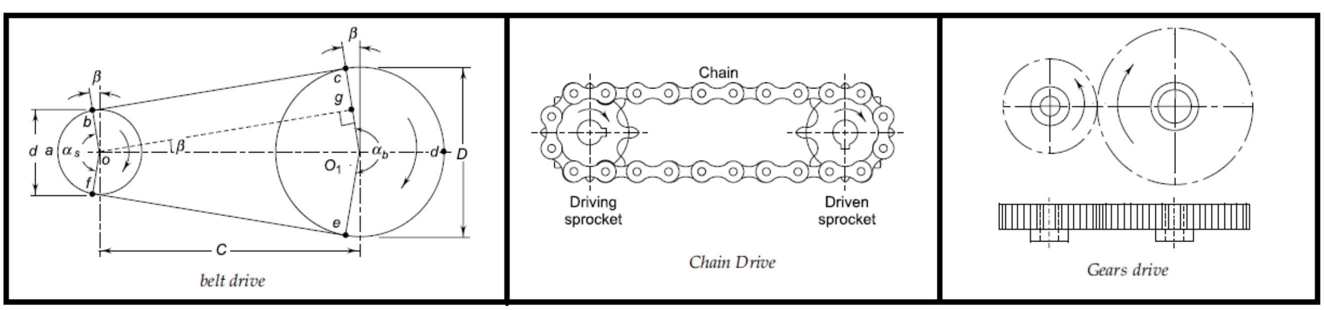


Figure 4-10 Different types of drive [34]

V-belt systems are applied in this thesis because of their benefits over other belts and pulley drives. The main benefits of the belt include silent operation, smoothness, dependability, flexibility, affordability, minimal lubricant requirement, ease of assembly and disassembly, and the ability to use multiple belts simultaneously.

4.6.1. Design of V-Belt.

Transmitted power= 7.5 Kw

The first step is to determine the correction factor according to service it depends on service type and operating hour. From Appendix-B table 0-1 service type medium duty, type of driven machine is generator and operating hour 16 to 24hr the correction factor (Fa)is 1.3.

$$F_a = 1.3$$

Based on the correction factor according to service calculate the design power.

$$P_D = PxF_a$$

Where $P_D = Design\ power,\ \ P = Transmitted\ power,\ \ \ F_a = Correction\ factor$

$$P_D = 9.75Kw$$

Determine the cross section of the belt based on the design power and higher speed in rpm from Appendix-B figure 0-2. The higher speed was the generator speed with 1500r.p.m and the design power where 9.75 KW B belt section is selected.

On Appendix-B table 0-3 the recommended minimum pitch diameter of the pulley for B belt section is 200mm. The smaller pulley diameter placed on the generator shaft.

$$D_1 = 200\ mm$$

To calculate the bigger diameter of the pulley speed ratio relation is needed.

Turbine speed (Driver) =568.3r.p.m

Generator speed (Driven)=1500r.p.m

$$\frac{N_1}{N_2} = \frac{D_1}{D_2}$$

Where $N_1 = speed\ of\ generator\ \ \ D_1 = Pulley\ Diameter\ of\ generator$

$N_2 = speed\ of\ turbine\ \ \ D_2 = Pulley\ Diameter\ of\ turbine$

The diameter of the turbine becomes after inserting the speed and generator pulley diameter

$$D_2 = 527.9mm$$

The standard value for B section belt form Appendix-B table 0-4 that is next to 517.42mm is

$$D_2 = 530\ mm$$

Calculate the pitch length of the belt required Lp: -

$$L_p = 2C + \frac{\pi}{2}(D_1+D_2) + \frac{(D_2-D_1)^2}{4C}$$

C is the center distance between the generator and turbine shaft. The minimum center distance will be

$$C \geq \frac{D_1+D_2}{2} \qquad C \geq \ 365mm$$

The center distance must be greater than 365mm, for this case let's take C= 1 meter to give enough space between the generator and turbine.

$$L_p = 2x1 + \frac{\pi}{2}(0.2 + 0.5) + \frac{(0.53 - 0.2)^2}{4x1}$$

$$L_p = 3.1733m, \quad 3173.3mm$$

The standard value for B section belt form Appendix-B table 0-5 that is next to 3173.3mm is

$$L_p = \ 3200mm$$

Changing the pitch length than it requires variation occurs and to accommodate this variation correction factor is needed the correction factor form Appendix-B table 0-6 belt pitch length correction factor Fc

$$F_c = 1.08$$

Calculating the corrected center distance by considering the standard pitch length selected

$$3.2 = 2C + \frac{\pi}{2}(0.2 + 0.5) + \frac{(0.53 - 0.2)^2}{4C}$$

$$C = 1.013m$$

Calculating the angular contact for smaller pulley

$$\theta_s = 180^o - 2sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$$

$$\theta_s = 180^o - 2sin^{-1}\left(\frac{530 - 200}{2x1013}\right)$$

$$\theta_s = 170.625^o$$

The standard angle is 180° for power rating is to accommodate this variation arc contact factor is used. Form Appendix-B table 0-7 the arc contact factor Fd

$$F_d = 0.97$$

The power rating (Pr) of single B section V-Belt in Kw from Appendix-B table 0-8 is

$$P_r = 5.23Kw$$

The number of belts can be calculated from the following formula

$$Number\ of\ belt = \frac{P\ x\ F_a}{P_r\ x\ F_c\ x\ F_d}$$

$$Number\ of\ belt = \frac{7.5\ x\ 1.3}{5.23\ x\ 1.08\ x\ 0.97} = 1.78\ \approx 2$$

Form the above calculation the number of belts to drive the generator is 2.

Finally, the V-belt specification from the calculation is

Type: - B section V-belt

Diameter of the generator pulley is 200mm

Diameter of the turbine pulley is 530mm

Center distance is 1013mm

Pitch length of the belt is 3200mm

Belt specification is B 3200 Lp.

CHAPTER FIVE

5. RETSCREEN ANALYSIS AND MATLAB SIMULINK SIMULATION

In this section modeling and simulation of a micro hydropower system using RETScreen Clean Energy Management and Mathlab Simulink softwires.

5.1. RETScreen Expert Analysis

RETScreen Clean Energy Management software is a software package developed and launched by the government of Canada in 2016. The software enables the comprehensive identification, evaluation, and optimization of the technical and financial viability of potential renewable energy, energy efficiency, and cogeneration projects as well as the measurement and verification of facilities' actual performance, the identification of opportunities for energy production and savings, and portfolio management of numerous facilities. RETScreen software is engineering software used in renewable energy sources like solar PV, wind, and hydropower. For this case, it is uses for micro-hydropower System.

5.1.1. RETScreen Energy Analysis

In this section the system's flow duration, efficiency, and power curves will be analyzed.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	15.9	63.0%	25.94	5.48	79.4	3.1	22.4	65	183
February	16.4	66.0%	18.34	5.47	79.3	2.6	24.4	45	179
March	17.9	66.0%	64.48	5.64	79.3	3.1	25.6	3	245
April	17.6	71.0%	67.58	5.27	79.3	3.6	24.1	12	228
May	17.8	67.0%	77.43	5.17	79.3	3.1	21.8	6	242
June	16.6	74.0%	127.04	4.47	79.4	2.6	18.6	42	198
July	15.0	83.0%	251.27	3.77	79.4	2.1	16.9	93	155
August	15.0	85.0%	189.83	3.73	79.4	2.1	16.8	93	155
September	15.6	79.0%	83.01	4.50	79.4	2.6	17.3	72	168
October	15.8	69.0%	40.23	5.47	79.4	3.6	17.8	68	180
November	15.2	66.0%	18.19	5.65	79.4	4.1	19.3	84	156
December	15.6	69.0%	10.25	5.27	79.4	3.6	20.5	74	174
Annual	**16.2**	**71.5%**	**973.59**	**4.99**	**79.4**	**3.0**	**20.4**	**658**	**2,262**
Source	Ground	Ground	NASA	Ground	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

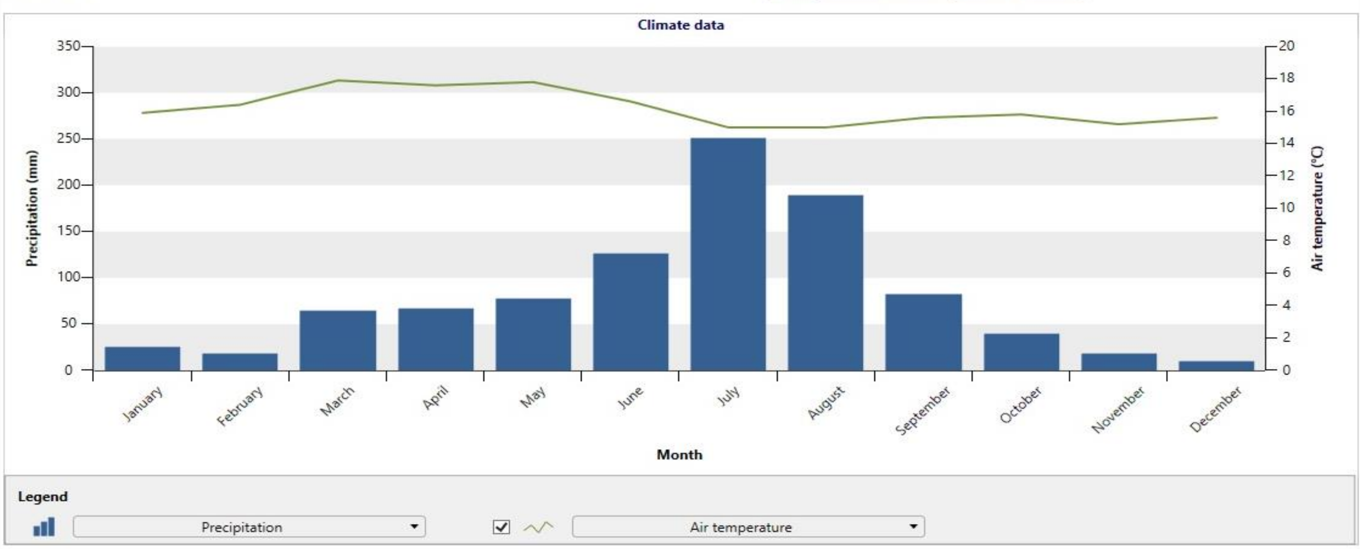


Figure 5-1 Metrological data for the Akaki river area

After entering the site's coordinates (8.87°N latitude and 38.78oE longitude), the NASA satellite collected the site metrological data, which is shown in figure 5-1.

The annual energy output for a micro-hydropower system is based on regional site circumstances and system characteristics using the energy model. In this case study, the residual flow—the smallest flow that is left over as a result of environmental circumstances like drinking water and evaporation problems is considered to be 0.01 m3/s.

Performing energy analysis and putting the information into RETScreen's energy analyzer at level 2 analysis to obtain the capacity factor, flow and power duration curves, and turbine efficiency curves.

Table 5-1 RETScreen Energy model data

Hydro turbine	
Description	Hydro turbine - 7kW (75%)
Note	

Level	
Level 1	Level 2

Hydro turbine - Level 2		
Resource assessment		
Proposed project		Run-of-river
Hydrology method		User-defined
Gross head	m	2.8
Maximum tailwater effect	m	0.196
Residual flow	m^3/s	0
Percent time firm flow available	%	100%
Firm flow	m^3/s	0.04
Hydro turbine		
Design flow	m^3/s	0.459
Type		Kaplan
Turbine efficiency		Standard
Number of turbines		1
Manufacturer		Global Hydro Energy
Model		Kaplan Turbine
Design coefficient		4.5
Efficiency adjustment	%	0.35%
Turbine peak efficiency	%	68.3%
Flow at peak efficiency	m^3/s	0.34
Turbine efficiency at design flow	%	68.3%

The data for the turbine efficiency curve is presented in table format and shows the total efficiency of the chosen number of turbines throughout the whole flow range (from 0 to 100% of the design flow). The data for the turbine efficiency curve is input based on the percentage of the design flow.

Table 5-2 RETScreen Flow duration and turbine efficiency

Flow-duration and turbine efficiency curve data

%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	61.76	0.00	0	0.00
5%	52.61	0.00	1	0.00
10%	43.47	0.00	1	0.00
15%	34.33	0.06	1	0.06
20%	30.27	0.31	1	0.31
25%	28.75	0.47	1	0.47
30%	13.47	0.57	1	0.57
35%	3.01	0.63	1	0.63
40%	2.40	0.66	1	0.66
45%	2.14	0.67	1	0.67
50%	2.08	0.68	1	0.68
55%	1.85	0.68	1	0.68
60%	1.57	0.68	1	0.68
65%	1.17	0.68	1	0.68
70%	0.81	0.68	1	0.68
75%	0.46	0.68	1	0.68
80%	0.34	0.68	1	0.68
85%	0.22	0.68	1	0.68
90%	0.09	0.68	1	0.68
95%	0.04	0.68	1	0.68
100%	0.04	0.68	1	0.68

The turbine efficiency graph displays the total efficiency of the chosen number of turbines for the entire flow range (from 0 and 100% of the design flow).

