CHAPTER 1

INTRODUCTION

1.1 Background

Hydropower is generated by using electricity generators to extract energy from moving water. Hydro power has been used for hundreds of years. Historically people used the power of rivers for agriculture and wheat grinding. Today, rivers and streams are used to produce energy. There are several forms of hydro power such as waterwheels, hydroelectricity, dam less hydro and tidal stream power.

Hydroelectricity is usually associated with the building of large dams. Hydropower plants capture the energy of falling water to generate electricity.

Hydropower on a small-scale is the exploitation of a river's hydro potential without significant damming, and is one of the most environmentally benign energy options available.

Hydropower large and small is by far the most important of the renewable for electrical power production. The world's technically feasible hydro potential is estimated at 14370 TWh/year which is equal to 100% of today's global electricity demand. [1]

1.2 Problem statement

Often, small and isolated communities are without electricity even in countries with extensive grid electrification. Despite the high demand for electrification, grid connection of small communities remains unattractive to utilities due to the relatively low power consumption. Additionally, other sources of energy such as oil and gas are too costly. There is a need for household energy generator that will reduce cost and produce electricity. Since remote areas are located near moving sources of water such as rivers and waterfalls, hydro power is the viable of renewable energy that can be implemented. Unfortunately, dams are very expensive to build and causing problems for animals that used to live there. In order to reduce cost and to minimize the impact on the environment, the small-hydropower system is proposed. This project aims to design a pico hydro turbine which can produce electricity for household consumption in small and isolated communities.

1.3 Significance of study

A model of the pico hydro turbine will be designed. This model will be suited for local use at remote areas. Result obtained from this study will be used to recommend the design over pico hydro turbine for the domestic use in Malaysia. This study could help rural communities to have access to alternative energy supplies.

1.4 Objective

Upon completing the project, a few objectives need to be achieved. The objectives of study are as follows:

1. To design a pico hydro turbine that can produce sufficient energy for small communities in remote areas.
2. To simulate the design using CATIA® Computer Aided Design and ANSYS® software.

1.5 Scope of Study

The scope of work for this project is to conduct a study on the current use of hydropower which has been applied as a source of energy. The design, applications and principles of pico hydro turbine will be reviewed. The current design of pico hydro turbine will be analyzed to propose a design for a pico hydro turbine which can produce sufficient energy for small communities in remote areas. The average consumption of kilowatts for household use in a day is to be determined. Engineering calculation will be carried out to determine all the parameters needed in designing the pico hydro turbine. Design using CATIA® computer software and stress concentration analysis on several parts of the hydro turbine will be done using ANSYS® computer software. The expected deliverable will be a new design of pico hydro turbine which can produce enough electricity for household use in rural areas. The final design will encompass the mechanical compartments of the hydro turbine. The electrical component will be sourced from available designs.

1.6 Relevancy of the project

Due to the rapid increase of world population and depletion of fossil fuels, other clean and renewable sources of energy must be developed. As we all know Malaysia is a country that has many rivers and waterfalls. The abundance of water sources in Malaysia makes this project viable for alternative power generation since it is an economical solution for alternative power generation. Pico hydropower is an increasingly important means of generating primary electricity using the water resource of small rivers or waterfalls. A clean, cost-effective and renewable energy source such as a pico hydropower is a well developed technology and ideal for deployment in remote areas that is far from the gridlines.

.CHAPTER 2

LITERATURE REVIEW

2.0 Hydropower

Hydro power is generated by using electricity generators to extract energy from moving water. Hydropower plants capture the energy of falling water to generate electricity. The basic principle of works for a hydropower is a turbine converts the kinetic energy of falling water into mechanical energy. Then a generator converts the mechanical energy from the turbine into electrical energy.

Most conventional hydroelectric plants include four major components (see figure 2.1)

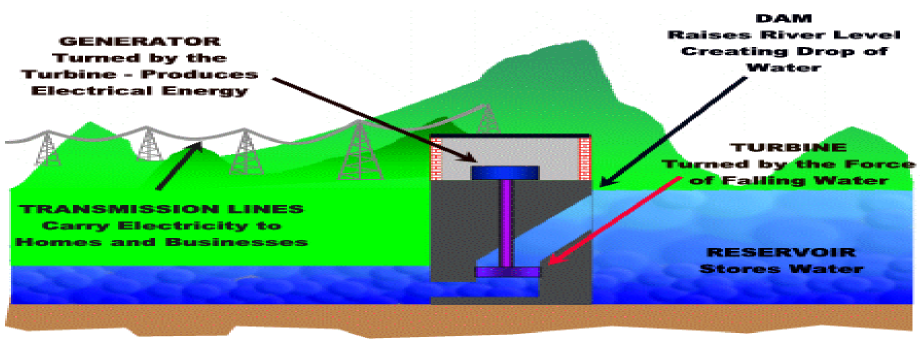

Figure 2.1: Major Components of hydroelectric plants

The functions of each component are listed below:-

i) **Dam –** The function of Dam is to raise the water level of the river to create falling water and to control the flow of water. The reservoir that is formed is, in effect, stored energy.

ii) **Turbine –** The function of the turbine is to convert the kinetic energy of falling water into mechanical energy. The force of falling water pushing against the turbine's blades causes the turbine to spin. The kinetic energy from the rotating blades then is converted into mechanical energy.

iii) **Generator –** The function of the generator is to convert the mechanical energy produced by the turbine into electric energy. The generator is connected to the turbine by shafts and possibly gears so when the turbine spins it causes the generator to spin also.

iv) **Transmission line -** The function of the transmission line is to conduct electricity from the hydropower plant to homes and business.

2.1 History of hydropower.

Hydro power started with the wooden waterwheels. Water wheels of various types had been use in many parts of Europe and Asia for some 2000 years, mostly for milling grain. A water wheel is a system for extracting usable power from the water flowing in a river or stream. Water wheels are divided into two categories which are undershot and overshot.

For undershot wheels, it is vertically-mounted water wheels that are rotated by water striking paddles at the bottom of the wheel. It has the advantage of being cheaper and simpler to build, but is less powerful and can only be used where the flow rate is sufficient to provide torque.

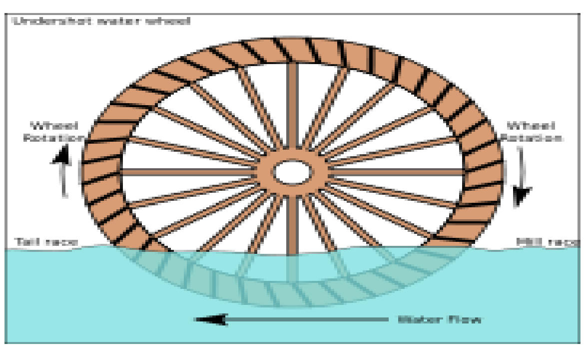

Figure 2.2: Picture of undershot water wheels

The overshot water wheel is more complicated, but much more efficient as almost all of the water flow is used for power. A dam and a pond or lake are built and used to channel water to just below the top of the wheel where it collects in buckets. The weight of the water in the buckets turns the wheel as the buckets on the other side are empty and therefore lighter. When a filled bucket has caused the wheel to rotate, and that bucket has reached the bottom of the wheel, it is inverted and the tail water falls out. The bucket that continues around the wheel empty until it gets back up to the top to be filled again.

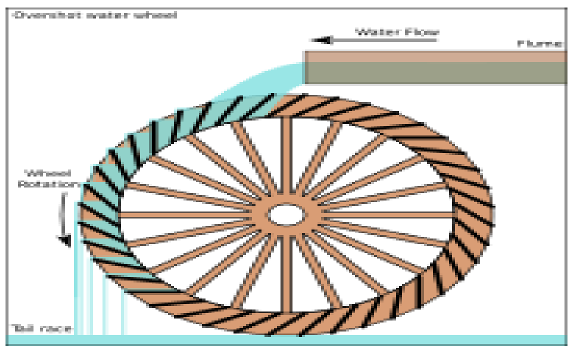

Figure 2.3: Picture of overshot water wheels

2.1.1 Stream wheels

The interest in renewable energy has led to a re-evaluation of the possibilities of micro- and pico hydropower applications. The current unused potential in the UK in the area of low head micro-hydropower ($P < 100$ kW, $h < 2$m) is estimated at 600 – 1000 MW. There are two main reasons why small hydropower with low head differences is not exploited [1]:

1. Conventional turbines are not economical

2. Turbines are thought to have negative effects on the ecology.

Recently, water wheels have been demonstrated to be efficient energy converters for small hydropower with head differences h of more than 1 m. From the 18th Century onwards, stream wheels were frequently employed in order to generate mechanical energy. They were considered cost effective since little civil engineering work was required for a stream wheel installation. It was quickly realized that the power output from stream wheels in slow flowing situations was small.

Stream wheels for energy production have not been built for more than 80 years. This is probably caused by the fact that their efficiencies are low, there was no need for the exploitation of small and very small hydropower sources and since there is very little engineering information about stream wheels available. Today, stream wheels could be of interest for special applications where local fast flows occur in a river or canal, or as energy converters for fast surface flows such as encountered in larger rivers or tidal currents. [1]

2.1.1.1 Stream wheels in subcritical, shallow flow

Stream wheels in subcritical flows were only built occasionally. They were considered cost-effective since little work on the stream itself was required. However, the power output for stream wheels is considered low.

