

DESIGN AND DEVELOPMENT OF MINI HYDROPOWER TRANSMISSION SYSTEM



BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MECHANICAL AND MANUFACTURING) WITH HONOURS

2022



Faculty of Mechanical and Manufacturing Engineering Technology



Keevanish A/L Suresh Chandra

Bachelor of Mechanical Engineering Technology (Mechanical and Manufacturing) with Honours

2022

DESIGN AND DEVELOPMENT OF MINI HYDROPOWER TRANSMISSION SYSTEM

KEEVANISH A/L SURESH CHANDRA



Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this "DESIGN AND DEVELOPMENT OF MINI HYDROPOWER TRANSMISSION SYSTEM" entitled is the result of my own research except as cited in the references. The "DESIGN AND DEVELOPMENT OF MINI HYDROPOWER TRANSMISSION SYSTEM" has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Mechanical and Manufacturing) with Honours.

Signature : Supervisor Name TS. AZRIN BIN AHMAD Date 11 JANUARY 2023 - - - - - -TEKNIKAL MALAYSIA MELAKA UNIVERSITI

DEDICATION

Dedicated to my beloved parents Mr. Suresh Chandra and Mrs. Sheela Pillai, who have respected and supported me in everything I do. Dedicated to Ts. Azrin Bin Ahmad, who taught and guided met throughout the journey of completing the final year project.



ABSTRACT

A hydropower plant is a device that generates energy by moving water. Small hydropower is a sustainable energy source that helps to minimise reliance on fossil fuels while reducing greenhouse gas emissions significantly. Remote locations, on the other hand, are far from any big city that has a significant waterpower plant. As a result, remote areas' access to energy is constantly limited. Furthermore, the functioning of the large hydroelectric plant necessitates the construction of a dam, which devastates the natural and environmental ecology of the area. As a result, a Pico hydropower system that is both environmentally friendly and capable of providing electricity to remote places is required. In addition, runof-river hydropower plants account for most small hydropower plants. In design and development of this project, the house of quality was used to identify user and technical requirements, the morphological chart was used to develop several conceptual designs, the Pugh method was used to select the best gear for a pico hydropower system, and finally failure mode and effect analysis was used to identify potential failures of gears and ways to overcome the problem. In this research, the fabrication of micro hydropower plant was fabricated and the result shows that the micro hydropower plant is capable of producing 14.22 V of electricity at the water speed of 0.072 m^3/s . Furthermore, the fabrication of the gear was successful, and the simulation result also shows a promising result. It shows that the gear will only fail at the torque of 8500 N.m and proved that the gear is sturdy and robust thus it will not easily fail. As a conclusion, the result has successfully fulfilled the objectives stated in chapter 1. The fabricated hydropower plant can be very useful to be applied in the rural areas.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Loji kuasa hidro adalah satu mekanisme yang menghasilkan kuasa elektrik mengunakan aliran air. Loji kuasa hidro menghasilkan kuasa elektrik yang boleh diperbaharui yang membantu mengurangkan pengunaan bahan api fosil dan mengurangkan penyebaran gas rumah hijau. Selain daripada itu, kawasan pendalaman terletak jauh dari kawasan bandar vang mempunyai logi kuasa hidro yang besar. Ini menyebabkan kuasa elektrik yang diberikan kepada kawasan pendalaman terhad. Tambahan pula, loji kuasa hidro yang besar mempunyai empangan, yang menyebabkan kerosakkan alam sekitar. Justeru, sebuah penjana kuasa air yang kecil (pico) diperlukan untuk menyalurkan bekalan elektrik kepada kawasan pendalaman dan mesra ekologi. Kaedah-kaedah yang digunapakai adalah "house of quality", untuk mengenalpasti keperluan penguna dan keperluan teknikal, "morphological chart" untuk membangunkan beberapa konsep rekabentuk, kaedah "Pugh" untuk memilih gear yang paling sesuai untuk membina loji kuasa hidro kecil (pico) dan akhir sekali, "failure mode and effect analysis" untuk mengenalpasti potensi kegagalan sesebuah gear dan cara untuk mengatasinya. Dalam penyelidikan ini, fabrikasi loji kuasa mikro hidro telah dibuat dan keputusan menunjukkan loji kuasa hidro mikro mampu menghasilkan 14.22 V elektrik pada kelajuan air 0.072 m³/s. Tambahan pula, fabrikasi gear telah berjaya dan hasil simulasi juga menunjukkan hasil yang memberangsangkan. Ia menunjukkan bahawa gear hanya akan gagal pada tork 8500 N.m dan membuktikan bahawa gear itu kukuh dan teguh dengan itu ia tidak akan mudah gagal. Kesimpulannya, hasilnya telah berjaya memenuhi objektif yang dinyatakan dalam bab 1. Loji janakuasa hidro yang difabrikasi boleh digunakan dan diaplikasikan di kawasan luar bandar.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ليسيا ملاك

ACKNOWLEDGEMENTS

Firstly, I would like to express my heartfelt gratitude to everyone who made it possible for me to complete this report. I owe a special thanks to Sir TS. Azrin Bin Ahmad, my finalyear project supervisor, whose stimulating suggestions and encouragement assisted me in coordinating my project, especially in writing this report. Without your invaluable supervision, advice, support, and patience, this would have not been possible.

Furthermore, I would like to extend my sincere appreciation to the Faculty of Mechanical and Manufacturing Engineering Technology for the funding opportunity to complete my final year project at University Technical Malaysia Melaka. My gratitude extends to my course mate, Mr. Prakash and Mr. Karthigesan, who helped me to assemble the parts and gave suggestion about the design of the hydropower system.

Last but not least, abundance of thanks to my dearest parents for their continuous support, love and understanding.



TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	ii
ABSTRAK	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
	· · · · ·
LIST OF FIGURES	IX
LIST OF SYMBOLS AND ABBREVIATIONS	xi
LIST OF APPENDICES	xii
CHAPTER 1 INTRODUCTION 1.1 Background Study 1.2 Problem Statement 1.3 Research Objective TI TEKNIKAL MALAYSIA MELAK 1.4 Scope of Research	$ \begin{array}{c} 1 \\ 1 \\ 3 \\ 4 \\ 4 \end{array} $
CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction2.2 Distribution Network Configurations and Components	5 6
2.2.1 Direct Transmission	6
2.2.2 Indirect Tranmission	6
2.2.3 Types of Gear	6 10
2.3 Turbines	10
2.4 Generator	12
2.4.1 Generator Selection	13
2.5 Penstock	14
2.6 Morphological Chart Consider to merge this topic in Chap 3	15
2.7 Performance Analysis of Pice Hydropower Generator	17
2.7.1 Calculation of the Net Head	17
2.7.2 Calculation of Water Flow Rate	17
2.7.4 Calculation of Power	I'/
2.7.4 Calculation of Gear	18

	2.7.5 Runner Design	18
	2.7.6 Diameter of Nozzle of Jet	18
	2.7.7 Number of Buckets	18
	2.7.8 Open Circuit Test	18
	2.7.9 Efficiency of PHP	19
2.8	Summary of Literature Review	21
CHAI	PTER 3 METHODOLOGY	31
3.1	Introduction	31
3.2	Flow Chart	31
3.3	Research Phases	33
	3.3.1 Phase 1	33
	3.3.2 Phase 2	33
3.4	Quality Function Deployment (QFD)	33
3.5	Morphological Chart	36
3.6	Pugh Method	37
3.7	Material Selection for Pico Hydropower Components	38
3.8	Failure Mode and Effect Analysis (FMEA)	39
CHAI	PTER 4 RESULTS AND DISCUSSION	40
4.1	Introduction	40
4.2	Morphological Chart	40
4.3	Pugh Method	40
4.4	Conceptual Designs	42
4.5	Design of Pico Hydropower Components	44
	4.5.1 Penstock	44
	4.5.2 Turbine	45
	4.5.3 Gear	45
	4.5.4 Valve alive	46
	4.5.5 Shaft	47
4.6	Material selection of each pico portable hydropower system components.	47
	4.6.1 Penstock	47
	4.6.2 Turbine	48
	4.6.3 Shaft	48
	4.6.4 Gear	48
4.7	Detailed Design of the Pico Hydropower Plant	48
4.8	Failure Mode and Effect Analysis (FMEA)	50
4.9	Finite Element Analysis of Planetary Gear	51
	4.9.1 Meshing of the Planetary Gear	51
	4.9.2 Stress Strain Analysis of Frame	52
4.10	Bill of material and cost	54
4.11	Experimental analysis in river	55
4.12	Theoritical calculation analysis.	56
	4.12.1 Calculation of gear ratio	56
	4.12.2 Calculation of torque	56
	4.12.3 Calculation of turbine speed	57
	4.12.4 Turbine power	57
	4.12.5 Power output and efficiency	58

CHAPTER 5	CONCLUSION	59
REFERENCES		61
APPENDICES		67



LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Comparison between gear drive planetary gear drive.	9
Table 2.2	The classification of hydropower plant based on the generated power	
	output.	12
Table 2.3	Example of Morphological chart design selection.	16
Table 2.4	Summary of previous research findings.	19
Table 3.1	The Quality Function Deployment (QFD) table.	36
Table 3.2	The criteria analysed in the Pugh method.	38
Table 3.3	Material selection	39
Table 3.4	The FMEA analysis of the Pico hydropower plan.	40
Table 4.1	Morphological Chart	41
Table 4.2	اويومرسيني بيڪيڪل مليسيا ملاڪ	42
Table 4.3	Developed conceptual design. AL MALAYSIA MELAKA	43
Table 4.4	FMEA analysis of the gear.	50
Table 4.5	Data of mesh for the polyamide 12 gear.	51
Table 4.6	Bill of material.	54
Table 4.7	Experimental result of the water powered generator.	55
Table 4.8	Calculation of torque.	56
Table 4.9	Calculation of turbine speed	56
Table 4.10	Calculation of turbine power.	57
Table 4.11	Calculation of power output.	58
Table 4.12	Calculation of efficiency.	58

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	The spur gear.	7
Figure 2.2	The orthogonal bevel gear.	7
Figure 2.3	Belt transmission	8
Figure 2.4	The planetary gear.	8
Figure 2.5	Schematic illustration of Planetary gear.	9
Figure 2.6	The flow of electricity generation from turbine to consumer.	13
Figure 2.7	Example of Pugh method.	18
Figure 3.1	Methodology flow chart.	30
Figure 4.1	Penstock.	47
Figure 4.2	Turbine.	47
Figure 4.3	اويتومر سيتي بيڪتيڪل مليسيا ملاڪ	48
Figure 4.4	Valve ERSITI TEKNIKAL MALAYSIA MELAKA	48
Figure 4.5	Shaft .	49
Figure 4.6	The isometric view of the detailed Pico hydropower system design.	49
Figure 4.7	The front view of the detailed Pico hydropower system design.	50
Figure 4.8	The side view of the detailed Pico hydropower system design.	50
Figure 4.9	The exploded view of the detailed Pico hydropower system design.	50
Figure 4.10	Meshing of Planetary gear.	52
Figure 4.11	Equivalent stress simulation with contour view.	53
Figure 4.12	Equivalent strain simulation with contour view.	53
Figure 4.13	Total deformation simulation with contour view.	54

Figure 4.14	Overall fabricated pico hydropower plant	55
Figure 4.15	Planetary Gear.	56



LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
PHP	-	Pico hydropower plant
kW	-	Kilo watts
PHPP	-	Pico Hydro Power Plant
PHPG	-	Pico Hydro Power Generator
GMA	-	General Morphological Analysis
QFD	-	Quality Function Deployment
VOCs	-	Voice of Customers
PVC		Polyvinyl Chloride



LIST OF APPENDICES

APPENDIX

TITLE

PAGE

67

APPENDIX A

Gantt Chart

UTERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background Study

The development of the global economy relies heavily on the availability of energy. Many industrial, residential, and agricultural operations have risen rapidly in order to meet the wants of consumers. As a result, worldwide primary energy consumption is anticipated to climb by 1.6 percent year between 2009 and 2030. Traditional biomass for cooking remains popular in many countries and 1.6billion people still do not have access to electricity. According to UN-Energy, the world's environmental sustainability suffers tremendously as a result of this energy deficit (Yah et al., 2017). To close the energy gap, it is vital to have more equitable and convenient access to energy services.

