DESIGN AND DEVELOPMENT OF SIMPLE PELTON WATER TURBINE FOR PICO HYDRO GENERATION SYSTEM

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of in Electrical Engineering with Honours.

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2018

DECLARATION

I hereby, declared this report entitled “Design and Development of Simple Water Turbine for Pico Hydro Generation System” is the results of my own research except as citied in references.

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Dedicated to my beloved mother, father and my elder sisters

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ABSTRACT

Hydro energy is one of the renewable energy that can be fetch and harvest from the flow of water by using the appropriate mechanism and system that can generate efficiently of electricity. There are many types of hydro energy which are large hydroelectric, small hydroelectric, micro hydroelectric and pico-hydroelectric. Each type generates different amount of output energy that can be consumed as utility. Now days, many rural places lack of electricity utilities and left out due to the cost and geography condition. So, the hydro energy is oftentimes considered to be called green energy because there is no emission of gas that give greenhouse effects related with the output of the electricity. Pico hydroelectric size is selected in this project because it can utilize even a small flow of water to generate electric. Those small flow of water is used to rotate hydro's pelton turbine to drive the mechanical shaft that connected with generator. This mechanical power is then being used to drive a generator in order to generate electrical power. Extensive study on generator, buck boost, turbine component, and the system circuit are the core for this development. During the development of this pico hydroelectric project, software such as Solid work is involve in designing the suitable pelton blade and wheel turbine. The designated model will be printed in 3D model parts, so that it can be assembled to become complete pico wheel water turbine. The purpose use 3D model because it made by light and strong material. The designed turbine should be capable to meet performance specification for hydropower generation, such as an adequate minimum rate of flow's water and the type of turbine design used. Besides, the technology is environmentally in term of pollution to nature, capital cost and life expectancy. This type of pico hydration commonly give output power below 5 kilowatts, nevertheless still there are various part of losses power occur in the process generating the output. Thus, affected the efficiency and output rate of the system. The expectation from this pico hydroelectric is it can supply current and voltage for small load such as resistor or charging purpose.

ABSTRAK

Tenaga hidro elektrik adalah tenaga yang boleh diperbaharui yang boleh dimiliki dan dituai daripada aliran air dengan menggunakan kaedah mekanisme dan sistem yang boleh menghasilkan elektrik. Tenaga hidro terdapat pelbagai jenis antaranya hidro elektrik besar, hidro elektrik kecil , hidro elektrik mikro dan hidro elektrik piko. Setiap jenis hidro elektrik menghasilkan jumlah tenaga elektrik yang boleh digunakan sebagai sumber elektrik. Pada masa kini, banyak kawasan pendalaman yang kekurangan kemudahan elektrik dan ketinggalan dari segi perkhidmatan tersebut ini disebabkan kos pembinaan dan keadaan geografi. Jadi, tenaga hidro seringkali di pertimbangkan untuk dipanggil sebagai tenaga hijau kerana tiada penghasilan gas yang memberi kesan kepada rumah hijau dengan tenaga yang dihasilkan untuk menjana elektrik. Hidro elektrik piko dipilih untuk projek ini kerana boleh menghasilkan elektrik walaupun aliran yang kecil. Aliran air yang kecil itu digunakan untuk memusingkan pelton turbin untuk memacu syaf mekanikal yang disambung kepada generator. Kuasa mekanikal ini digunakan untuk memacu generator untuk menghasilkan kuasa elektrik. Penyelidikan terhadap generator," buck-boost", komponen turbin dan sistem lita adalah teras terhadap penghasilan projek ini. Dalam penghasilan projek hidro elektrik piko ini, perisian seperti "Solid Works" terlibat dalam mencipta bilah pelton yang sesuai dan roda turbin. Reka bentuk yang siap akan dicetak menjadi beberapa bahagian model 3D, oleh itu di pasang menjadi piko roda turbin yang lengkap. Tujuan menggunakan 3D disebabkan cetakan tersebut diperbuat daripada bahan yang kuat dan ringan. Reka bentuk hendaklah berlandaskan spesifikasi hidro elektrik piko tersebut seperti mencukupi tahap minimum aliran air dan jenis turbin yang digunakan. Disamping itu, teknologi adalah mesra alam dari segi pencemaran terhadap alam sekitar, kos pembinaan dan jangka hayat. Hidro elektrik piko ini, selalunya menghasilkan kuasa bawah 5 kilowatt, walaupun begitu, hidro elektrik piko masih ada lagi bahagian yang menyebabkan kehilangan kuasa yang berlaku dalam proses penghasilan tenaga elektrik. Oleh itu, kecekapan dan kadar janaan sistem akan terjejas. Jangkaan daripada hidro elektrik piko ini agar dapat menyalurkan arus elektrik dan voltan untuk beban yang kecil seperti perintang atau untuk tujuan mengecas.

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LIST OF ABBREVIATIONS

CHAPTER	CONTENT
Pgross	Gross Power
Pnet	Net Power (power usefully delivered)
η	Efficiency
P	Power
g	Gravity
H	Head
HP	Horse Power
PMDC	Permanent Magnet Direct Current Generator
Q	Flow Rates
RPM	Rotation per Minutes
KW	Kilo Watt
MW	Mega Watt
DC	Direct Current
AC	Alternating Current
m	Mass
V	Volume of Water
Hgross	Vertical Distance
a	acceleration
ρ	Density
mg	Weight

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CHAPTER 1

INTRODUCTION

1.1 Project Background

There are many sorts of renewable-energy resources that can be utilize in this world but there is one most power renewable energy that has successful and proven track record which is hydroelectric power. This type of renewable energy is the most demanding for utility system and capable to generate until 10GW.The main reason why this hydro generation is so desirable is due to the environmental friendly. The operation of hydro output generation is does not contribute atmospheric pollution. The term that refer to its clean energy is "Green Energy". The hydro generation system consists of two parameter that usually exist in the system that is the amount of water flow or called flow rate of water and the vertical height. The name pico hydro is a term used for hydroelectric power generation within 5kW.Although, the pico hydro power could achieve 5kW, in this project the target output is less than 1000W.The pico hydro power can be implemented in small communities or remote area that far away from utility service. It can provide those places with small amount of electricity for example to power up one or two fluorescent light bulbs and other electrical appliances. This Final Year Bachelor Project is entitling Design and Development of Simple Pelton Water Turbine for Pico Hydro Generation Using Low Flow Water Resources. The purpose of this project is to develop and produce a hydro generation system that can provide clean and sufficient energy for small scale area or small community that required for the target area based on flow rate of water. Flow rate is main component of the hydro generation electric. Water quantity is defined as water flow rate. Based on the journal Basar, M.F et al,. (2011) it is the volume of water passing per second and it can be expressed as volume per time, with the unit of cubic per meter second.

1.2 Project Motivation

The rural areas always outreach from the electricity; thus, it is motivated as people living in society it feels responsible to study and start this project to create a renewable energy at minimum level of cost so that it can be installed especially at remote location. Nowdays, transferring energy to the rural places are difficult due to costing and generally the electricity generation comes with a big size that will install permanently in the specific area. The solution to handle for those places that lack of power generation is by developing and designing a low cost and handy renewable energy generator which is pico hydro system. The existence of 3D printer allows this project to utilize the machine in order to realize the Industrial Revolution 4.0 by printing the solid model of pico wheel and pelton turbine.

1.3 Problem Statement

The remote and rural place are always left behind in term of utilities and technologies. The places also less develop due to cost and structure of land condition. Normally cost is main factor in determine the optimum hydro system for specific location. If the location or place to put the pico hydro system is promising, thus the cost in developing the optimum hydro system will be in sensible range. Next, to design a good water turbine the mechanical and electrical relationship are important and must be taken into account in Designing and Development of Simple Pelton Water Turbine for Pico Hydro Generation. Chosen of turbine and design are the most essential parameters to be determined in designing the low cost and portable pico hydro turbine, which is either to use the reaction turbine or impulse turbine. Generator also a main factor in developing in this project. The appropriate type of turbine will give affect the output power generates, so, selection of generator must be considered either it can generate power at the determine rate.

For those reasons, during process of designing, it is essential to develop a great generator and turbine at smaller size with an efficient operational system, reliable, affordable, economically viable and socially acceptable to ensure it will generate a smooth mechanical rotation and output.

1.4 Objectives

The main objective for this project is to design and develop an electrical generation system based on hydro power. The objectives of this project are listed below and must be achieved and fulfilled to complete this project.

1. To design and develop a low-cost pelton hydro turbine using 3D Printer
2. To analyse the performance of the Pico-hydro system in terms of input and output efficiency.
3. To identify the possibility of the pico hydro turbine to generate electricity in certain speed.

1.5 Scope of Work

This project is conducted to design and develop hydro generation system which capable to produce range between 0 - 1000W of power generation. Hence, the appropriate component and method used during designation process plays a significant role in obtaining the water power which refers as the flow of water.

1.6 Final Year Project Outline

Chapter 1 elaborates the problem statement, objective, project motivation and scope of this project.

Chapter 2 explanation the literature study related to this project. Study on previous research by other researcher, project design and system are conducted to ensure the successfulness of the project. This chapter also describes the part and component comparison that suitable use for this project.

Chapter 3 describes the methodology to determine head, water flow, losses in pipeline system, components used and calculation output power from the system.

Chapter 4 discusses the result and analysis from the performance test of the system. A few calculations have been done to execute this system.

Chapter 5 provides conclusion and recommendation for further work of this project

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Hydroelectric is one of the most electric power generating that does not give effect on the greenhouse and environmentally. It is produced by change of potential vitality of a mass of water streaming in a waterway or stream with particular vertical fall. Alluding from (Pico hydro 2003) it is the broadly utilized type of sustainable power source, representing 16 percent of worldwide power age. Hydroelectric power is the reasonable, least expensive wellspring of vitality, sustainable and less contamination amid operation

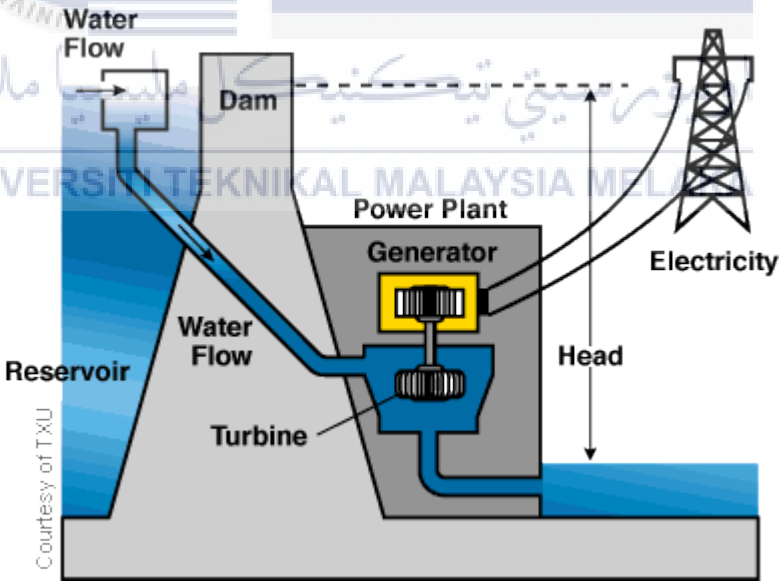

Figure 2.1: Hydro Power Plant

(Source: http://gemasaintifika.blogspot.my/2012/07/)

2.2 Hydropower

Hydropower is a power that form from a high potential energy which is running water or falling water. A previous century in early 19th century, the hydropower is early source to generate electricity. This shows the hydropower has long exist as the main generator to supply electricity to the community of human kind. The first ever built hydropower plant was at Niagara Falls in 1880. Nowdays, demanding in electricity due to increasing of human population showing massive interest in build a hydropower in order to use electricity un their daily life. [2]

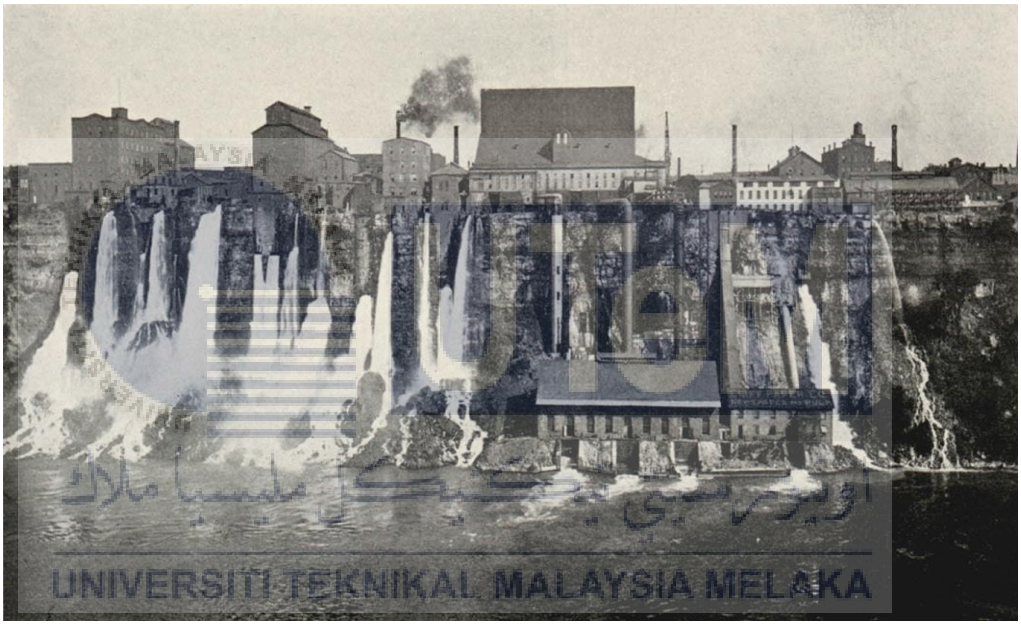

Figure 2.2: Hydro Plant at Niagara Falls

(Source: http://www.teslasociety.com/exhibition.htm)