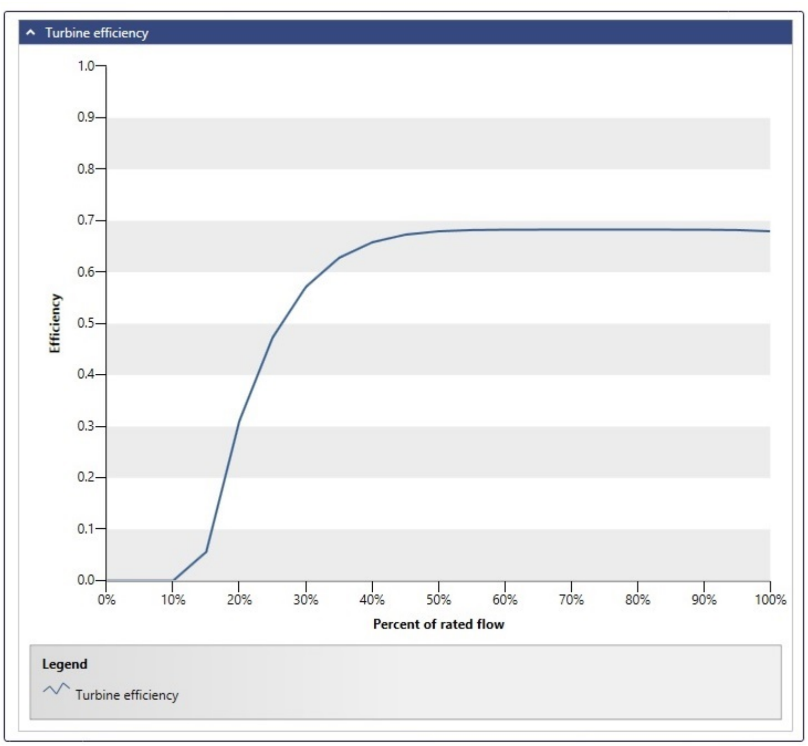


Figure 5-2 RETScreen turbine efficiency curve

The following list shown in Table 5-5 includes losses estimation by RETScreen and the summary of energy model results.

Table 5-3 Losses and result of energy model

Losses		
Maximum hydraulic losses	%	7%
Miscellaneous losses	%	12%
Generator efficiency	%	95%
Availability	%	100%
Summary		
Power capacity	kW	6.7
Available flow adjustment factor		1
Capacity factor	%	83.4%
Electricity export rate		Electricity exported to grid - annual
	$/kWh	0.23
Electricity exported to grid	MWh	48.7
Electricity export revenue	$	11,192

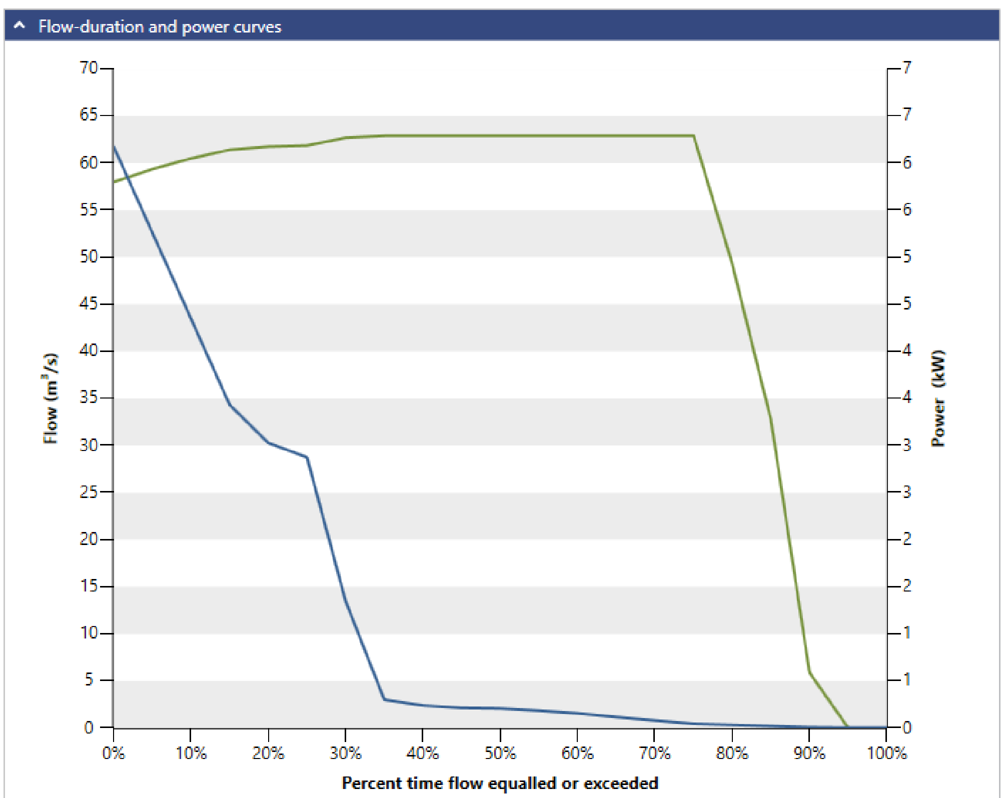


Figure 5-3 RETScreen Flow and Power Duration Curve

Figure 5-3 shows the outcome, the flow and power duration curves. The power curve shows certain increments, constant, and decrement values as a result of the flow rate and the tailwater effect. 6.7 Kw is the capacity power's output result. Hydropower plant capacity factors typically vary from 40 to 95%. The computed capacity factor in this particular case is 83.4%, falling between 40 and 95%.

5.1.2. RETScreen Cost Analysis

RETScreen software's has three levels of cost analysis. Each have its own level of analysis in the first level it is the lower level with low data is feed. The second and specially the third level is more detailed cost estimations are detail data is feed in the parameters like initial cost annual cost, annual saving and periodic costs in the cost analysis sheet by estimated quantity and unit cost. There is other method of cost analysis on the third level offered by RETScreen is "hydro formula costing method". The Hydro formula costing method tool estimates small hydro project costs using formulae derived from the costs of numerous completed small hydro projects. The results are automatically transferred to the cost analysis worksheet. Since the research is in Ethiopia and the software is developed in Canada the following relationship is used.

In this thesis, the cost of building equipment in Ethiopia is equal to 1.2 times the cost in Canada. To calculate the ratios, costs must be expressed in the same currency. By adjusting the predicted prices for the local components of the task, the model uses this value to estimate the cost of projects outside of Canada.

In this study, the fuel price in Ethiopia is equal to 1 as compared to Canadian costs (this figure is entered as the decimal ratio to the price in Canada). Note that while computing the ratios, costs must be expressed in the same currency. By adjusting the calculated prices for the local components of the task, this number is employed in the model to estimate the cost of projects outside of Canada.

In this study, the wage differential between Ethiopia and Canada costs is equal to 0.5 (this figure is entered as the decimal ratio in relation to Canadian wage). The ratios must be calculated using costs that are expressed in the same currency. In the model, this variable is used to adjust the calculated costs for the local components of the job in order to estimate the costs of projects outside of Canada.

In this research the adjustment factor to allow for the relative cost of manufacturing the equipment in Ethiopia as compared to in Canada is 1.1 (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).

In this research the exchange rate to convert the calculated Canadian dollar costs into dollar 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, 0.741 $/CAD.

Due to the greater difficulty of building (i.e. due to higher transportation expenses, a shorter construction season, a higher cost of equipment, material, and labor, etc.), projects located in cold regions will cost more. For the purposes of RETScreen, a site is considered to be in a cold climate if, on average, it is located in a region with at least 180 days of frost (freezing temperatures) annually. The project's location is not in a region with a harsh environment.

In hydro formula costing method, the design flow rate 0.459m^3/s which can be used by the Kaplan turbine and the gross head 2.8m is filled in the data sheet. 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.

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%. In this research the system has low head, the hydraulic loss is 7%.

In this research 12% miscellaneous loss is assumed. 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.

In this section 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. Since the project is near the main rode the estimated length of road is around 0.5km. 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. For this project flat, gently undulating terrain no rock outcrops are selected.

In this section whether or not cannel is required for the small hydro project. For this project cannel is included with the assume 150-meter cannel made of rock is feed in the RETScren data sheet.

This section covers whether or not a penstock is necessary for the small hydro project. The user specifies the expected length of the required penstock(s), the number of identical parallel penstocks that will be necessary as part of the small hydro project, and the permitted penstock head loss factor for projects that involve one or more parallel penstocks. The cost of the project's penstock component is determined using these numbers. For this research paper the penstock length is 12.7m length. It is the ratio of the available gross head to the permissible head loss in the penstock(s), represented as a percentage. Values typically fall between 1 and 4%. The chosen head loss for this project is 4%.

In this section the type of grid that the transmission line will connect to, the projected distance, the complexity of the terrain over which the transmission line will be built, and the voltage (kV) of the transmission line that will be required to connect the site with the nearest currently-existing transmission line of acceptable voltage and capacity. In this research paper the power is 6.7KW and the voltage is 0.4KV for this substation is not needed.

The research tunnel is required for the small hydro project and Another assumption is that any tunnel required to carry out a micro-hydro project would make it unprofitable.

As shown in Table 5 1 below, the total initial cost of the MICRO HYDROPOWER system is $ 275,000.

Table 5-4 RETScreen Cost Analysis

Initial costs (credits)		Amount	Adjustment factor		Amount	Relative costs
Feasibility study	$	9,000	1	$	9,000	3.3%
Development	$	10,000	1	$	10,000	3.6%
Engineering	$	25,000	1	$	25,000	9.1%
Power system						
Hydro turbine	$	169,000	1	$	169,000	61.5%
Road construction	$	2,000	1	$	2,000	0.73%
Transmission line	$	0	1	$	0	0%
Substation	$	0	1	$	0	0%
Balance of system & miscellaneous						
Penstock	$	9,000	1	$	9,000	3.3%
Canal	$	8,000	1	$	8,000	2.9%
Other	$	43,000	1	$	43,000	15.6%
Subtotal:	$	60,000		$	60,000	
Total initial costs	**$**	**275,000**		**$**	**275,000**	**100%**

5.1.3. RETScreen Emission Analysis

As part of the RETScreen Clean Energy Management Software, an Emission Analysis worksheet is provided to help the user estimate the greenhouse gas emission reduction (mitigation) potential of the proposed facility. There are 3 level of analysis under the emission analysis. For level 1, this emission reduction analysis worksheet contains three main sections: Base case electricity system (Baseline), GHG emission and GHG reduction revenue. For levels 2 and 3, it contains five main sections: Base case electricity system (Baseline), Base case system GHG summary (Baseline), Proposed case system GHG summary (Plan), GHG emission reduction summary and GHG reduction revenue. The Base case electricity system and Base case system GHG summary sections provide a description of the emission profile of the baseline system. The Proposed case system GHG summary section provides a description of the emission profile of the proposed facility. Based on the information entered by the user in the sections before, the GHG emission reduction summary section provides an overview of the estimated GHG emission reduction. Results are determined in terms of averted equivalent tons of CO2 annually. The result form the software is shown in the figure 5-4.

22.3 tCo2 is equivalent to 4.1 Cars & light trucks not used

22.3 tCo2 is equivalent to 9570.5 Liters of gasoline not consumed

22.3 tCo2 is equivalent to 51.8 Barrels of crude oil not consumed

22.3 tCo2 is equivalent to 7.7 Tons of waste recycled

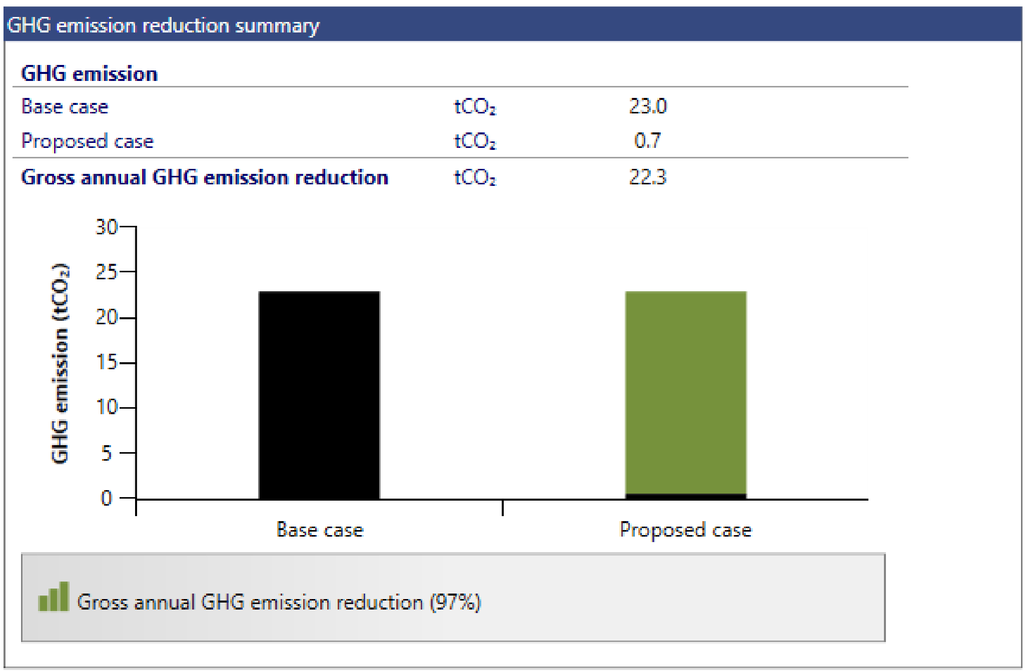


Figure 5-4 RETScreen Emission Analysis

5.1.4. RETScreen Financial Analysis

One of the primary benefits of using the RETScreen software is that it facilitates the project evaluation process for decision-makers. Using level 2 analysis the financial analysis worksheet, with its financial parameters input items like inflection rate, discount rate, debt ratio, project life time, debit ratio, and debit term its calculated financial viability output items like IRR, simple payback, NPV, payback period allows the project decision-maker to consider various financial parameters with relative ease.