A renewable energy resource is the most environmentally friendly form of energy that does not contribute to climate change. In addition to reducing secondary waste, this source of energy can also be sustainable for current and future societal needs. Renewable energy made up 14 percent and 19 percent of worldwide power generation in 2010 and 2012, respectively. According to Malaysia's renewable energy commission, a 5.5 percent increase in electricity generated from renewable sources was planned for 2012 by a government body.

Hydropower is the world's most frequently used renewable energy source, accounting for 19 percent of the world's total electricity generation. According to the Department of Energy (DOE), large hydropower is defined as power stations with more than 30 MW of generation capacity. Small hydropower facilities have a generation capacity of 100 KW to 30 MW. For the purposes of this definition, micro hydropower plants are those with an output of 5 to 100 kW (Razan et al., 2012). With the right application of advanced technology, water heads as high as 2 meters can be used to generate power efficiently. The grid network's uneconomical planning is to blame for the energy challenges in rural and hilly places. A low-cost alternative for these outlying locations is micro-hydropower. For rural and hilly places where extending the grid system would be prohibitively expensive, it is an excellent answer to energy problems.

Hydroelectric hydropower with a maximum output of five kilowatts is known as Pico hydroelectric power. Using Pico hydroelectricity, which can power just one or two fluorescent light bulbs and a TV or radio in each of 50 houses, is ideal for remote, rural communities. Current research and development efforts to develop this green Pico hydro power technology are quite exciting. There are various advantages in terms of capacity, costeffectiveness, size, design, and installation when these efforts are compared to other larger hydroelectric sources of power. In addition to being inexpensive, Pico hydro can enhance the lives of people in developing countries and rural areas where the government has difficulty constructing transmission lines. To generate electricity at Pico, we used proven hydropower technologies. The generator will be powered by the spinning of the turbine, which will generate electricity. This is the most crucial aspect of hydropower concepts.

It is presented in this thesis how a Pico hydropower project's transmission infrastructure was designed and developed. The turbine, penstock, shaft, and the entire hydropower plant were all taken into account throughout the analysis. To test this hydroelectric system, the water of a nearby river was used as a source of water. The hydroelectric plant consists of a water intake, penstock, hydro turbine, gear system with shaft, and generator.

1.2 Problem Statement

Hydroelectric plants do not produce the waste heat and gases that are produced by plants that are fueled by fossil fuels. These emissions are a key contributor to issues such as air pollution, global warming, and acid rain. The challenge is that, despite the fact that hydropower plants are a renewable source of energy that is great for the environment, the construction of a dam for a hydropower plant may cause damage to or have a negative impact on the environment both upstream and downstream while the dam is being built. A pico hydropower (PHP) system is a more environment friendly renewable energy. This is because the hydraulic works can be made simple and large constructions such as dams are usually not required. This PHP is simple to be installed due to the parts like pipes, generators and others are usually cheap and easy to find.

In addition, the construction of dams slows the flow of water, which reduces the amount of oxygen that is present in the water. There is a possibility that decreasing oxygen levels behind the dam will lead to decreased oxygen levels further downstream. When there is less oxygen in the water, it is more difficult for some fish species to survive, which can have a negative effect on the ecosystem of a river. Dams pose a significant risk to the migratory of fish, particularly for species like salmon that are reliant on rivers for their reproductive processes.

This pico hydropower system has become more and more important due to few reasons. The first is the system is this system is close to the demander place, hence the development cost is way much cheaper and the money is saved up. Besides, micro hydropower system has become more demandable due to the increasing of energy price worldwide.

1.3 Research Objective

The main aim of this research is to design of a better micro hydropower gear system, which should be evaluated in real-world conditions. Specifically, the objectives are as follows:

- i. To identify the technical requirements of a pico hydropower transmission system.
- ii. To study and design the improvement of pico hydropower transmission system which should be tested at real condition.
- iii. To analyze the efficiency and power output of the pico hydropower transmission system.

1.4 Scope of Research

Defining the project's scope means determining exactly what it is that must be studied in order for it to proceed smoothly. The scope of this research are as follows:

- i. An appropriate transmission system for use with the modified water turbine must be selected and built.
- ii. Pico hydropower system, which may produce 200W to 5kW of power.
- iii. Installing a hydropower plant.NIKAL MALAYSIA MELAKA
- iv. Showing that this customised water turbine is capable of generating power in a realworld environment (full scale).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The availability of electric electricity is essential to the functioning of daily life because it is a necessity. The disparity between the demand for and supply of energy continues to expand, and as a result, its provision is becoming increasingly unfeasible. As a result, the majority of rural areas do not have connection to the power grid. As a direct consequence of this, there is a substantial demand for the generation of power in rural areas. The Pico Hydro Power Plant (PHPP) is one of the developing alternatives for rural electrification. This is due to the fact that it was created in close proximity to valleys and small rivers that are located far away from the national grid. The amount of electricity that can be generated using PHPP ranges from 0 kW to 5 kW. The powerhouse of the PHPP is located directly on the runway stream, and there are only minimal facilities for directing water towards the powerhouse; as a result, there is no requirement for a hydro governor. As a consequence of this, PHPP does not require the use of a reservoir in order to produce energy. The water that comes from the runway stream is diverted to the tailrace so that it can be used to create energy. The water is then redirected back to the runway stream. In contrast to large hydroelectric power plants, the Philippine Hydroelectric Power Plant (PHPP) has a marginal impact on the environment. The PHPP Powerhouse is situated in a place far from the national grid, which should result in a reduced need for maintenance. In addition, the powerhouse needs to be equipped with a reliable control system in order to maintain constant power generation. A reliable control system will have a consistent transmission, which will ultimately lead to consistent speeds for both the turbine and the generator. Because of the

uneven flow of water, a hydroelectric system without a hydro governor will have variable turbine speed, which will result in variable generator speed. The installation of PHPP is a challenging endeavour to undertake because there is currently no technological breakthrough that can keep the speed of the generator constant. As a consequence of this, an innovative design for the transmission system is required in order to keep the speed of the generator constant despite variations in the speed of the input turbine.

2.2 Distribution Network Configurations and Components

2.2.1 Direct Transmission

In direct transmission, the turbine and generator shafts are connected in a direct connection, resulting in extremely high efficiency. This means that both turbine and generator must be custom-built, which is a waste of time and money. As a result, it is not suited for PHPP use.

2.2.2 Indirect Tranmission

An indirect transmission system is used to ensure that the turbine and generator are operating at the same speed. To compensate for the fact that normal generators operate at a substantially greater rate of rotation per minute, a speed multiplier is used in PHPP. Many indirect transmission technologies are available for PHPP according to literature. Because of its limited efficiency and load sharing capacity, chain and belt drive is only employed in applications requiring a low transmission ratio and generating power of less than 3 kW.

2.2.3 Types of Gear

Belts, chains, and gears are a few of the possibilities for connecting the generator to the turbine in hydro systems. Their cost is so low that they aren't a substantial part of the overall plant cost when utilised with standardised turbines for modest hydropower projects that require gearing. The advantages and downsides of each type can be found:

i. **Spur Gears**, due to their relatively limited transmission ratio, which is required by their total dimensions, these devices are often utilised for low-power applications only. Figure 2.1 shows the spur gear.



ii. Orthogonal Bevel Gears, this type of transmission system is only suitable for low-

power applications because it can only be utilised with a modest transmission ratio. Figure 2.2 shows the orthogonal bevel gear.



Figure 2.2 The orthogonal bevel gear.

iii. Belt Transmission, trapezoidal belt transmissions are the most common in

hydropower plants, although their efficiency is low, making them ideal for low-

power applications. Gear belt transmissions are most efficient for tiny units with capacities of less than 3 kW, when the efficiency is crucial. Figure 2.3 shows the belt transmission gear.



Figure 2.2 Belt transmission gear.

iv. **Planetary Transmission**, with its compact design and middling efficiency, it's employed in a small hydroelectric power plant on Prut River. Figure 2.4 shows the planetary gear.



Figure 2.4 The planetary gear.

Table 1 shows the comparison between gear and planetary transmission. The planetary gear drive has high power to weight ratio with high load carrying capacity. Also,

more than one speed ratio is achieved when compared to fixed axis gearbox. Planetary gearbox has good efficiency, reliability, and compactness hence it is preferred for PHPP.

Types of transmission	Efficiency	Application	
system			
Gear transmission	75-85%	Low Transmission	
Planetary gear transmission	95%	High Transmission	

Table 2.1 Comparison between gear drive planetary gear drive.

In PHPP, generator operates at higher speed than the turbine. Figure 1 shows the schematic illustration of a planetary gear. Depending on the conditions at the input, a conventional planetary gear drive either increases or decreases speed. Planetary gear transmission functions as a speed multiplier when the ring gear is fixed, the turbine is linked to the carrier for input, and the sun gear is attached to the generator for output. Similar to how sun gears work as speed reducers, planetary gear transmissions serve as speed reducers when input motion is applied to the sun gear and output is taken from the carrier. The output speed changes in proportion to the input speed by a quantity called the transmission ratio. Since variable turbine speed cannot be controlled to maintain constant output speed, if the turbine speed fluctuates, the generator speed will also change. In order to maintain consistent generator speed, a fresh idea must be developed.



Figure 2.5 Schematic illustration of Planetary gear.

The small hydroelectric facilities, which are built for specific water flow and head values, are situated along rivers. The production of energy stops when the river flow reaches a certain threshold. Unless the tiny systems are large enough to run regardless of river flow, they might not always be able to provide electricity. These restrictions set by the water flow may be exceeded due to the tiny hydro electromechanical equipment's design. A gearbox placed between the turbine and the generator can be used to improve angular velocity. Because there is little water flow, the hydro turbine shaft may revolve considerably more slowly than what is needed by conventional electric generators. The pace of multiplication might vary between three and five times. However, employing a transmission to achieve the required speed multiplication has drawbacks linked to the system's effectiveness, overall size, and cost.

2.2.4 Gearbox

There are three major types of gearboxes used in small hydropower plants: belt transmission, parallel shaft and planetary gearbox. First, friction losses are substantial, and as the multiplication ratio grows, so does the overall size. In order to raise the transmission ratio, more stages must be connected in series in the second scenario. While increasing the transmission ratio, this configuration also increases the gearbox's total size. The input and output shafts are coaxial in planetary gearboxes, resulting in a reduction in total dimensions and a lighter and more compact design.