2.3 Classification of Hydro Generation

There four types of scales in hydro generation:

i) Large

This scale hydroelectric power stations are predominant seen as the biggest power creating facilities on the planet, with some hydroelectric facilities equipped for producing more than double the introduced capacities of the current nuclear power stations. This large hydro

generation could create from over a couple of hundred megawatts to more than 10 gigawatts power. [4]

ii) Small

Small hydro is hydro power generation that normally to provide electricity for a small community areas or industrial plant. It can generate electricity within 10 gigawatts of power. This type of hydro plant will be connected to a conventional electrical distribution network as low cost renewable energy. The small hydro is often built at rural area that isolated from the national electrical distribution network which is difficult to get those utility services. As we know the small hydro plant normally requires minimal reservoir and hardware construction work, so the plant normally give low impact on surrounding ecosystem and better friendly environment compared to large type of hydro. [4]

iii) Micro

This hydro power can create 100kW of energy. This hydro power able to supply and give a very extensive of energy to an isolated house or little group of people or even can consider associating with electric power grid. This type of hydro system has widely used and installed around the world. Generally, countries that less fuel product are more likely to install this kind of hydro system, in order to reduce the purchase of fuel from third party country. [4]

iv) Pico

This kind of hydropower could generate under 5kW, due to the term given" pico" and small scale of hydropower mechanism. Thus, it could provide electricity in tiny, isolated communities that require only small use of power. Generally, this type of hydropower does not require reservoir, it can be set up a run of the river, with the small attachment of pipes that connect together to collect the flow of water and become one high potential

water energy which will going hit the turbine before returning to the stream. [4]

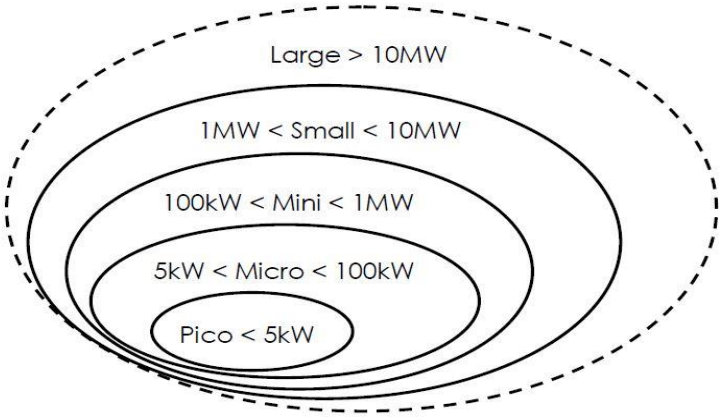

Figure 2.3: Classification of Hydro power plant based on the power output (Source: M.B. Farriza)

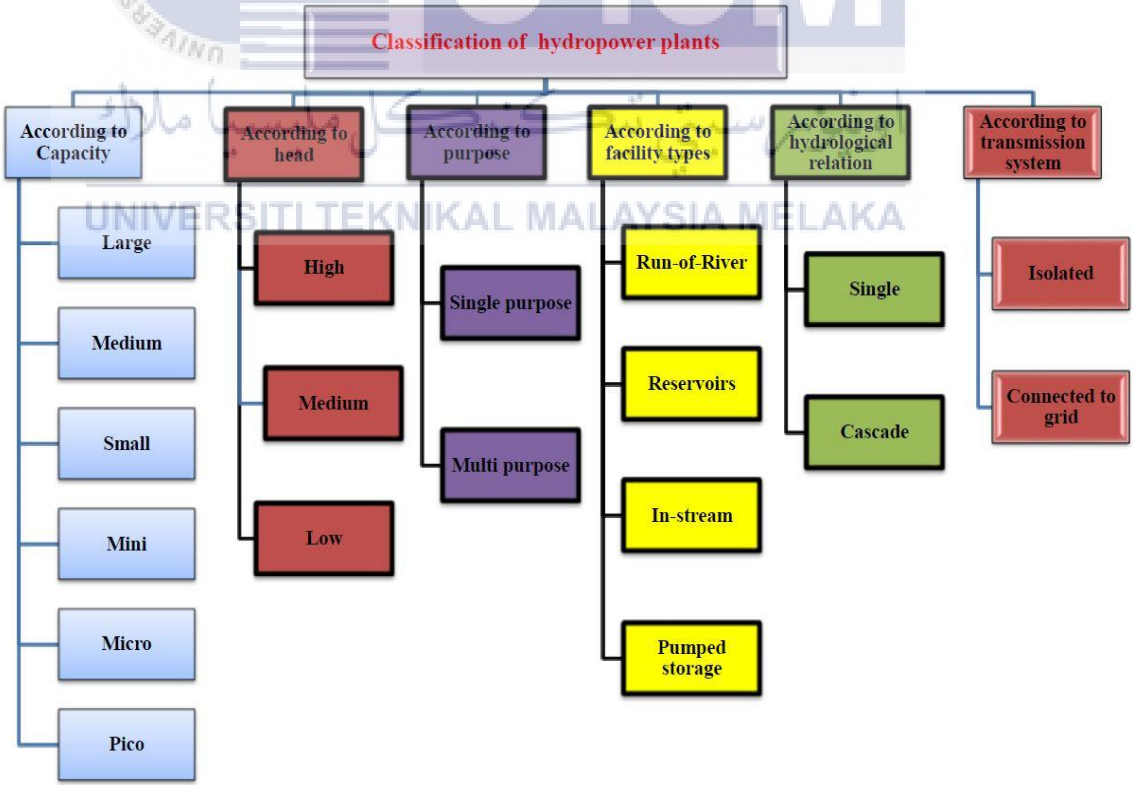

Figure 2.4: List all classification of Hydro power plants (Source: Ganesh Kumar, www.slideshare.com)

2.4 Implementation of Pico-Hydro Generation in Malaysia.

According to the recent researchers, the usage of pico hydropower system is still in the beginning and small amount of application. The component and technology of hydro system are still likely imported from outside Malaysia. This kind of technology could give positive impact to the country, thus make the government to alert or set their vision on this sort of innovation. Based on the new approach in 2010, the Ministry of Energy, Green Technology and Water has proclaimed to expand local resources assets to contribute toward national power supply. The policy is to strengthen the vision of the government for upcoming years which to be the most creative, smart, brilliant and great in making technology for own usage. Next, the government also hope that the pico hydro power can contribute to the national supply which could save the budget spending on the subsidy in electricity for citizen. The oldest and first pico hydropower has been develop and create is at Universiti Kebangsaan Malaysia (UKM). The project is being develop at Kampung Tuil Kelantan at rural place such aborigine's village. The project also a collaboration between the Global Peace Mission and UKM researcher. It is financed by the Ministry of Science and Technology and Innovation of Malaysia. The power that capable been produced is within 220 AC voltage. The second project is more to low flow and low head of hydro system. The site project for the second pico hydropower is at UKM this time. This pico hydropower has ability to generate output power until 60 watts. The system of water flowing developed using the pond located within the university compound. The output is still in range of low output power with the head one meter because it is to small even for charging the battery. After that, development is keep moving forward to solve the flaws that happened in previous project. The project is established, assigned and being built at Sri Aman, Sarawak at remote village. (Basar, MF et al, (2011) state from the journal, the system has capability to generate 3kilowatts power by optimizing a very limited head. Lastly, the fourth project was done with proper solution and method. [3]

Based on the H. Zainuddin et al., (2011) the fourth project was completed by the few specialists from UTeM where the pico hydro age framework utilized just for the devouring of water disseminated to houses. This kind of venture is using the water conveyed to house rather utilizing of stream and lake. Nowdays, the Pico hydro is much more prominent even in Malaysia. The development materials and method are easier than other category of hydro power generation. No wonder why this project is eye catching to the researcher for to improve and develop even more effective system for Pico hydro power. [4]

Figure 2.5: Pico hydro power plant at UKM, Bangi.

(Source: Basar, M, F et al)

2.5 Final year Project May 2008: Design and Develop a Pico Hydro Generation System Using Permanent Magnet Alternator.

The previous project was conducted and developed by UTeM fourth year student 2008. The purpose is to produce pico-hydro power system using hydroelectric concept with hope it could be installed at small and save space area such as home or other commercial building but the system produced was big and not suitable at such places. The turbine is straightforwardly combined with 500 watts changeless magnet alternator as generator. Pulley or belting framework isn't fundamental as this sort of perpetual magnet alternator is intended to deliver high power at low speed. Ergo, this

system is believed able to reduce the losses of transmission during pulley system operation. [5]

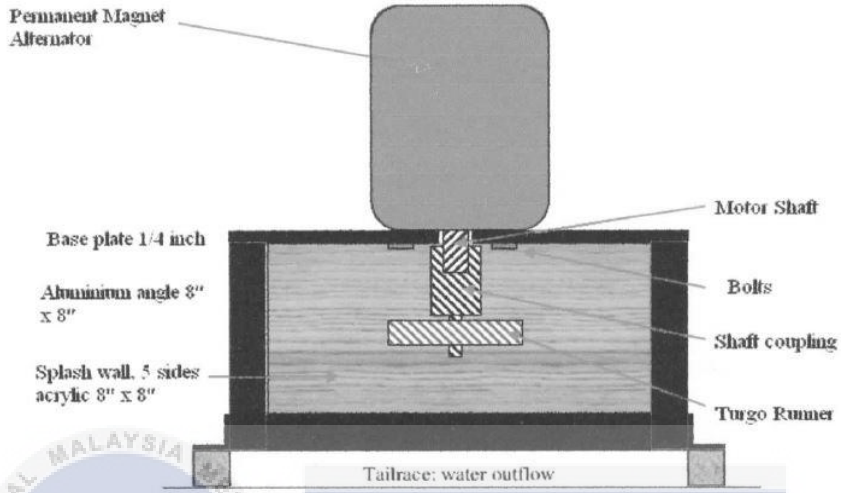

Figure 2.6. The designated pico hydropower system.

The turbine was moved by using the water jet pump, thus the power generated by the system is expected to supply the water jet pump and extra loads. That means, the system has an ability to achieve more than 100% efficiency which is not possible. Next, this system need to be injected with outer energy source to operate this system. Hence, the objective of this project was almost achieved but due to needed of outer source electrical energy it increases recent electricity bill when using the system.

2.6. Design and Development of Pico Micro Hydro System by Using House Hold Water Supply.

The system was designed by Gunjan Yadav and A.K Chauhan. It consists of pelton turbine and an alternator. The turbine blade is made from stainless steel spoons and are fabricated on the cycle rim. The rectifier is used to convert the AC to DC for charging purposed. The project makes two different head where for case one is 20 feet and second case 10 feet height. Both cases use same parameter of flowrate and proposed power which are 0.285 l/s and 8.408 W respectively. Lastly, the highest current and voltage the pico hydro system can obtained is 5.646 V and 6.87 mA. The

power generated is 0.02878 W which is less efficient and quite different from proposed power.

Figure 2.7: The pico micro hydro system

The experiment was conducted at Raman Hostel, in India. It used 1000L of water tank as forebay which height 21 feet from the ground. The project also used pulley system to provide greater rotation for alternator where the large pulley is ten times bigger than the small pulley at the alternator. [20]

2.7 Pico-Hydro System.

Pico hydro framework is water control that generate up to 5 kW. It was given the name "Pico" by Nigel Smith since its needs some unique methods for deduction to smaller scale, little and bigger hydropower. The energy created by the pico-hydro power is just competent to use for little sum power. This kind of hydro power depends on the basic essential operation of hydropower. There are two fundamental parts in hydro power that is head and rate of water stream.

2.7.1 Head and Flow

1. Head

Head in this hydropower system is define as vertical drop of water and which refer as water pressure. It also known as vertical displacement (feet, meter) from forebay or pressure hit per square inch. It can be categorized into two:

i) Static Head
ii) Dynamic Head.