Fig. 2.4 shows the assumptions for the theory of the subcritical stream wheel, with the flow being obstructed by a blade of depth $d \approx t$:

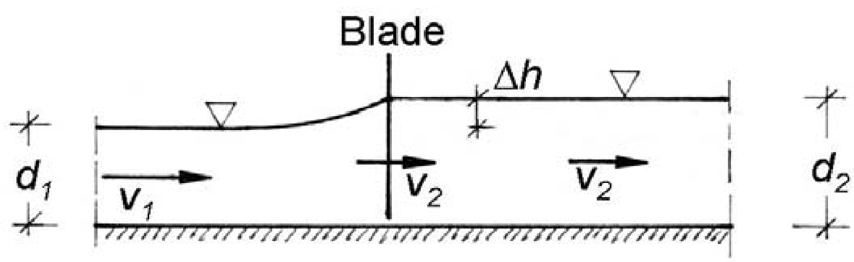

Fig. 2.4: Subcritical flow in channel

The power is generated by the momentum exchange between flow and blade, leading to a higher water level in front and behind of the blade. The power P is then given as:

$$P = \rho_w b d_2 v_2 (v_1 - v_2)^2 \quad \text{(eqn. 1)}$$

The power maximum occurs for $v_2 = 0.5\ v_1$; with a maximum efficiency of 29.6%. The wheel itself in this case acts as a weir, increasing the water level in front and behind of it. This effect should be noted when considering an application of this technology [1]

2.2 Hydropower Design

There important thing in designing the hydropower includes head, dams and power.

i) **Head-** Water must fall from a higher elevation to a lower one to release its stored energy. The difference between these elevations is called head

ii) **Dams –** Types of dams include:

a. high-head (50m or more)

b. medium-head (10 to 50m)

c. low-head (less than 10m)

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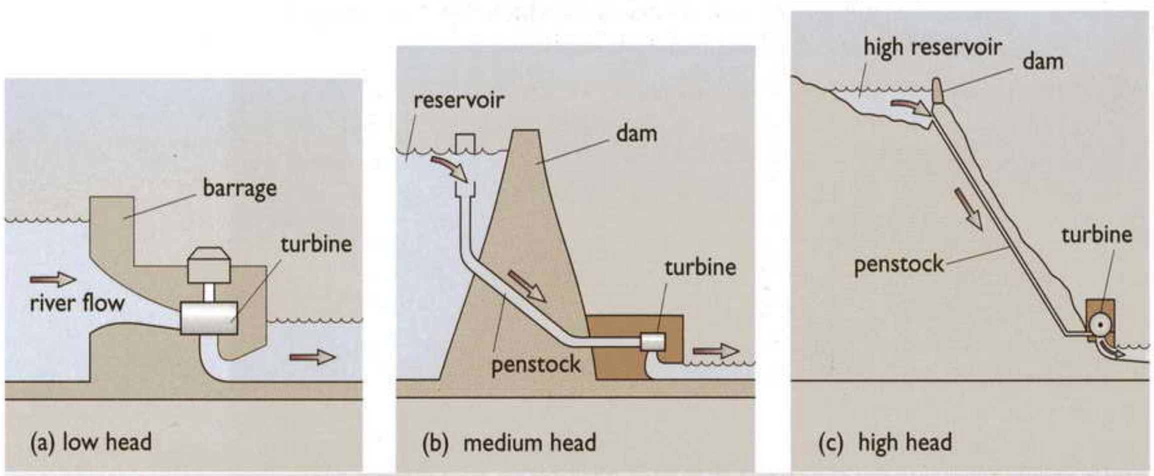


Figure 2.5: Types of Hydroelectric installation

iii) **Power -** In hydropower system, power is proportional to the product of *head x flow* [2]

2.3 Small scale hydro

Hydropower has various degree of ‘smallness’. But there are still no internationally agreed definitions of small hydro. Normally small hydro power is classified in terms of their capacity. Small hydro capacity may vary at different times and in different countries but it has no strict definition.

As for Malaysia, the classifications of small hydro power are as follows:

Table 2.1: Classification of Small Hydro power

Small-scale hydro	Capacity (kW)
Pico hydropower	Less than 5 kW
Micro hydropower	25 kW
Mini hydropower	25-500 kW
Small hydropower	501-5000 kW

2.4 Pico Hydropower

Pico hydro is hydro power with a maximum electrical output of five kilowatts. Hydro power systems of this size benefit in terms of cost and simplicity from different approaches in the design, planning and installation than those which are applied to larger hydro power. Recent innovations in pico hydro technology have made it an economic source of power even in some of the world's poorest and most inaccessible places. It is also a versatile power source. AC electricity can be produced enabling standard electrical appliances to be used and the electricity can be distributed to a whole village. Common examples of devices which can be powered by pico hydro are light bulbs, radios, televisions, refrigerators and food processors. Mechanical power can be utilized with some designs. This is useful for direct drive of machinery such as workshop tools, grain mills and other agro-processing equipment [3]

Pico hydropower is a very small hydropower unit suitable for a single household or a small group of households. It is a comparatively cheap option for millions of people who at present live in areas of development countries which are not electrified and where a hydro resource exists. It is becoming a mature technology, which should now be considered as part of alternatives to grid extension, diesel generator, solar power and other energy systems currently being use in rural areas.

2.4.1 Basic of Pico Hydropower

A pico hydro system makes use of the power in falling water. Figure 2.6 shows the layout of a pico hydro system. Each of the components has been described in more detail below.

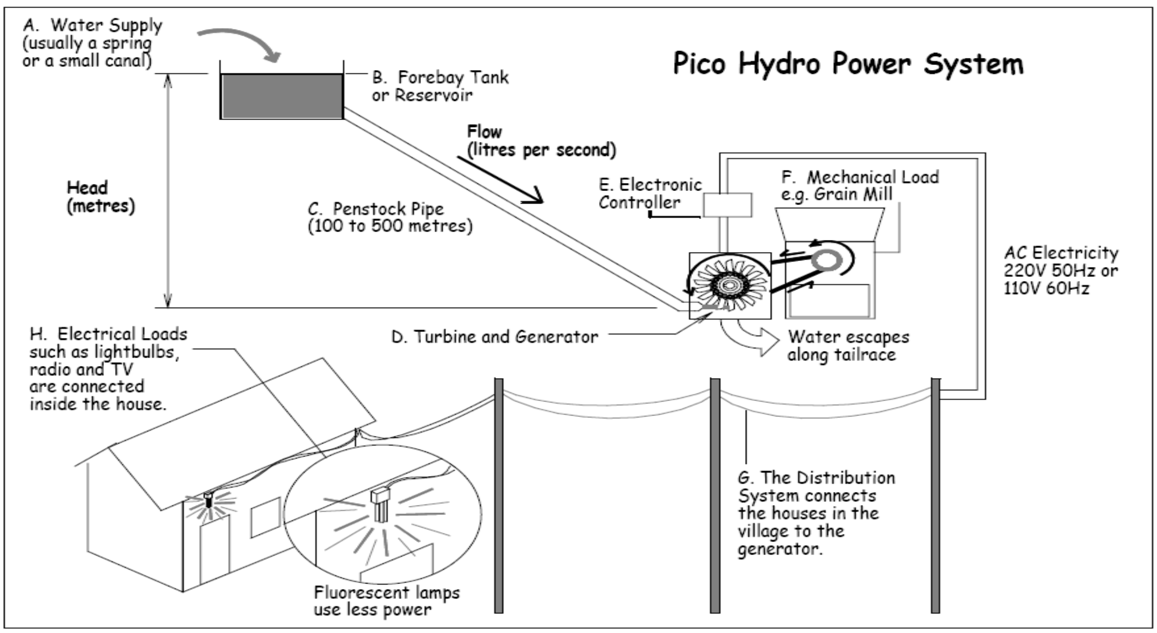


Figure 2.6: Components of pico hydro system

i. Water source

The source of water is a stream or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else.

ii. Forebay tank

The water is fed into a forebay tank. This is sometimes enlarged to form a small reservoir. A reservoir can be a useful energy store if the water available is insufficient in the dry season.

iii. Penstock

The water flows from the forebay tank or reservoir down a long pipe called the penstock. At the end of the penstock it comes out of a nozzle as a high-pressure jet.

iv. Turbine

The power in the jet, called hydraulic power or hydro power is transmitted to a turbine runner which changes it into mechanical power. The turbine runner has blades or buckets which cause it to rotate when they are struck by water. The turbine is a general name that usually refers to the runner, the nozzle and the surrounding case. The runner typically spins in 1500 rpm. The turbine is attached to a generator. The purpose of the generator is to convert rotating power into electrical power. This is how the water flowing in a small stream can become electricity.

v. Power

Power is measured in Watts (W) or kilowatts (kW). Pico hydro power has a maximum electrical power output of 5 kW. There are three types of power in hydro power project which are waterpower (hydraulic power), mechanical power and electrical power. The water power (or hydraulic power) will always be more than the mechanical and electrical power. This is because, as the power is converted from one form to another, some is lost at each stage as illustrated in figure 2.6: [3]