Table 5-5 RETScreen Financial Analysis

Financial viability		
Pre-tax IRR - equity	%	10%
Pre-tax IRR - assets	%	5.6%
Simple payback	yr	246
Equity payback	yr	15.7
Net Present Value (NPV)	$	30,779
Annual life cycle savings	$/yr	3,372
Benefit-Cost (B-C) ratio		1.4
Debt service coverage		0.05
GHG reduction cost	$\$/tCO_2$	-151
Energy production cost	$/kWh	0.582

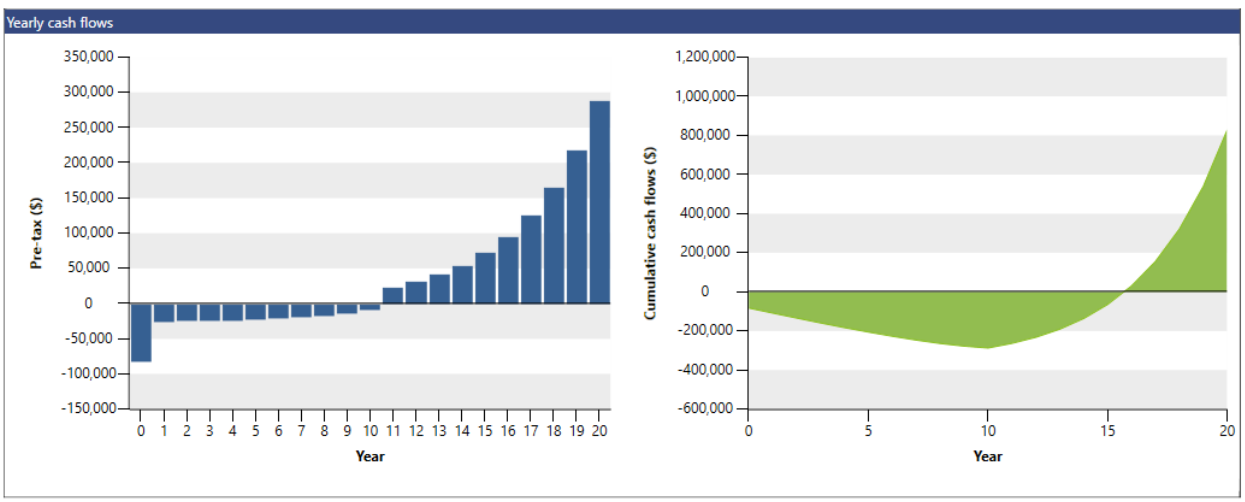


Figure 5-5 RETScreen Financial Analysis for pre-tax and cumulative cash flow.

As seen in the above Figure 5-5 the net pre-tax cash flows, which are the yearly net flows of cash for the project before income tax. It represents the estimated sum of cash that would be paid or received each year during the entire life of the project. The model calculates the cumulative cash flows, which represent the net after-tax flows accumulated from year 0. Form table 6.1 RETScreen financial analysis the payback period is 15.6 years; the net present value is $ 30,779 and the annual lifesaving is $ 3,372.

5.1.5. RETScreen Risk Analysis

In order to assess the impact of the uncertainty on the pre-tax equity IRR, pre-tax IRR of assets, after-tax equity IRR, after-tax IRR of assets, equity payback, Net Present Value (NPV), or energy production cost, the risk analysis must specify the uncertainty associated with a number of key input parameters.

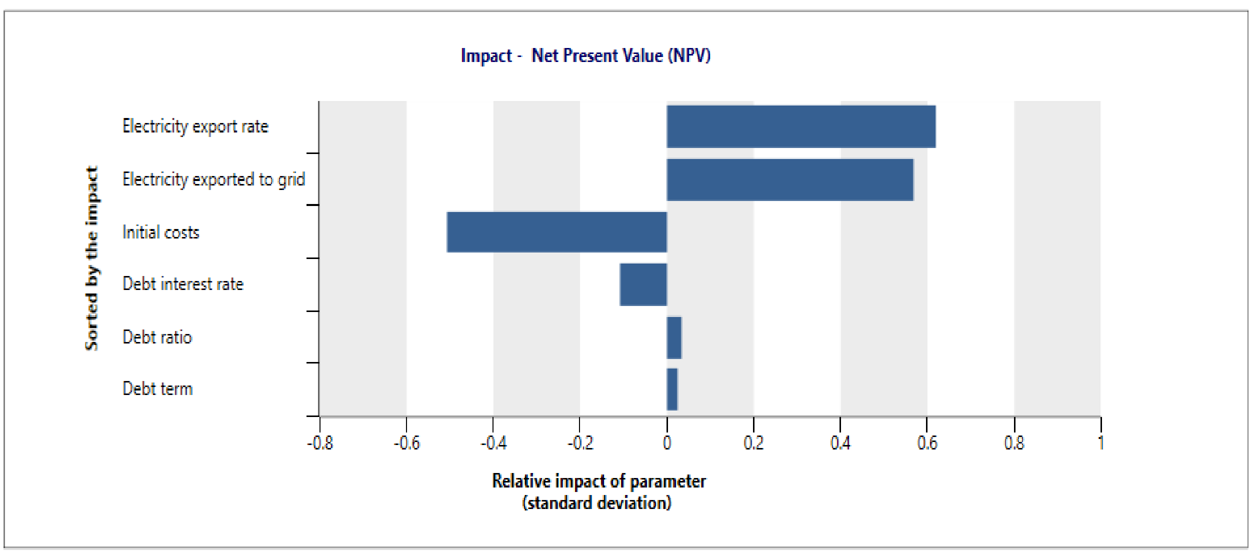
Table 5-6 RETScreen Risk Analysis

Risk analysis

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

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	275,000	25%	206,250	343,750
Electricity exported to grid	MWh	48.66	25%	36.50	60.83
Electricity export rate	$/MWh	23.00	25%	17.25	28.75
Debt ratio	%	70.0%	25%	52.5%	87.5%
Debt interest rate	%	7.00%	25%	5.25%	8.75%
Debt term	yr	10	25%	8	13

Figure 5-6 Impact graph of the risk analysis result



5.2. MATLAB Simulink Analysis

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Simulink is a block diagram environment for model-based design and multidomain simulation. It provides continuous testing and verification of embedded systems, simulation, automatic code creation, and system-level design. For modeling and simulating dynamic systems, Simulink offers a graphical editor, configurable block libraries, and solvers. Because of its integration with MATLAB®, you may export simulation results for additional analysis and include MATLAB algorithms into models.

Modeling and simulation analysis using MATLAB SIMULINK software are presented in this section. At the conclusion of the study, simulation results are also displayed along with explanations of the yearly flow rate, flow through the penstock, mechanical output from the turbine, turbine speed and mechanical output from the hydropower, for each of the 12 months of the year. In the last, in appendix-C, is the MATLAB code and MATLAB SIMULINK model on appendix-D.

5.2.1. Yearly Flow Rate

The average yearly flow rate data (m3/s) for the Big Akaki river are shown in this part on separate sheets, each of which is labeled with the name of a month and an excel file listing the daily flow rate data beneath it. MATLAB code is used to import the flow rate data into the MATLAB workspace. Figure 5.7 shows MATLAB SIULINK to display the average annual flow rate data separated by each month with the vertical axis representing the flow rate and the horizontal axis representing the number of days.

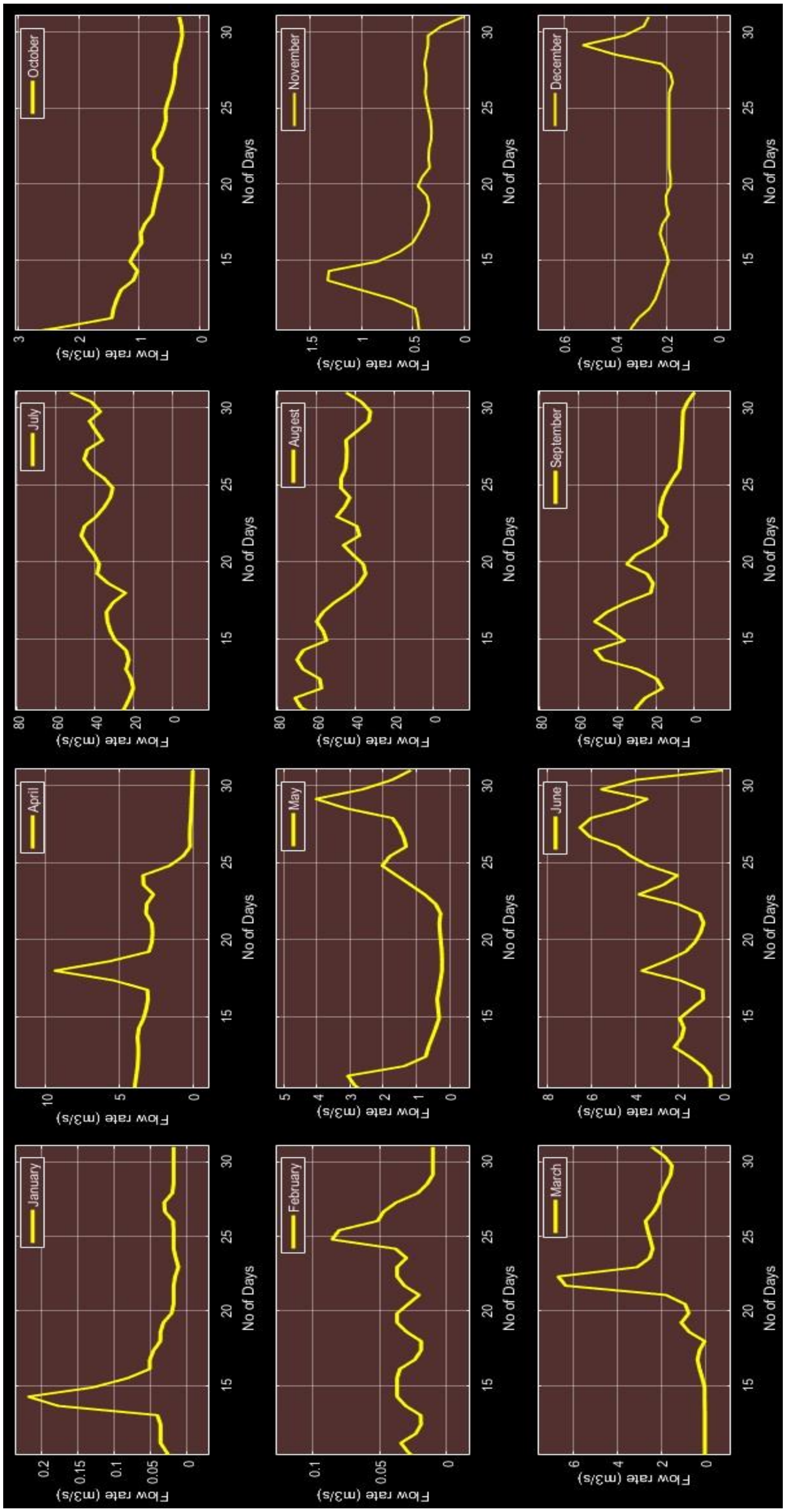


Figure 5-7 Flow rate data (m3/s) for each month

5.2.2. Flow through the penstock

This section analyzes the flow rate inside the penstock. Inside the penstock, the flow rate should be less than or equal to 0.459m3/s, which is the design flow rate for this study research paper. To achieve this, the flow rate that are greater than 0.459 m3/s will come to 0.459 m3/s using MATLAB code. On figure 5.8, the output of MATLAB SIMULINK for the 12-month average yearly flow rate data split by each month is displayed.

The straight line shows the flow rate is 0.459m3/s and other up and down shows the flow rate below 0.459m3/s.

5.2.3. Mechanical output for the turbine

In this section, MATLAB SIMULIK was used to examine the mechanical power from the turbine. The Kaplan turbine has a 7.41KW mechanical output power. Figure 5.9 shows twelve month the mechanical power produced by the turbine with the number of days on the horizontal axis and power value on vertical axes.

5.2.4. Turbine speed

In this section, MATLAB SIMULIK was used to examine the turbine speed of the Kaplan turbine. The Kaplan turbine's speed is affected by the river's flow rate. The turbine speed is going to decrease as the site's flow rate increases. Figure 5.10 shows twelve month the turbine with the number of days on the horizontal axis and power value on vertical axes.

5.2.5. Hydro power output power

In this section, MATLAB SIMULIK was used to examine the power output from the hydro power station. The mechanical output from the hydropower is 6.7KW. Figure 5.11 shows twelve month the mechanical power produced by the turbine with the number of days on the horizontal axis and power value on vertical axes. The amount of energy produced from the hydropower's mechanical output for the months of January, February, December, 20 days of March, 7 days of November, and 5 days each of April, May, and October is less than 6KW. Because the site's flow rate is below the design flow rate on these particular days, the output power is below the necessary level.