Table 2.1: Classification of Head

(Source: Basar, M.F et al)

Category	Head
Ultra-Low Head	Head below 3 metres
Low Head	Head between 3 metres and 30 metres
Medium Head	Head between 30 metres and 75 metres
High Head	H above 75 meters

2. Flow

The most essential component to run or operate the hydropower system is flow rate. The power generation of hydro power is almost depending on the vertical distance or drop of water flow(H) from forebay and the water flow rate (Q). The formulas that can be relate and used during calculation of rate of power flow. These formulas are basically the most fundamental of hydropower generation. [3]

$$P_{net} = \eta P_{gross} \quad (1)$$

$$P_{net} = \eta Q g P_{gross} \quad (2)$$

The weight of falling water that assistance by the gravitational power is alluding to the force that bring the water to drop to the base. Supposition can be made that make water going descending as a mass(m) and the acceleration (a) because of earth gravitational force(g) or weight (mg). So from all the power that featured, conclusion can be made that discharged is

$$Energy\ Produced = \eta P_{gross} \quad (3)$$

Based on the formula of energy released (3) , the mass of water can be replaced by density ((p).

$$Energy\ Produced = pV\ gH_{gross} \quad (4)$$

Plus, the volume of water (V) in equation of (4) can be substitute by volume flow rate of Q cubic meter every second. With that operation, it be produced new equation of energy released in joules that can be known as gross power in Joules every second or in watts in formula (5). According to the new formula (5) the energy produced per unit of time or otherwise called the estimation of accessible water power. Calculation of total power received by hydropower generation is

$$P_{gross} = pQgH_{gross} \quad (5)$$

Based on formula (5) , power that usefully delivered is :

$$P_{net} = (0.5)(1000)(10)QH_{gross} \quad (6)$$

Or the formula for power that usefully delivered is :

$$P_{net} = 5QH_{gross} \quad (7)$$

2.8. Turbine.

According to reference [6-8] the authors have discussed the numerous characteristics and efficiency of various types of hydro turbine. Acknowledged that every turbine uses basic rotary engine component that function to extract potential energy of moving fluid flow. The most basic structure of turbines has one moving part, a rotor assembly, which is known as shaft that blades attached. The moving fluid acts

on the blades by hitting it, or the blades react to the flow, so that the turbine rotate and impart energy to the rotor. The shaft is straightforwardly or belted to either a permanent magnet alternator, or a "synchronous" or induction AC generator. Every design of turbine has different value of efficiency but most of the turbines have efficiency range between 60% to 70%. [9]

Table 2.2: Groups of Impulse and reaction Turbine

(Source: Arvind Nimje, Gopal Dhanjode)

Turbine Type	Type of Head pressure		
	High	Medium	Low
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis Pump-as-turbine	Propeller Kaplan

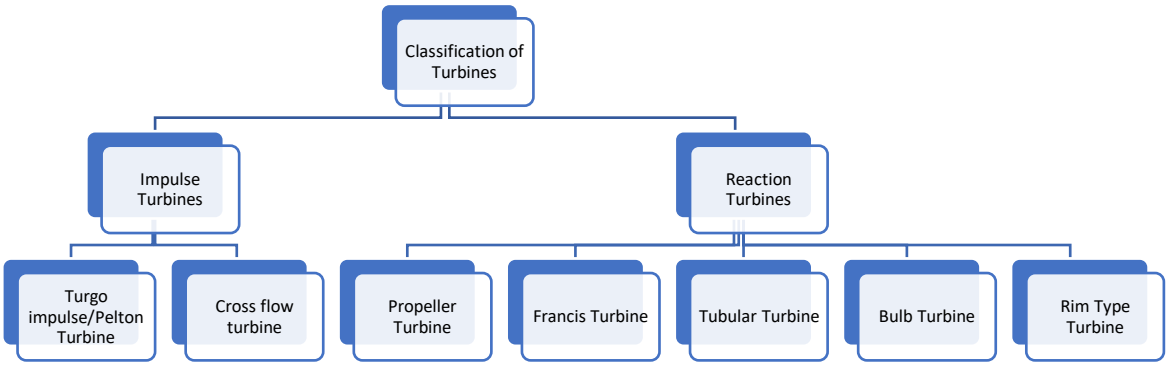

Figure 2.8: Classification of Turbine

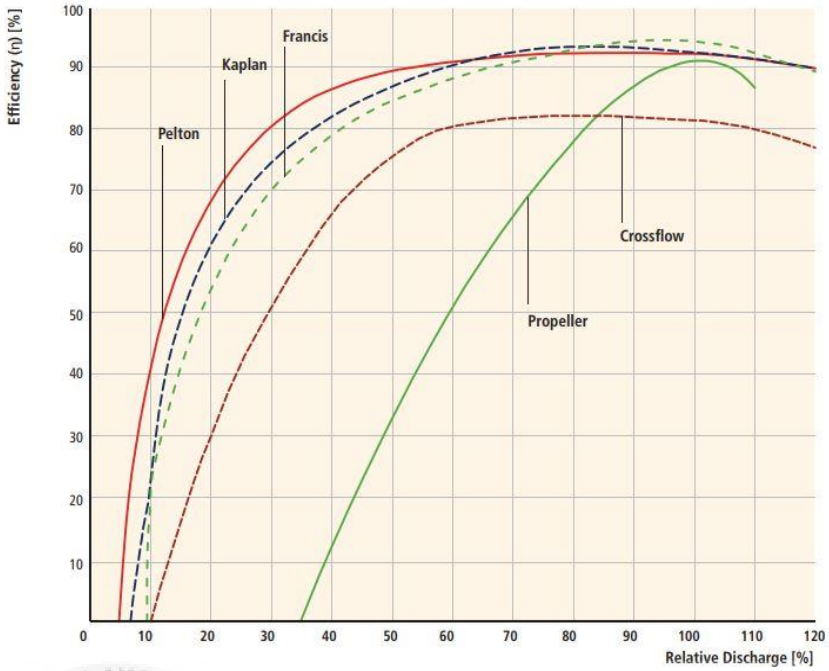

Figure 2.9: Typical Efficiency Curves for Different types of Hydro Power Turbine (Source: Arvind Nimje, Gopal Dhanjode)

2.8.1 Impulse Turbine

The impulse turbine is utilizing the speed of the water stream to move the turbine and release it's to atmospheric pressure. The turbine will keep running over when the majority of the bucket at the turbine is hit by the high speed of water. No suction will happen on the drawback of turbine, and the water will individual out of the base of the turbine lodging after hitting the turbine's bucket. Normally, an impulse turbine is great and appropriate for high head and low stream application. In term of cost, impulse turbines are less expensive than different turbines as there no perfect assemble and no painstakingly designed clearance are required. Example of turbine:

a) Pelton

This turbine was invented by Allan Pelton. It capable to obtain or extract the potential energy from the impulse of flowing water. The most efficient turbine compared with the other turbine in same category due to its design. Pelton's design has capability to

extracted almost all of the water's impulse energy this is due to Pelton's paddle geometry.

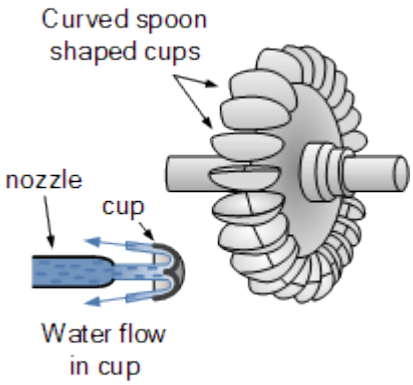

Figure 2.10: The structure of pelton turbine

(Source: http://www.alternative-energy-tutorials.com)

b) Cross Flow

The cross-flow turbine has axial or radial flows, in a cross-flow turbine the water passes via the turbine transversely, or across the turbine blades. It is more similar to a waterwheel; the water is conceded at its edge. After passing the runner, it leaves on the opposite side. Thus, it going through the runner twice provides extra efficiency during operation. The advantage utilizing this turbine, it helps clean the sprinter of little garbage and contamination. The cross-stream turbine is low-speed machine.

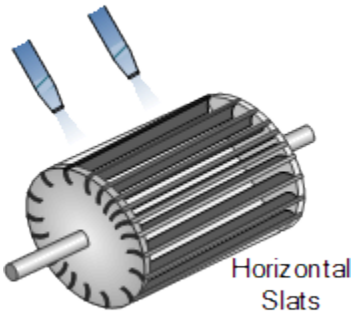

Figure 2.11: The structure of cross flow turbine

(Source: http://www.alternative-energy-tutorials.com)

2.8.2 Reaction turbine.

For this kind of water turbine structure, the turbine vanes are completely submersed in the flow of the water and are encased inside a pressurized compartment. A reaction turbine is powered basically by change in pressure, which referred as "pressure drop" over the housings body as this diminished in water pressure and velocity releases energy causing a response (thus the name) by moving the turbines vanes. The flow of water through a reaction turbine might be switched because of the point of the internal vanes, so a reaction turbine can likewise be utilized to pump water and the other way around. Example of reaction turbine:

a). Francis turbine.

The turbine is named after its designer James Francis, the structure is an outspread stream reaction kind of water turbine design in which the whole turbine wheel parts are inundated in water and encompassed by a pressurized spiral housing. The stream of water entering the housing under pressure and is guided through a set of fixed or adjustable slots called guide vanes around the casing which direct the stream of water to the turbines blades at the appropriate angle.

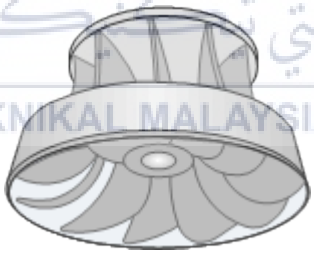

Figure 2.12: The structure Francis turbine

(Source: http://www.alternative-energy-tutorials.com)

c) Kaplan turbine

This turbine also named after it inventor named Victor Kaplan from Austrian. The structure of this turbine is an axial flow reaction type of water turbine that looks like a ships propeller. Due to same structure, Kaplan Turbine is also referred to as a Propeller Turbine. It has two propeller shaped rotor or more fixed or more adjustable blades. It also has set of fixed or adjustable guide vanes around the inlet of turbine to control its rotational speed which is similar to the previous Francis Turbine.

The operational of this turbine is the other way around to that of a ship propeller. The stream of water enters the turbine in a spiral heading through the bay vanes. Because of the cutting angle or edge and position of these vanes makes the water twirl creating a vortex inside the encased entry applying a force onto the rakish moulded propeller edges. The energy is delivered from the torque and rotation of Kaplan blades when there are force of whirling water pushing against the vanes.

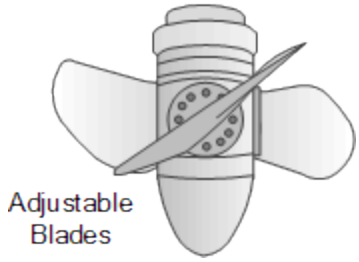

Figure 2.13: The structure Kaplan turbine

(Source: http://www.alternative-energy-tutorials.com)

2.9 Generator

There is various type of generators exist in this world. The generators are dived into two types which are AC and DC generators. Both have advantage and disadvantage and used for a specific task. The power generators is one of electrical machine that has ability to generate power and transforming the mechanical energy into electrical energy. Those power produced could be used to light up electrical appliance if sufficient power is supplied. Thus, this is why this machine is really important and usefully for location that lack or isolated from electric utilities. The power generators do not limit their function as to power up small communities, it also used in vehicle such as hybrid vehicles, trains, airplanes and boats. There are lot of sort power generators now days as mentioned above. One of kind is Direct Current (DC) generator. But the Alternate Current (AC) generator widely used. Despite that, there a few considerations that could be taken why DC Generator is more preferable over AC generator. [15]

The DC generator has ability to generate high current at small value of voltage requirement for purpose charging the battery and application for direct current loads [3] Next, a DC generator does not need extra power supplies or battery chargers. Plus,

DC generators have no need extra component such as rectifier because rectifier only reduces the efficiency and reliability of the system. The structure of DC generators, the halves of one split ring that revolves alongside with the coil are connected to different both ends of coil. The immobile metal brushes are linked to the spilt rings as external circuit. So, the combination of those two structures is referred “commutator”. Hence, a generally DC generator that has many coils and sections in its commutator provides much better of current.

The DC generator can produce smoother output if the arranging of coils is in regular pattern around the armature. The brushes are arranged to make contact only with the commutator bars corresponding to the coils producing the greatest emf at a particular time. As a result, it keeps the voltage output “ripples “at mean value instead fluctuating between zero and the maximum value twice per revolution. Assumption can be made, the more coils exists in the DC motor, the smoother the output DC voltage ripple. This is an advantage for use with equipment that needs a steady voltage rather than sinusoidal varying voltage. This cannot be achieved with using an AC generator without the addition of a rectifying and smoothing circuit. The last advantage than should be considered is the permanent magnet field generators is their size. The size of PMDC is quite small and can replace the wound filed with ceramic permanent magnets. The smaller size includes the generator’s ring and magnet assembly which providing substantial savings in both size and weight.

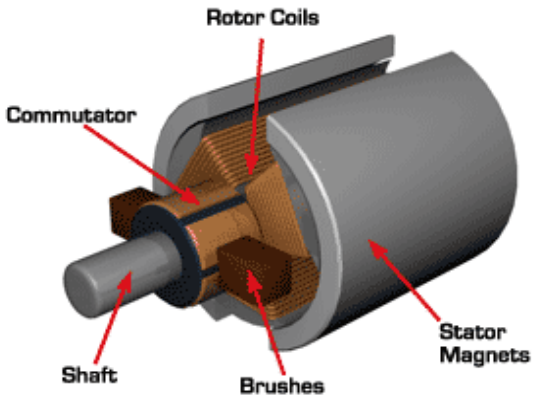

Figure 2.14: Permanent magnet DC Generator

(Source: https://www.electrical4u.com)

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

The chapter will explain in detail regarding the development of the pico-hydro turbine generation. According the flow chart that has been built below, it going to be used as guider to manage and conduct the experimental during process of development. The guidance includes the selection of the turbine design type of motor and other important requirements. Each box will state the procedure that will be done and conveyed amid testing.

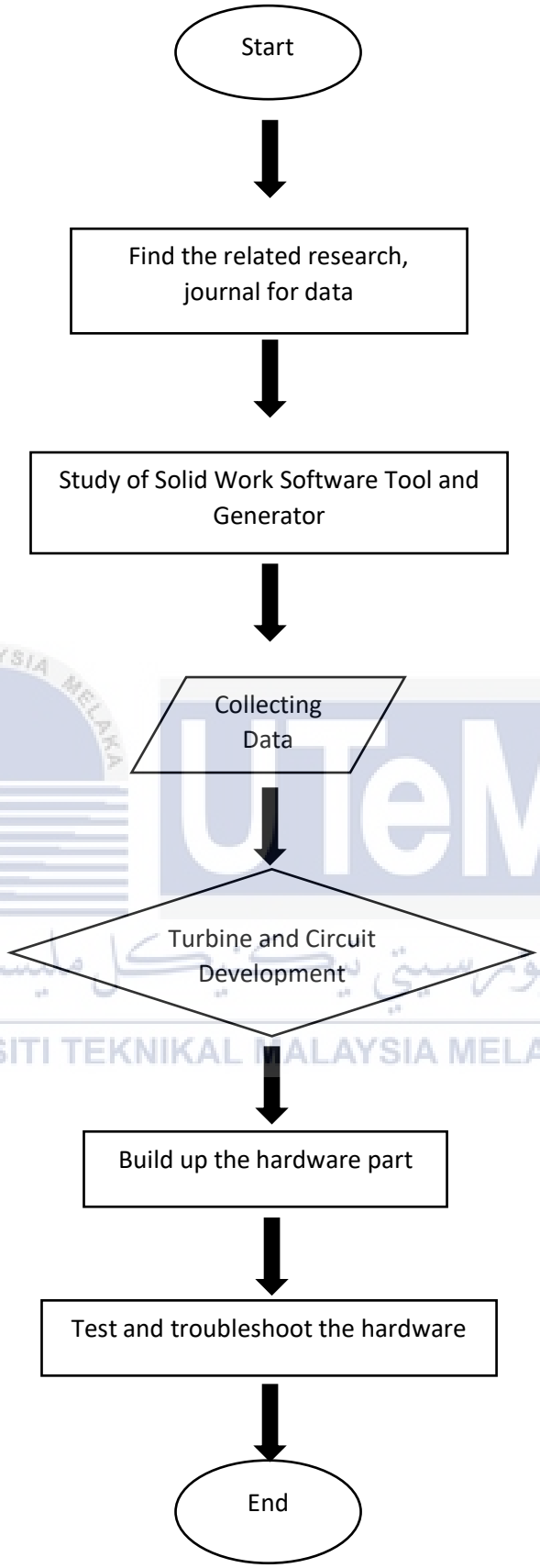

Figure 3.1: Flow chart progress for the final year project.