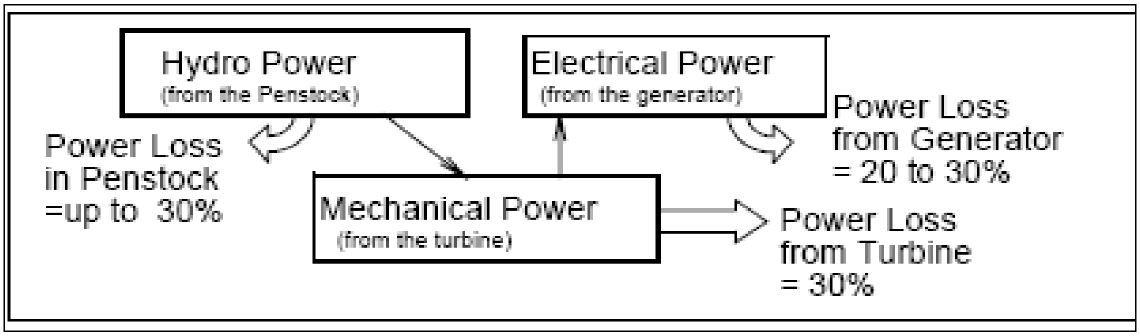


Figure 2.7: Power lost at each stage during the conversion from a water jet to electricity

The biggest loss usually occurs when the power in the jet of water is converted into rotating, mechanical power by hitting the turbine runner. On a well-designed and constructed scheme approximately one third (30%) of the power of the jet will be lost here. The losses can be much higher on poorer quality schemes. A further 20% to 30% will be lost in the generator when the mechanical power is converted to electricity. Some power is also lost in the penstock. Water in contact with the walls of the pipe is slowed down by friction. This power loss is expressed in meters of head loss. Its value is typically up to 20%-30% of the total head.

vi. Efficiency

Efficiency is the word used to describe how well the power is converted from one form to another. A turbine that has an efficiency of 70% will convert 70% of the hydraulic power into mechanical power (30% being lost). The system efficiency is the combined efficiency of all the processes together. The system efficiency for electricity generation using pico hydro is typically between 40% and 50%. [5]

2.5 Turbines

Turbine is the part of the system which harnesses the hydro power and turns it into mechanical (rotating) power.

2.5.1 Basic concepts and parameters of turbines

i) Water head

In Bernoulli's equation the mechanical energy of a unit weight of liquid can be expressed by its specific value *H*: [1]

$$\boxed{H = z + \frac{p}{\rho g} + \frac{v^2}{2g}} \qquad \text{(eqn.2)}$$

Where $z =$ elevation (m) $p =$ pressure (N/m^2)

$g =$ gravity (m/s^2) $\rho =$ liquid density, (kg/m^3)

$v =$ Velocity of liquid, (m/s)

ii) Hydropower

Hydro turbines convert water pressure into mechanical power, which can be used to drive an electricity generator. The power available is proportional to product of pressure head and volume flow rate. The formula for any hydro system's power is:-[1]

$$\boxed{P_w = \eta\rho \text{ gQH}} \qquad \text{(eqn.3)}$$

Where P = Hydropower (watt)

$\rho =$ Density of water volume

g = Acceleration due to gravity (m/s^2)

Q = Flow rate passing through turbine (m^3/s)

H = Effective pressure head (m)

2.5.2 Classifications of turbine

There are two main types of hydro turbines which are impulse and reaction. The type of hydropower turbine selected for a project is based on the height of standing water (referred to as "head) and the flow, or volume of water, at the site. Other deciding factors include how deep the turbine must be set, efficiency, and cost.

For reaction turbine, the rotor is enclosed in pressure casing and the runner blades are profiled. In contrast, an impulse turbine runner operates in air, driven by a jet of water and the water remains at atmospheric pressure before and after making contact with the runner blades.

2.5.2.1 Impulse Turbine

There are three types of impulse turbine in use which are the Pelton, the Turgo and the cross flow. Each of the design has their own characteristic.

A Pelton turbine (Figure 2.7) consists of a set of buckets or cups mounted around a hub. A high speed jet of water is directed at a series of buckets set around the hub. Each bucket has a central splitter which splits the jet in two and directs it almost back in the direction it came from and outwards from the rim of the wheel. Pelton turbines are not immersed in water. Kinetic energy of the water jets is transferred to the turbine. [4]

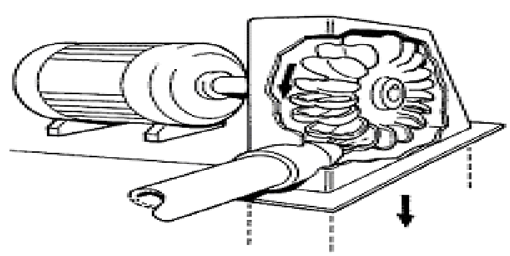


Figure 2.8: Photo of typical Pelton turbine

As for Turgo turbine, the design is similar to Pelton turbine, but the jet is designed to strike the plane of the runner at an angle (typically 20^{o}) so that the water enters at one side and exits on the other. A Turgo turbine can have a small diameter runner than a Pelton turbine for an equivalent power.

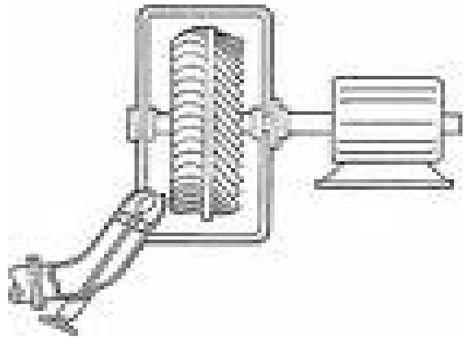


Figure 2.9: Photo of Turgo turbine

2.5.2.2 Reaction Turbine

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbine includes the Propeller and the Francis turbine.

Francis turbine is a radial-flow turbine with water flowing in a radial direction inward over the curved runner blades toward the centre of the turbine. The runner is most commonly mounted in a spiral casing with internal adjustable guide vanes.

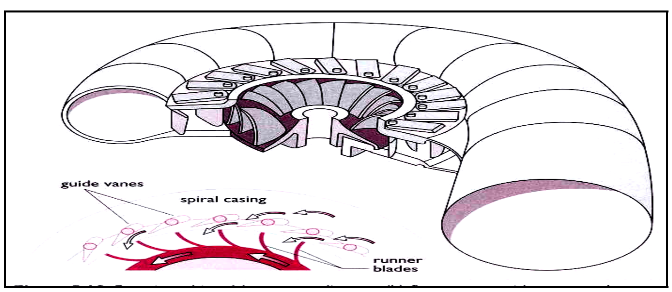


Figure 2.10: Schematic diagram of Francis turbine

Reaction turbine requires more sophisticated fabrication than impulse turbine because they involve the use of more complicated profiled blades together with carefully profiled casings. Below is the classification of turbines due to head (Table 2.2) and ranges of application of turbines due to head, capacity and flow rate (Figure 2.10):- [4]

Table 2.2: Impulse and reaction turbine

Turbine type	**Head Classification**		
Impulse	High (>50m)	Medium(10-50m)	Low(<10m)
	Pelton Turgo	Cross flow Turgo	Cross flow
Reaction		Francis	Francis Propeller Kaplan

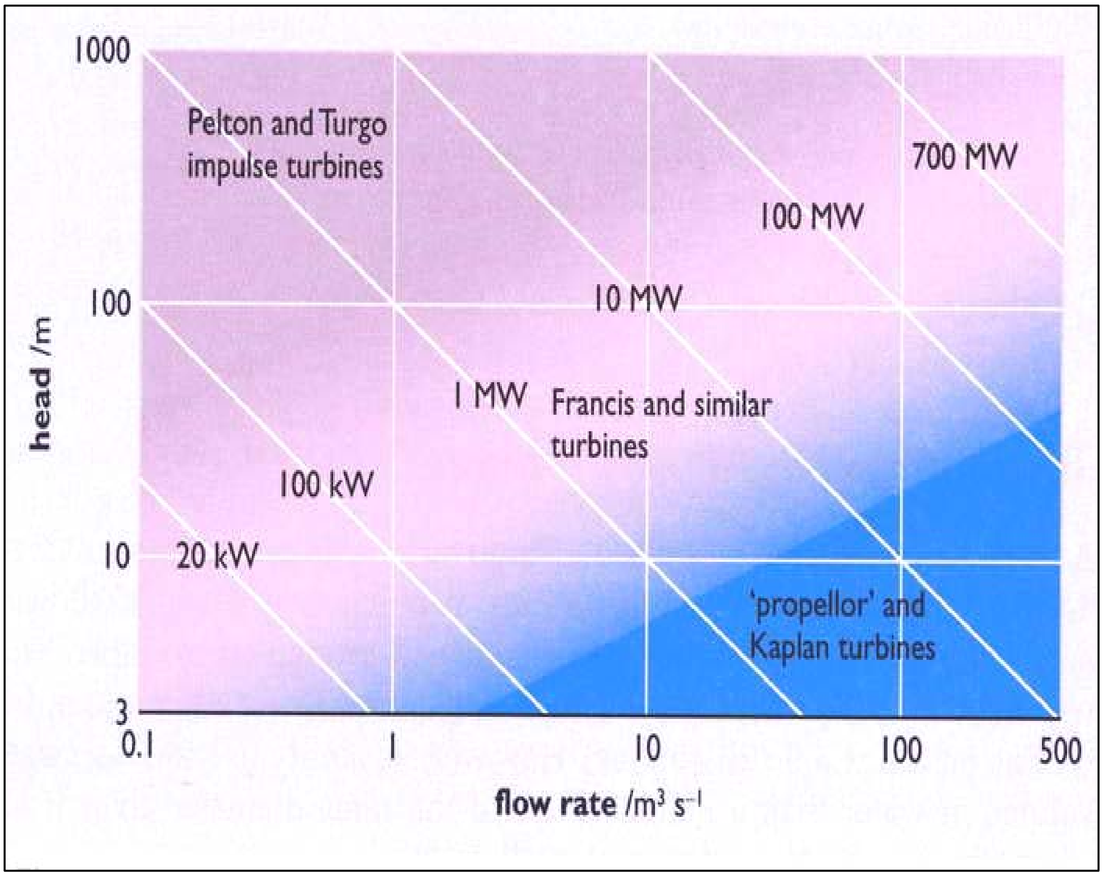


Figure 2.11: Ranges of application of different types of turbine.