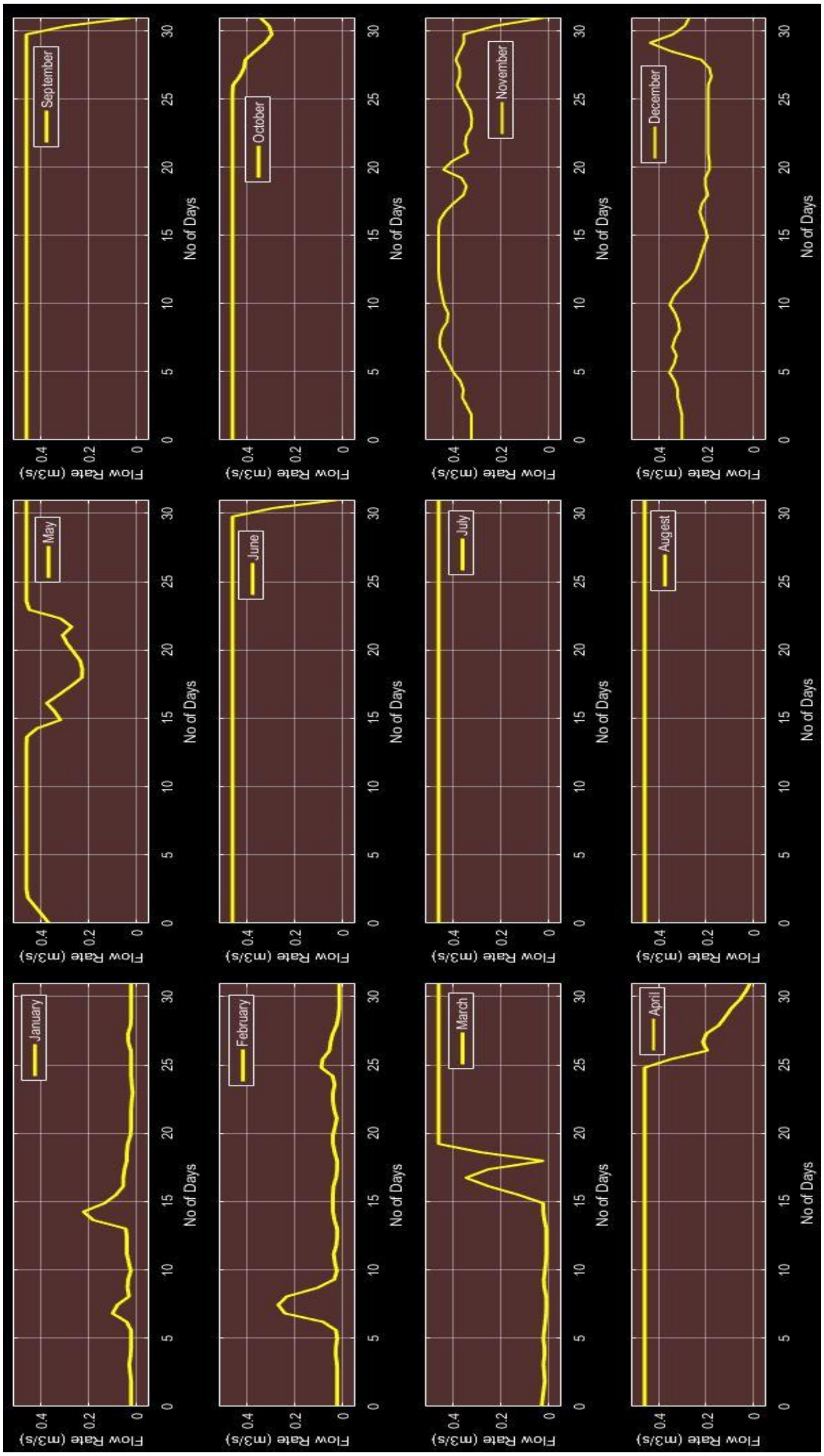


Figure 5-8 Flow rate through the penstock (m3/s) for each month

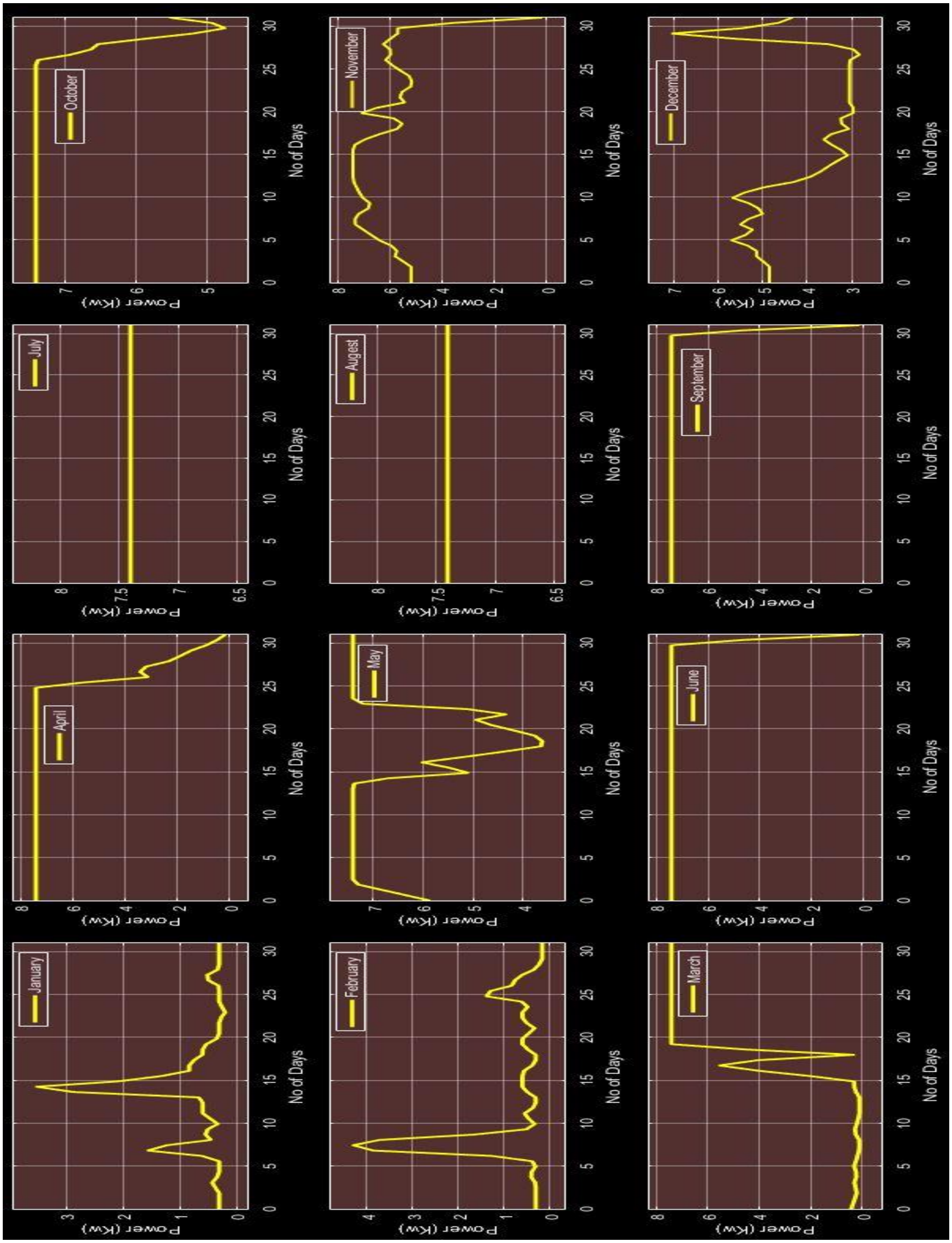


Figure 5-9 The Mechanical output from the turbine (Kw) for each month

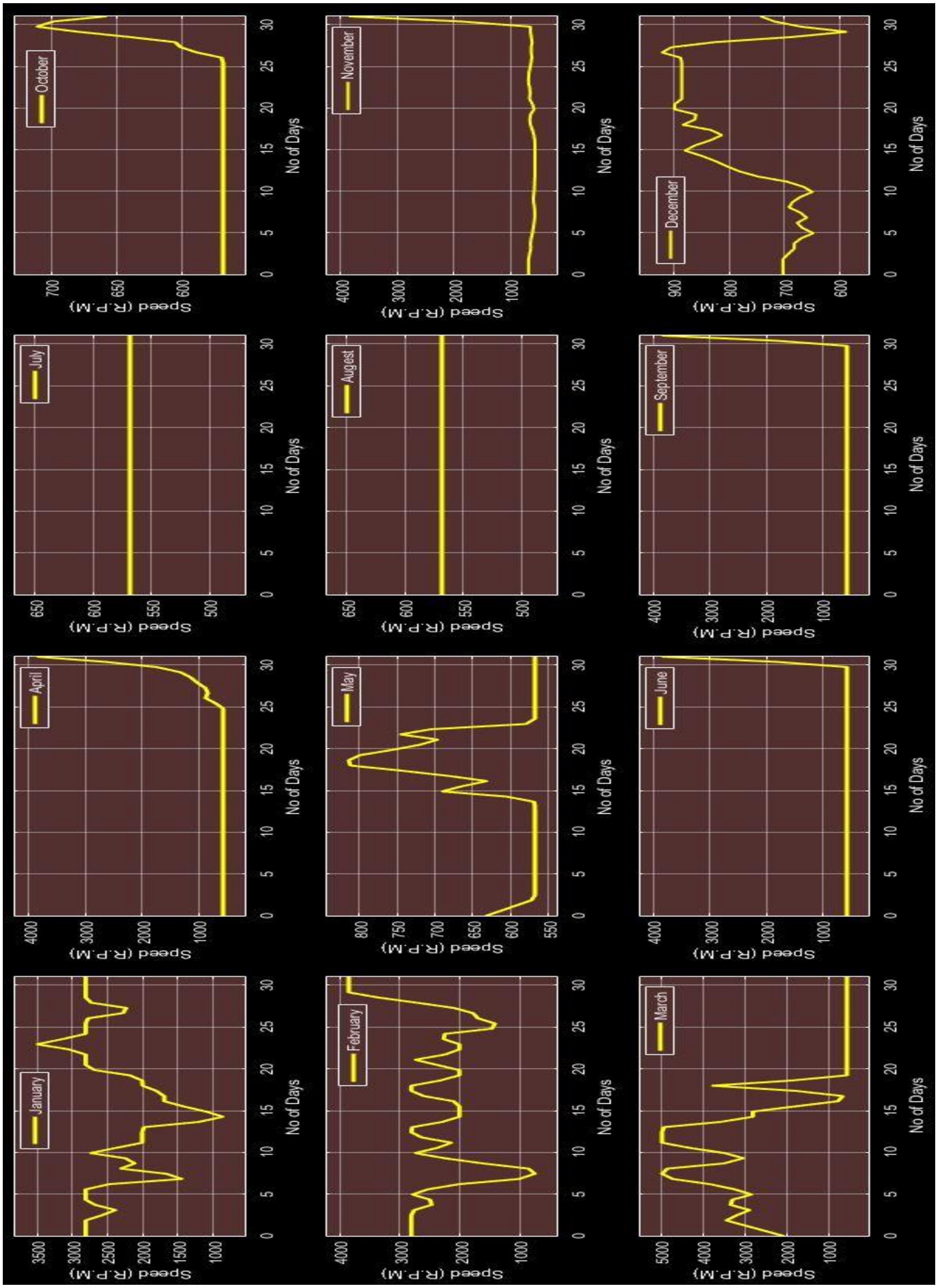


Figure 5-10 Turbine speed in RPM vs number of days for each month

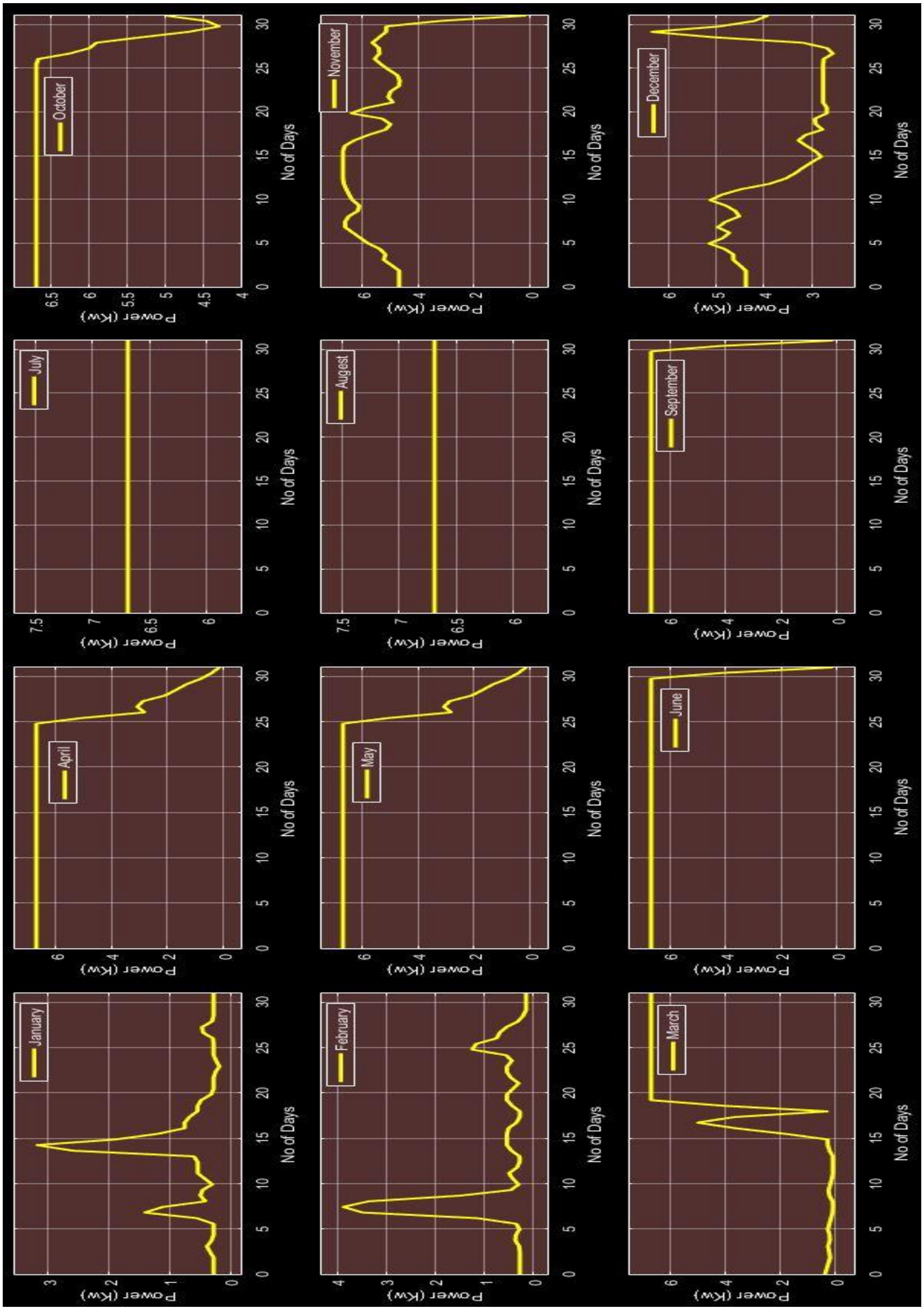


Figure 5-11 MICRO HYDROPOWER system output power

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

The overall findings of the thesis are presented in this chapter, along with a determination of whether the problem has been resolved or not, such as if the solution addresses the problem outlined in the problem statement. This part also discusses how the study will progress in the future and provided recommendations based on the study's findings.