3.2 Turbine Development.

In this project of pico hydro design, it uses the pelton turbine blade that screwed at waterwheel then it will attach at the generator shaft. The Pelton blade is designed by solid works software.

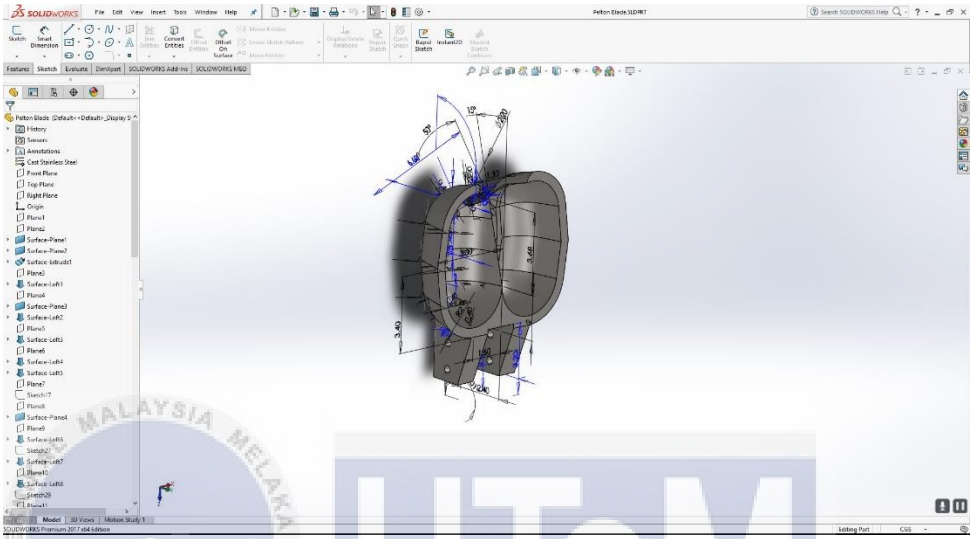

Figure 3.2: The interface of Solid Works software

3.3 Determining Head (Falling Water)

Head is compulsory and need to be consider during designing the hydro turbine system. Head is measured from the source of falling water that available at turbine and also referred as pressure of falling water. During determining head (falling water), gross or “static” head and net or “dynamic” head must be considered. The gross head is the displacement or vertical drop from forebay until the point where the water is released from pipe system and hits the turbine. While for the net head is more refer as the actual head. It can be determined by subtracting the gross head with head losses in pipe system. The losses in pipe system are depend on the diameter, type and length of the pipes system. Next gross head is used to approximate power availability and determine general feasibility, but net head is used to determine the actual power available. The water filled-tubes and combined with attachments of calibrated pressure gauge at end tip of tubes are the convenient method to determine the head.

$$H = 0.704 \times P \qquad (3.1)$$

Where H = Head (meter)

P= Pressure (psi)

One psi of pressure is for every 2.31 ft. or 0.704 meter in concept of water pressure [16].

The equation (3.1) will be used to determine the power output and power input during power calculation. The water pressure referred as the net head of the system that crucial to identify the actual power available

3.4 Determining Water Flow Rate

The most basic and easiest method to measure the water flow inside the penstock or pipe system is the "bucket" method. This method need the bucket and stopwatch. The stopwatch will be used to identify the time taken for water flow to fill up the known capacity bucket. This method need extra cautions during measuring the water, thus it must be repeated couple times to achieve accurate measurement. The rate that the container fills is the flow rate.

3.5 Determine Power

The power output generate from the rotating generator will calculate and tabulate properly for further study. Then the data will analyse and make comparison. To determine power both head and flow are compulsory to produce power. Power is measured in watt (W) or kilowatts(kW). The power from water will always bigger than the mechanical and electrical power. This is due to losses of power at every stage during energy conversation.

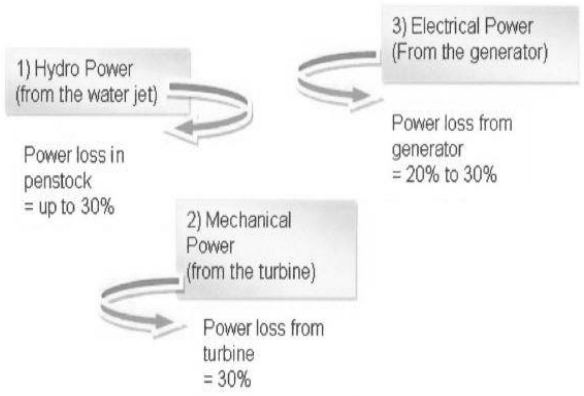

Figure 3.3 The flow of power conversion and loss for every stage of energy transformation

(Source: H. Zainuddin)

The significant loss often occurs during conversion of energy from potential energy or power in pipe system into rotating or mechanical energy by hitting the turbine blade. Next power loss occurs in generator which 20% to 30% during the conversion of energy from mechanical power to electrical power.

For calculation of available power, the simple formula for potential input and output power are as follow [4]:

Input Power(watt)= H x Q x g

Output Power (watt) = H x Q x g x η

H= Head (in meter unit)

Q= Flow rate (in litre/second unit)

g= gravity (9.81m/s)

$\eta = efficiency$

Hence, the rule of thumb for efficiency to estimate the potential output power is normally 50% to 60%. These are some of the conversion factors that may need when evaluating a hydro power site:

1 inch = 2.54 centimetres; l foot = 0.3048 meters;

1 meter = 3.28 feet; l cf = 0.028 cubic meters (cm); 1 m3 = 35.3 cf;

1 gallon = 3. 785 litres; l cf = 28.31 litres; 1 cfs = 1698. 7 litres per minute;

1 cubic metre per second = 1000 litre per second;

1 cubic foot (cf)= 7.48 gallons;

1 cubic foot per second (cfs) = 448.8 gallons per minute (gpm);

1 cubic meter per second (m3/s) = 15842 gpm;

1 pound per square inch (psi) of pressure = 2.31 feet (head) of water;

1 kilowatt (kW) = 1.34 horsepower (hp); 1 hp = 7 46 Watts.

3.6. Block Diagram

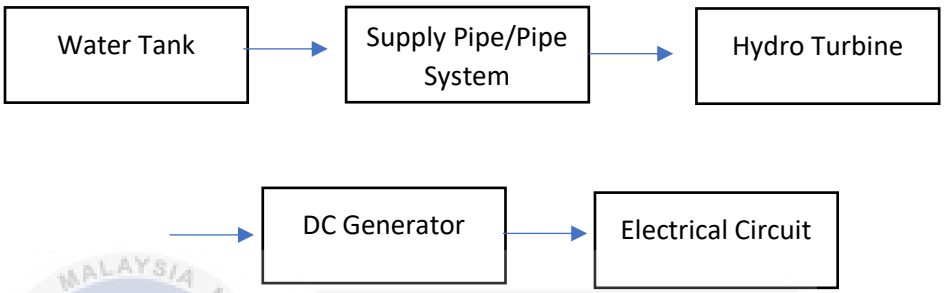

Figure 3.4: Block Diagram of The System

Based on the block diagram figure 3.3, it is show the overall setup of the pico hydro water turbine generator. The water tank will refer any reservoir water that could be used as the water storage. Then it goes to pipe system which is penstock. Penstock or pipeline system may have referred as PVC pipes that collect water from the water tank and provide path for water flow to reach the hydro turbine. After the water reach the hydro turbine, it will hit the turbine cause the rotation of turbine. The turbine is attached or connected with the DC generator. The process of rotation in DC generator will occur the transformation of energy from mechanical energy to electrical energy. The electrical energy such power, current and voltage will feed to electrical circuit. The electrical circuit will consist of boost or buck-boost converter and charging circuit.

3.7 The Simple Pelton Water Turbine for Pico Hydro Generation System

Figure 3.5: Front View of Pico Hydro Generation System

Figure 3.6: Left View of Pico Hydro Generation System

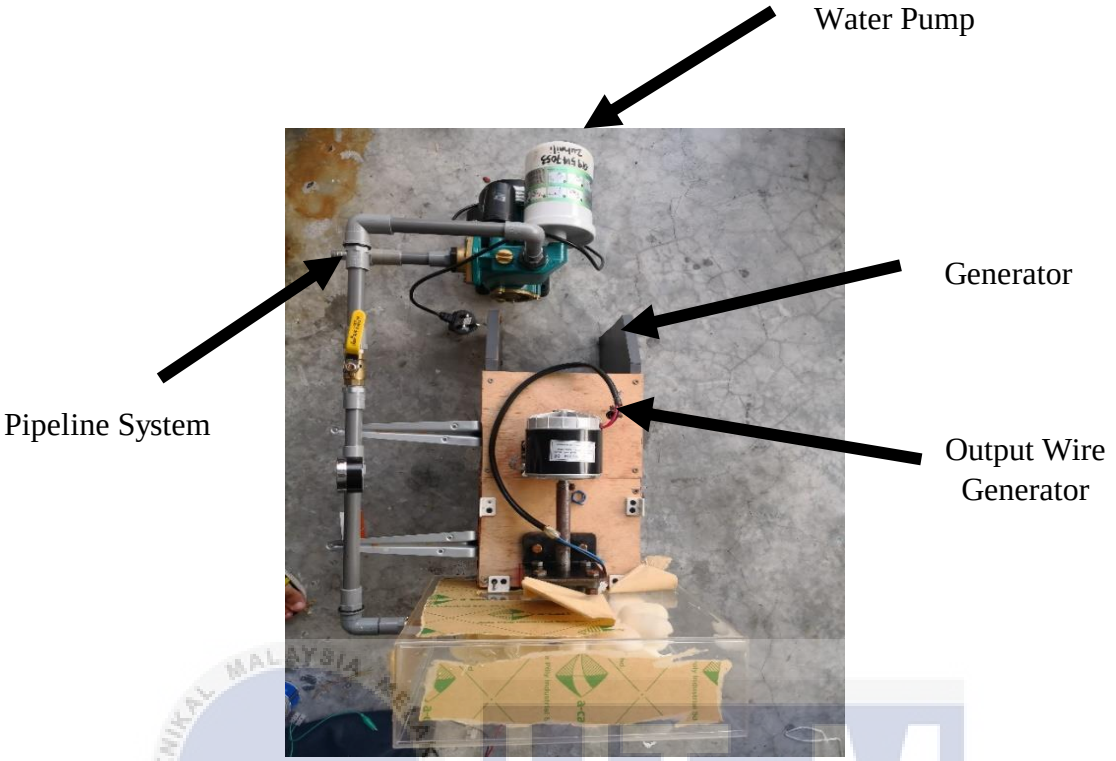

Figure 3.7: Top View of Pico Hydro Generation System

Figure 3.8: Right View of Pico Hydro Generation System

3.8 Gantt Chart

This project is planned from starting until the end of Final Year Project 2. It is required to ensure the planning activities will be accomplished based on the deadline. The project timeline is planned as shown in Table 3.1

Table 3.1 FYP Gantt Chart

No	Activities	Duration (weeks)																												
		Semester 1													Semester 2															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Briefing final year project																												
2	Project title selection																												
3	Identify project objective and problem																												
4	Literature review																												
5	Designing the draft of the Final Year Project report																												
6	PSM 1 report																												
7	Submission PSM 1																												
8	Presentation PSM 1																												
9	Developing The Hardware																												
10	Performance Analysis for Pico Hydro System																												
11	Making Improvement for Pico Hydro System																												
12	PSM 2 report																												
13	Submission PSM 2																												
14	Presentation PSM 2																												

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, it will discuss the result about the design and development of simple pelton water turbine for pico hydro generation system. The results will analyse and the problems will identify throughout this project. This result shall guide the for the future students or junior to use it as improvement

4.2 Hardware Implementation

4.2.1 Design of Pelton Blade

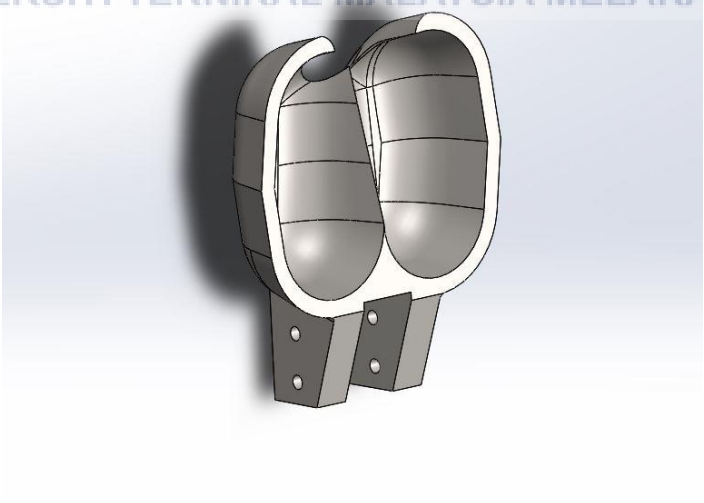

Figure.4.1 Pelton blade design using Solid work

The Figure 4.1 shows the design of pelton blade that produced using 3D printer. It will attach onto the turbine wheel. It may consist six or eight pelton blades that will attach around the wheel in order to increase the efficiency of rotation by letting the water flow hitting the pelton repeatedly.