Low-head hydroelectric power plants' standard machine solution is an asynchronous generator coupled to a turbine via a gear increasing speed (usually the squirrel cage induction machine). This is a widely used and widely abused approach. The construction of power plant buildings and their flood protection is essential for a multi-element energy producing system. Hydrotechnical construction for low-head projects costs 50% to 70% of the entire

investment. The basic solution eliminates the construction's economic feasibility for those at the bottom of the food chain. Using a gearbox has the drawback of introducing mechanical losses into the system. Using oils and greases is also against the law at the moment. The rated efficiency of a low-cost asynchronous generator at 75% power is maintained, but its electrical losses rise by up to 60% below that level. The availability of replacement parts and the ease with which repairs and maintenance can be carried out are among the advantages.

2.3 Turbines

In hydroelectric power plants, equipment known as hydro turbines are utilised to convert the kinetic energy of moving water into the rotational energy needed to turn a shaft. This results in the production of electricity. When water is fed to the blades of these turbines, it causes them to rotate or spin in reaction. In the field of hydropower, often known as the generation of power from water, these turbines are an absolutely necessary component. The turbine is the most important component of a hydroelectric power plant since it is where the water's potential energy is transformed into the rotating force that powers the generator (A. Nasir, 2013). The potential energy of the falling water is converted into the kinetic energy of falling water as a result of the force of gravity (Nasir, 2014). When the kinetic energy of the moving water in hydraulic turbines is used to turn blades or vanes, the form of the energy that is produced is transformed into mechanical energy. The generator rotor is turned by the turbine, which results in the conversion of the mechanical energy into electrical energy. If the amount of water flowing through the turbines is decreased, the amount of available power will likewise decrease, and vice versa. When a small, mini, or micro run river turbine is installed into a canal, there is no need for a larger dam. Instead, all that is required is a little dam, which must be constructed in a way that does not do any harm to the aquatic life or cause any destruction to the land (Williams & Simpson, 2009). There is also another type of run river turbine that functions independently of the dams. The capacity of the upstream and

downstream streams, in addition to the head difference between them, determine how much energy may be recovered from the water.

In the past few years, a multitude of articles have emphasised the need of utilising turbines with a straightforward design and straightforward construction in order to attain the lowest possible beginning costs for hydropower facilities (Derakhshan & Nourbakhsh, 2008). According to Paish (2005), hydropower turbines are experiencing rapid growth in the field of power generation, particularly in rural and hilly areas. As a result, the power generated by these turbines can meet a variety of load demand requirements on a grid supply. Table 2.2 provides a classification of hydropower systems based on the amount of power that they generate.

Table 2.2 The classification of hydropower plant based on the generated power output.

Hydropower Plant	Electricity Output
Large	> 100 MW
Medium	> 15 – 100 MW
Small	> 1 - 15 MW
Mini	> 100 kW – 1 MW
2) Micro June , South	> 5 kW - 100 kW
Pico	** <5 kW

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.4 Generator

An electric generator is a machine that creates electricity from some other form of power. There are a wide variety of generators for generating electricity. This discovery by Michael Faraday, a British scientist, in 1831 led to the development of the majority of the world's electrical generators, which are based on his findings. The Faraday disc, the first electricity generator based on this magnetism-to-electricity ratio, led to the development of the modern electromagnetic generators.

An electromagnet, rather than a conventional magnet, is used in electromagnetic generators. A basic electromagnetic generator consists of a stationary cylinder (the stator)

surrounded by an electromagnetic shaft (the rotor) made of insulated coils of wire. Rotating the rotor causes a separate electric conductor to form in each part of the wire coil. One huge current is formed by the currents in each section. This current is the electricity that travels from the generators to the customers via power lines. Nearly 90% of the electricity generated in the United States comes from electromagnets powered by kinetic (mechanical) prime movers. Figure 2.6 shows the flow of electricity generation from turbine to consumer.



Figure 2.6 The flow of electricity generation from turbine to consumer.

2.4.1 Generator Selection

There are a number of factors to consider when deciding how many and what size units to use for an isolated pico-hydro station that provides all of a power system's output, such as its load curve. The economics of equal-sized hydro-units can also be impacted by hydraulic equipment, the penstock, the draught tube, and other construction elements (Varughese & Michael, 2013).

The primary generator requirements for a micro-hydro station include output power in kW, kVA capacity, kHz, stator winding connection, voltage, current, power factor, speed, cooling technique, temperature increase, type of excitation, excitation voltage, and machine reactance. With a big diameter and short rotor, they are known as pico-hydro generators, which are low-speed machines of salient-pole type. The power factor for which the generator is designed up to (0.95) lagging. The generator speed is governed by the turbine speed, which depends on the specific speed of the particular type of the turbine.

The power conversion efficiency of a conventional generator at low speed, on the other hand, is not so high, the speed must be enhanced by means of a gearbox and/or a belt. Such components, on the other hand, will add expense and require additional maintenance to the PHPG system. Hence, a low-speed direct-drive generator should be designed for the above system (Wei et al., 2020). (Wei et al., 2020). Some pioneering works for low-speed direct-drive generators have been reported for wind generating and PHPG system. Power conversion efficiency and cost are the key concerns of the existing low-speed generators of the PHPG system. Induction generator and synchronous generator are frequently utilised as the generator of PHPG system. Early PHPG plants employ a conventional synchronous generator with a DC excitation method. Considerable efficiency and automatic voltage management can be achieved, but at a high price.

The squirrel-cage induction generator is also suited for PHPG system, because of low cost, resilience and low fault level (Braga et al., 2015). (Braga et al., 2015). In order to compensate for the absorbed reactive power, capacitor banks will have to be installed, which will raise the cost. Since PMSGs with multi-pole structures have high efficiency and cheap cost, they are a good contender for the PHPG system's generator (Ducar & Ion, 2012). However, optimization of performance and reduction of production costs are not taken into account.

2.5 Penstock

Pipelines transport water from the dam or reservoir to the turbine via penstocks. A penstock's material, length, inner diameter, and layout are all critical since they have a significant impact on PHP's startup costs and overall performance. The water turbine's impeller is turned by the penstock, which increases the speed and power of the water flow.

Because the penstock is a costly part of the system, it must be shortened and narrowed in diameter. In order to optimise penstock setups for PHP systems, researchers Fraenkel et al. (1999), Maher & Smith (2001), and Alexander & Giddens (2008) provided crucial guidance. Williams and Simpson (Williams & Simpson, 2009) researched the optimum head losses of penstocks in PHP systems in more recent years. The results of the study show that a configuration for less than 10% head loss in the gross head type is likely to offer the most useful options for consumers. To prevent air bulbs from forming and causing damage to the water turbine and pipelines, the penstock should always be kept firmly down.

However, the erection method and materials also play an important role. Because of this, penstock material and associated criteria such as surface roughness, design pressure, method of jointing, weight and ease of installation, availability, and maintenance are carefully considered when selecting penstock material (Mishra et al., 2012). Selection of the best material is a significant task in designs for mechanical, electrical, thermal and chemical applications (Cicek & Celik, 2010). Hydropower design incorporates material selection as an input consideration. Many novel materials are used in modern life to reduce weight, cost, and improve performance (Huang et al., 2010). A typical penstock water velocity of 3 m/s is positioned at a slope of more than 45 degrees.

2.6 Morphological Chart Consider to merge this topic in Chap 3

It is based on Fritz Zwicky's General Morphological Analysis (GMA) method for investigating complex non-quantifiable problems (Ritchey, 2013; Ritchey, 2017). Problem decomposition (design divergence) is used to generate various sub-solutions for each of these (problem decomposition), and then selection and combination of the appropriate subsolutions into alternative overall solutions (design convergence) are employed (Cross, 2000; Magrab, Gupta, McClusky and Sandborn, 2010; Pahl and Beitz, 1996; Roozenburg and Eekels, 1995; Wright, 1998). The solution space is expanded in search of all conceivable ways that can operate as a solution for a subfunction using this method, which is advised for usage in the early phases of idea creation. This includes a search for form, as the word (morph-) implies. The morphological chart method, according to Richardson, Summers and Mocko (2011), has the following advantages: it broadens the design space that can be explored; it generates new concepts that would otherwise go unconsidered; and it represents a wide range of concepts that allow the unexpected matching of components to be taken into consideration.

To show sub-solutions, the morphological chart uses a table with a first-column subfunction list and numbers in the heading row cells (Table 2.3). As a first step in this method, it is necessary to identify the functions that the final solution is expected to perform. This can be done using various methods, such as function analysis (Sapuan, 2005), brainstorming (Yang, 2009), determining product design specifications, and customer requirement analysis (Wright, 1998). A sub-function is expected to be considered while filling out the morphological chart (Wright, 1998), and this works best when the sub-functions are considered as independent of one another as possible (Wright, 1998). (Cross, 2000; Roozenburg and Eekels, 1995).

Table 2.3	Example of	Morphologica	l chart design s	selection.

Design Features	Design 1	Design 2	Design 3	Design 4
Feature 1				
Feature 2				
Feature 3				
Feature 4				
Feature 5				

2.7 Performance Analysis of Pice Hydropower Generator

2.7.1 Calculation of the Net Head

For the pico-hydro scheme, hydraulic head H can be calculated at any location where elevation z, pressure p, and velocity v are known using:

$$Hg = p/\rho g + v2/2g + z$$
 (2.1)

The net Head,

$$Hn = Hg - Hf$$
(2.2)

Hg = The gross head which is the vertical distance between water surface level at the intake to the turbine.

Hf = Total Head losses due to open channel .These losses approximately equal to 6% of gross head. The jet head, Hj = Cv2 Hn (2.3)

2.7.2 Calculation of Water Flow Rate

The water flow rate can be calculated by the measuring the river or stream flow velocity and its cross-sectional area, then:

$$Q = A \times V \tag{2.4}$$

A = Area of channel

V = Velocity of stream

2.7.3 Calculation of Power

$$P = \rho \times g \times Q \times Hi \tag{2.5}$$

Where ρ is the density of the fluid and g is gravity.

2.7.4 Calculation of Gear

$$N_p \times d_p = n_c \times (d_p + d_s) - n_s \cdot d_s$$
(2.6)

In this equation, n_p denotes the rotational speed and d_p the diameter (pitch circle) of the planetary gear. For the sun gear, the speed is denoted by n_s and the diameter by d_s . The rotational speed of the carrier is denoted by n_c

2.7.5 Runner Design

The mean velocity of the free jet emerging from the nozzle of the turbine is determined from the net head, by the equation:

$$Vj = Cv\sqrt{2g} \times Hn$$
 (2.7)

At the best efficiency point the circumferential speed of the runner is connected with the jet velocity via the relation.

$$U = (0.46 - 0.47) \times Vj$$
 (2.8)

Hence the Diameter or runner is

ALAYSI

اونيوم سيتي تيڪ
$$M = 60 * U/\pi N$$
 مليسيا ملاك (2.9)

Where N is the speed of runner in rpm.