6.1. Conclusion

In order to address issues with electrification, micro hydropower systems are a better option for green energy solutions. Designing, simulating, and assess the potential of the site and techno-economic viability of the micro hydropower system in the case of the Big Akaki River was the major goal of this study. The detailed work in this thesis includes data collection, currying out flow duration curve, selecting and designing Kaplan turbines, selecting generators, and designing the connection of the turbine and generator. The goal of this case study was to address the issue of poor street lighting in the targeted region. The yearly flow rate data, flow through the penstock, turbine mechanical output power turbine, turbine speed, and output power form hydropower station are all included in the simulation findings. From these results, we can conclude that the design and simulation result shows that with the gross head of 2.8m (2.408m net head) and 0.459m3/s design flow rate which was 75% of the time, the output power form the turbine is 7.41Kw, based on the output power form the turbine 7.5Kw generator was selected and electricity production from the micro hydropower was 6.7KW of power. As determined by the street light energy analysis, which indicates that 6Kw of electrical power is required to light the area, while 6.7Kw of electrical power is generated therefore the electrical energy generated by hydropower in this study will address the issue of insufficient street lighting.

6.2. Recommendation

In this section, some of the research's upcoming projects are included. Due to the river's potential for micro hydropower, the system will produce energy. By supplying power to the roadway and making it bright at night, the system serves the community by lowering the number of accidents. Since the system works for 75% of the time in addition to this power source, other researchers will devise a method to make up for the remaining 25% of the time, such as the solar system and the construction of a reservoir to store water. As seen in from flow through the penstock section in figure 5-8 works the system operates effectively from mid-March to October, and for November and December by building a reservoir, the reduced flow rate will be compensated. Finally, the winter months of January through mid-March have the lowest flow rates. During these months, sunshine is abundant and solar systems can be utilized.

REFERENCE

[1] A. D. Hailu and D. K. Kumsa, "Ethiopia renewable energy potentials and current state," *AIMS Energy*, vol. 9, no. 1, pp. 1–14, 2020.

[2] A. Asnake, "the Ethiopian Energy Sector-Investment Opportunities," *Uk-Ethiopia Trade Invest. Forum 2015*, p. 24, 2015.

[3] Y. A. S. Abnet Gezahegn Berhe, Dawit Benti Erena, Imam Mahmoud Hassen, Tsion Lemma Mamaru, "City profile," *Cities*, vol. 20, no. 5, pp. 361–374, 2017.

[4] H. Yohannes and E. Elias, "Contamination of Rivers and Water Reservoirs in and Around Addis Ababa City and Actions to Combat It," *Environ. Pollut. Clim. Chang.*, vol. 01, no. 02, 2017.

[5] S. Ranjan, "Automatic Street Lights on / Off Application Using Iot Automatic Street Lights on / Off," vol. 8, no. 8, pp. 38–47, 2017.

[6] V. Uniyal, N. Kanojia, and K. Pandey, "Design of 5kw Pico Hydro Power Plant Using Turgo Turbine," vol. 7, no. 12, pp. 363–367, 2016.

[7] H. Sharma and J. Singh, "Run off River Plant : Status and Prospects," *Int. J. Innov. Technol. Explor. Eng.*, vol. 3, no. 2, pp. 210–213, 2013.

[8] A. Kumar *et al.*, "Second Order Draft Contribution to Special Report Renewable Energy Sources (SRREN) Title: Hydropower (Sub)Section: All Remarks: Second Order Draft."

[9] S. Sangal, A. Garg, and D. Kumar, "Review of Optimal Selection of Turbines for Hydroelectric Projects," *Rev. Optim. Sel. Turbines Hydroelectr. Proj.*, vol. 3, no. 3, pp. 424–430, 2013.

[10] B. Abdullah Nasir, "Suitable Selection of Components for the Micro-Hydro-Electric Power Plant," *Adv. Energy Power*, vol. 2, no. 1, pp. 7–12, 2014.

[11] T. OHSHIMA, "T → Mγ:: Status and Prospects," no. May 2001, pp. 327–337, 2002.

[12] S. Hydro and P. Analysis, *RETScreen ® International CLEAN ENERGY PROJECT ANALYSIS :* 2004.

[13] M. I. Yuce and S. Yuce, "Pre-feasibility assessment of small hydropowen projects in Turkey by RETScreen," *J. Am. Water Works Assoc.*, vol. 108, no. 5, pp. E269–E275, 2016.

[14] Y. R. Pasalli and A. B. Rehiara, "Design Planning of Micro-hydro Power Plant in Hink River," *Procedia Environ. Sci.*, vol. 20, pp. 55–63, 2014.

[15] I. Loots, M. Van Dijk, B. Barta, S. J. Van Vuuren, and J. N. Bhagwan, "A review of low head hydropower technologies and applications in a South African context," *Renew. Sustain. Energy Rev.*, vol. 50, no. 2015, pp. 1254–1268, 2015.

[16] H. M. Aung, N. A. San, and W. P. P. Myo, "Design and Performance Analysis of a Low Head Propeller Turbine," *Int. J. Sci. Eng. Technol. Res.*, vol. 03, no. 10, pp. 1891–1895, 2014.

[17] H. H. Win, T. T. Htike, M. G. Phyo, and M. Maung, “Optimum Runner Design of 10kW Propeller Turbine,” vol. 3, no. 2, pp. 329–334, 2019.

[18] Z. M. Chan and Z. N. Aung, “Design calculation of Kaplan Turbine Runner Blade for 15kw Micro Hydropower Plant,” vol. 5, no. 4, pp. 14–16, 2020.

[19] M. I. Abid, M. S. Khalid, M. Kamran, M. Arshad, M. F. Masood, and T. Murtaza, “Design and Optimization of the Micro-Hydro Power System for Remote Areas of Pakistan,” vol. 4, no. 3, 2020.

[20] N. A. Fadhil, M. Elmnifi, O. D. H. Abdulrazig, and L. J. Habeeb, “Design and modeling of hybrid photovoltaic micro-hydro power for Al-Bakur road lighting: A case study,” *Mater. Today Proc.*, vol. 49, pp. 2851–2857, Jan. 2022.

[21] G. Subhashini, D. Munandy, and R. Abdulla, “Generating a lighting system by using Pico hydro system,” *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 15, no. 4, pp. 1565–1573, 2017.

[22] G. T. Tessema, “Feasibility Study on Mini-hydroelectric Power Plant for Rural Electrification,” no. 821210, 2017.

[23] Department of Energy Philippines, “Roadway Lighting Guidelines,” *Republic of the Philippines Department of Energy[1] Department of Energy Philippines, “Roadway Lighting Guidelines,” Republic of the Philippines Department of Energy, 2017. [Online]. Available: https://www.doe.gov.ph/sites/default/files/pdf/energy_efficie*, 2017. [Online]. Available: https://www.doe.gov.ph/sites/default/files/pdf/energy_efficiency/doe-road-light-2017.pdf?withshield=1.

[24] F. P. Report, B. Kumar, M. Er, S. Lamichhane, and E. Faculty, “FEASIBILITY ASSESSMENT OF A HYDROPOWER PLANT : A CASE STUDY IN LOWER MARDI RIVER , NEPAL FEASIBILITY ASSESSMENT OF A HYDROPOWER PLANT : A CASE STUDY IN LOWER MARDI RIVER , NEPAL,” 2015.

[25] S. Asian, “CHAPTER 5 DESIGN FOR CIVIL STRUCTURES,” no. i.

[26] R. Kumar and S. K. Singal, “Penstock material selection in small hydropower plants using MADM methods Penstock material selection in small hydropower plants using MADM methods,” *Renew. Sustain. Energy Rev.*, vol. 52, no. August 2015, pp. 240–255, 2022.

[27] M. K. Singhal and A. Kumar, “Optimum Design of Penstock for Hydro Projects vailable for Optimized Design esign of Penstock Relations Available for Optimum Diameter of Penstock,” vol. 4, no. 4, pp. 216–226, 2015.

[28] F. Reichl and J. Hack, “Derivation of flow duration curves to estimate hydropower generation potential in data-scarce regions,” *Water (Switzerland)*, vol. 9, no. 8, 2017.

[29] M. San and N. Nyi, “Design of Cross Flow Turbine and Analysis of Runners Dimensions on Various Head and Flow Rate,” *Int. J. Sci. Res. Publ.*, vol. 8, no. 8, pp. 586–593, 2018.

[30] M. M. Oo, “Design of 50 kW Kaplan Turbine for Micro hydro Power Plant,” vol. 3, no. 2, pp. 264–270, 2019.

[31] J. Susanto and S. Stamp, “Local installation methods for low head pico-hydropower in the

Lao PDR," *Renew. Energy*, vol. 44, no. August 2012, pp. 439–447, 2012.

[32] R. K. Bansal, "A Textbook of Fluid Mechanics and Hydraulic." p. 1130, 2018.

[33] A. Zhamalovich, Z. Alaibek, and D. Obozov, "Selection of Generator for the Micro Hydro Power Plant," *Am. J. Sci. Res.*, vol. 8, no. 3, pp. 104–108, 2013.

[34] T. Edition, "Design of machine elements," *J. Franklin Inst.*, vol. 256, no. 2, p. 199, 1953.

[35] https://www.gpsvisualizer.com/elevation

[36] http://indmicrohydro.blogspot.com/2010/05/manning-coefficient-nfor-several.html