2.5 Case Study 1: Community Pico Hydro in Sub-Saharan Africa.

Site: Kathamba, Kirinyaga District kenya

This case study describes a pico hydro plant using a Pelton turbine directly-coupled to an induction generator which has an electrical output of 1.1kW.

Below are the details of the pico hydro system:-

Length of penstock : 158 m
Diameter of penstock: 110 mm (PVC pipe)
Net Head : 28 m
Flow into turbine : 8.4 ℓ / s
Turbine generator efficiency: 48%.

The water source is a small spring with a flow rate of at least 5l/s during 90% of the year and has never been known to run completely dry. Approximately 80m³ of storage has been provided at the intake to ensure that the turbine can be kept running for long periods. There are 65 households within a 550m radius of the turbine house and these are all being connected to the generator using a single-phase distribution system and insulated copper conductors. Each house has a 230V supply which is sufficient for one or two energy-saving lamps and a radio. [6]

2.6 Case study 2: Community Pico Hydro in Sub-Saharan Africa:

Site: Thima, Kirinyaga District, Kenya

Below are the details of pico hydro system:-
Length of penstock : 158 m
Diameter of penstock: 110 mm (PVC pipe)
Net Head : 18 m
Flow into turbine : 28 ℓ / s
Turbine generator efficiency: 45%.

This case study describes a pico hydro plant using a ‘pump-as-turbine’ directly-coupled to an induction motor as generator which has an electrical output of 2.2kW. The water source is the Rutui River which has a flow rate of more than 100l/s during 90% of the year. The minimum flow, measured after an unusually long period of dry weather, was 84 l/s. There are around 160 households within a 900m radius of the turbine house and 110 of these are being connected to the generator using a single-phase distribution system with insulated copper conductors. Each house has a 230V supply which is sufficient for one or two energy-saving lamps and a radio.

2.8 Selection of Material

The performance of a device is limited by the properties of the material of which it is made, and by the shapes to which this material can be formed. Under some circumstances a material can be selected satisfactorily by specifying ranges for individual properties. More often, performance depends on a combination of properties, and then the best material is selected by maximizing one or more performance indices. Material selection has four basic steps:

a) **Translation** of design requirements into a material specification express as a function which includes the design objective, constraints and free variables.

b) **Screening** out of materials that fail to meet the design constraints

c) **Ranking** by ability to meet objectives; material indices

d) **Search** for supporting information for promising candidates

2.9 Gear Wheel System

The gear wheel is a basic mechanism. Its purpose is to transmit rotary motion and force. A gear is a wheel with accurately machined teeth round its edge. A shaft passes through its center and the gear may be geared to the shaft. Gears are used in groups of two or more. A group of gears is called gear train. The gears in a train are arranged so that their teeth closely interlock or mesh. The teeth on meshing gears are the same size so that they are of equal strength. Also, the spacing of the teeth is the same on each gear.

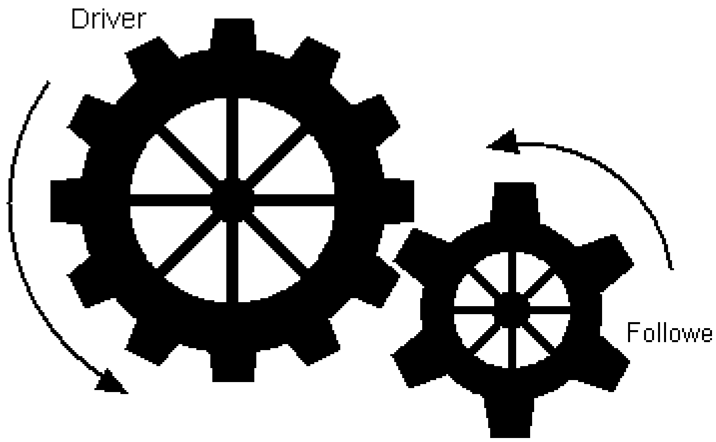


Figure 2.12: Gear train

There are few types of gears such as bevel gears, helical gears, worm gears, spur gears and others. However for this project, spur gear is chosen. Spur gear is one of the most important ways of transmitting a positive motion between two shafts lying parallel to each other. A pair of well made spur gears can give a smooth, regular, and positive drive which is one of the greatest importances in many engineering designs.

In a simple gear train of two spur gears, the input motion and force are applied to the driver gear. The output motion and force are transmitted by the driven (follower) gear. The driver gear rotates the driven gear without slipping. When two spur gears are meshed the gears rotate in opposite directions. (Figure 2.12)

CHAPTER 3

METHODOLOGY

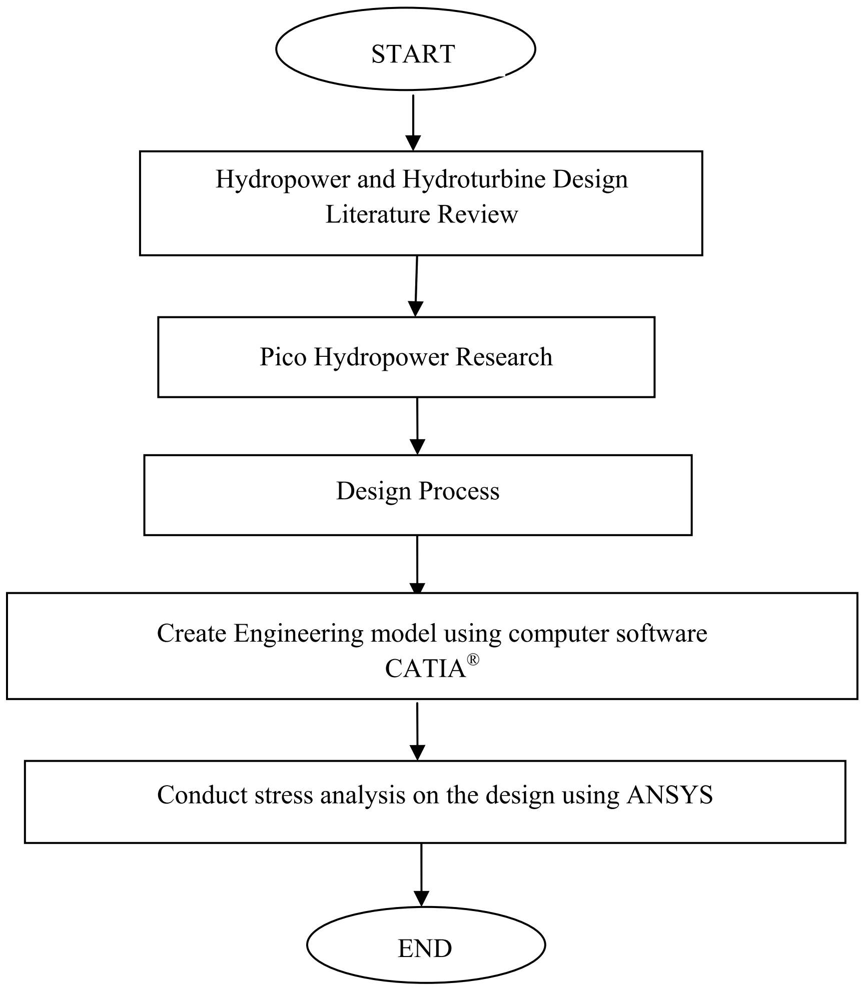


Figure 3.1: Process flow design of Pico Hydro turbine

3.1 Literature Review

During the literature review, research and study will be done on the hydropower types, working principle, hydropower classification and design of hydropower. This is important and gives direction to understand the currently used and application of hydropower.The information is gathering referring to respective books, journals and thesis develops by external and internal parties.

3.2 Pico Hydropower Research

In the research, pico hydropower principles will be studied and current application and design of pico hydropower will be reviewed. The pico hydropower output will be calculated as to meet the average power demand in remote areas.