4.2.2 Design of Turbine Wheel

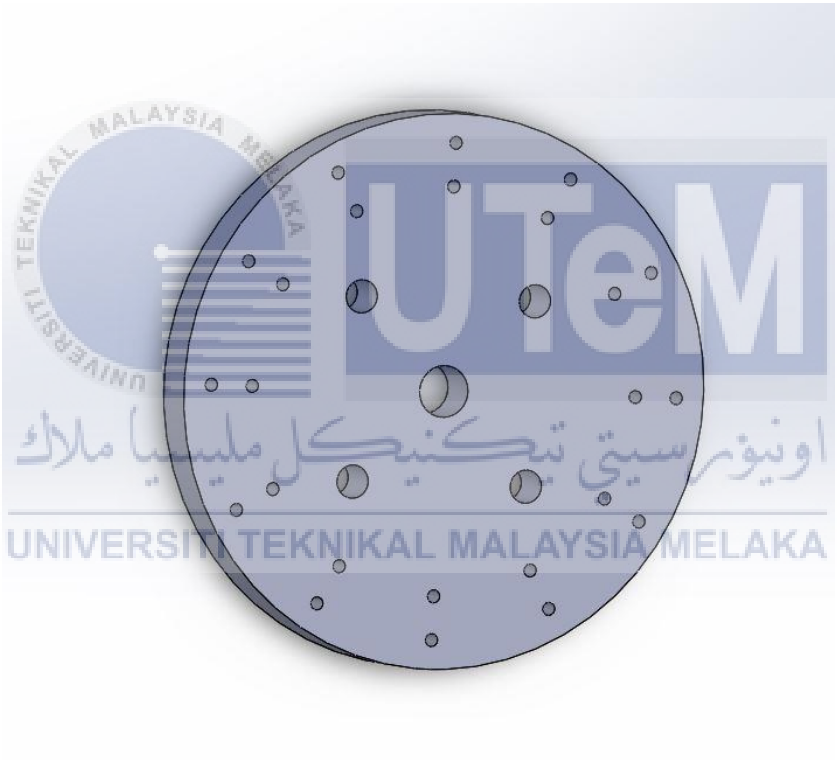

Figure 4.2: Turbine wheel that attached with pelton blade

The Figure 4.2 shows the expected design of wheel turbine that will be used to attach the pelton blade at around the wheel.

4.2.3 Hardware for Electrical Part

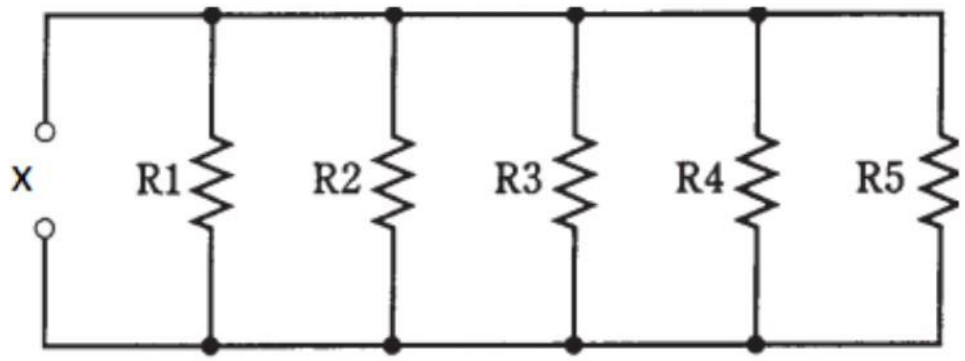

Figure 4.3: Parallel Resistor Circuit

Parallel resistor circuit is used to determine the efficiency of the pico hydro generator system. The X is the generator input to the parallel circuit. Each resistor represents the value of the resistor that attached such as 10 Ω, 100 Ω 150 Ω. Then, the resistor will pull out one by one to find out which value of resistor produce the greater output. The breadboard is used for ease the process determining the value of resistor.

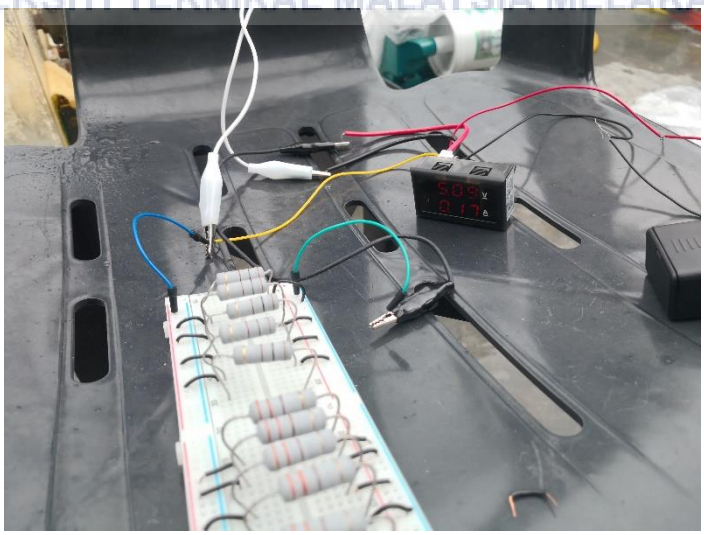

Figure 4.4: The Breadboard That Attached with Resistors

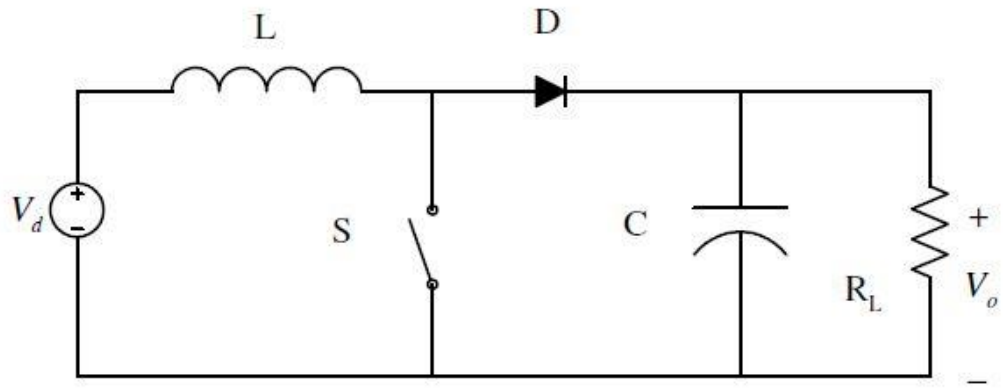

Figure 4.5: Basic Schematic Design for DC-DC Boost Converter

The Figure 4.3 shows the basic design of DC DC Boost Converter that will be used in electrical part for step up voltage. Then the output of DC DC boost converter will feed to the load.

Figure 4.6: DC-DC Boost Converter

4.2.4 The system of penstock/pipeline

Pipeline system are important for pico hydro system, it brings the water from the reservoir or forebay to the turbines machine and certain turbines also require piping system that to discharge water away from turbine machines. The pipeline system could be long or short, it depends on the distance between the reservoir of water or source and the turbine. Next, in order to reduce the friction loss in pipeline system, minimum length should be considered for to achieve optimum conversion of energy into electricity. Polyethylene or PVC pipe is commonly used for choice of low cost scale.

The pipeline system is created to produce high pressure of water to enable the rotation of turbine. The design must be in good in delivering the water flow and less friction in order to avoid low water pressure after flowing out from nozzle.

Proposed piping specification:

i) Nozzle – variable
ii) Elbow – 90 degrees
iii) Tee – flanged
iv) Straight connector
v) Valve – ball valve
vi) Pressure Gauge – 0 to 10 bars
vii) Main pipe – 1.5 mm diameter
viii) Turbine – pelton turbine

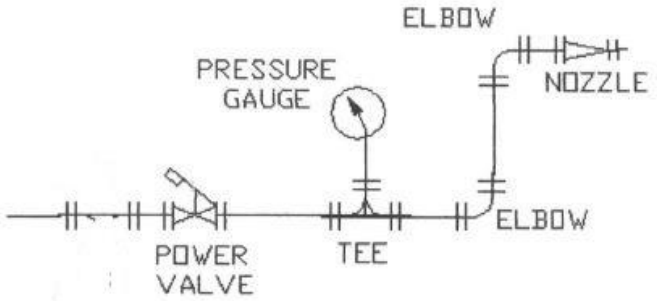

Figure 4.7: Pipe System That Used for Measuring Applied Pressure

4.2.5 Permanent Magnet Direct Current Generator.

The generator used for this project is permanent magnet DC generator. The reason chose this type of generator because the generator does not produce power fed back to the machine during rotation, thus the power generated will feed to the load. The lack of this PMDC generator is the highest output is influenced by the immanent strength of the magnets. This means the output of generator is limited due to this concept.

4.2.6 Concept Idea of The Design

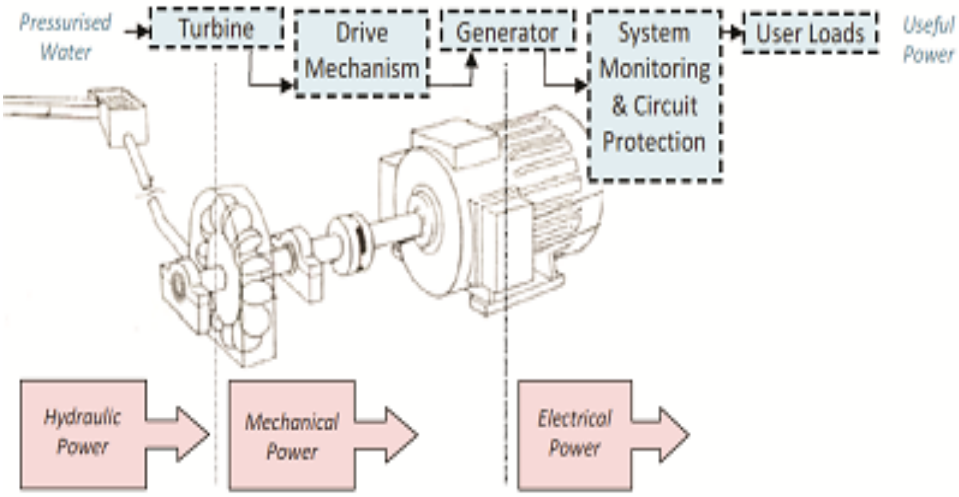

Figure 4.8: The Concept and Design of Pico Hydro Turbine.

4.3 The Result

4.3.1 Experimenting the Performance of Pico Hydro System

There are several tests were performed to identify the performance and identify the capability of the pico hydro system. The first test was included the open circuit test. This test was to achieve the result of the current and voltage produced if there is no load applied when the pico hydro system operate. Next, the second test was to require the maximum power delivered during the operating of the pico hydro system.

4.3.2 Experiment the Open Circuit Test

Normally the open circuit test is performed to analyse the generator output performance without connecting the load. This method to find the weakness and strength of the system. The compulsory data or information regarding this test are tabulated such as rate water flow, the voltage and current of open circuit test, generator speed and water pressure level. The water flow is pressurised by the automatic water

pump. This purpose to get the maximum pressure and head of this experiment can achieve.