Appendix A: - Five Year Average Flow Rate Data

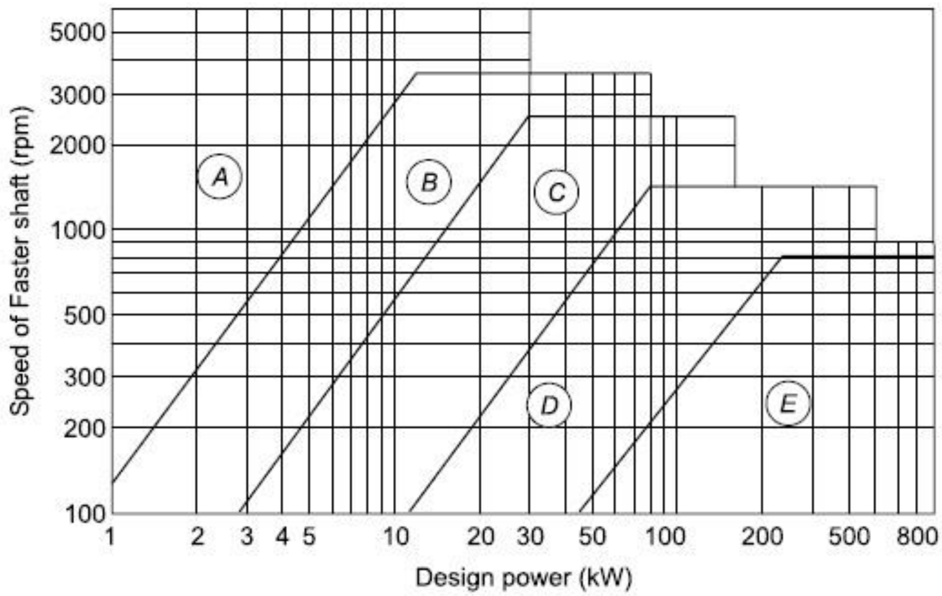
Table 0-1 Yearly Flow rate data

Month / No Day	January	February	March	April	May	June	July	August	September	October	November	December
1	0.0188	0.0188	0.0188	5.127	0.4112	1.0736	13.7766	33.0302	44.5588	8.8896	0.3212	0.3004
2	0.0188	0.0188	0.0118	4.972	0.5674	1.0224	20.363	27.0784	31.8448	8.7416	0.3212	0.3004
3	0.0272	0.0188	0.0188	5.2716	4.676	0.766	20.4316	43.8642	45.8898	5.6208	0.3596	0.3184
4	0.0188	0.0272	0.0118	4.6038	0.7214	0.7008	26.5226	43.7692	52.3866	2.065	0.353	0.3184
5	0.0188	0.0188	0.0188	4.2282	4.5302	0.669	28.333	33.4248	53.6704	4.4478	0.3982	0.3548
6	0.0188	0.0272	0.0118	4.4688	4.464	0.9032	17.9256	47.4732	36.7616	7.862	0.4284	0.3184
7	0.1142	0.2852	0.006	4.1014	2.0384	1.2034	24.0136	41.7624	40.9686	3.9096	0.4666	0.3458
8	0.0272	0.2428	0.006	3.954	2.6772	0.5772	24.1032	56.871	40.4104	3.3204	0.4474	0.3094
9	0.0368	0.0368	0.0188	3.6734	6.2862	0.7008	30.3608	36.3718	30.6634	3.339	0.411	0.3184
10	0.0188	0.0188	0.0118	4.0228	2.1142	0.6378	26.9302	60.4534	32.3982	3.2758	0.4378	0.3548
11	0.0368	0.0368	0.006	3.87	3.504	0.4798	22.6868	74.7646	27.8998	1.4592	0.449	0.3184
12	0.0368	0.0188	0.006	3.7232	0.7704	1.0528	19.5734	52.8784	13.4348	1.4122	0.4864	0.252
13	0.0368	0.0188	0.006	3.7068	0.6388	2.222	24.0462	67.0256	28.8098	1.304	1.0008	0.2294
14	0.2568	0.0368	0.0188	3.7978	0.4566	1.6846	21.7386	72.02	57.835	0.9812	1.5164	0.2114
15	0.1128	0.0368	0.0188	3.2926	0.2964	1.9992	30.6112	52.744	33.3628	1.1718	0.7562	0.1892
16	0.0516	0.0368	0.23	3.046	0.384	0.886	33.5092	60.7528	52.8796	0.9564	0.5136	0.2114
17	0.0516	0.0188	0.3844	3.0994	0.299	0.933	34.2894	55.3398	42.5854	0.9806	0.4216	0.2294
18	0.0368	0.0188	0	9.5286	0.224	3.7522	24.0698	43.2742	22.217	0.7804	0.353	0.1892
19	0.0368	0.0368	1.2034	3.0562	0.224	1.837	39.2292	34.5004	20.8426	0.7344	0.335	0.2072
20	0.0188	0.0368	0.6558	2.7398	0.2664	1.1512	37.56	36.3846	37.717	0.6618	0.473	0.1796
21	0.0188	0.0188	1.1898	2.7438	0.3116	0.8526	43.7806	47.3866	21.7074	0.6136	0.335	0.1892
22	0.0188	0.0368	8.549	3.3738	0.2502	1.1458	48.4608	34.1354	12.359	0.8106	0.353	0.1892
23	0.0118	0.0368	2.7474	2.6386	0.7862	4.005	38.7676	50.811	18.3118	0.6616	0.3198	0.1892
24	0.0188	0.0242	2.3516	3.9082	1.4786	1.6784	32.4404	41.7732	16.8716	0.5596	0.3198	0.1892
25	0.0188	0.1008	2.5286	1.014	2.1624	3.7944	30.4858	49.0406	13.2318	0.5712	0.353	0.1892
26	0.0188	0.0516	2.7332	0.1922	1.3018	4.711	41.8558	45.3112	7.7066	0.4736	0.382	0.1892
27	0.0368	0.0446	2.143	0.2214	1.4282	6.7228	47.4852	44.3968	7.0354	0.4136	0.3636	0.168
28	0.0188	0.0188	1.985	0.1346	1.7516	5.9218	34.8736	45.0656	6.3538	0.4038	0.3894	0.224
29	0.0188		1.5768	0.099	4.3498	2.9594	44.1434	33.4646	6.1632	0.3282	0.353	0.563
30	0.0188		1.489	0.0408	2.079	6.3542	35.0122	32.15	5.684	0.283	0.353	0.3004
31	0.0188		2.4218		1.1656		52.6878	44.9492		0.3422		0.2686

Appendix B: - Standard Design Data

Table 0-1 Correction factors according to service load [34]

Service	*Type of driven Machine*	*Type of driving units*					
		AC Motor: normal torque, squirrel cage, synchronous and split phase *DC Motor.* shunt wound-multi cylinder IC engine over 600 rpm			*AC Motor.* high torque, induction, single phase *DC Motor:* series and compound wound single *cylinder IC engine,* Multi cylinder I C engine under 600 rpm-line shaft, *clutches and brakes*		
		Operational hours per day (h)			Operational hours per day (h)		
		0-10	10-16	16-24	0-10	10-16	16-24
Light duty	Agitator, blower, exhauster, centrifugal pumps, compressor and fans up to 7.5 kW and light duty conveyor	1.0	1.1	1.2	1.1	1.2	1.3
Medium duty	Belt conveyor, fans over 7.5 kW, generator, line shaft, machine tools, presses, positive displacement pumps and **vibrating screen**	1.1	1.2	1.3	1.2	1.3	1 .4
Heavy duty	Bucket elevator, hammer mill, piston pump, saw mill, exciter and wood working machinery	1.2	1.3	1.4	1 .4	1.5	1.6
Extra-heavy duty	Crusher, mill and hoist	1.3	1.4	1.5	1.5	1.6	1.8

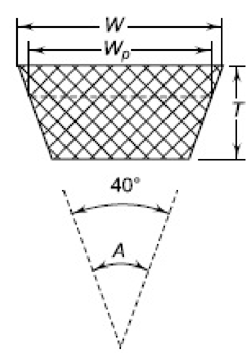


Selection of Cross-section of V belt

Figure 0-1 Selection of cross section of V belt [34]

Table 0-2 Dimension of standard cross section [34]

Belt section	Pitch width Wp (mm)	Nominal top width W(mm)	Nominal Height T (mm)	Recommended Minimum pitch diameter of pulley (mm)	Permissible Minimum pitch diameter of pulley (mm)
z	8.5	10	6	85	50
A	11	13	8	125	75
B	14	17	11	200	125
C	19	22	14	315	200
D	27	32	19	500	355
E	32	38	23	630	500



Dimensions of V belt

Table 0-3 Preferred pitch diameters of pulleys (mm) [34]

Belt section					
Z	A	B	C	D	E
50	75	125	200	355	500
53	80	132	212	375	530
56	85	140	224	400	560
60	90	150	236	425	600
63	95	160	250	450	630
67	100	170	265	475	670
71	106	180	280	500	710
75	112	190	300	530	750
80	118	200	315	560	800
85	125	224	355	600	900
90	132	250	375	630	1000
95	140	280	400	71 0	1120
1 00	150	300	450	750	1250
112	160	31 5	500	800	1400
125	170	355	530	900	1500
140	180	375	560	1000	1600
160	190	400	600	1 060	1800
180	200	450	630	1 120	1900
200	224	500	710	1250	2000
250	250	530	750	1400	2240
315	280	560	800	1500	2500
400	300	600	900	1600	-
500	315	630	1000	1800	-
630	350	710	1200	2000	-
800	400	750	1250	-	-
-	450	800	1400	-	-
-	500	900	1600	-	-
-	560	1000	-	-	-
-	630	1120	-	-	-
-	710	-	-	-	-
-	800	-	-	-	-
Tolerance on the pitch diameter is± 0.8percent					

Table 0-4 Nominal pitch lengths of standard size of v belts [34]

Pitch lengths of belts LP (mm)					
Z	A	B	C	D	E
405	630	930	1560	2740	4660
475	700	1000	1760	31 30	5040
530	790	1 1 00	1950	3330	5420
625	890	121 0	21 90	3730	61 00
700	990	1370	2420	4080	6850
780	1 1 00	1560	2720	4620	7650
920	1250	1690	2880	5400	91 50
1 080	1430	1760	3080	61 00	12230
1 330	1550	1950	331 0	6840	13750
1420	1640	21 80	3520	7620	15280
1 540	1750	2300	4060	841 0	16800
	1940	2500	4600	9140	
	2050	2700	5380	10700	
	2200	2870	61 00	12200	
	2300	3200	6820	13700	
	2480	3600	7600	15200	
	2570	4060	91 00		
	2700	4430	10700		
	291 0	4820			
	3080	5370			
	3290	6070			
	3540				

Table 0-5 Correction factors for belt pitch length [34]

Correction Factor	Belt pitch length (mm)					
	Belt cross section					
	Z	A	B	C	D	E
0.80		630				
0.81			930			
0.82		700		1560		
0.83			1000		2740	
0.84		790		1760		
0.85			1100			
0.86	405	890			3130	
0.87			1210	1950	3330	
0.88		990				
0.89						
0.90	475	1100	1370	2190	3730	4660
0.9 1				2340		
0.92	530		1560	2490	4080	5040
0.93		1250				
0.94				2720	4620	5420
0.95	625		1760	2800		
0.96		1430		3080		6100
0.97			1950		5400	
0.98	700	1550		3310		
0.99		1640	2180	3520		6850
1.00	780	1750	2300		6 100	
1.02		1940	2500	4060		7650
1.03					6840	
1.04	920	2050	2700			
1.05		2200	2850	4600	7620	9150
1.06		2300				
1.07	1080				8410	9950
1.08		2480	3200	5380		
1.09		2570			9 140	10710
1.10		2700	3600			

Table 0-6 Correction factor for arc of contact [34]

$\frac{D-d}{C}$	Arc of contact on smaller pulley (in degrees)	Correction Factor Fd
0.00	180	1.00
0.05	177	0.99
0.10	174	0.99
0.15	171	0.98
0.20	169	0.97
0.25	166	0.97
0.30	163	0.96
0.35	160	0.95
0.40	157	0.94
0.45	154	0.93
0.50	151	0.93
0.55	148	0.92
0.60	145	0.91
0.65	142	0.90
0.70	139	0.89
0.75	136	0.88
0.80	133	0.87
0.85	130	0.86
0.90	127	0.85
0.95	123	0.83
1.00	120	0.82

Table 0-7 Power rating of single V belt [34]

Section A	D	75	80	85	90	100	106	112	118	125
	Pr	0.73	0.86	0.99	1.12	1.38	1.5	1.63	1.81	2.00
Section B	D	125	132	140	150	160	170	180	190	200
	Pr	2.24	2.46	2.77	3.30	3.60	4.00	4.39	4.77	5.23
Section C	D	200	212	224	236	250	265	280	300	315
	Pr	6.14	6.81	7.68	8.20	9.40	10.11	11.10	12.10	12.50
Section D	D	350	375	400	425					
	Pr	15.7	17.5	19.3	20.60					

Table 0-8 Standard pipe wall thickness

PIPE WALL THICKNESS

Wellgrow Industries Corp.

ASTM A312, A358, A778, A53, A106, API 5L   ASME/ANSI B36.19 B36.10

Nominal Pipe Size Inches	Outside Diameter		Wall thickness: mm													Figures based on austenitic steel			
	In	mm	SCH 10	SCH 20	SCH 30	SCH STD	SCH 40	SCH 60	SCH XS	SCH 80	SCH 100	SCH 120	SCH 140	SCH 160	SCH XXS	SCH 5 S	SCH 10 S	SCH 40 S	SCH 80 S
1/8	0.405	10.29	1.24			1.73	1.73		2.41	2.41							1.24	1.73	2.41
1/4	0.540	13.72	1.65		1.85	2.24	2.24		3.02	3.02							1.65	2.24	3.02
3/8	0.675	17.15	1.65		1.85	2.31	2.31		3.2	3.2							1.65	2.31	3.2
1/2	0.840	21.34	2.11		2.41	2.77	2.77		3.73	3.73				4.78	7.47	1.65	2.11	2.77	3.73
3/4	1.050	26.67	2.11		2.41	2.87	2.87		3.91	3.91				5.56	7.82	1.65	2.11	2.87	3.91
1	1.315	33.40	2.77		2.90	3.38	3.38		4.55	4.55				6.35	9.09	1.65	2.77	3.38	4.55
1 1/4	1.660	42.16	2.77		2.97	3.56	3.56		4.85	4.85				6.35	9.7	1.65	2.77	3.56	4.85
1 1/2	1.900	48.26	2.77		3.18	3.68	3.68		5.08	5.08				7.14	10.15	1.65	2.77	3.68	5.08
2	2.375	60.33	2.77		3.18	3.91	3.91		5.54	5.54				8.74	11.07	1.65	2.77	3.91	5.54
2 1/2	2.875	73.03	3.05		4.78	5.16	5.16		7.01	7.01				9.35	14.02	2.11	3.05	5.16	7.01
3	3.500	88.90	3.05		4.78	5.49	5.49		7.62	7.62				11.13	15.24	2.11	3.05	5.49	7.62
3 1/2	4.000	101.60	3.05		4.78	5.74	5.74		8.08	8.08				-	-	2.11	3.05	5.74	8.08
4	4.500	114.30	3.05		4.78	6.02	6.02		8.56	8.56		11.13		13.49	17.12	2.11	3.05	6.02	8.56
5	5.563	141.30	3.4			6.55	6.55		9.53	9.53		12.7		15.88	19.05	2.77	3.40	6.55	9.53
6	6.625	168.28	3.4			7.11	7.11		10.97	10.97		14.27		18.26	21.95	2.77	3.40	7.11	10.97
8	8.625	219.08	3.76	6.35	7.04	8.18	8.18	10.31	12.7	12.7	15.09	18.26	20.62	23.01	22.23	2.77	3.76	8.18	12.7
10	10.750	273.05	4.19	6.35	7.80	9.27	9.27	12.7	12.7	15.09	18.26	21.44	25.4	28.58	25.4	3.4	4.19	9.27	12.7
12	12.750	323.85	4.57	6.35	8.38	9.53	10.31	14.27	12.7	17.48	21.44	25.4	28.58	33.32	25.4	3.96	4.57	9.52	12.7
14	14.000	355.60	6.35	7.92	9.53	9.53	11.13	15.09	12.7	19.05	23.83	27.79	31.75	35.71	35.71	3.96	4.78		
16	16.000	406.40	6.35	7.92	9.53	9.53	12.7	16.66	12.7	21.44	26.19	30.96	36.53	40.49	40.49	4.19	4.78		
18	18.000	457.20	6.35	7.92	11.13	9.53	14.27	19.05	12.7	23.88	29.36	34.93	39.67	45.24	45.24	4.19	7.78		
20	20.000	508.00	6.35	9.53	12.7	9.53	15.09	20.62	12.7	26.19	32.54	38.1	44.45	50.01	50.01	4.78	5.54		
22	22.000	558.80	6.35	9.53	12.7	9.53	-	22.23	12.7	28.58	34.93	41.28	47.63	53.98	53.97	4.78	5.54		
24	24.000	609.60	6.35	9.53	14.27	9.53	17.48	24.61	12.7	30.96	38.89	46.02	52.37	59.54	59.54	5.54	6.35		
26	26.000	660.00	6.35	12.7	-	9.53	-		12.7										
28	28.000	711.20	6.35	12.7	15.88	9.53	-		12.7										
30	30.000	762.00	6.35	12.7	15.88	9.53	-		12.7							6.35	7.92		
32	32.000	812.80	6.35	12.7	15.88	9.53	17.48		12.7										
34	34.000	863.60	6.35	12.7	15.88	9.53	17.48		12.7										
36	36.000	914.40	6.35	12.7	15.88	9.53	19.05		12.7										
38	38.000	965.20				9.53			12.7										
40	40.000	1016.00				9.53			12.7										
42	42.000	1066.80				9.53			12.7										
44	44.000	1117.60				9.53			12.7										
46	46.000	1168.40				9.53			12.7										
48	48.000	1219.20				9.53			12.7										
52	52.000	1321.00				9.53			12.7										
56	56.000	1422.00				9.53			12.7										
60	60.000	1524.00				9.53			12.7										
72	72.000	1829.00				9.53			12.7										

Website: www.pipefittingweb.com   Email: wellgrow@pipefittingweb.com   Fax: 886-423112578

Table 0-9 Available Asynchronous generator less than 100KW [33] .