3.3 Design Process

i. Approximate power consumption for household per day

The need of hydropower in rural areas is identified based on the research done.

ii. Definition stage

The practical limitation has been set up. Then the approximate power consumption is in a day is calculated in order to estimate the power output required. The pico hydropower output will be finalized as to meet the average power demand in remote areas. Design will encompassed the mechanical compartment of the pico hydro turbine only.

iii. Preliminary design stage,

During the preliminary design stage, several sketches of the alternative assemblies were done. The conceptual sketches are not detailed and serve as a first representation of the prospective designs for the pico hydro turbine.

iv.Detailed design stage.

a) Constraints

In order to design hydro turbine, power output limitation has been set up. Whenever a constraint is applied, the solution possibilities are reduced.

b) Product requirement

To determine the specifications of product, searches have been done through existing product, journals and other sources to identify the driving technology of the product such as power, materials, weight and others. Product requirements includes:-

- Performance parameter (force, speed, torque)
- Required features
- Desired features
- Size
- Weight
- Cost
- Environment
- Maintenance requirements
- Expected life

c) Material selection analysis

Selection of material is done based on the product requirements. The analysis is done using decision matrix to ensure selection of the best material for the design. All weighted criteria will be evaluated on each materials and the best material will be chosen.

d) Mathematical Model

With a tentative design direction, a specific mathematical model of the pico hydro turbine system was established in order to perform analysis. Models of the stress and deflection states expected at the turbine element (wheel, blade and shaft) are then defined with appropriate stress and deflection equation. The results from those models are evaluated in conjunction with the properties of the chosen engineering material.

e) Simulation

Detailed engineering drawings of the final design for the pico hydro turbine is created using CATIA® computer software. Stress concentration analysis of the turbine wheel and shaft will be conducted in order to ensure that those elements can withstand the hydrostatic pressure exerted by the water.

3.5 Gantt Chart

The following Gantt chart is the schedule for this project for the first semester

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Awarded														
2	Preliminary Report (Research)														
3	Submission of Preliminary Report														
4	Design process (preliminary design)														
5	Submission of progress report														
6	Detailed design (mathematical model of hydropower element)														
7	Design and Modeling using CATIA (first draft)														
8	Result gathering														
9	Submission of Interim Report														
10	Oral presentation														

Process   Suggested milestone

Figure 3.1: Gantt Chart for First Semester

The following Gantt chart is the schedule for this project for the second semester

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Detail design (mathematical model of turbine element)	■	■	■	■										
2	Submission of Progress Report I				●										
3	Design and Simulation (CATIA)					■	■	■	■						
4	Submission of Progress Report II								●						
6	Seminar									●					
7	Project work continue									■	■				
8	Poster Exhibition											●			
9	Stress Concentration Analysis (ANSYS)											■	■	■	
10	Submission of Dissertation (softbound)													●	
11	Oral presentation													●	
12	Submission of Dissertation (hard bound)														●

■ Process ● Suggested milestone

Figure 3.2: Gantt Chart for Second Semester

CHAPTER 4

RESULT AND DISCUSSION

4.1 Approximate Power Consumption for Household per day

First of all the approximate power consumption for household per day is calculated (refer table 4.1). Assume normal village house comprises of a living room, 3 bedrooms and a kitchen.

Table 4.1: Average Power Consumption

Appliance	**Watts**	**Units**	**Total Watts**
Lighting	6 W	5	30 W
Ceiling fan	2 W	5	10 W
Refrigerator	47.5 W	1	47.5 W
Ironing	100 W	1	100 W
Cooking purposes (blending,toaster)	100 W	1	100 W
Entertainment (radios, television)	10 W	1	10 W
Total			**297.5 W**

i. Based on table 4.1, the average power consumption for household per day is 297.5 W
ii. For small communities (3 houses), the average power consumption is:
297.5 *3 = 892.5 W

iii. Total power demand is 892.5 W which is approximately **1kW.** Thus, the pico hydro turbine is designed to produce **1kW** power.

4.2 Hydro turbine design

Below is the preliminary design of the pico hydro turbine. This serve as the first concept of the design before proceed to the next stage in the design process.

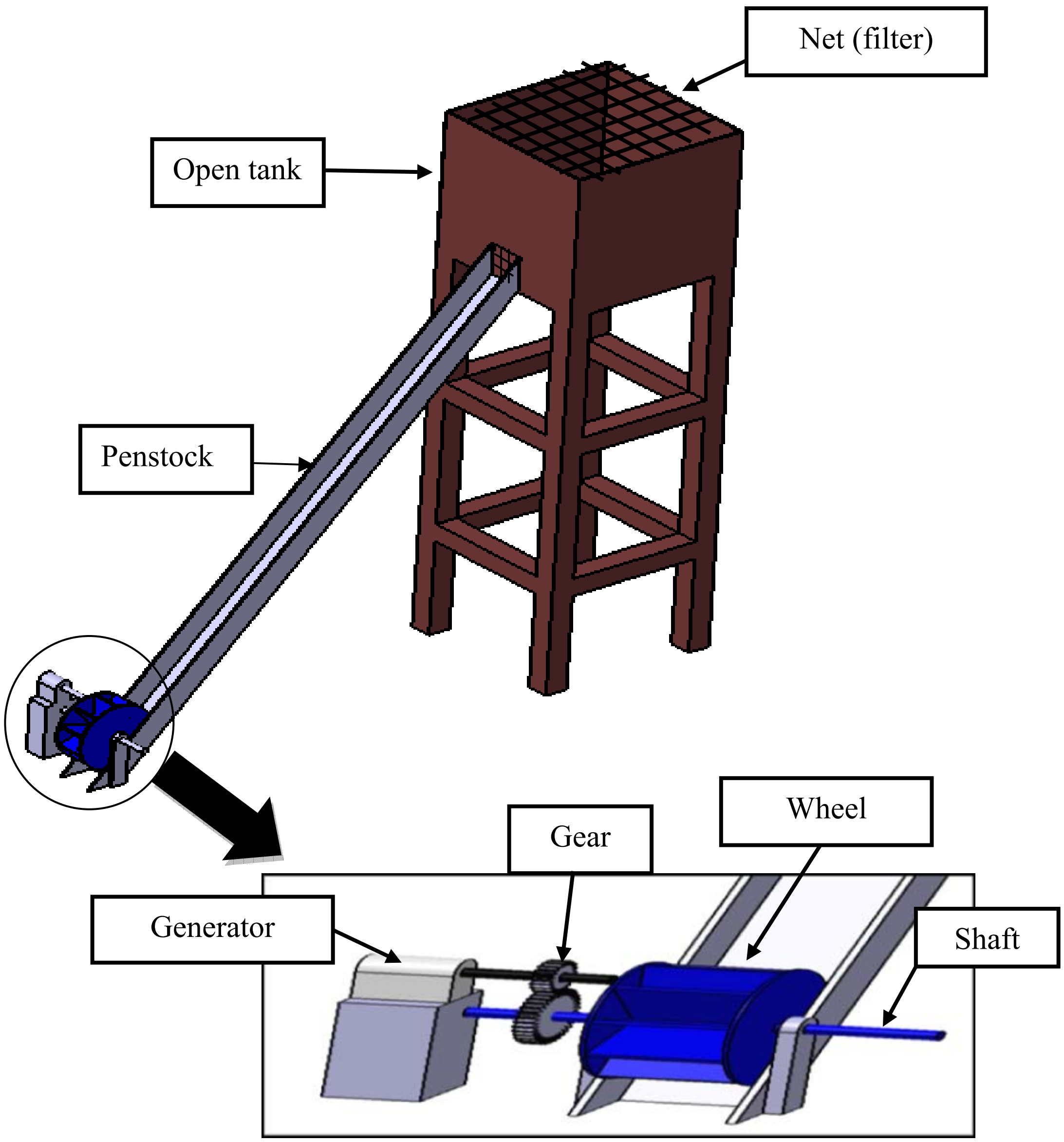


Figure 4.1: Labeled Drawing for Pico hydro turbine design

Figure 4.1 shows the labeled drawing for pico hydro turbine design. Basically the design consists of an open tank, penstock, wheel and generator.

4.2.1 Principle of Operation

The design will be installed near the waterfall as the water will be directly diverted into tank by a canal. The function of a net is to filter all the debris before entering the tank, thus only clean water will flow in the penstock. The force of falling water pushing against the wheel, thus cause the wheel to rotates. The kinetic energy from the rotating wheel then is converted into mechanical energy.

Meanwhile, the function of the generator is to convert the mechanical energy produced by the turbine into electrical energy. The generator is connected to the wheel by shafts and gear so when the wheel rotates, causes the generator to rotate also. The gear is designed to transmit motion from the turbine shaft to load shaft (generator) in order to avoid damage of the generator if overloading.

4.3 Constraint

A constraint has been set up in designing the pico hydro turbine. The power output of pico hydro turbine must be between 0.9 kW and 5 kW to ensure meet the power demand.

4.4 Product Requirements

Below is the table of desired criteria with its weighted percentage.

Table 4.2: Product Criteria and Weight

No.	Criteria	Weighted Percentage
1	Cost	25
2	Reliability	30
3	Weight	5
4	Safety	5
5	Performance	35
	Total	100

The most desirable criteria would be performance. This is followed by cost. Pico hydropower should cost less since it is designed for community in remote areas. Next is reliability where the product can perform its intended function satisfactorily without failure at given age. Since this design is based on water, thus the reliability of the product is one of the most important criteria that have to be considered. The least desired criteria are weight and safety.