Table 4.1: The Result for Open Circuit Test

Speed (rpm)	Voltage(V)	Current (I)	Power (W)	Pressure (psi)	Head (m)	Rate of Flow Water (litre/second)
434	5.5	3.00	18.1500	20	14.1	0.5357
388	5.13	2.71	13.9023	18	12.7	0.4530
345	4.85	2.41	11.6885	16	11.3	0.4451
305	3.90	2.13	8.3070	14	9.9	0.3896
255	3.55	1.78	6.3190	12	8.5	0.3571
205	3.15	1.43	4.5045	10	7.0	0.3093
160	2.40	1.12	2.6880	8	5.6	0.2344
103	1.75	0.72	1.2600	6	4.2	0.2174
46	1.14	0.32	0.3648	4	2.8	0.1488
24	0.41	0.17	0.0697	2	1.4	0.1250

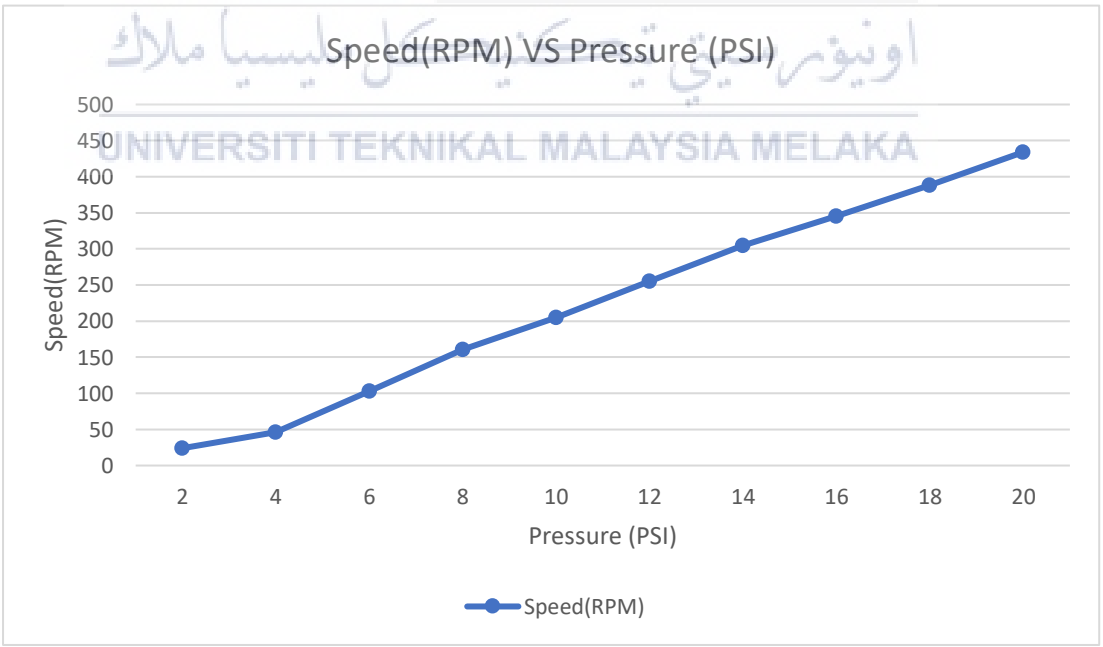

Figure 4.9: Speed Vs Pressure Graph

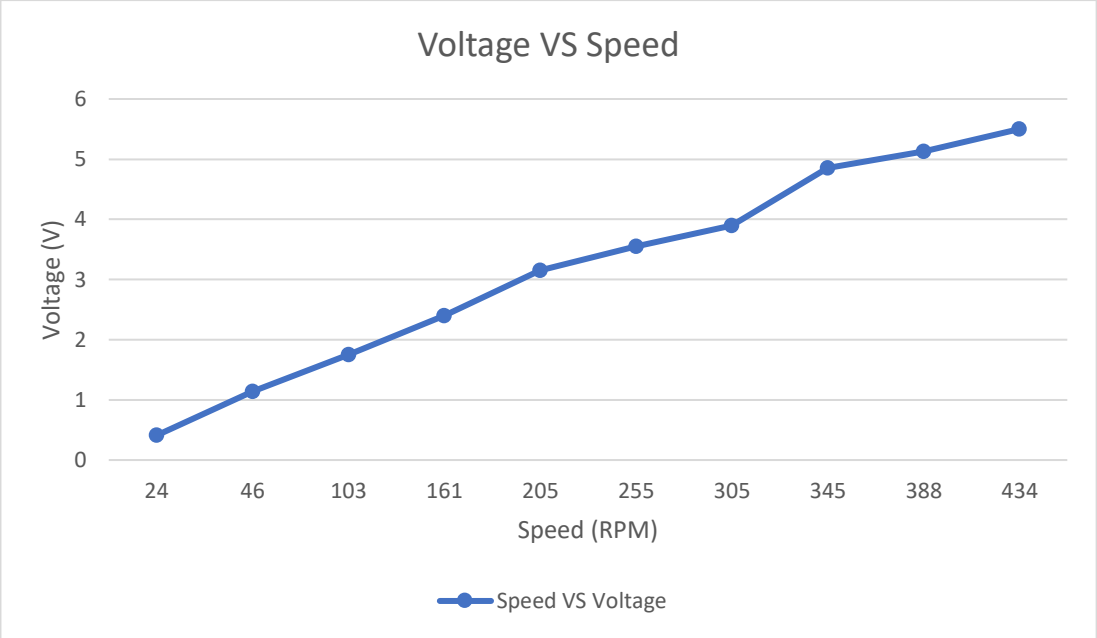

Figure 4.10: Voltage Vs Speed Graph

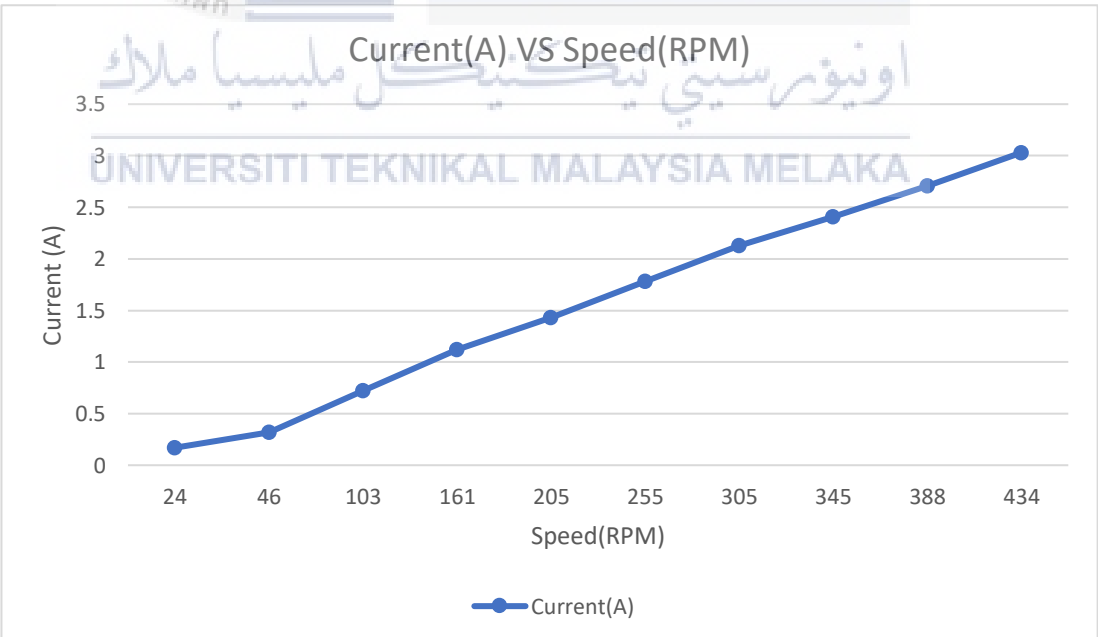

Figure 4.11: Current VS Speed Graph

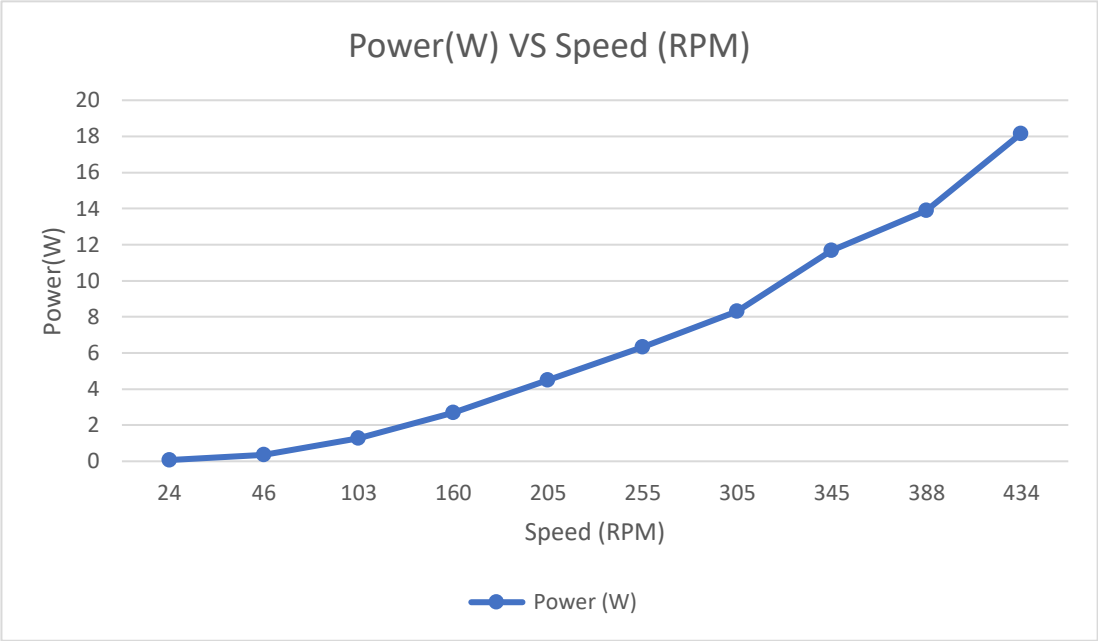

Figure 4.12: Power Vs Speed Graph

4.4 The Highest Power of This Pico Hydro System Achieved

The test will conduct to determine or observe the DC generator performance. In terms of power output and efficiency. A few resistors are used to vary the output power. The value of power output then will compare with the proposed system of power. As a result, the efficiency of power delivered can be determined. The prime mover for this pico hydro system is used the pipeline water system. The output voltage of the generator is maintained at 5.5V at initial operation before applying any resistor. The prime mover which controlled by the water of flow rate by adjusting the valve of the pipeline system. Thus, to maintain at 5.5 V the valve is adjusted until the multi-meter reached or maintained at 5.5 V with 20 psi applied.

The data of water pressure level is measured to identify the maximum output power at the certain time. It is compulsory in order to determine the number in percentage of the efficiency of generated output from the pico hydro system.

Plus, the rate of water flow is determine using the bucket method. The steps and method are already discussed in Section 3.4. Hence by using the 1.5 litre of bucket, the following data of water flow rate is tabulated below:

2.8 Seconds ⟹ 1.5 litres of water

1 minute ⟹ 31.4 litre of water

Thus, 1.5 litres / 2.8 seconds = 0.5357 litre/second

After the experiment has been carried out, the data recorded is tabulated below. Form the table below, it seems the maximum power that pico hydro system could generate is at 3.78 W. The value of this maximum power is quiet low to act as supply generator for various electrical appliances.

Table 4.2: The Output Power When Tested with Different Value of Resistor

Resistor (Ω)	Voltage (V)	Current (A)	Power (W)	Speed (RPM)
2	3.57	1.06	3.78	257
2.5	3.72	0.95	3.34	285
3.33	3.85	0.79	3.04	297
5	4.13	0.65	2.69	314
10	4.59	0.39	1.80	334
20	4.92	0.20	0.98	356
25	5.04	0.17	0.86	374
33	5.20	0.12	0.62	396
50	5.30	0.07	0.37	409
100	5.42	0.02	0.11	424

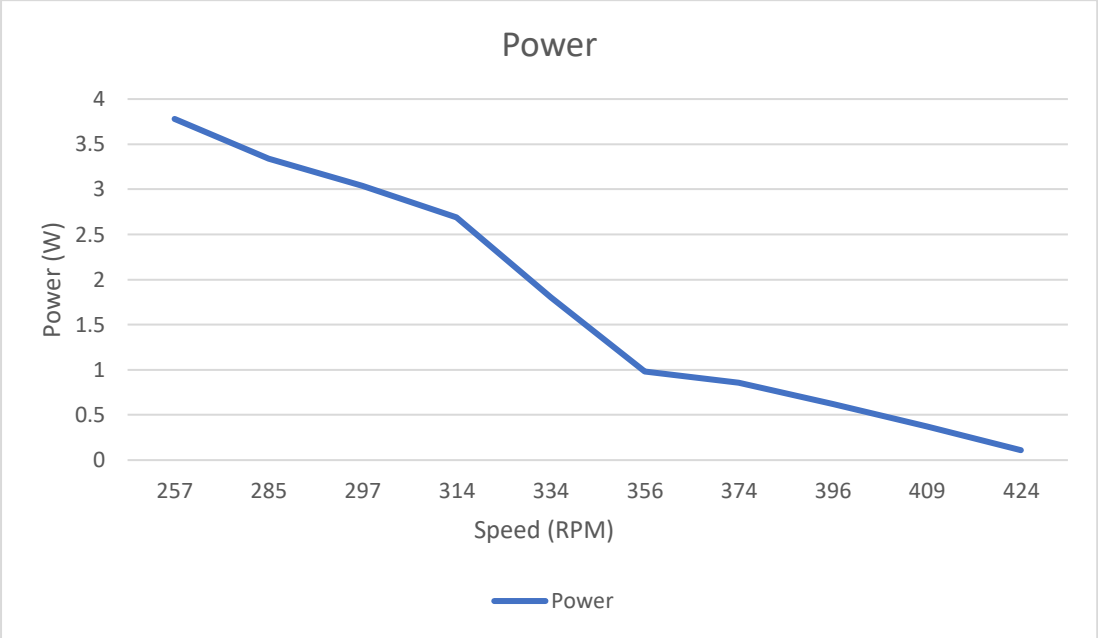

Figure 4.13: Power Vs Speed Graph

Table 4.3: Maximum power delivered test results using DC-DC Boost Converter which connected with Bulb.