Motor type	Motor power KW	Motor weight, kg	Weight of excitation condensers, kg
AIR80A4	1.1	11.9	0.3
AIR 80A4	1.5	13.8	0.4
ANR.90L4	2.2	18.6	0.6
ANR100S4	3.0	25.0	0.8
AMR100L4	4.0	31.0	1.2
AIR112I4	5.5	49.0	1.0
ANR132S4	7.5	70	1.2
AIR132I4	11.0	83.5	2.1
AMR160S4	15.0	130	2.8
AIR160i4	18.5	145	3.4
ANR180S4	22.0	170	4.1
AIR180I4	30.0	190	5.5
A200i4	37.0	245	6.4

Appendix C: - MATLAB Code

```
%%%%%Analyzing Hydropower system using MATLAB Simulink%%%%%

%%%%%%%%%%%%%%%%%%%%%Adding 12-month flow rate data
days=1:1:31;
D=days';
January=xlsread('Flow Rate Data.xlsx');
February=xlsread('Flow Rate Data.xlsx',2);
March=xlsread('Flow Rate Data.xlsx',3);
April=xlsread('Flow Rate Data.xlsx',4);
May=xlsread('Flow Rate Data.xlsx',5);
June=xlsread('Flow Rate Data.xlsx',6);
July=xlsread('Flow Rate Data.xlsx',7);
August=xlsread('Flow Rate Data.xlsx',8);
September=xlsread('Flow Rate Data.xlsx',9);
October=xlsread('Flow Rate Data.xlsx',10);
November=xlsread('Flow Rate Data.xlsx',11);
December=xlsread('Flow Rate Data.xlsx',12);

%%%%% Specifying the penstock flow rate based on the design flow rate
using MATLAB SIMULINK%%%%%

Qd=0.459; % Design flow rate (m3/s)

%%%% For the month of January
for i=1:length(January)
January(i);
if January(i)>=Qd
PenJanuary(i)=Qd;
elseif January(i)<Qd
PenJanuary(i)=January(i);
end
end

%%%% For the month of February
for i=1:length(February)
February(i);
if February(i)>=Qd
PenFebruary(i)=Qd;
elseif February(i)<Qd
PenFebruary(i)=February(i);
end
end

%%%% For the month of March
for i=1:length(March)
March(i);
if March(i)>=Qd
PenMarch(i)=Qd;
elseif March(i)<Qd
PenMarch(i)=March(i);
end
end
```

```
%%%% For the month of April
for i=1:length(April)
April(i);
if April(i)>=Qd
PenApril(i)=Qd;
elseif April(i)<Qd
PenApril(i)=April(i);
end
end

%%%% For the month of May
for i=1:length(May)
May(i);
if May(i)>=Qd
PenMay(i)=Qd;
elseif May(i)<Qd
PenMay(i)=May(i);
end
end

%%%% For the month of June
for i=1:length(June)
June(i);
if June(i)>=Qd
PenJune(i)=Qd;
elseif June(i)<Qd
PenJune(i)=June(i);
end
end

%%%% For the month of July
for i=1:length(July)
July(i);
if July(i)>=Qd
PenJuly(i)=Qd;
elseif July(i)<Qd
PenJuly(i)=July(i);
end
end

%%%% For the month of August
for i=1:length(August)
August(i);
if August(i)>=Qd
PenAugust(i)=Qd;
elseif August(i)<Qd
PenAugust(i)=August(i);
end
end

%%%% For the month of September
for i=1:length(September)
September(i);
if September(i)>=Qd
PenSeptember(i)=Qd;
```

```
elseif September(i)<Qd
PenSeptember(i)=September(i);
end
end

%%%% For the month of October
for i=1:length(October)
October(i);
if October(i)>=Qd
PenOctober(i)=Qd;
elseif October(i)<Qd
PenOctober(i)=October(i);
end
end

%%%% For the month of November
for i=1:length(November)
November(i);
if November(i)>=Qd
PenNovember(i)=Qd;
elseif November(i)<Qd
PenNovember(i)=November(i);
end
end

%%%% For the month of December
for i=1:length(December)
December(i);
if December(i)>=Qd
PenDecember(i)=Qd;
elseif December(i)<Qd
PenDecember(i)=December(i);
end
end

%% Defining constant parameters and different types of losses

rho=1000; % Density of water (kg/m3)
g=9.81; % Gravity (m/s2)
Hg=2.8; % Gross head (m)
hydlos=0.07; % Hydraulic losses
tailos=0.07; % Taile race losses
Hn=Hg*(1-(hydlos + tailos)); % Net head (m)

kd=0.46; % constant that links the turbine's diameter to the design
flow rate
d=kd*(Qd^0.473); % Reaction turbine runner size (mm)

ks=800; % constant factor that relates net head to specific speed of
turbine
nq=ks*(Hn^-0.5); % Specific speed of the turbine

eg=0.95; % Generator efficiency
ltrans=0.02; % Transformer losses
lpara=0.03; % parasitic electricity losses
```

```
etd=0.683; % Turbine efficiency at the design flow rate
pd=rho*g*Qd*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-lpara); %
Maximum power capacity of the turbine
n=(nq*(Hn^(5/4)))/sqrt(pd/1000); % Turbine speed (RPM)

enq=((nq-170)/700)^2;%specific speed adjustment to peak efficiency

ed=(0.095+enq)*(1-(0.789*(d^(-0.2))));%Runner size adjustment to peak
efficiency

Rm=4.5; % turbine manufacturer coefficient
ep=0.905-enq+ed-0.0305+0.005*Rm;% turbine peak efficiency

Qp=0.75*Qd; % peak efficiency flow

%%%%% Calculating the available power capacity of the turbine for each
month at each flow rate %%%%%

%%%% For the month of January
AVPOJanuary=rho*g*PenJanuary*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of February
AVPOFebruary=rho*g*PenFebruary*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of March
AVPOMarch=rho*g*PenMarch*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of April
AVPOApril=rho*g*PenApril*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of May
AVPOMay=rho*g*PenMay*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of June
AVPOJune=rho*g*PenJune*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of July
AVPOJuly=rho*g*PenJuly*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of August
AVPOAugust=rho*g*PenAugust*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of September
AVPOSeptember=rho*g*PenSeptember*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of October
AVPOOctober=rho*g*PenOctober*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of November
AVPONovember=rho*g*PenNovember*Hg*(1-(hydlos+tailos))*etd/1000;
%%%% For the month of December
AVPODecember=rho*g*PenDecember*Hg*(1-(hydlos+tailos))*etd/1000;

%%%%%Calculating the turbine speed for each month at each flow rate
(RPM)%%%%%

%%%% For the month of January
TUSPJanuary=(nq*(Hn^(5/4)))./sqrt(AVPOJanuary);
%%%% For the month of February
TUSPFebruary=(nq*(Hn^(5/4)))./sqrt(AVPOFebruary);
%%%% For the month of March
TUSPMarch=(nq*(Hn^(5/4)))./sqrt(AVPOMarch);
%%%% For the month of April
TUSPApril=(nq*(Hn^(5/4)))./sqrt(AVPOApril);
%%%% For the month of May
```

```
TUSPMay=(nq*(Hn^(5/4)))./sqrt(AVPOMay);
%%%% For the month of June
TUSPJune=(nq*(Hn^(5/4)))./sqrt(AVPOJune);
%%%% For the month of July
TUSPJuly=(nq*(Hn^(5/4)))./sqrt(AVPOJuly);
%%%% For the month of August
TUSPAugust=(nq*(Hn^(5/4)))./sqrt(AVPOAugust);
%%%% For the month of September
TUSPSeptember=(nq*(Hn^(5/4)))./sqrt(AVPOSeptember);
%%%% For the month of October
TUSPOctober=(nq*(Hn^(5/4)))./sqrt(AVPOOctober);
%%%% For the month of November
TUSPNovember=(nq*(Hn^(5/4)))./sqrt(AVPONovember);
%%%% For the month of December
TUSPDecember=(nq*(Hn^(5/4)))./sqrt(AVPODecember);

%%%%%Calculating available power capacity of the hydropower system each
month at each flow rate%%%%%

%%%% For the month of January
HYPOJanuary=rho*g*PenJanuary*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
%%%% For the month of February
HYPOFebruary=rho*g*PenFebruary*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
%%%% For the month of March
HYPOMarch=rho*g*PenMarch*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of April
HYPOApril=rho*g*PenApril*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of May
HYPOMay=rho*g*PenApril*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of June
HYPOJune=rho*g*PenJune*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of July
HYPOJuly=rho*g*PenJuly*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of August
HYPOAugust=rho*g*PenAugust*Hg*(1-(hydlos+tailos))*etd*eg*(1-ltrans)*(1-
lpara)/1000;
%%%% For the month of September
HYPOSeptember=rho*g*PenSeptember*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
%%%% For the month of October
HYPOOctober=rho*g*PenOctober*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
%%%% For the month of November
HYPONovember=rho*g*PenNovember*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
%%%% For the month of December
HYPODecember=rho*g*PenDecember*Hg*(1-(hydlos+tailos))*etd*eg*(1-
ltrans)*(1-lpara)/1000;
```