4.5 Material Selection Analysis

Material selection will be based on product's requirement and function of each component. Decision matrix table are used in this analysis. The following steps show the process of choosing the best material for each component.

Table 4.3: Rating for Evaluation

5- point scale	Description
0	Inadequate
1	Weak
2	Satisfactory
3	Good
4	Excellent

a) Wheel

Table 4.4: Decision Matrix for Wheel Material

		Material			
Design Criterion	**Weight factor**	**Mild steel**		**Stainless steel**	
		Score	**Rating**	**Score**	**Rating**
Reliability	0.30	3	0.90	4	1.20
Ease of fabrication	0.28	4	1.12	1	0.28
Cost	0.25	3	0.75	1	0.25
Weight	0.05	2	0.10	2	0.10
Availability	0.12	4	0.48	4	0.48
TOTAL	1.00		**3.35**		2.31

Table 4.4 shows that mild steel scored higher point compared to stainless steel. Mild steels are stiff and strong. Welding mild steels requires that special precautions be taken. However, welding mild steel presents far fewer problems than welding stainless

steels. Stainless steels corrosion resistance is better than mild still, however the use of protective coating may increase the mild steel corrosion resistance. Other than that, mild steel is easily available and less in cost.

b) Shaft

Table 4.5: Decision matrix for Shaft

Design Criterion	Weight factor	Material			
		Stainless steel		**Aluminium**	
		Score	**Rating**	**Score**	**Rating**
Reliability	0.30	4	1.2	2	0.6
Ease of fabrication	0.28	2	0.56	3	0.84
Cost	0.25	3	0.75	2	0.50
Weight	0.05	2	0.10	3	0.10
Availability	0.12	4	0.48	4	0.48
TOTAL	1.00		**3.09**		2.52

Table 4.5 shows that stainless steel scored higher point compared to aluminium. Stainless steel is better for shaft material because of its high modulus of elasticity. Besides, stainless steel also has a great corrosion resistance in oxidizing environments. Aluminium is generally less strong compared to stainless steel. Other than that, aluminium is relatively high cost compared to steel of the same strength.

For other components, the chosen materials are:-

- Tank – Aluminium
- Penstock – Aluminium

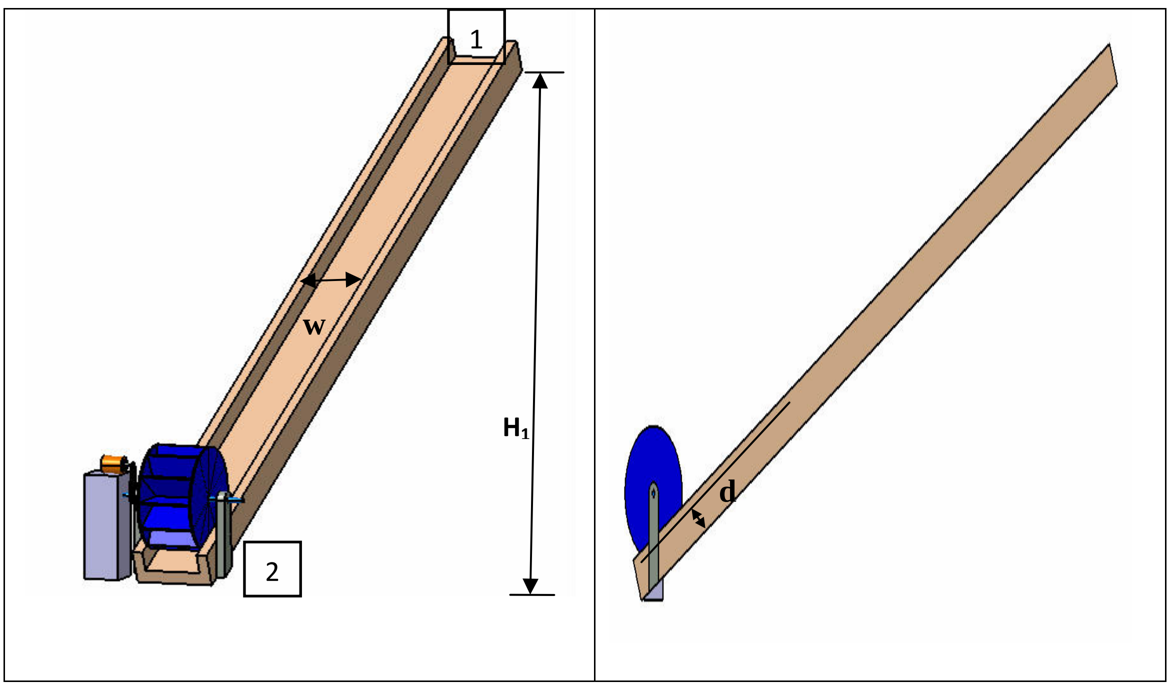
4.6 Mathematical Model

4.6.1 Hydropower design

Table 4.6: Technical Summary of the Pico Hydro turbine

Power output required	1.0 kW
Water source	Waterfall with average flow rate between 200-500 l/s [13]
Net Head	2.3 m
Flow into turbine	110.84 l/s
Storage provided	0.512 m^3
Penstock	Length : 3 m Width : 0.17 m

4.6.2 Hydropower calculation



Picture 4.2: Penstock of Pico Hydro turbine

i) From Bernoulli's equation,

$$\boxed{\frac{P_1}{\rho g}+\frac{V_1}{2g}^2+H_1=\frac{P_2}{\rho g}+\frac{V_2}{2g}^2+H_2}, \quad \text{(eqn.4)}$$

Since it is an open system, $P_1=P_2=P_{atm}$,

$V_1 = 0$, $H_2 = 0$

Thus eqn.4 becomes:

$$H_1 = \frac{V_2^2}{2g}$$

$$V_2 = \sqrt{2gH_1}$$
$$V_2 = \sqrt{2(9.81m/s^2}(2.3m)$$
$$V_2 = 6.718m/s$$

ii) The flow of water in a penstock, Q = VA

= 6.718 m/s (0.15* 0.11) m^2

= **0.1108 m^3/s= 110.8 l/s**

Flow rate of waterfall in Malaysia ranges from approximately 200 l/s to 500 l/s. [13] Thus, flow rate at the canal, Q_c is always greater than flow rate at the penstock, Q. This will ensure continuous flow of water at the penstock.

iii) From eqn. 2; Hydropower, P_w = ρgQH

= 1000kg/m^3 (9.81 m/s^2)(0.1108 m^3/s)(2.3m)

= 2500 Watt

4.6 .3 Turbine Design

a) Blade design

Material: mild steel

Material Properties:- $\sigma_y = 250 Mpa$

Based on typical building beam design, a typical factor of safety with respect to yielding in tension is 1.67. [9]

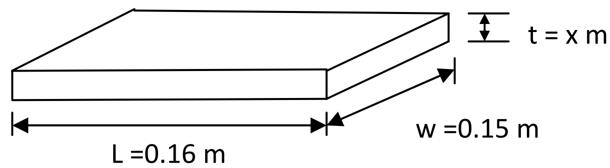


Figure 4.3: Blade design

To design a beam to resist bending stress, the required section modulus, S is calculated:

$$S = \frac{M_{\max}}{\sigma_{allow}}; \qquad \text{(eqn. 5)}$$

$$\sigma_{allow} = \frac{\sigma_y}{n}; \qquad n = \text{factor of safety}$$

$$= \frac{250 Mpa}{1.67} = 150 Mpa$$

Because the flow of water inside the penstock is static, there is no acceleration, thus the pressure distribution is hydrostatic.

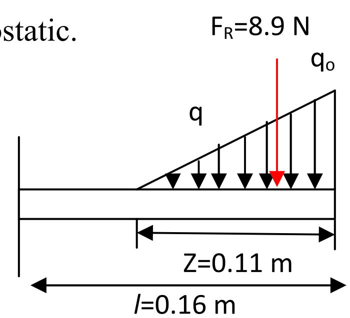


Figure 4.4: Hydrostatic force on blade

i) Hydrostatic pressure, P = $\rho_w gz$

$$= 1000kg/m^3(9.81m/s^2)(0.11m)$$

$$= 1079.1Pa$$

v) Intensity of the load, $w, = bP$

$$=(0.15m)(1079.1Pa)$$

$$=161.85N/m$$

vi) Magnitude of resultant force, F_R = area of triangle

$$= \frac{1}{2}(0.11m)(161.85N/m)$$

$$= 8.9N$$

vii) Line of action passes through the centroid of triangle. Hence

$$\bar{x} = 0.16m - \frac{1}{3}(0.11m) = 0.123m$$

viii) $q_o = \frac{qL}{x}$

$$= \frac{161.85N/m(0.16m)}{0.11m}$$

$$= 235.418N/m$$

ix) $M_{\max} = \frac{q_o L^2}{6}$

$$= 1.00445N.m$$

x) From eqn. 5,

Section Modulus, $S = \frac{1.00445Nm}{150*10^6 Pa}$

$$= 6.696*10^{-7}\text{ m}$$

$S = \frac{bh^2}{6}$; $h^2 = \frac{6.696*10^{-7}(6)}{0.15}$ $h = 0.52cm$

xi) Minimum thickness of the blade, h = 0.52 cm

Thus chosen thickness of the blade, **t = 1 cm**

a) Wheel Design

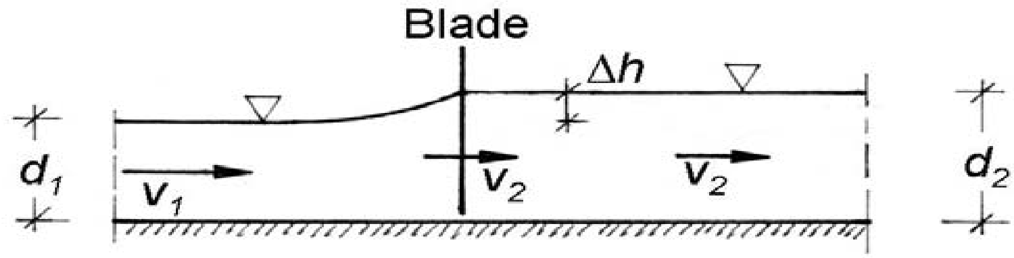


Figure 4.5: Subcritical Flow in channel

Based on the assumptions for the theory of the subcritical stream wheel, with the flow being obstructed by a blade of depth d ≈ t, the power is generated by the momentum exchange between flow and blade, leading to a higher water level in front and behind of the blade. [1]