2.7.6 Diameter of Nozzle of Jet

$$d = \sqrt{4Q/\pi Vj} g \tag{2.10}$$

2.7.7 Number of Buckets

$$Z = 15 + D/2dh$$
 (2.11)

2.7.8 Open Circuit Test

In most cases, the OCT is used to test PHP's overall performance in the absence of any external stress. It is measured each hour for 24 hours a day, the PHP yield voltage and the generator's speed. The methods previously discussed are used to record the water pressure and flow levels (Sopian & Razak, 2009). In order to obtain authentic performance data while using distributed water sources, OCT is generally carried out at household HP/PHP stations. Finally, by graphing and analysing the measured data over the OCT, the optimal water flow rate and ideal period for running the PHP system could be determined.

2.7.9 Efficiency of PHP

Predominantly, the productivity of the PHP system is evaluated and determined by using the subsequent formula (Yadav, 2014):

Efficiency(
$$\eta$$
) = $\frac{P_{out}}{P_{in}} \times 100\%$ out (2.12)

The output power (Pout) is obtained from the peak power delivered test. Whilst the input power (Pin) is achieved from the data of OCT during performing maximum power delivered test. The overall formulas for any HP/PHP system's power input or output are:

$$P_{out} = \rho x g x H x Q$$

$$P_{in} = \eta x \rho x g x H x Q$$
(2.13)
(2.14)

Where,

- P_{in} = Input power (HP/PHP)
- P_{out} = Output power (W, watts)
- ρ = Water source's density (kg/m3)
- g = Gravitational acceleration (9.81 m/s2)
- H = Effective head or pressure (m).
- η = the hydraulic effectiveness of the water turbine (%)
- Q = Water flow rate (m3/s or L/s)

Several studies have shown that the best turbines have a maximum hydraulic efficiency of 80–90 percent. A typical micro-hydropower (MHP) generation efficiency ranges from 60 to 80 percent (Paish, 2002).
2.8 Summary of Literature Review

Table 2.4	Summary	of	previous	research	findings
1 uoie 2. i	Summary	O1	previous	rescuren	intuings.

Title	Author	Problem Statement	Objectives	Methodology	Finding
Pico Hydro: Clean	(Sopian & Razak,	Other forms of	The focus of this	It is affordable,	When there is a
Power From Small	2009)	renewable energy,	research is on pico	ecologically benign,	substantial seasonal
Streams	S.	such as solar	hydro, a run-of-river	and the turbine may	fluctuation in flow
	5	photovoltaic	application that does	be produced locally.	rate, the crossflow
	ũ –	modules, which are	not require a dam or	Several developing-	turbine shows to be a
	-	only accessible for a	reservoir to store	country applications	viable turbine for low
	-	few hours every day,	water.	are emphasised.	flow and low head
	6	are extremely		Small-scale hydro	installation. When
	45 -	expensive.		turbines and their uses	given appropriate
	1/10			in the power	head and flow rate,
				generation	this low-cost turbine
	shall (environment are	may produce three
	سا ملاك	mb. D	n win	discussed. Finally, the	times the amount of
		. 0 .		study examines	energy produced by
			4 ³	Universiti	solar panels at a lower
	LIMIVEDOI		I MALAVEL	Kebangsaan	rate.
	UNIVERSI	II IENNINA	L MALATON	Malaysia's (UKM)	
				attempts to promote	
				this technology for	
				the rural	
				electrification	
				initiative.	
Developing a	(Soewardi & Putra,	However, there are	The goal of this	Consumer demands	The findings of this
Portable	2018)	still several issues	research was to	were identified	study revealed that

Hvdroelectric		with the current	redesign a portable	through a survey, and	the suggested
Generator Using		portable design, such	hydroelectric power	the axiomatic design	portable generator
Axiomatic Design		as its large size and	generator that could	technique was utilised	design may boost user
Method		unappealing	meet user needs.	to derive design	satisfaction by up to
		appearance; it is		parameters through a	73.67 percent,
		unpractical and risky		mapping process	indicating that it is
	1 A.V.	to operate, resulting in		based on customer	distinct from the
	MALAIS	ineffective and		attributes and	present design. At a
	2	wasteful use of the		functional	5% significance level,
	E.	generator, as well as		requirements. To test	the design generated
	2	putting people's lives		the idea, a statistical	is also valid to fulfil
	×.	in danger. This is		study was performed.	user requirements,
	F	because the design			such as being robust,
	-	does not fulfil the			waterproof,
	5 =	user's requirements.			appealing,
	°2. =				lightweight, compact
	Allen				in size, and portable.
Low head pico hydro	(Williamson et al.,	Under 5 kW, the	Using quantitative	The end user'sspecific	Depending on the
turbine selection	2014)	requirements are	and qualitative	requirements dictate	ultimate top-level
using a multi-criteria	سا ملاك	frequently different	studies of 13 turbine	the us a the	requirements, a
analysis	12	from those of larger	system architectures	quantitative and	propeller turbine with
		size turbines, and	reported in the	qualitative selection	a draught tube or a
	UNINCOS	qualitative criteria	literature, this	criteria. Individual	single-jet Turgo
	UNIVERSI	become increasingly	research presents a	scores from this	turbine has been
		important in	technique for	analysis are weighted	demonstrated to be he
		selection. By using	determining which	depending on the	optimum option for a
		non-typical	turbine architecture is	perceived relative	particular low head,
		components like as	best suited for a low	relevance of each of	variable flow
		low-speed generators,	head pico hydro	the criteria in	specification using
		pico hydro turbines	specification.	comparison to the	this approach.
		can be used outside of	1	original specification,	

		these standard application domains, such as at lowerheads.		and the overall weighted score is used to choose a	
				turbine variation.	
A review on turbines	(Jawahar & Michael,	Various organisations	This research looked	This article contains a	While comparing the
for micro hydro	2017)	throughout the world	at the turbine of a	comprehensive	functioning of other
power plant	AL AV	have looked into the	small hydro plant	overview of turbines	current systems for
	Warnin	design of micro hydro	from the standpoint of	available in India and	comparable operating
	S.Y	power plants because	increasing efficiency	other nations. The	conditions, this study
	S	it has the potential to	while keeping the	head selection, runner	demonstrates an
	3	provide 🐔 greater	project's overall cost	diameter, and	improvement in
	Ť.	performance than	per kW within a	achievement are also	turbine design.
	F	traditional fossil fuels	certain range.	discussed.	Because most power
	-	in meeting energy			plants nowadays
	5	needs. Improvements			employ huge turbines
	°2. =	in hydro power, when			for low power
	Allen	considered as part of			generation, losses and
		the energy portfolio,			total costs rise, this
	the l	will result in lower	/ 0 .	* 1	survey will be useful
	2No lu	greenhouse gas	i Su i	au nous	in lowering plant
		emissions and		. 0	costs.
		improved grid			
		malleability.			
A review on micro	(Erinofiardi et al.,	Large hydro power	The situation of micro	This study examines	There should be a
hydropower in	2017)	plants are less	hydropower in	the present state of	genuine effort to
Indonesia		appealing in the	Indonesia is discussed	micro hydropower in	overcome some of the
		current world	in this research.	Indonesia and the role	roadblocks to the
		economy due to		of micro hydropower	growth of micro
		environmental		in meeting the	hydro, so that this
		concerns and high		country's energy	most advantageous of
		construction costs.		demands. This article	renewable energy

	HALAY:	AREL PKA		goes on to discuss the key renewable energy resources accessible in Indonesia, as well as the problems and potential for promoting renewable energy technology, before concluding with recommendations for renewable energy development and acceptance in Indonesia.	power plans may be achieved. The government's goal is to have a bigger share of renewable energy sources in Indonesia's energy mix.
Design and	(Kader et al., 2016)	Large-scale	This article discusses	Solid Works software	This idea
Construction of a	AINO	hydropower projects	the core principle of	was used to create a	significantly
Mini-Hydrodynamic		can be contentious	hydropower	prototype turbine.	improves total
generator	chil (because they alter	generating in this	The turbine power	efficiency. This tiny
	سا ملاك	downstream water	project.	and speed were	hydro power
	14	supplies, inundate		directly proportional	generator's power
		precious nabitats, and	4 ³	to the site head,	determined To
	LINIVERSI	human relocation	I MALAVSU	fluctuation of the site	summarise if this
	OTTIVETO	numan relocation.	la metaren on	water flow rate there	concept is
				were specified places	implemented in a
				for maximum turbine	hydroelectric power
				power and speed. The	plant, the output of
				force of water at a	electricity generation
				high velocity rotates	will grow.
				the turbine. Because	

				the turbine shaft is	
				connected to two	
				dynamos, the rotation	
				of the turbine results	
				in the rotation of both	
				dynamos.	
Prototype Design of	(Weking &	The biggest issue with	Create a prototype of	The effect of water	The outcome of this
Micro Hydro Using	Sudarmojo, 2019)	micro hydropower	micro hydro using	pressure and the slope	investigation using
Turbine	2	plants is that their	Archimedes Screw	of the altitude angleon	homemade equipment
Archimedes Screw	31	water discharge does	Turbine to	the rotation produced	in angle 400 with the
for Simulation Of	2	not continue year	hydropower practical	by the Archimedes	largest generator
Hydropower Practical	ă -	after year due to	in a laboratory to	screw turbine will be	round (rpm) of 3765
Of Electro	E C	weather conditions.	expand a college	discussed in this	(rpm), greatest power
Engineering Students	-	Knowing a right of	student's expertise in	article so that the	of 10.91096 watt,
	5 <u>8</u> =	micro hydro's	the hydropower area.	voltage, current,	torque of 0.60257Nm,
	*3 =	characteristic is not a		power generated by	and efficiency of
	Alter	simple thing to do,		the generator, torque,	14.07 percent.
	an .	because each micro		and efficiency can be	_
	111	hydro installation	1 0	observed.	
	2Nolu	area is regarded a	· Si ·	auto mar	
	5	unique place.			
Micro Hydro-Electric	(Karim, 2017)	Because of	Population		Estimating micro-
Energy Generation-	UNID /EDOI	population increase,	expansion,		hydro energy
An Overview	UNIVERSI	industrialization, and	industrialisation, and	AMELAKA	potential as a function
		modernization,	modernization have		of head and flow rate,
		energy is needed now	all increased the need		as well as planning,
		more than ever.	for energy. CO2		benefits, and
		Carbon dioxide	emissions and the		limitations, will be
		(CO2) emissions and	depletion of		discussed to offer a
		the depletion of	traditional energy		fundamental
		traditional energy	sources need the use		

		sources need the use	of renewable energy		understanding of
		sources among which	bydro apargy appears		mero-nyero systems.
		budro anargu annoarg	to be the most		
		to be the most	denondoble		
		demondable	dependable.		
D'	$(\mathbf{V}_{2}, \mathbf{l}_{2}^{*}, \mathbf{u}_{2}, \mathbf{t}_{2}, \mathbf{t}_{2})$	The bish sector and		The foundation of all	Té
Pico nyaropower	(Kadier et al., 2018)	The high costs and	The goal is to give	The fundamental	It may be concluded
(PHP) development	1. 10	negative	Malaysia and other	ideas or concepts of	that the HP/PHP, as a
in Malaysia:	3	environmental effects	Southeast Asian	PHP were discussedin	renewable power
Potential, present	S	associated with big	countries with critical	this work for a better	generation
status, barriers and	5	HP plants have helped	strategic implications	knowledge and	technology, is a viable
future perspectives	i i	to focus attention on	for the development	recognition of this	solution for realistic,
	F	tiny or pico-scale HP	of pico hydropower	sort of energy or	long-term
	-	plants, which have far	plants	power generation	decentralised remote
	SA =	fewer of these effects.		system. In addition,	region electrification
				the current state of	and power generation
	Allen			PHP in Malaysia, as	systems, particularly
				well as the existing	in mountainous
	111	112	1 0	installed capacity and	locations with
	2Nolin	cel alu	· Si ·	potential of PHP	abundant HP
				energy resources, are	resources.
	-			examined. Aside from	
				that, the paper	
	UNIVERSI	TI TEKNIKA	L MALAYSI/	discusses the	
				obstacles to PHP's	
				spread in Malaysia, as	
				well as the major	
				difficulties and	
				prospects for PHP's	
				future development in	
				Malaysia.	