Resistor	Voltage(V)	Current (A)	Power (W)	Speed (rpm)
41	4.96	0.12	0.60	400
43	6.08	0.14	0.85	385
47	8.00	0.17	1.36	366
51	10.2	0.2	2.04	341
56	12.3	0.22	2.71	324
58	14.0	0.24	3.36	315
60	15.0	0.25	3.75	310

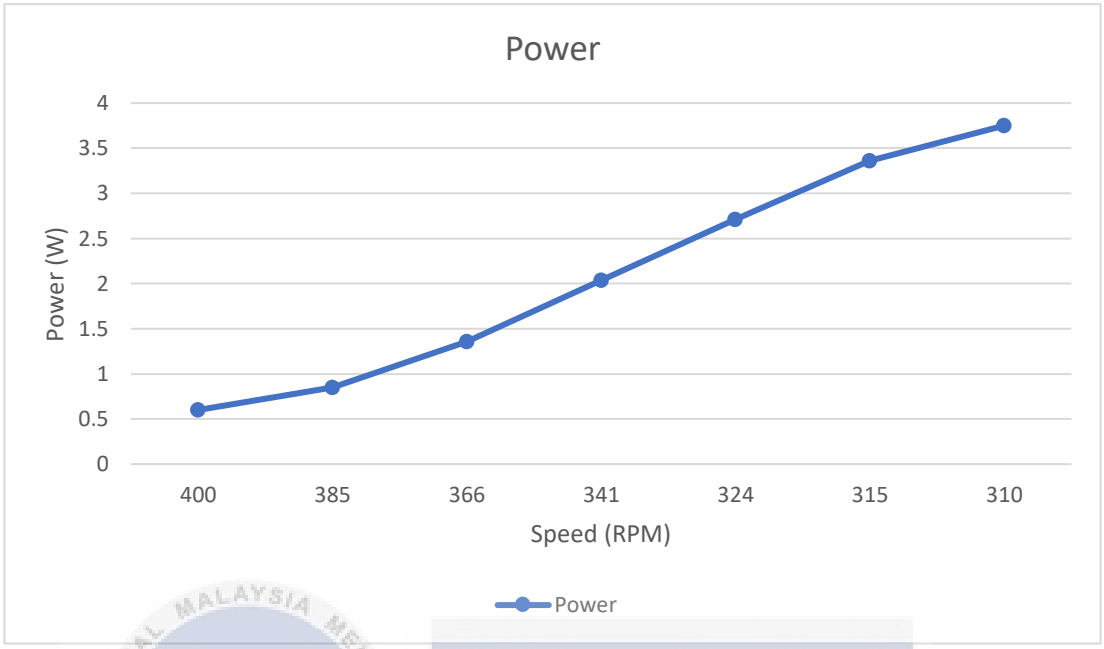

Figure 4.14: Power Vs Speed

4.5. The Calculation of Power Generated by The Pico Hydro System

The output generated by this pico hydro system can be determined by using the proper equation from the Section 3.5. The highest water pressure recorded from the Table 4.1 is 20 psi. Since the head is the measurement for the pressure of falling water from the top until hit the turbine which expressed in water column. Although, the head measurement for this project is determined by the pipe system which the pressure gauge is attached at the pipe system. The purpose doing so is to identify the value pressure applied that hit on the turbine. The value pressure then is converted into head which unit is in meter.

The conversion process is like below:

1 pound per square inch (PSI) of pressure is equal to 2.310 feet (head) of water.
The highest recorded value is 20 psi, then it converted by time the value with 2.31.
Thus, the value is 46.2 feet. As Malaysia was using SI Unit which in meter.
1 feet equal to 0.3048 metres
Hence, the value head of the falling water is:
46.2 feet X 0.3048 metres = 14.08 metres

At the water pressure 20 psi, the value for its water flow rate is 0.5357 litres/ second. After that, in order to calculate the efficiency of the system the value of the potential output power and input power must be determined. Those values are calculated based on the formula discuss in Section 3.5. Where the potential output power is considered 50 % from the input potential power this due to losses in every part of the pico hydro system such loses in pipeline system, conversation between mechanical power into electrical power and electrical system.

Input Power in watt is Hx Q x g
H= 14.08 metres
g =9.81 metre/second
Q = 0.5357 litre/seconds
The value input power is 73.99 W

While the Output Power in watt is H x g x Q x η
H = 14.08 metres
g = 9.81
Q =0.5357 litres /seconds
η = 50%
The value output power is 37 W

The value from the theoretical value is quiet high compared with the value of the predetermined output power in Table 4.2. From the tabulated data, the real output power of the pico hydro system is within 3.78 W. Therefore, the efficiency is

Efficiency, $\eta = \frac{Actual\ Power\ Output}{Theoritical\ Power\ Output}$ X 100

$= \frac{3.78\ W}{37\ W}$ X 100

= 10.21 %

Table 4.4: The Other Efficiency of This Generator with Different Value of Resistor

Resistor (Ω)	Generator Efficiency (%)
2	10.2
2.5	9.00
3.33	8.20
5	7.30
10	4.90
20	2.65
25	2.32
33	1.70
50	1.00
100	0.30

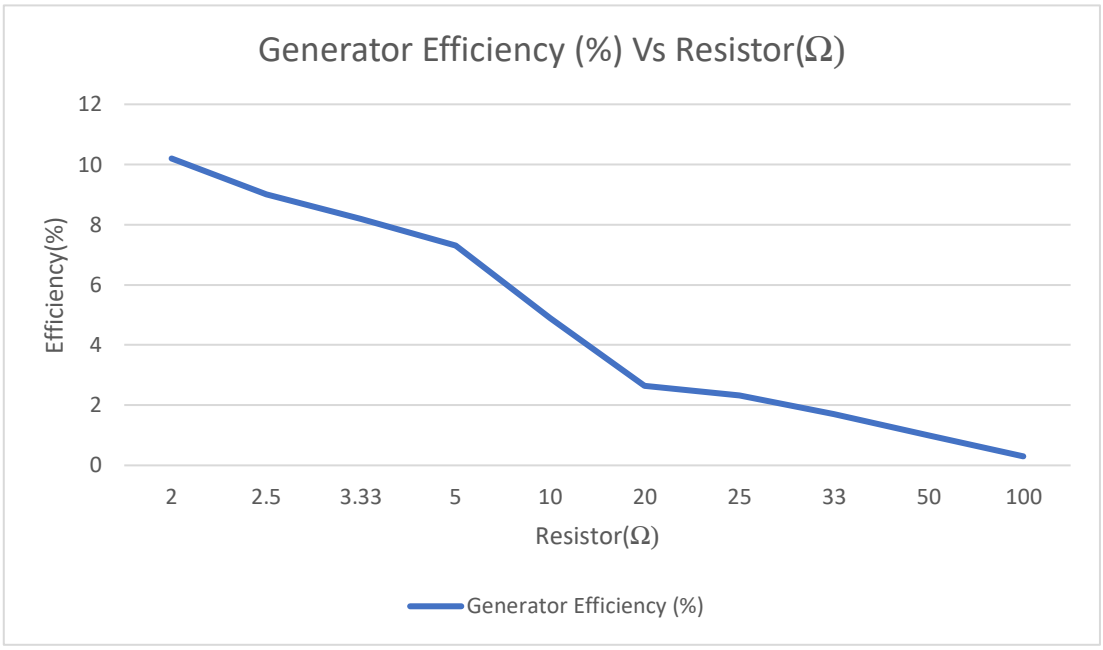

Figure 4.15: The Efficiency of The Pico Hydro System with Different Value of Resistor (Load)

The result of the efficiency is low. This probably due to the losses happen in the pipe system and generator. Further research regarding this project should be done for improvement and commercial use

4.6 The Automatic Water Pump Act as Simulator of Waterfall

An automatic water pump has been used to create a simulator pressure of waterfall. This is compulsory to show function and determine the performance of the pico hydro system. The automatic water pump is essential part for demonstrating during exhibitions or presentation of Final Year Project 2. The usage of automatic water pumps the pressure recorded is 20 psi which equals to 1.37895 bar. When the value 20 psi is converted into head of the waterfall its approximately 14 metre height of waterfall. This above the average of height waterfall in Malaysia, it probably could apply this turbine for the purpose of generating electricity. The Kijang Waterfall located at Kampung Esok, Negeri Sembilan has height 116 metre. The pico hydro system could be applied at the waterfall with proper pipeline system from the top where the water is falling.

Figure 4.16: Kijang Waterfall located at Kampung Esok, Negeri Sembilan.

Table 4.5: Specification of Water Pump

Automatic Water Pump	
Power Source	240 V/ 50 Hertz
Maximum Suction	8 metres
Pressure switch ON OFF	 1.3 kgf/cm^2 2.3 kgf/cm^2
Maximum Capacity	34 litre / minute

Model FYUGA: WP -370	
Power Output	370 watts
Maximum Head	32 metres
The Water Pump Speed	2900 RPM
Water Inlet and Outlet Diameter	25mm

CHAPTER 5

CONCLUSION

5.1. Conclusion

As a conclusion, this project need a proper and define parameter in order to design and develop the pico hydro turbine. The previous research must be learnt before starting any idea in developing this project. So, journals, previous research and final year project must be learnt for to fetch any related essential information that could be used for this project and future work. If not, the project will find difficult to initiate and complete. Furthermore, this project more related to hardware implement, thus, technical skill should be excellent so that the design and developing process run flawlessly. Lastly, performances analysis must be done especially for this project in order to get the data result. The data result could be used for improvement of pico hydro water turbine during process of development and also for future research.

The pico hydro system of this project is succeed develop. The are many considerations need to take account especially the generator, pipeline system and the head of the water or pressure applied on the turbine. These parameters are compulsory to develop a pico hydro generator system. Basically, the generator is the main element to produce the desired output in this project. The current or voltage generated are depend on the rotation inside of the generator, the fast the rotation the more the voltage and current generate.

After that, the water pressure applied or head of the falling water. The potential energy or power carried by the water is quite high but due to the pipeline system, there are reduction in terms of power before the water hits the turbine. This because the potential energy carried by the water is reduce by the friction inside the pipeline system. As acknowledged, the longer the pipeline system the more the friction that cause the reduction of the potential energy carried by the water and the water flow rate also be reduced and then which affect the pressure applied on the turbine.

Next, the design of the propeller turbine. The design should be parallel with the size of the generator that will be connected by the shaft. If the turbine is too small and the generator is big, it is difficult to rotate which cause the rotational of the turbine will be low in rpm. Low rpm means less voltage and current will be generated.

The 3D printed design quite reliable, the material used such ABS has strong ability to withstand upon the high-water pressure without any broken pieces. This shows the 3D design turbine can be used as alternative turbine instead using the stainless steel or any alloy or carbon made turbine. The 3D printed turbine is lighter and strong. The lighter turbine or less heavy turbine contribute a lot in rotation of turbine compared with the steel, allow or carbon turbine. This allows the rotation speed can be increased and get the better result of voltage and current output.

Lastly, the data from the performance result of this pico hydro system shows the highest power that could be generated within 15 watts with the voltage and current outputs V and A respectively. These values of outputs have capability to store energy and charge power bank. It also capable to light up small bulb.

5.2 Recommendation

The many recommendation can be applied on pico hydro system project. These recommendations are crucial for future work and junior's student who tend to involve in development of pico hydro system. It could be a guideline to ensure the development they make are better and more quality and convenience design plus it can be commercial in the local or overseas market. The recommendation is

5.2.1 Pulley System Between Turbine Wheel and Shaft.

This recommendation or suggestion is offer the rotation of the generator increase. The increases are depending on the size ratio applied between the driver and driven pulley. Assuming the driver pulley is the turbine with diameter size 15cm while the driven pulley is the generator with diameter size 5 cm. When the driver pulley or turbine is rotating at 400 rpm, the driven pulley will rotate at 1200 rpm. The value of 1200 rpm can produce within 10.5 V at rated voltage and speed which are 24 V and 2750 rpm respectively.

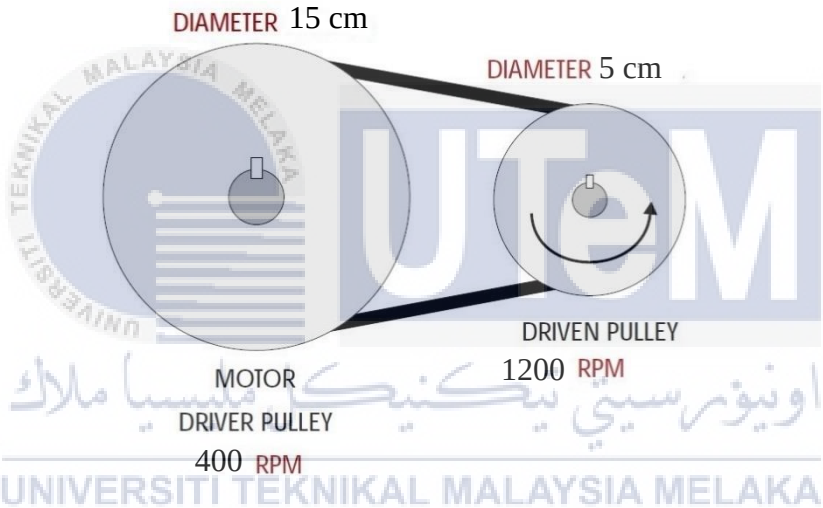

Figure 5.1: Proposed Pulley System

$$\frac{Diameter\ of\ Driver\ Pulley}{Diameter\ of\ Driven\ Pulley} = \frac{15\ cm}{5\ cm} = 3$$

1: 3 = Driver: Driven

Velocity/ Speed of Rotation of Driven Pulley Wheel = RPM of Driver Pulley X 3

= 400 X 3

= 1200 rpm at Driven Pulley

After the application of the pulley system, the driven pulley will rotate faster than the driver pulley as the driven pulley has small diameter than driver pulley.

5.2.2 Apply a Gear System

Its acknowledged the voltage level produced by the pico hydro system is within V and the output around W with the maximum of generator rotation at 434 rpm. Other than pulley system, the gear ratio system could be applied to increase the rotation of the rotor generator. The gear ratio system could help in producing the high rpm for the rotor generator by applying a proper size of gear system. Below is the proposed concept of "cascaded gear train". By assuming the gear, A is the pelton turbine's wheel. It rotates in a clockwise at 400 rpm.

Figure 5.2: Proposed Gear System

GEAR A	GEAR B	GEAR C	GEAR D
300 TEETH	100 TEETH	200 TEETH	50 TEETH

The RPM at gear B:

A/B = 300/100 = 3

400 RPM X 3 = 1200 RPM

The size of gear B is smaller than gear A thus the rotation speed of B is faster and increase. While the gear C is rotate at the speed as B since it fixed to B.

After that, the RPM at D (the shaft that connected with generator)

C/D = 200/50 = 4

1200 RPM at C X 4 = 4800 RPM

The gear D has small size than C, therefore it rotates faster. The rotation at D will increase more output generated by the generator.