The power P is then given as:

$$P = \rho_w b d_2 v_2 (v_1 - v_2)^2 \qquad [1]$$

The power maximum occurs for $v_2 = 0.5\ v_1$;

Assume d_2=0.18m,

$$P = (1000kg/m^3)(0.15m)(0.18m)(3.359m/s)(6.718m/s - 3.359m/s)^2$$
$$= 1023Watt$$

Thus mechanical power output, $\mathbf{P_M = 1023\ Watt}$

b) Shaft Design

Material: stainless steel

τ_{allow} : 100 Mpa

From previous calculation, Mechanical power P_M= 1023watt, =1023 N.m/s

i) $P = T\omega$ where, P = power

T = torque

ω = angular velocity

ii) $\omega = \frac{v_2}{r}$; where; v = velocity of water

r= radius of the wheel

$$= \frac{6.718 m/s}{0.18 m}$$

$$= 37.32 rad/s$$

iii) $P = T\omega$; $T = \frac{P}{\omega}$

$$= \frac{1023 N.m/s}{37.32 rad/s}$$

$$= 27.41 Nm$$

iv) By using the torsion formula, we can determine the size of the shaft's cross section. Specifically the geometric parameter becomes;

Geometric parameter, = $\frac{J}{c} = \frac{T}{\tau_{allow}}$

Where τ_{allow} = allowable shear stress in the shaft

T = resultant internal torque acting at the cross section

J = the polar moment of inertia of the cross sectional area

c = outer radius of the shaft

Since the shaft is tubular, $J = \frac{\pi c^4}{2}$

$$\text{Thus; } \frac{J}{c} = \frac{\pi}{2}\frac{c^4}{c} = \frac{T}{\tau_{allow}} \qquad [10]$$

$$c^3 = \frac{2T}{\pi \tau_{allow}}$$

$$c = \sqrt[3]{\frac{2(27.41)}{\pi(100*10^3)}} = 0.56cm$$

Minimum diameter for shaft = 0.56 * 2 = 1.12 cm

Chosen diameter for shaft = **3 cm**

c) Gear design

The gear in this turbine is designed to transmit motion from the turbine shaft to load shaft (generator) in order to avoid damage of the generator if overloading. The speed of the turbine shaft will depend on the site conditions and the type of generator used.

A turbine shaft speed based on the number of generator poles should be used to calculate the speed ratio. The number of poles (usually 4 but sometimes 2, 6 or 8) can be found on the information plate on the side of the generator. [3]

Table 4.7: Generator shaft speeds and head range for direct drive

Number of Poles	Approx Head (m)	Design Speed of Turbine/ Generator Shaft (rpm)
2	>80m	3000
4	25 - 80	1500
6	<25	1000

Based on the table 4.1, the design speed of generator shaft is approximately 600 rpm.

- Angular velocity of turbine shaft, w_1 = Angular velocity of the wheel

$$= 37.32\ rad/s$$

$$= 37.32 \frac{rad}{\sec} * \frac{1rev}{2\pi rad} * \frac{60\sec}{1\min}$$

$$= 356rpm$$

- Speed ratio = turbine shaft rpm (w_1) / load shaft rpm (w_2)

$$= \frac{\omega_1}{\omega_2} = \frac{356}{600} = \frac{89}{150}$$

This design scenario is complicated by a nonfractional velocity ratio. It will be impossible to obtain the appropriate number of teeth for the gear. This is solved by rounding the turbine shaft rpm to 350 so that we will get a fractional value of velocity ratio.

Thus, the new velocity ratio, VR = $\frac{350}{600} = \frac{7}{12}$

- *Torque =9.55 H/n,* [11]

Where *H= power*

n = shaft speed

$$T = 9.55 \frac{1023}{356}$$

$$= 27.44\ Nm$$

- Horsepower = *Tn/63025* [11]

$$= \frac{27.44(356)}{63025}$$

$$=0.155$$

- Spur gear selection

Based on the horsepower, the diametral pitch of the gear is selected.

Because this application involves general gearing, a pressure angle of $20^0$is used.

- Referring to table 10.6 [Appendix D],an estimate of diametral pitch P_d= 24
- VR = $\frac{350}{600} = \frac{7}{12}$
- VR = $\frac{\omega_1}{\omega_2} = \frac{N_2}{N_1}$
- $N_2 = \frac{\omega_1}{\omega_2} N_1$

Using $N_1 = 54$ $N_2 = 31.5$

$N_1 = 21$ $N_2 = 12.25$

$\boldsymbol{N_1 = 36}$ $\boldsymbol{N_2 = 21}$

$N_1 = 42$ $N_2 = 24.5$

Thus, the smallest integer combination is 36 and 21. Table 10.7 confirms that these gears are commercially available. [Please refer Appendix E] [12]

- Loading on spur gears

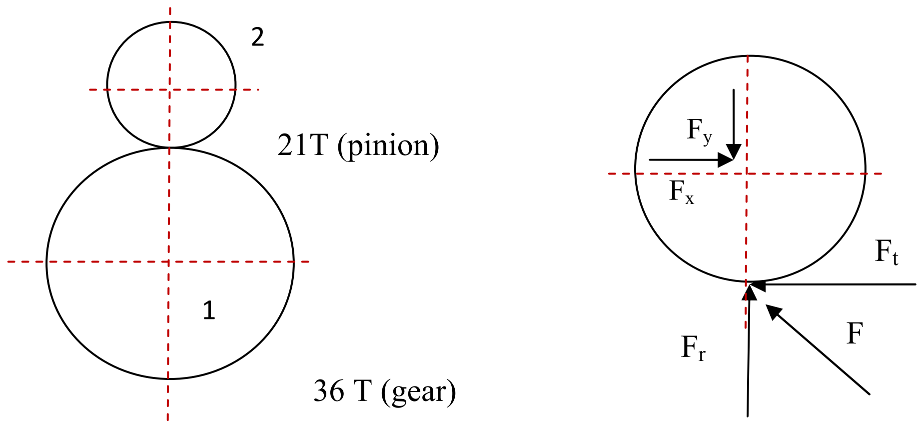


Figure 4.6: Free Body Diagram of Spur Gears

The magnitude of tangential component:-

$F_t = 2P_d\, T_p / N_p$

$= 2(24)(27.44)/36$

$= 36.6$ N

The radial component:-

$F_r = F_t \tan \varphi$

$= 36.6 \tan 20^o$

$= 13.32$ N

The resultant force:-

$F = F_t / \cos \varphi$

$= 36.6 / \cos 20^o$

$= 38.94$ N

Thus the resultant force acting on a shaft is **38.94 N**

4.6.4 Turbine efficiency

i) Turbine efficiency, $E = \frac{P_M}{P_w} x100$

$$= \frac{1023Watt}{2500Watt} x100$$

$$= \mathbf{41\%}$$

The turbine efficiency is within the range of pico hydropower efficiency which is between 40%-50%.