Appendix D: - SIMULINK Model

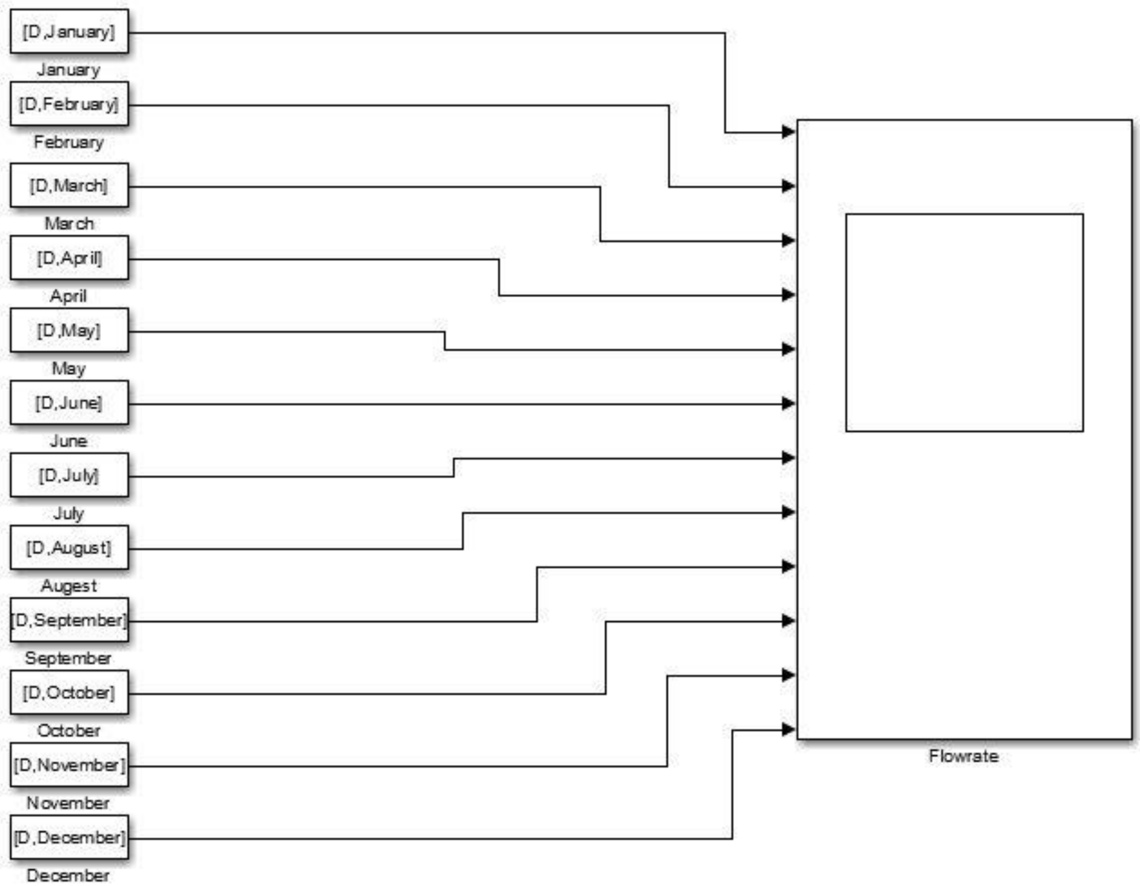


Figure 0-1 Yearly Flow rate SIMULINK MODEL

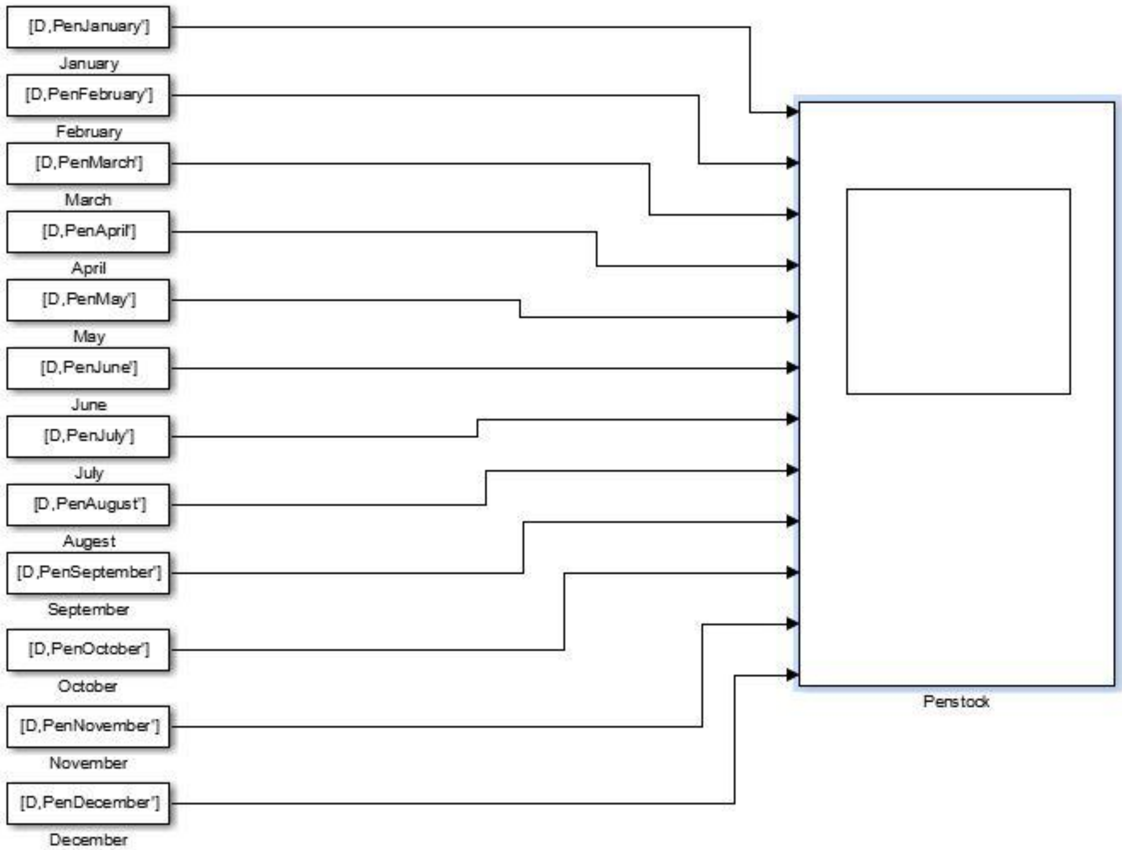


Figure 0-2 Flow rate through the penstock SIMULINK MODEL

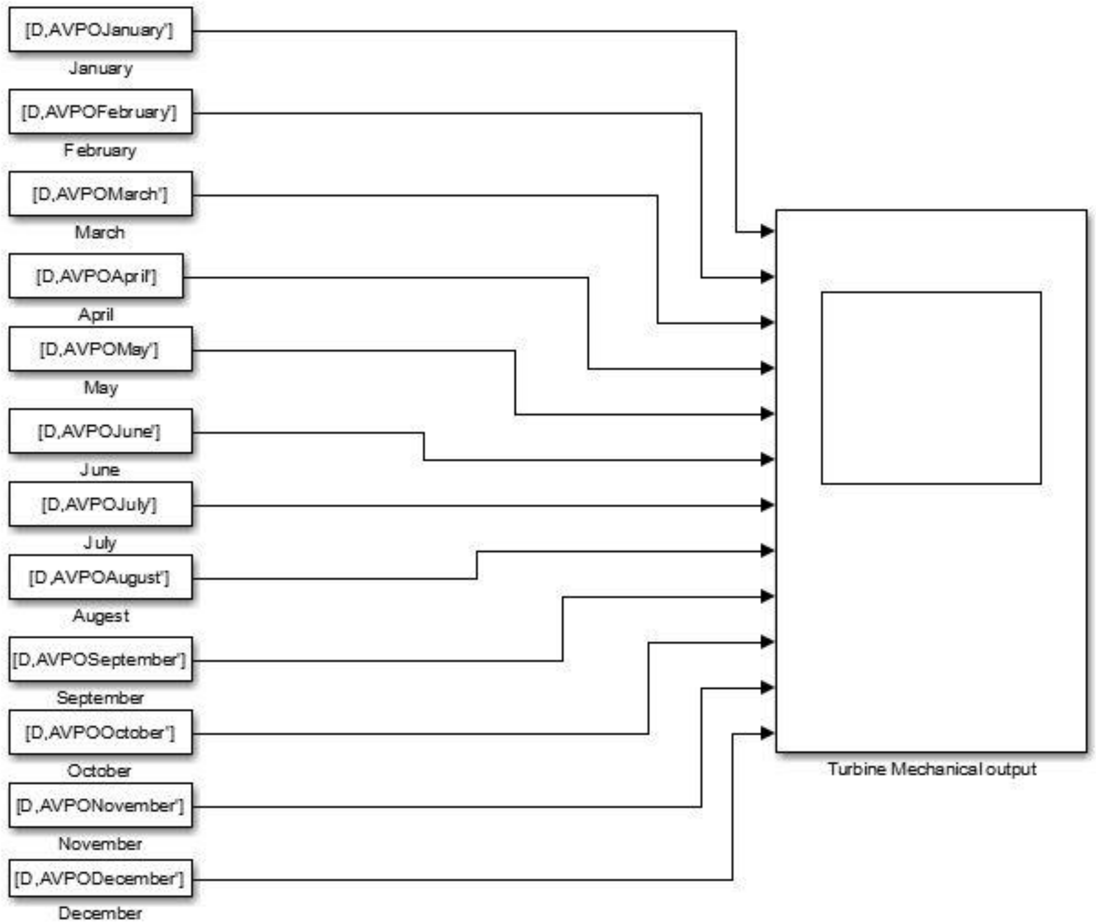


Figure 0-3 Turbine Mechanical output SIMULINK MODEL

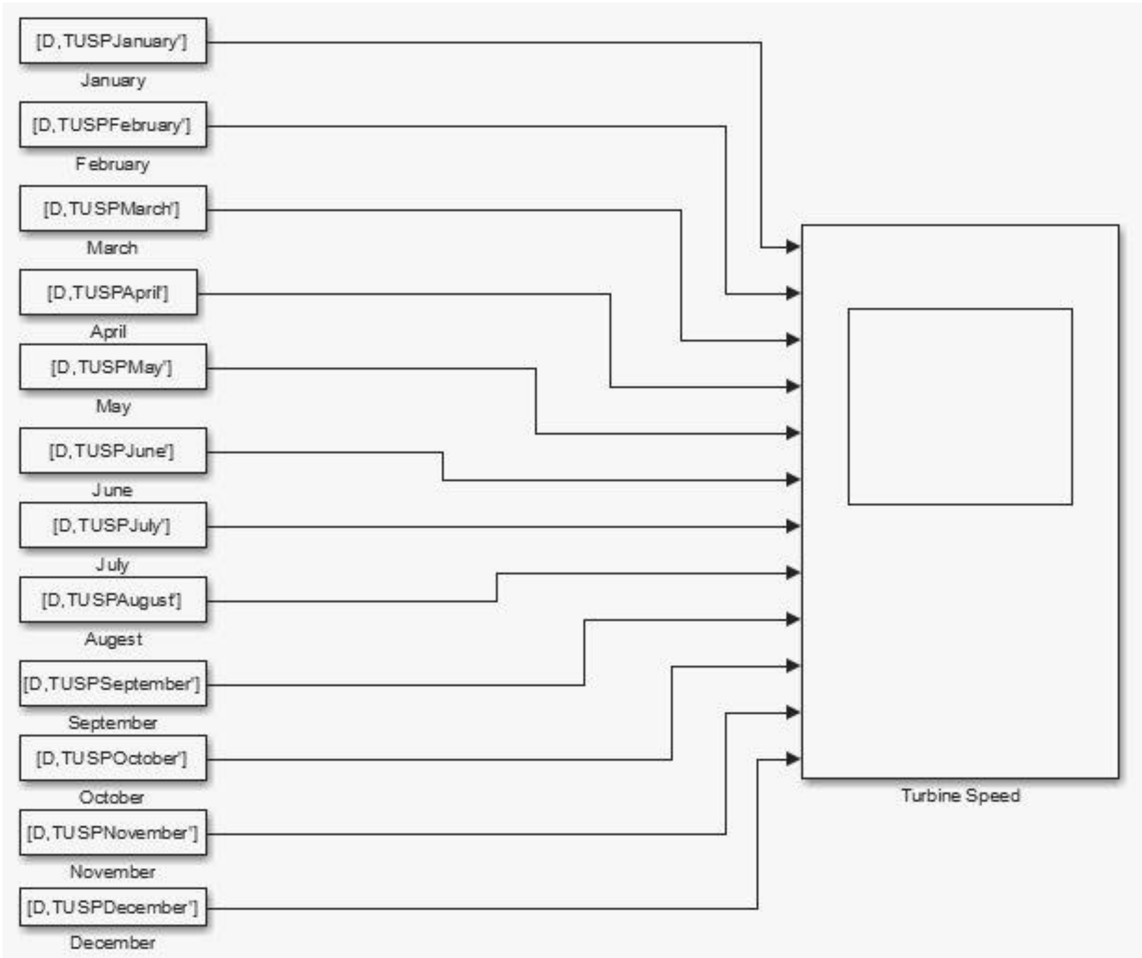


Figure 0-4 Kaplan turbine speed SIMULINK MODEL

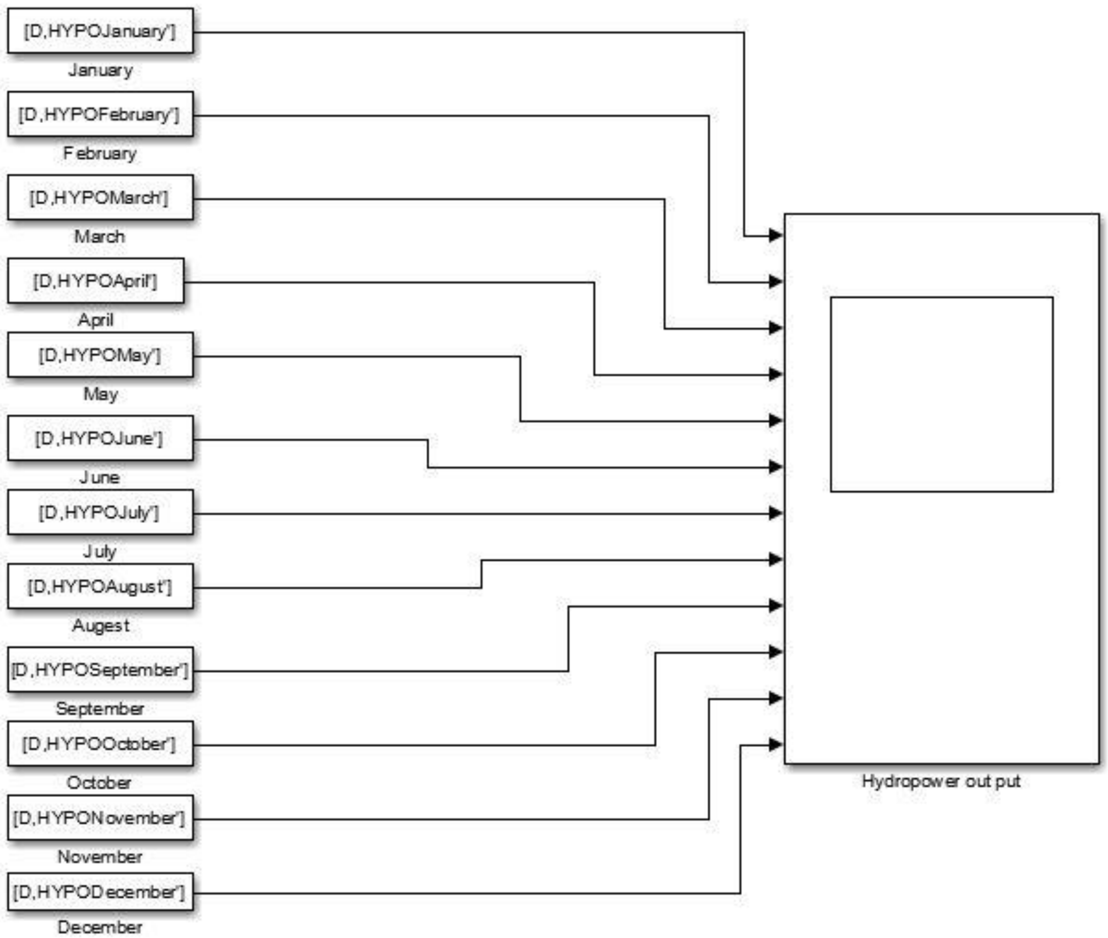


Figure 0-5 Hydropower output SIMULINK MODEL