Conceptual design of	(Bhargav et al., 2018)	Hydro governors are	Due to its increased	For MHPP, a	As a result, the
planetary gearbox		not used in the	efficiency and small	proposed planetary	planetary gearbox's
system for constant		MHPP, resulting in	size, a planetary gear	gearbox system is	basic architecture
generator speed in		turbine speed	transmission system	being designed to	may be employed to
hydro power plant		fluctuations. For	is being investigated	keep the generator	maintain a constant
		consistent power	for MHPP to achieve	speed constant.	generator speed. A
	ALAYS	generation, MHPP	this.	ADAMS software is	MHPP that generates
	Macrice	requires either speed		used to develop,	continuous power of 5
	and the second s	or torque		model, and analysethe	kW at a constant
	E.	amplification of the		conceptual	generator speed of
	3	generator.		gearbox.	1490 rpm is examined
	1	P			and certified in this
	F				research.
Design and	(Ighodalo	The use of gas power	This research aims to	The turbine study was	Water flow rate test,
Construction of a	Okhueleigbe, 2018)	plants for energy	design and build a	conducted using	stator coil resistance
Mini Hydro Turbine	3A =	(power) generation	mini hydro turbine	Pelton's wheel design.	test, output voltage
Model	Allen	has become a global	generator that can be	Potential energy is	test, power quality
		challenge as the world	made available at the	contained in water	test, and rotational
	del (shifts away from	consumer level, in	kept at a three-meter	speed test wereamong
	- No hu	polluting generating	order to improve	height in a tank or	the testsconducted for
		systems and facilities	power generation and	reservoir, and this	thisstudy. The output
		toward those that are	availability at a lower	water is permitted to	power result indicates
	LININ/EDOI	environmentally	cost without polluting	fall on the turbine	that domestic
	UNIVERSI	friendly. As a result,	the environment, in	wheel, which spinsthe	electricity can be
		hydro schemes should	order to help	turbine. By turning	created at the
		be encouraged in	developing countries	the runner linked to	individual household
		conjunction with	boost power	the turbine blade, the	level, which willassist
		renewable sources of	generation and	potentialand kinetic	strengthen and
		power generation to	quality of power to	energy	stabilise the national
		help developing	their power	available in the water	grid.
		countries reach their	consumers.	is transferred to	

		power stabilisation		mechanical energy.	
		stage.		The runner is linked	
				to the rotor (which	
				contains the	
				permanent magnet)	
				and the stator (which	
	A AVI			contains the	
	MALAIS	14		windings) of the	
	2	20		alternator, which is	
	S.			kept at an acceptable	
	S.	*		air gap from the rotor	
	i i i i i i i i i i i i i i i i i i i	P		for effective	
	F C			induction. The	
				voltage is tapped out	
	5 <u>4</u>			as a single phase	
	2A =			output from the stator,	
	Alter			which is utilised to	
	- an			power domestic	
	1.1.1	1 12	1 .	appliances and other	
	Male.	colo 15	· Si ·	machinery that	
				require electricity.	
Numerical Simulation	(Bhargav et al., 2019)	The input velocity of	An auxiliary gearbox	Analytical	When the test
and Experimental		the turbine fluctuates	with planetary	calculations are used	findings are compared
Validation of	UNIVERSI	with the flow of the	gearbox is devised in	to construct the	to the analytical
Planetary gearbox		water stream, as does	this work to maintain	planetary gear and	approach and
System Design to		the generator speed.	constant generator	auxiliary gearbox	multibody dynamic
Govern Constant		As a result, the	speed for a variety of	based on these	simulation results,
Generator Speed in		difficulty is to come	input turbine speeds.	criteria. The entire	they are shown to be
Hydro Power Plant		up with a gear		system is simulated	in close agreement.As
		arrangement that		such that Multi Body	a result, the
		would keep the		Dynamic simulation	developed system can

		generator speed		can be used tovalidate	maintain a consistent
		constant.		kinematic analysis	generator speed when
				(analytical approach)	the turbine speed
				and FEA can be used	fluctuates.
				to analyse stresses	
				in the	
	AV AV			planetary gearbox	
	MALAIS	14		system. To keep the	
	2	7.C.		generator speed	
	S	S		constant, the auxiliary	
	3	8		unit and planetary	
	Ť.	P		gearbox are	
	F			manufactured and	
				tested under no load	
	1			conditions.	
Efficiency analysis of	(Wegiel et al., 2016)	The fluctuating	The efficiency of a	The variable speed	The variable speed
an energy conversion	AINO	hydrological	small hydropower	operating approach	operation used in this
system for a variable		circumstances	plant's energy	was employed to	method enhances
speed small	del (inherent in run-of-	conversion is	achieve great	efficiency under
hydropower plant	سا ملاتے	the-river projects, on	investigated in this	efficiency over a wide	varying hydrological
	13	the other hand, need	research.	range of water flows.	circumstances,
		operations throughout	4 ⁴	In order to match the	especially when the
	LIND/EDGI	a wide range of water	L MAL AVOL	load and manage the	output power is low.
	UNIVERSI	flow and head	L MALATSI	power flow from the	Furthermore, the
		fluctuations. To		generator to the grid,	range of operations
		maintain high		a Power Electronic	has been greatly
		efficiency in energy		Unit is required in the	expanded.
		conversion systems,		energy conversion	
		certain control		system.	
		annroachad and			

		system topologies are			
		required.			
Review on numerical	(Chitrakar et al.,	Current state of the art	The goals of this	The numerical	There have been
techniques applied in	2020)	at the intended	study are to present an	approaches that have	experiments where an
impulse hydro		working load, Pelton	overview of the	been used in the field	entire domain was
turbines		turbines can achieve	numerical techniques	of impulse hydro-	represented,
	ALAY	over 90% efficiency.	used in the subject of	turbines during the	including manifolds,
	Manual	However, by	impulse turbines, as	last 15 years are	nozzles, and the
	1 Alexandre	adjusting the design	well as to lay the	discussed in this	runner of the Pelton
	3	of the nozzles, runner,	groundwork for	work. CFD	bucket, resulting in a
	3	and/or housing, these	developing a viable	techniques may be	thorough description
		turbines' efficiency at	approach for future	classified into two	of jet-to-jet and jet-to-
	F	off-design conditions	research in this topic.	categories: Eulerian	bucket interactions.
	-	might be improved.		and Lagrangian. From	The Lagrangian
	SA =	Furthermore, given		the existing literature,	technique was shown
		the existing mesh		the methodologies	to be more
	Allen	quality, validating		involved in	appropriate for
	- (1.1)	numerical solutions		constructing the	investigating the free
	the l	remains a difficult	1 0 .	numerical model,	surface flow of
	200 4	task.	i Su i	various flow studies,	impulse turbines, with
				design optimizations	encouraging findings.
				applied, and	
	LININ /EESO		L BRAIL AND	validations have been	
	UNIVERSI	II TEKNIKA	L MALAYSI/	reviewed.	

•

CHAPTER 3

METHODOLOGY

3.1 Introduction

The research techniques utilised to carry out the study are thoroughly defined in this chapter. The researcher describes the procedures used in gathering, organising, and analysing the data and information required to meet the study's objectives and questions. The research design, research tools, data sources, data gathering methodologies, datapresentation approaches, and analytical techniques employed have explanations and justifications. The method's whole implementation process is described in detail.

3.2 Flow Chart

It is envisaged that the project would involve numerous diagrams and graphs. As a visual representation of the process, a flow chart is crucial. Different types of stream processes are depicted in the flow chart by the various shapes. Lines and bolts are used to demonstrate the methods. Figure 3.1 shows the project's flow diagram. The segment demonstrated a method for explaining the problem. This is the answer to the problem's elimination.



Figure 3.1 Methodology flow chart.

3.3 Research Phases

3.3.1 Phase 1

Phase 1 begins with the inception and conceptualization of the project over the first 14 weeks of the project. Additionally, the current problem statement for the project will be determined in order to find relevant research in this phase. The house of quality approach and morphological chart are used to construct the pico hydropower design. Pugh's approach is used to analyse the conceptual designs to determine the optimum design concept.

3.3.2 Phase 2

At the end of the course, the second phase of the project begins. The implementation and analysis stages are included in this phase. An evaluation of the project's influence on water treatment facilities will be carried out following the completion of a feasibility study. Next, data collection will begin at the control site, including measurements of the water channel (m), flow rate (m3/s), and water speed (m/s). The system's components are modelled in three dimensions using a variety of methods, including hand sketches and the commercial software SolidWork. Metalworking operations such as welding, bending, and lathing will necessitate physical labour during fabrication. After the system model is built, it will be tested in the field. The turbine's output power (W), torque (rpm), and water flow and jet flow velocity (m/s) will all be measured on site in order to examine the effect of these parameters on turbine performance.

3.4 Quality Function Deployment (QFD)

In order to better understand the needs of your customers, quality function deployment (QFD) is a useful tool to help you build new goods and services. The features and styles of the company's current products can also be tweaked to meet changing customer

demands (Singh et al., 2018). QFD aids in the comprehension of the significance customers have on the various expectations they set for themselves (Haiyun et al., 2021). It's difficult to figure out exactly what they desire. Most of the time, there are too many clients, and they all have distinct expectations, which may conflict with one other. For example, some consumers anticipate a hydroelectric plant to produce a lot of power, while others are looking for better efficiency. One other category of buyers may be looking for a mix of both power and mileage. When asked about their expectations, customers have a particular way of expressing themselves. Engineering or technical requirements can be derived from these expectations, known as 'voices of customers' (VOCs).

As a result, it is a powerful tool for developing new products and enhancing product quality, reducing time to market, and minimising production costs. It brings the voice of the client into the product development process. In this study, QFD is utilised as a strategy for developing a product that meets the needs of the Pico hydropower plant. Table 3.1 depicts the QFD needed to meet the hydropower plant's requirements.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ونيوم سيتي تيكنيكل مليسيا ملاك



Table 3.1 The Quality Function Deployment (QFD) table.

Based on data of Quality Function Deployment, the importance six critical specifications that should be highlighted in order to develop a pico portable hydropower generator are the lightweight, portability, size of turbine, ease of fabrication and ease of maintenance.