4.7 Stress Analysis

Stress analysis is performed on the turbine component after design process completed. This is done by using computer software ANSYS. Below are the steps performed and results from the analysis:-

a) Wheel

<table>
<tr><th>Step no</th><th>Description</th></tr>
<tr><td>1</td><td>Apply selected material to the drawing (in this case mild steel). The properties of mild steel are:
<table>
<tr><td>Young's Modulus</td><td>1.9e+011 Pa</td></tr>
<tr><td>Poisson's Ratio</td><td>0.27</td></tr>
<tr><td>Density</td><td>7861.1 kg/m³</td></tr>
<tr><td>Tensile Yield Strength</td><td>2.5e+008 Pa</td></tr>
</table></td></tr>
<tr><td>2</td><td>Apply static structural (hydrostatic pressure)</td></tr>
</table>

3

Plot results:

Hydrostatic pressure solution – Deformed Mesh

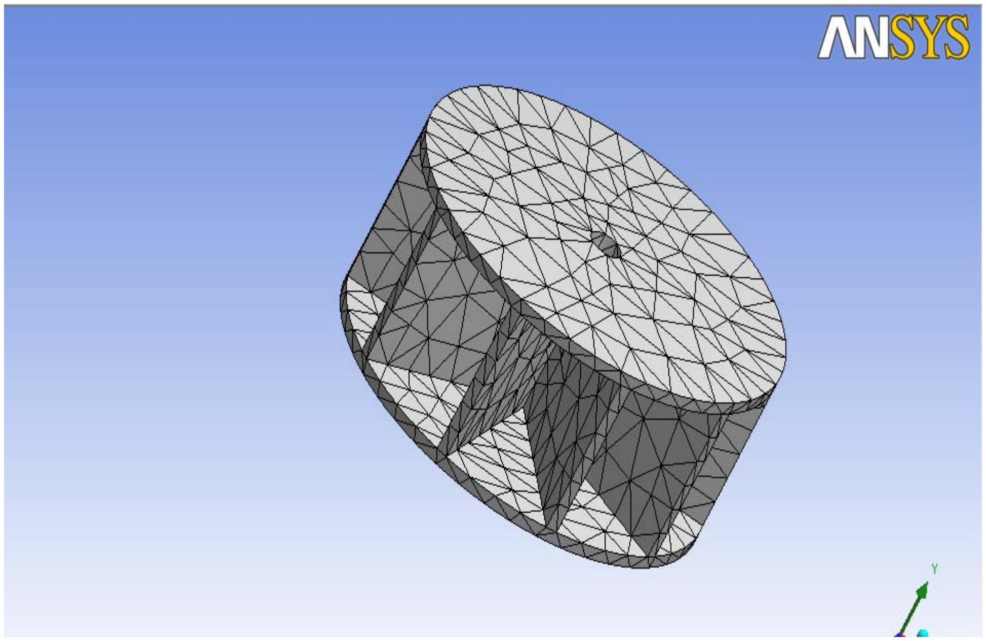


Figure 4.7: Full view of meshing on the wheel

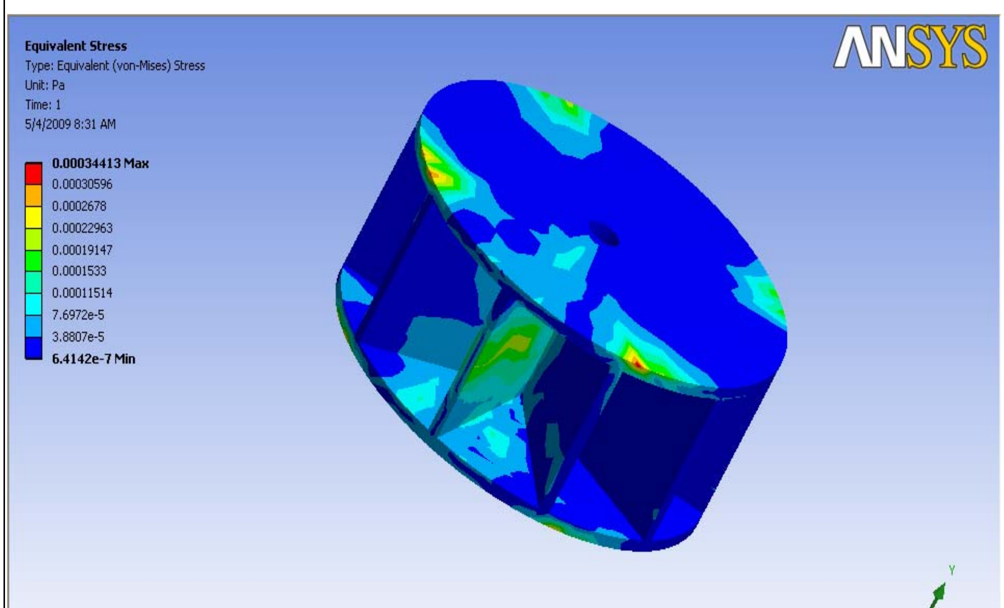


Figure 4.8: Full view of Equivalent(von-Mises) Stress on the wheel

4	**Interpret Result:** From the Von Mises Stress diagram, the results yield maximum value of 3.4413e-004 Pa and minimum value of 6.4142e-007 Pa. From Figure 4.8, it shown that there are small portion of maximum stress area concentrating right between joint of the blade and base plate which are contoured in red colour. However, by comparing the maximum stress value with yield strength value, this wheel can withstand the hydrostatic pressure exerted by the water without failure.

b) Shaft

<table>
<tr><th>Step no</th><th>Description</th></tr>
<tr><td>1</td><td>Apply selected material to the drawing (in this case stainless steel). The properties of stainless steel are:
<table>
<tr><td>Young's Modulus</td><td>1.89e+011 Pa</td></tr>
<tr><td>Poisson's Ratio</td><td>0.28</td></tr>
<tr><td>Tensile Yield Strength</td><td>2.8e+008 Pa</td></tr>
</table>
</td></tr>
<tr><td>2</td><td>Applied load on shaft

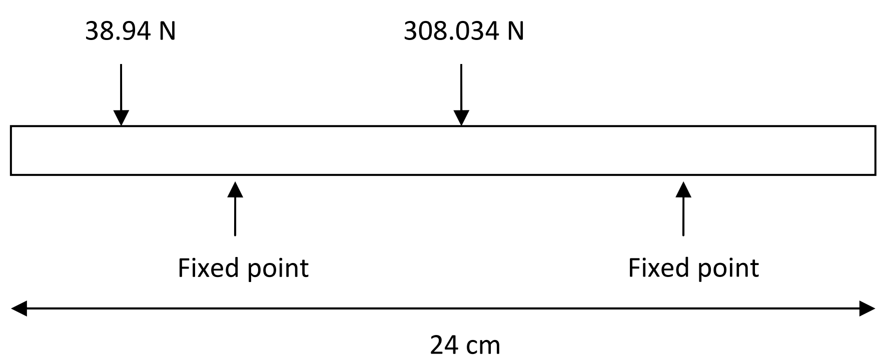


Figure 4.9: Free body diagram of applied load on shaft

Force exerted by wheel = (31.4 kg)(9.81 ms^{-2})= 308.034 N</td></tr>
</table>

<table>
<tr><td>3</td><td>

Plot results:

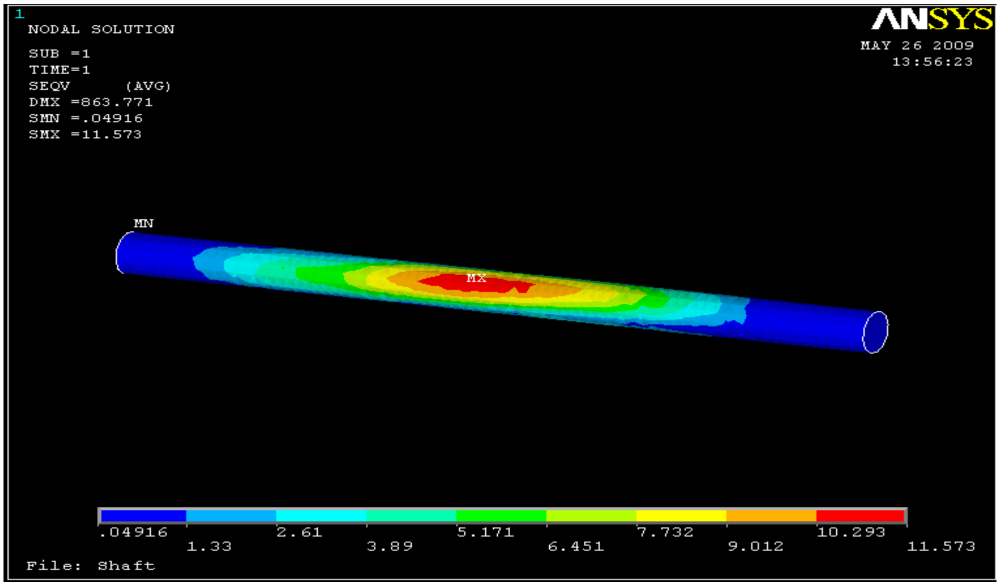


Figure 4.10: Full view of Equivalent (von-Mises) stress on shaft

</td></tr>
<tr><td>4</td><td>

Interpret result:

From the Von Mises Stress diagram, the results yield maximum value of 863.771 Pa and minimum value of 11.573 Pa. From figure 4.10, it shown that the maximum stress area concentrating at the centre of the blade. By comparing the maximum stress value with yield strength value of stainless steel, this shaft can withstand the applied load without failure.

</td></tr>
</table>

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design of the pico hydro turbine has been completed. The design is capable of producing electricity for small communities in remote area. To accomplish this project, structured design process had been successfully adhered to. As presented in chapter 4, the material selection has been done based on the product requirements. The mathematical model of the the turbine has been designed. Detailed engineering design is created using CATIA and stress concentration analysis on the design is performed by using ANSYS. The project has enabled me to understand more on hydropower and the design process. It can be concluded that this project is a success and completed within agreed time frame.

5.2 Recommendation

As for recommendation and future works, detail study and analysis of the mechanical power transmission component such as bearing and lubrication can be done. Detail dynamic and kinematic analysis should be done in order to ensure the reliability of the design. The design of the wheel should be improved in terms of the shape or manufacturing process since from the stress analysis it shows that maximum stress area concentrating right between the blade and base plate that will lead to crack initiation.