5.2.3 Avoid Using Wooden Material

The hydro system always encounters with the water. In order to make a prototype turbine, wooden material mandatory must avoid to ensure long term of experiment and result analysis. Wooden material cannot bare with splash of water. It is easily could damage the structure of wooden material. The woody part will be easy to rupture or broke. Especially for the base part. The base part is easily exposed to the water splash thus the wooden are easy to broke and growth fungus

5.2.4 Use Low RPM Generator or Alternator

The usage of low RPM DC Motor or Generator will produce more power output at low speed of rotation. This could reduce the pressure needed to rotate the turbine

that attached to the generator or motor. The old type of generator required large amount expenditure of energy to produce a feasible amount of power. Generally, the low rpm generator or motor starts generating power just at single RPM. This due to the materials made of inside the generator. It uses powerful material such as neodymium magnets that create a permanent magnetic field around the conducting coils. Next, low rpm generator has high number of turns in the stator coil to ensure induced voltage produce easily.

Figure 5.3: The Low RPM DC Motor

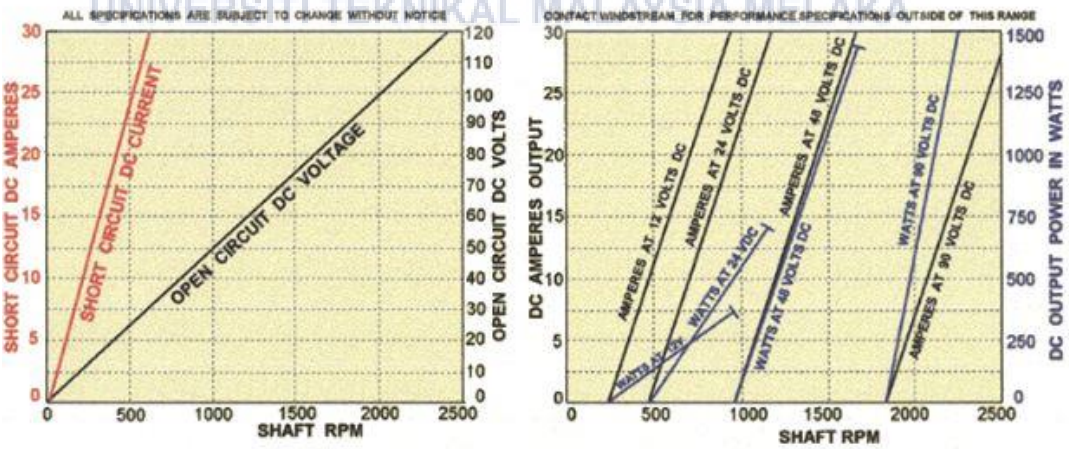

Figure 5.4: The Possibility Current and Voltage for The Low Rpm DC Motor

Figure 5.5: The Alternator that can be used as Generator for Hydro System

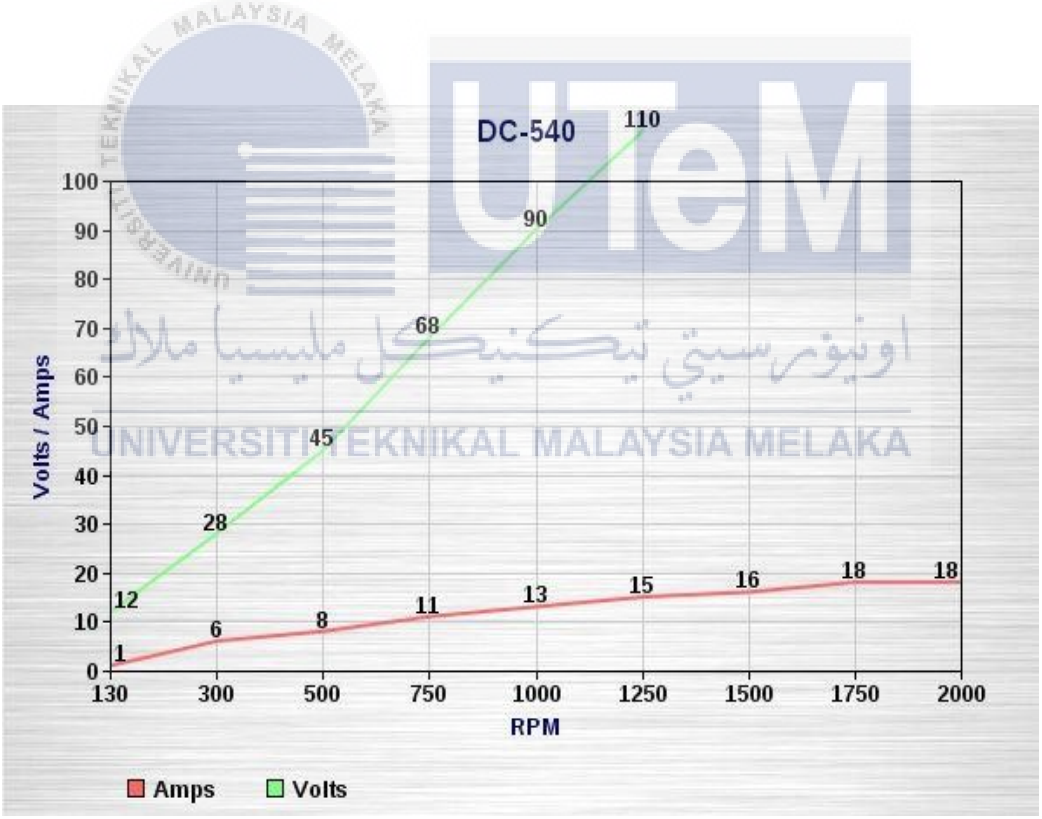

Figure 5.6: The Voltage and Current at Specific Speed for This Alternator

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APPENDIX A

Generator

Motor Specification

Model MY 1016	
Voltage	24 VDC
Rated Current	19.2 A
Rated Speed	2750 RPM
Output	350 W

APPENDIX B

3D Printer Located at Block F, Mechatronic Laboratory

APPENDIX C

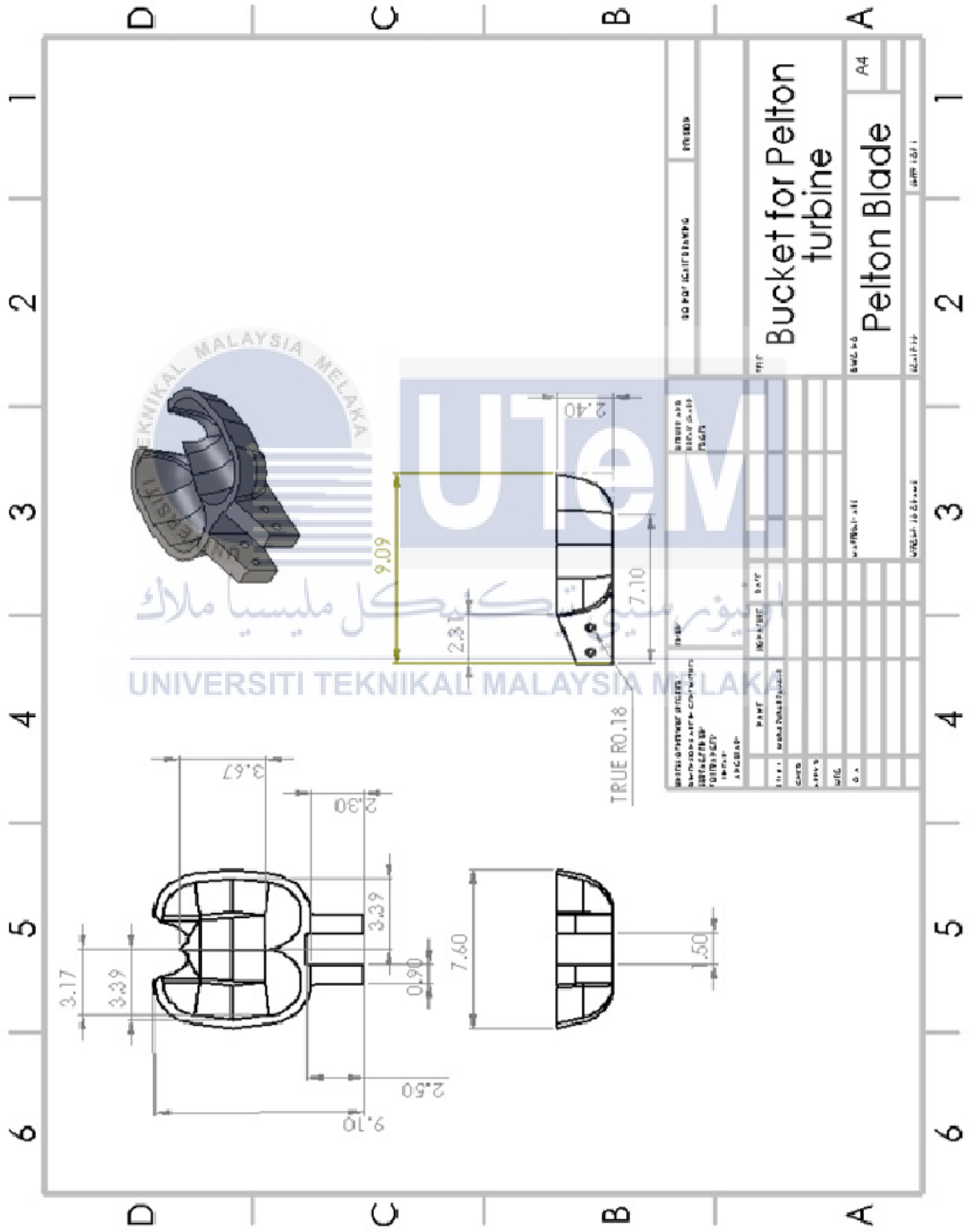
Pelton Blade Printed By 3D Printer

APPENDIX D

Pelton Wheel Printed By 3D Printer

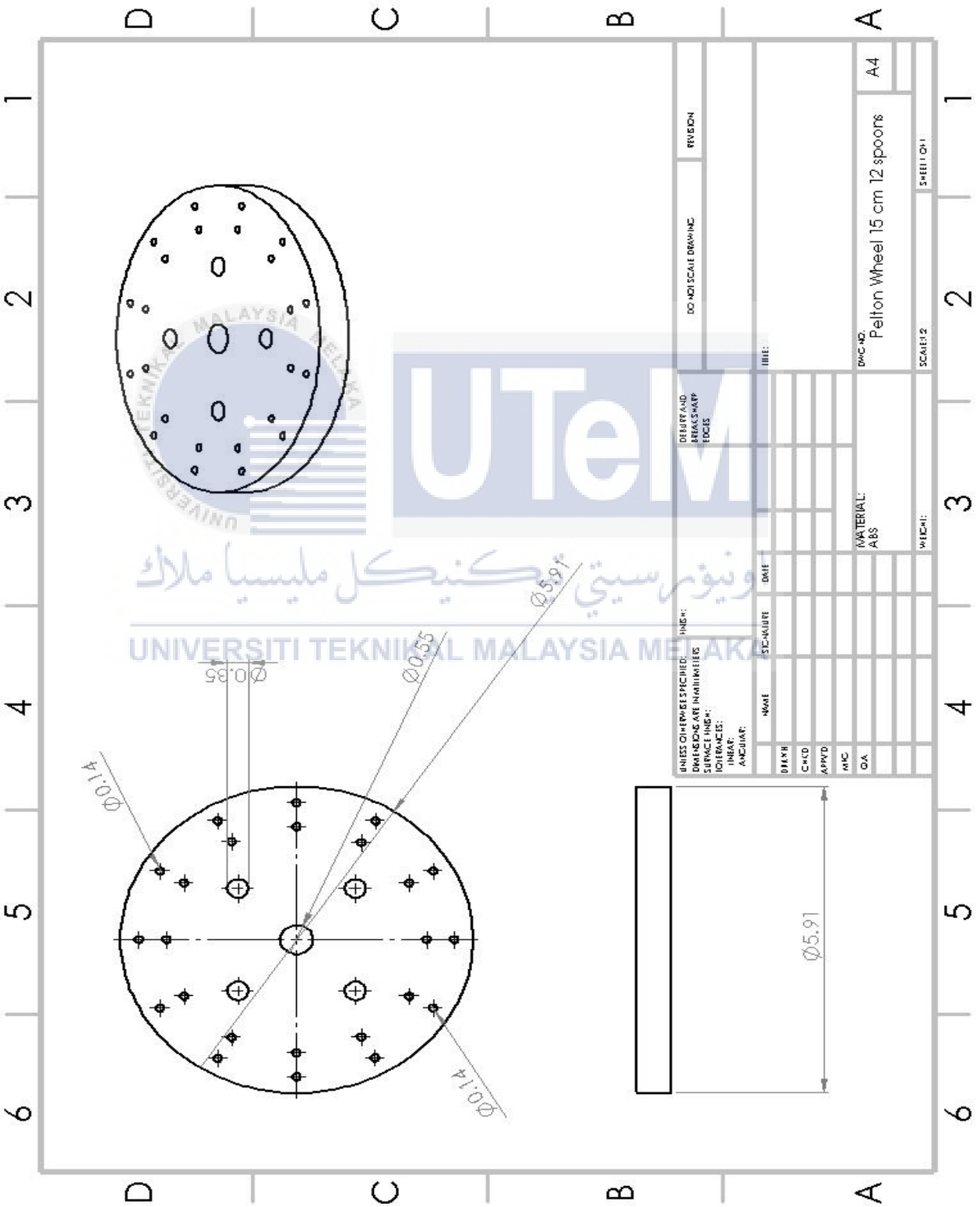
APPENDIX E

Dimension(cm) of Pelton Turbine



APPENDIX F

Dimension(cm) of Pelton Turbine



APPENDIX G

The Operation of Pico Hydro Generation System