3.5 Morphological Chart

In order to produce new unique designs for the Pico hydropower plant, the first step is to combine all ideas. Design concepts will be generated by combining ideas from many sources. The ultimate concept design would be chosen by the designers from among all of the concept designs created. This proposed hybrid method makes use of the morphological chart (MC) to organise all of the ideas. The design component options for the hydropower plant were merged one by one to form the conceptual design. Conceptual designs were compiled from all of the available MC options. All conceptual designs were later assessed as part of the selection process for the final one.

To put it another way, it's an analysis of how something works. Designers must have a deep understanding of a wide range of engineering functions and how they are applied in order to build a good chart. This diagram will explain how each specific function a few has, if not many, ways to perform it. Concept generation is the final phase in the morphological chart process. It is possible to synthesise numerous solutions from each function to construct concepts once the subproblems have been solved. The first column following the functions can be devoted to a single notion. A list of engineering functions must first be compiled in order to begin the morphological chart for biomimicry.

The first step in creating a morphological chart is to compile a list of all the functions that are required. The level of information for each of these functions should be the same. Functional decomposition helps with this. That some aren't more specific than others is critical to keep in mind. A list of potential solutions is provided for each function. Charts with the functions either in a row at the top or in a column on the left side are the most common approach to display the data. In a row/column next to each function, list the various solutions. The number of means for each function can be added together to provide an idea of how long the list will be.

3.6 Pugh Method

In a decision matrix, this is an iterative decision-making procedure that works well for comparing several concepts based on pre-established requirements. Breaking down the method into the following steps has been done successfully (Emetitiri et al., 2020).

Step 1: Establish criteria for comparison

The notions are compared on this basis. It was decided to base the evaluation criteria on the goals of the thesis project, the design and production assignment, and the deadlines for completing those tasks. Table 3.4 shows the criteria and their description.

Number	Criteria	Description
1	Ease of fabrication	The gear should be easily fabricated.
2	Cost	Due to developing a pico portable hydropower system, the gear must be inexpensive
3	Lightweight	To relocate the pico hydropower system without difficulty.
4	Size of gear	The size of the gear needs to be in small scale to improve the portability.
5	Ease of maintenance	Able to attach and detach the gear.
	ىل ملىسيا ملاك	اونىۋىرسىتى تىكنىك

Table 3.2 The criteria analysed in the Pugh method.

Step 2: Selecting Alternatives to be compared "UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Recirculation, a mixture of both the lifting mechanism and the recirculation concept, and a combination of both are all possibilities.

Step 3: Evaluate the alternatives

It gets a "+" if it's better than the reference model in every way, but it gets a "-" when the opposite is true (Onn et al., 2020). If there is no discernible variation from the reference, it receives a "S" rating. Using the number of "+," "-," and "S" that each alternative received, the final score for each alternative is computed. A "+" is worth one point, a "-" is worth one point, and a "S" is worth zero points. The design with the most points is regarded as the best.

Step 4: Compute the satisfaction

Concepts and data are compared to generate four scores for each criterion. In addition to representing the Plus (+) and Minus (-) scores, the overall total and the weighted total are all represented by them.

3.7 Material Selection for Pico Hydropower Components

PAINO -

chi (

Choosing materials is a critical step that must be taken very seriously. Component performance and product integrity might be adversely impacted by the material utilised. Poor material selection can also lead to higher manufacturing costs by increasing the utilisation of certain resources. The shelf life of a product can be extended, and the product's overall performance can be improved by using the right material. Durability should be the primary consideration while selecting materials. There have been materials used in the design of a hydroelectric plant.

Material	نل مایسیا ما Copper	Polyamide 12	Stainless Steel	PVC
Properties				
Corrosion	High	No	Very Low	No
Resistance			, 	
Conductivity	Yes	No	Yes	No
Density (G/Cm ³)	8.96 G/Cm ³	1.01 G/Cm ³	8.03 G/Cm ³	1.38 G/Cm3
Yield Strength (Psi)	20,000 Psi	798 - 24600 Psi	31200 Psi	500 - 10600 Psi
Electrical Resistivity (Ω M)	1.72 X10-8 Ω M	Insulant	6.9×10−7 Ω M.	Insulant
Young's Modulus (<i>E</i> ,Gpa)	130 Gpa	1.935 Gpa	190 Gpa	3.4 Gpa.

Table 3.3 Material selection.

1/

3.8 Failure Mode and Effect Analysis (FMEA)

For the most part, the aim of an FMEA is to prevent the likelihood that a new design, process, or system fails to meet the specified requirements under particular conditions such as defined purpose and enforced constraints on the scope of the study (Dev et al., 2018). The FMEA is used to assess customer needs and build products and processes that reduce the likelihood of failure modes occurring, with a focus on safeguarding the health and safety of employees and the safety of the systems. Use of the FMEA approach is primarily for the purpose of identifying and evaluating the causes and effects on the system of potential failure system states and for providing a solution to eliminate or lessen the chance of their occurrence and the severity of their effect through evaluation (Vazdani et al., 2017). As a result of implementing the FMEA approach, the project's timeline, cost, and product quality and dependability are all shortened, and operational safety is improved while at the same time warranty returns are reduced (Putra et al., 2018). Increased customer satisfaction will lead to increased competitiveness and a better image for a company in today's marketplace, which is why these benefits are sought for. Example of an FMEA table can be seen in Table 3.7. These include RPN (Risk Priority Number), R (Severity Score), O (Opportunity Score), and D (Detection Score) (Guo et al., 2017). Use a rating scale to evaluate each factor in the formula, as each product has a particular set of qualities, hence the scale is different.

No	Potential Failure	Impact	Causes	Suggestion and measures	S	0	D	RPN
1								
2								
3								
4								

Table 3.4The FMEA analysis of the pico hydropower plan.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss about the result obtained from this project. The results are essentially the outcome of the field test for the critical functions of the project. The results of the test are analysed for the impact on these initiatives and the outcomes are discussed.

4.2 Morphological Chart

4.3 Pugh Method

In 1991, Stuart Pugh devised an evaluation grid that has been widely adopted since. Total Design - Integrated Methods for Successful Product Engineering (Linda Lnmo) is the basis for this part. The Pugh matrix is another name for this one. Because of their structure and control, Pugh said, matrices are the ideal way to organise an evaluation and convey it. The Pugh matrix aids in the comparison of several options in terms of important factors. Identifying a notion that best fits the criteria is the goal. As stated earlier, the Pugh Matrix is not a mathematical matrix, but rather an easy-to-understand structure for expressing one's thoughts and the criteria used to evaluate them. The criteria are expressed on the vertical axis using one leg of the matrix. Visualizing alternate concepts is done by using the horizontal axis (Figure 2.7). + (plus): better than, superior to, S is the same as a defined reference notion and - (negative) means that it is worse. At the same time, each criterion is rated for all the situations. Each concept's capacity to meet requirements, as well as its strengths and drawbacks, are summarised in a bottom-of-the-matrix summary. Because there are so many alternative answers to a given problem, Pugh points out that it is difficult to analyse all of them, hence it is vital to conduct concept development and evaluation in an orderly fashion. Team members must affirm and endorse the preferred notion until the method and matrix have been iterated enough times. Pugh claims that key outputs of concept selections by using the evaluation matrix are:

- i. A clearer picture of what is needed.
- ii. A deeper comprehension of the design challenge.
- iii. A better grasp of the issues and possible solutions.
- iv. A comprehension of the ways in which the offered solutions interact with one another, which can lead to the development of additional solutions.
- v. An understanding of the factors that contribute to the strength or weakness of a concept.
- vi. A catalyst for the development of new ideas. Making it difficult for individuals to push their own incorrect beliefs is another benefit of the Pugh matrix.

سا ملاك	undo.	4	option 1	ontion 2	ontion 7	option A	ley
criteria	w	eight	option	option 2	options	option 4	-
UNIVERS	ITI TE	KNI	KALI	MALA	YSIA	MELA	KA
_		-					1
							1
							1
+							1
0		-					
total							1

Figure 2.7 Example of Pugh method.

An individual's overall score is calculated by subtracting the number of plus scores from the number of minus scores received. Using this information, we were able to assess how satisfied we were with the choices. Multiplying and adding each score by the importance weights yields the tallied total. The gear type selection is analysed using Pugh method. A worm gear is set as the datum for the other types of gears.

	Table	4.2	Pugh	method
--	-------	-----	------	--------

Criteria	Baseline/Datum	Pulley	Spur	Planetary	Orthogonal
Ease of fabrication	0	+	-	-	-
Cost	0	S	+	+	S
Lightweight	0	S	S	+	S
Size of gear	0	-	-	S	-
Ease of maintenance	0	+	+	+	S
Total	1	0	2	-2	
Rank	2	3	1	4	

Based on the Pugh method in Table 4.2, the planetary gear is selected as the best gear to be used in the pico portable hydropower system. It is followed by pulley, spur and lastly orthogonal gear.

4.4 Conceptual Designs

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

There are four conceptual designs developed by using morphological chart as shown

in Table 4.3.

No.	Conceptual Design	Description
1		The design is developed by combining several components. The combinations are as follows: Planetary Gear (A1), Shaft (B3), Penstock (C2), and Pelton Turbine (D4).
2	The second secon	The design is developed by combining several components. The combinations are as follows: Belt and Pulley (A2), Shaft (B1), Penstock (C4), and Crossflow Turbine (D1).

Table 4.3 Developed conceptual design.



4.5 Design of Pico Hydropower Components

4.5.1 Penstock

The function of the penstock is to collect and flow the water into the hydropower system. Moreover, the penstock is fabricated widely to collect more water to increase the water pressure. Figure 4.1 shows the detailed design of the penstock.



Figure 4.1 Penstock.

4.5.2 Turbine

The function of the Pelton turbine is to rotate when water hits the hemispherical cup. The turbine is connected to the gear and the generator to produce electricity. Figure



Figure 4.2 Turbine.

4.5.3 Gear

The function of the planetary gear is to convert the kinetic energy of the water to mechanical energy to produce electricity by the generator. Furthermore, it helps to increase

the rotation at the generator to improve the efficiency of the system and power output. Figure 4.3 shows the detailed design of the gear.



Figure 4.3 Gear.

4.5.4 Valve

The function of the nozzle is to increase the water pressure hitting the hemispherical cup to increase the speed of the turbine rotation. Figure 4.4 below shows the detailed design of the nozzle.



Figure 4.4 Valve.

4.5.5 Shaft

The function of the shaft is to connect the turbine and all the way to the generator.

It also acts as a support to hold the turbine and the gear. The detailed design of shaft is

shown in Figure 4.5.



4.6 Material selection of each pico portable hydropower system components.

One of the most important parts of an efficient engineering design is material choice since it affects the design's dependability from an industrial and financial perspective. A fantastic design could not turn out to be a successful product if the best material combinations can't be found. In this aspect engineers use several facts of materials to come to the most reasonable decision. They are mainly concentrated on the properties of the materials which are identified as the potential materials for that specific design.

4.6.1 Penstock

The material to fabricate the penstock is by using polyvinyl chloride (PVC). Because PVC is corrosion-resistant, river water will not cause it to corrode. Furthermore, because PVC is an excellent current insulator, there is no electrical leakage. PVC also possesses high yield strength and young's modulus, which means it can withstand the pressure of river water.

4.6.2 Turbine

The turbine fabrication is done by using polyamide 12 as the material. The density of the material would enable for turbine rotation. Furthermore, because the material is an excellent current insulator, there is no electrical leakage. Besides from that, the turbine is made using Selective Laser Printing, thus the chosen material will be incorporated in the design.

4.6.3 Shaft

The shaft used in this project will be made out of stainless-steel material. The material is corrosion free, and stainless-steel properties causes it to minimise the impact of the spinning rate of the shaft for a long-term period. Stainless steel has a very low electric conductivity thus it wouldn't allow current leakage.

4.6.4 Gear

The gear will be fabricated using polyamide 12. The weight of the material would work turbine rotation. Furthermore, because the material is an excellent current insulator, there is no current leakage. Besides from that, the gear is made using Selective Laser Printing, thus the chosen material will be incorporated in the design.

4.7 Detailed Design of the Pico Hydropower Plant

The figures below show the detail design of the pico hydropower system by using SolidWorks 2021. This design will be fabricated accordingly and tested for power generation.



Figure 4.6 The isometric view of the detailed Pico hydropower system design.



Figure 4.7 The front view of the detailed Pico hydropower system design.



Figure 4.8 The side view of the detailed Pico hydropower system design.



Figure 4.9 The exploed view of the detailed Pico hydropower system design.

4.8 Failure Mode and Effect Analysis (FMEA)

Table 4.3 shows the FMEA analysis of the gear when the system is running. It can be observed that Micro pitting is the most critical failure and difficult to be detected to the naked eye.

	6	N. L. L	1/_	1 a	. 1			
Item	Potential Failure	Causes	Impact	Suggestion and measures	S	0	D	RPN
1	Gear stop rotating	Lubricant film is too thin. Metal particles, dirt, and rust in lubricant	NIKAL MAI Tooth profile destroyed Gear tooth	Higher viscosity lubricant Use appropriate lubricant	KA 10	2	5	100
2	Breakage Failure Overload Breakage	Excessive tooth load Bearing seizure	wear Tooth surface deformation	Reduce the contact surface Increase the hardness	8	4	5	160
3	Micro pitting	Surface distress caused by excessive stress Local frictional heating	Causes complex damage and inefficient energy production	Use coating, use polished and hardened materials, and use of high-quality lubricant	8	4	7	224
4	Bearing Failure	Use of improper and non-compatible oil seals Use of wrong and no approved lubricants	Gear misalignment	Use appropriate sealing and lubricant	6	5	2	60

Table 4.4 FMEA analysis of the gear.

4.9 Finite Element Analysis of Planetary Gear

A typical simulation of static analysis in Ansys Mechanical analysis began by selecting the material first and determining the fixing points, then applied the relative loads to run the set up. By using Ansys simulation, the designers and engineers could determine the suitability of material used in their product based on the result of tensile tests (Tanikella, Wittbrodt & Pierce, 2017). The tensile properties usually were used in order to predict the behavior of the material and the forms of loading other than uniaxial tension. in the rotating system of the mini hydropower plant turbine, the strength of the gear is the primary concern. that's the maximum stress that the polyamide 12 can withstand can be analyzed through the analysis. The tensile strength of the polyamide 12 is 48 MPa based on the standard DIN EN ISO527.

4.9.1 Meshing of the Planetary Gear

Meshing must be done on the design before the simulation is solved. Mesh is a type of geometric structuring applied to a design to assist define its physical shape. The higher the level of meshing detail, the more accurate the data provided. In Ansys, the meshing parameter configuration is presented in Table 4.5.

Element Order	Program Controlled			
Element Size	5.0 mm			
Resolution	Default (2)			
Transition	Fast			
Span Angle Center	Coarse			
Smoothing	Medium			
Statistic				
Nodes	191679			
Elements	97875			

Table 4.5 Data of mesh for the polyamide 12 gear



Figure 4.10: Meshing of Planetary gear.

4.9.2 Stress Strain Analysis of Frame

Stress, strain, and displacement are the outputs of a stress-strain analysis simulation done on the frame using ANSYS, which assist forecast the behaviour of the structure and whether it is robust enough to keep together the components.

4.9.2.1 Equivalent Stress Simulation

Figure 4.11 illustrates the maximum equivalent stress value of 28.513MPa when a total of 5000 N.m is applied to the gear. This gear design is safe since the stress value is less than the material's yield strength of 48MPa. The gear reaches its failure when a total of 8500 N.m. The maximum equivalent stress value of 48.649 MPa was recorded when 8500 N.m is applied to the gear.



Figure 4.11: Equivalent stress simulation with contour view

4.9.2.2 Equivalent Strain Simulation

WALAYS/4

Given a load of 5000 N.m applied on the gear, the highest equivalent strain value obtained from the stress-strain analysis simulation is 0.02373 mm/mm. The strain simulation result is shown in Figure 4.12.



Figure 4.12: Equivalent strain simulation with contour view

4.9.2.3 Total Deformation

Given a load of 5000 N.m, the stress-strain analysis simulation shows a maximum deformation of 0.04576 mm. Because the value is too little to be detected in real life, the highest distortion occurs at the teeth of the gear, as illustrated in Figure 4.13. As a result, the structure for the gear is rigid and will not fail.



Figure 4.13: Total deformation simulation with contour view

4.10	Bill	of	material	and	cost
		-			

UNIVERSITI TELE 4.6: Bill of material

Item No.	Part Name	Quantity
1	Planetary gear	1
2	Ball bearing	2
3	Shaft	1
4	Wooden board	4
5	Bolts	12
6	Nuts	12
7	Screw	13

8	Washer	4
9	12/24V Magnet DC motor	1
10	Pelton Gear	1

4.11 Experimental analysis in river

Figure 4.19 shows the overall fabricated pico hydropower plant which has the capacity to produce voltage and water flow as shown in Table 4.7.



Figure 4.14: Overall fabricated pico hydropower plant

Fable 4.7: Experimental	result of the water	powered	generator
-------------------------	---------------------	---------	-----------

Variables	Testing 1
Voltage (V)	14.22
Water flow (m ³ /s)	0.072

4.12 Theoritical calculation analysis.

4.12.1 Calculation of gear ratio







Gear Ratio = 0.6

When the gear ratio is below than 1, the mechanism is called overdrive mechanism. This mechanism used when the system needs speed over torque. This mechanism increases the output of rotating speed but decreases the torque.
4.12.2 Calculation of turbine speed

It is possible to determine the turbine speed in rpm as:

$$N = \frac{60 \, x \, w}{2\pi}$$

1 able + Calculation of tarbine speed	Table 4.9:	Calculation	of turbine	speed
---------------------------------------	------------	-------------	------------	-------

Turbine speed (RPM)	
RPM = $(60 \times 18.55) / 2 \pi$	
= 177.14 rpm	

4.12.3 Turbine power

The power generated in turbine can be calculated using the formula below:



The maximum gross head was measured as 0.4m. Then the flow rate (Q) was

obtained from water flow meter. The flow rate of the water is $0.072 \text{ m}^3/\text{s}$.

The power of turbine was calculated as below:

Table 4.10: Calculation of turbine power

Turbine power	
$P_i = 1000 \text{ x } 9.81 \text{ x } 0.4 \text{ x } 0.072$	
$P_i = 282.53W$	

4.12.4 Power output and efficiency

$$P = m x g x Hnet x \eta$$

P = power, measured in Watts (W).

m = mass flow rate in kg/s (numerically the same as the flow rate in litres/second because 1 litre of water weighs 1 kg)

G = the gravitational constant, which is 9.81m/s^2

Hnet = the net head.

H = the product of all of the component efficiencies, which are normally the turbine, drive system and generator. For a typical small hydro system the turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93%, so the overall system efficiency would be:

0.85 x 0.95 x 0.93 = 0.751 i.e. 75.1%.

Then convert the flow rate in m3/s into litres/second by multiplying it by 1000, so:



CHAPTER 5

CONCLUSION

An environmentally beneficial and sustainable energy source is hydropower. When it comes to meeting peak demand and enhancing the dependability of the power system, hydro power plants are more responsive than most other energy sources due to their intrinsic capacity for immediate operation. Due to a lack of knowledge transfer, high costs, and limited component availability, sophisticated systems have been imported and deployed, and in some situations, these systems have developed faults or been unworkable. The success of local manufacturing of pico hydro turbines in other emerging nations may have contributed to the widespread acceptance of the technology. This was shown to be a workable option for Malaysia by build testing and prior experience. However, earlier locally constructed systems also failed, demonstrating the need for more durable solutions. Local specialists will be more capable because of further training and better working conditions. These individuals already have a high degree of aptitude and interest in pico hydro technology.

In this thesis, a comprehensive and extended research was conducted in design and the fabrication of the pico hydropower plant to be applied in any riverbanks. The fabrication of the pico hydropower plant consists of gear, turbine, shaft, generator, and penstock. The step-by-step procedure in selecting the best design was conducted with the implementation of QFD and morphological chart. Out of 4 preliminary designs, the morphological chart helped in selecting design 1 as the best design. The gear type that was selected to be fabricated is Planetary gear as it has good efficiency, reliability, and compactness. The fabricated PHP then undergoes several analysis such as structural analysis where the robustness of the fabricated gear is analysed. The result shows that the gear can withstand a total of 8000 Nm of torque before fail. This shows that the fabricated gear is robust and not easy to fail. Last but not least, the PHP was tested in the real-life situation and was experimented alongside the river to test its performance. The experiment was successful conducted, and the result shows promising data. The PHP is able to produce a total of 14.22 V when a speed of 0.0072 m³/s of water flowed through the PHP. This shows that the fabricated hydropower plant has been a successful project and can be used and applied for small scale appliances such as bulbs, power banks and more.



REFERENCES

A. Nasir, B. (2013). Design of Micro - Hydro - Electric Power Station. *International Journal of Engineering and Advanced Technology (IJEAT)*, 2(5), 39 – 47.

Abdullah Nasir, B. (2014). Suitable Selection of Components for the Micro-Hydro-Electric Power Plant. *Advances in Energy and Power*, 2(1), 7–12. https://doi.org/10.13189/aep.2014.020102

Alexander, K. v., & Giddens, E. P. (2008). Optimum penstocks for low head microhydro schemes. *Renewable Energy*, *33*(3), 507–519. https://doi.org/10.1016/j.renene.2007.01.009 Börekçi, N. A. G. Z. (2018). Design Divergence Using the Morphological Chart. *Design and Technology Education: An International Journal*, *23*(3), 62–87.

Braga, A. v., Rezek, A. J. J., Silva, V. F., Viana, A. N. C., Bortoni, E. C., Sanchez, W. D.
C., & Ribeiro, P. F. (2015). Isolated induction generator in a rural Brazilian area: Field performance tests. *Renewable Energy*, 83, 1352–1361.
https://doi.org/10.1016/J.RENENE.2015.05.057

-:-

Cicek, K., & Celik, M. (2010). Multiple attribute decision-making solution to material selection problem based on modified fuzzy axiomatic design-model selection interface algorithm. *Materials* & *Design*, *31*(4), 2129–2133. https://doi.org/10.1016/J.MATDES.2009.11.016

Derakhshan, S., & Nourbakhsh, A. (2008). Experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds. *Experimental Thermal and Fluid Science*, 32(3), 800–807. https://doi.org/10.1016/J.EXPTHERMFLUSCI.2007.10.004

Ducar, I. M., & Ion, C. P. (2012). Design of a PMSG for micro hydro power plants. *Proceedings of the International Conference on Optimisation of Electrical and Electronic Equipment, OPTIM*, 712–717. https://doi.org/10.1109/OPTIM.2012.6231949 Elbatran, A. H., Yaakob, O. B., Ahmed, Y. M., & Shabara, H. M. (2015). Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review. *Renewable and Sustainable Energy Reviews*, *43*, 40–50. https://doi.org/10.1016/J.RSER.2014.11.045

Feng, Z. kai, Niu, W. jing, & Cheng, C. tian. (2019). China's large-scale hydropower system: operation characteristics, modeling challenge and dimensionality reduction possibilities. *Renewable Energy*, *136*, 805–818. https://doi.org/10.1016/J.RENENE.2019.01.059

Fraenkel, P., Paish, O., Harvey, A., Brown, A, Edwards, R., & Bokalders, V. (1999). Microhydro power: a guide for development workers. *Intermediate Technology Publications*, *June*, 150. https://www.osti.gov/etdeweb/biblio/5564378%0Ahttps://oculgue.primo.exlibrisgroup.com/discovery/fulldisplay?docid=alma9922781903505154&conte xt=L&vid=01OCUL_GUE:GUELPH&lang=en&search_scope=MyInst_and_CI&adaptor= Local Search Engine&tab=Everything&query=any

Huang, H., Zhang, L., Liu, Z., & Sutherland, J. W. (2011). Multi-criteria decision making and uncertainty analysis for materials selection in environmentally conscious design. *International Journal of Advanced Manufacturing Technology*, *52*(5–8), 421–432. https://doi.org/10.1007/s00170-010-2745-9

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Jaliu, C., Saulescu, R., Diaconescu, D. V., & Neagoe, M. (2010). Conceptual Design of a Chain Speed Increaser for Small Hydropower Stations. *Proceedings of the ASME Design Engineering Technical Conference*, *6*, 321–328. https://doi.org/10.1115/DETC2009-86982 Maher, P., & Smith, N. (2001). PICO HYDRO FOR VILLAGE POWER A Practical Manual for Schemes up to 5 kW in Hilly Areas. *Development, May*.

Mishra, S., Singal, S. K., & Khatod, D. K. (2012). Effect of Variation of Penstock Parameter on Mechanical Power. *International Journal of Energy Science IJES IJES*, *2*(3), 110–114. https://www.academia.edu/download/48085102/IJES10062_2_3_110_114.pdf Ritchey, T. (2018). General morphological analysis as a basic scientific modelling method. *Technological Forecasting and Social Change*, *126*, 81–91. https://doi.org/10.1016/j.techfore.2017.05.027

Varughese, A., & Michael, P. A. (2013). Electrical Characteristics of Micro-Hydro Power Plant Proposed in Valara Waterfall. *International Journal of Innovative Technology and Exploring Engineering (IJTEE)*, 2(2), 128–131.

Wei, L., Nakamura, T., & Imai, K. (2020). Development and optimization of low-speed and high-efficiency permanent magnet generator for micro hydro-electrical generation system. *Renewable Energy*, *147*, 1653–1662. https://doi.org/10.1016/j.renene.2019.09.049

Williams, A. A., & Simpson, R. (2009). Pico hydro - Reducing technical risks for ruralelectrification.RenewableEnergy,34(8),1986–1991.https://doi.org/10.1016/j.renene.2008.12.0111986–1991.1986–1991.

Dev, K., Gurukula, S., Vishwavidyalaya, K., Srivastava, S., & Kangri Vishwavidyalaya, G. (2018). Failure Mode and Effect Analysis (FMEA) Implementation: A Literature Review. Journal of Advance Research in Aeronautics and Space Science, 5(1 & 2), 1–17. https://www.researchgate.net/publication/333209894

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Emetitiri, R., Ariavie, G., Martinez, E., Ramström, S., & Karlen, M. (2020). Concept Selection: An Improved Clog Resistance Testing Methodology for Wastewater Pump Using Pugh Decision Model. Advances in Engineering Design Technology, 2, 66–79. https://doi.org/10.37933/nipes.a/2.2020.6

Guo, Q., Sheng, K., Wang, Z., Zhang, X., Yang, H., & Miao, R. (2017). Research on Element Importance of Shafting Installation Based on QFD and FMEA. Procedia Engineering, 174, 677–685. https://doi.org/10.1016/J.PROENG.2017.01.205

Haiyun, C., Zhixiong, H., Yüksel, S., & Dinçer, H. (2021). Analysis of the innovation strategies for green supply chain management in the energy industry using the QFD-based

hybrid interval valued intuitionistic fuzzy decision approach. Renewable and Sustainable Energy Reviews, 143, 110844. https://doi.org/10.1016/J.RSER.2021.110844

Onn, C. W., Asmara, Y. P., Allybocus, S. A., & Orakzai, A. (2020). Selection of Pipeline Investigation Robot via Pugh Method. International Conference on Innovation and Technopreneurship 2020, 2020(September).

Putra, G. P., Rimawan, E., & Pusat, J. (2018). Maintenance Prevention on Coal Fired Power Plant. International Journal of Innovative Science and Research Technology, 3(8), 109–113. www.ijisrt.com

Singh, R. K., Rajput, V., & Sahay, A. (2018). A Literature Review on Quality Function Deployment (QFD). IAETSD Journal For Advanced Research In Applied Sciences, 5(8), 245–250.

Vazdani, S., Sabzghabaei, Gh., Dashti, S., Cheraghi, M., Alizadeh, R., & Hemmati, A. (2017). FMEA TECHNIQUES USED IN ENVIRONMENTAL RISK ASSESSMENT. https://doi.org/10.26480/ees.02.2017.16.18

Bhargav, Parameshwaran, M. A., Sivaraj, S., & Venkataram, N. (2018). Conceptual design of planetary gearbox system for constant generator speed in hydro power plant. MATEC Web of Conferences, 144, 01004. https://doi.org/10.1051/MATECCONF/201814401004

Bhargav, Parameshwaran, M. A., Sivaraj, S., & Venkataram, N. (2019). Numerical Simulation and Experimental Validation of Planetary gearbox System Design to Govern Constant Generator Speed in Hydro Power Plant. IOP Conference Series: Materials Science and Engineering, 624(1). https://doi.org/10.1088/1757-899X/624/1/012008

Chitrakar, S., Solemslie, B. W., Neopane, H. P., & Dahlhaug, O. G. (2020). Review on numerical techniques applied in impulse hydro turbines. Renewable Energy, 159, 843–859. https://doi.org/10.1016/j.renene.2020.06.058 Erinofiardi, Gokhale, P., Date, A., Akbarzadeh, A., Bismantolo, P., Suryono, A. F., Mainil, A. K., & Nuramal, A. (2017). A Review on Micro Hydropower in Indonesia. Energy Procedia, 110(December 2016), 316–321. https://doi.org/10.1016/j.egypro.2017.03.146

Ighodalo Okhueleigbe, E. (2018). Design and Construction of a Mini Hydro Turbine Model. American Journal of Modern Energy, 4(1), 1. https://doi.org/10.11648/j.ajme.20180401.11 Jawahar, C. P., & Michael, P. A. (2017). A review on turbines for micro hydro power plant. In Renewable and Sustainable Energy Reviews (Vol. 72, pp. 882–887). Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.01.133

Kader, G., Momin, S. A., Dutta, M., Hassan, S., & Hossen, A. (2016). Design and Construction of a Mini-Hydrodynamic generator Design and Construction of a Mini-Hydrodynamic generator. December, 0–5.

Kadier, A., Kalil, M. S., Pudukudy, M., Hasan, H. A., Mohamed, A., & Hamid, A. A. (2018). Pico hydropower (PHP) development in Malaysia: Potential, present status, barriers and future perspectives. Renewable and Sustainable Energy Reviews, 81(August 2016), 2796– 2805. https://doi.org/10.1016/j.rser.2017.06.084

Karim, A. (2017). Micro Hydro-Electric Energy Generation-An Overview. American Journal of Engineering Research (AJER), 6(2), 05–12.

Soewardi, H., & Putra, E. A. (2018). Developing a Portable Hydroelectric Generator Using Axiomatic Design Method. IOP Conference Series: Earth and Environmental Science, 171(1). https://doi.org/10.1088/1755-1315/171/1/012034

Sopian, K., & Razak, J. A. (2009). Pico hydro: Clean power from small streams. Proceedings of the 3rd WSEAS International Conference on Energy Planning, Energy Saving, Environmental Education, EPESE '09, Renewable Energy Sources, RES '09, Waste Management, WWAI '09, 414–419.

Wegiel, T., Borkowski, D., & Liszka, D. (2016). Efficiency analysis of an energy conversion system for a variable speed small hydropower plant. E3S Web of Conferences, 10. https://doi.org/10.1051/e3sconf/20161000100

Weking, A. I., & Sudarmojo, Y. P. (2019). Prototype Design of Micro Hydro Using Turbine Archimedes Screw for Simulation of Hidropower Practical of Electro Engineering Students. Journal of Electrical, Electronics and Informatics, 3(1), 6. https://doi.org/10.24843/jeei.2019.v03.i01.p02

Williamson, S. J., Stark, B. H., & Booker, J. D. (2014). Low head pico hydro turbine selection using a multi-criteria analysis. Renewable Energy, 61, 43–50. https://doi.org/10.1016/j.renene.2012.06.020



APPENDICES

APPENDIX A Gantt Chart

										H.	PR	lOJ	EC	T P	L A	INN	N	3																					
Li	st do	wn	the	ma	in :	ictiv	ity	for	the	pro	jec	t pı	opo	sal	. S	tate	the	tin	e fi	ram	e no	eede	ed fo	or e	ach	aci	tvity												
			_											202	21					_	_											_	1	202	2	_			
Project Activity																																							
	1	2	3	4	5	6	7	8	ę	9	1	1	1	1	1	1	1	1	1	1	2	1	2	3	4	5	6	7	8	9	1		1	1	1	1	1	1	1
DEVELOPMENT OF STUDY TOOLS	t							_			J	1	2	3	4	5	6	/	8	Э	0										U	,	1	2	3 4	4	5	6	/ 1
Topic Selection																																							
Discussion with Supervisor																																							
Gather Information																																							
Function Establishment																																						_	
DATA COLLECTIONS								4	L																				k									natio	
Product Architecture	e e							Brez								4					геак								Brez								sek	xami	
3D Modelling	Briefi							nester								M A					ster D								nester								ły We	ster E	
Finite Element Analysis	BP							id Ser								5					Selle								id Ser								Stu	Seme	
Detail Analysis	,A	Y	S,	10				N										1000											M									Final	
DATA PROCESSING AND ANALYSIS					1	10																																	
Data Entering & Pre-Post Analysis							7									1																							
Final Report & Dissemination of Project Findings]						1																-																
Project Presentation & Report Submission																							1																
V. Ses AIN	7																							7													-	,	
ملاك	4			s	l	A		<u>}</u>		_	_	2	~		2	-	_	2		3	Č	\$,,	/	~	•		5	,								

UNIVERSITI TEKNIKAL MALAYSIA MELAKA