Preliminary Study of Renewable Pico Hydro Electrification Schemes to Improve Current Electrification Method in Royal Belum

By

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16497

Dissertation submitted in partial fulfilment of

The requirement for the

Bachelor of Engineering (Hons)

(Mechanical)

JANUARY 2016

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(JASON NGU KAI SHENG)

ABSTRACT

PV/Diesel Power Generation Scheme was adopted to replace the stand-alone diesel power generation system in rural villages and schools in Malaysia. As the diesel fuel costs fluctuates highly over the year and the PV module showing inefficiency and incapability to totally replace diesel generators, hydro power is identified as an essential surplus to the current PV/Diesel system to reduce the fuel consumption in the system. Hence, this paper studies the preliminary elements and analyse the potential for PV/Diesel/Pico Hydro hybrid system to be applied in SK Sungai Tiang, Royal Belum, Perak. The comparison between PV/Diesel hybrid and PV/Diesel/Pico Hydro hybrid with emphasis placed on the amount of fuel savings and total cost needed to implement the PV/Diesel/Pico Hydro hybrid based on capital cost and operational & maintenance cost (O&M).

Keyword: PV/Diesel/Pico Hydro hybrid system; PV/Diesel hybrid system

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

According to the World Wildlife Fund (WWF) Organization, the research datum of this project, the Royal Belum or also known as Royal Belum State Park (RBSP) was officially announced as part of a protected reserve on the year 2007 under the Perak State Parks Corporation Enactment 2001. The 117,500 hectors park will operate under the management of Perak State Parks Corporation.

Within the state park, there are not many inhabitants except for the native Orang Asli. As the national grid is not extended to this region by the national electric utility company, Tenaga National Berhad (TNB), the natives have no access to electricity. The extension of national grid was ruled out as the rural population in this area is too small to justify the high cost needed for the project to be carried out. The rural customer utilization of electricity is estimated to be less than 50kWh/month and it fails in the lowest electricity tariff category of USD 0.013/kWh which is much less than the estimated cost of providing electricity of rural households which is around USD 0.10/kWh.

The issue of electricity needs in rural area was addressed by the Malaysia Government in the Government Transformation Programme (GTP) which aims to improve the living quality of the rural households. A total of more than twenty six thousands households was tapped to the national grid and starts to enjoy electricity. However, the local communities of Royal Belum area was not among those who were fortunate to enjoy the benefit due to the terrain conditions which does not permits grid connection. The local natives still faces electricity problem and the local schools in the area like Sekolah Rendah (SK) Sungai Tiang have to rely mainly on the diesel generators provided by the Ministry of Education to be able to power up the basic appliances like fans and lights so that the students can study with comfort.

The diesel generators are only short term solution to the main problem as the capital expenditure (CAPEX) and operating expenditure (OPEX) are very costly. The installation of the diesel generators alone can cost up to USD 4,000 to USD 12,000 per units and the operating cost which includes the diesel fuel cost, maintenance cost, fuel transportation costs etc estimated to be around RM431,578/ year. All these expenditure were borne by Ministry of Education year in year out, hence, Solar Hybrid System was put in place by coupling solar electric generation with the diesel generators to reduce the operating cost of the diesel generators. However, to ensure prolong electricity supply, the diesel system are still needed to be powered up to cover the inefficiency of the solar system during night time or during rainy season.

Hence, the introduction of a Mini Hydro Power Scheme seems to be logical as there are waterfalls in the area where the potential energy can be harvested and turned into electricity. This hydro power generation can be deemed as a surplus to the current Solar Hybrid System as the inefficiency of the solar panels during cloudy days, rainy days and during the haze season can be overcome by having the consistent flow of electricity generated by the mini hydro scheme. Excess power generation can be stored in deep cycle batteries and hence, providing 24 hours power supply to the school. A site survey have to be carried out to select proper hydro system that is suitable for the river characteristic: flow rate, river water level, river location, water head etc. Further study and analysis can be done to optimize the performance of the system to ensure high efficiency.

1.2 PROBLEM STATEMENT

In Royal Belum area, native Orang Asli has been living in the state of no electricity. Due to the geographical location of the area, Tenaga National Berhad deems that it is economically infeasible to extend the National Grid to this region to provide electricity. Local schools like SK Sungai Tiang has been using diesel generators-coupled with photovoltaic cells to provide electricity in the school compound with all the expenditure borne by the Ministry of Education. As we know, Diesel Generators are powered up by burning non-renewable source which is diesel fuel and needs to be maintained regularly which leads to high operational costs. We hope to harvest the nearby river flow to generate hydro energy as an alternative which is sustainable and environmental friendly.

1.3 OBJECTIVES

To study the renewable energy alternatives to the current method of rural electrification in Royal Belum by:

- Identify and analyse the current rural electrification method (PV/Diesel)
- Suggest alternatives to the current rural electrification method (PV/Diesel/Pico Hydro)
- Construct scaled-down prototype
- Suggest recommendation to the prototype built, if any

1.4 SCOPE OF STUDY

Most of the project from designing until prototype fabrication will be carried out in Universiti Teknologi PETRONAS campus as the facilities needed are provided to the students. Finished scaled down prototype may be tested in nearby waterfall area to identify any potential structural weaknesses, before carry out testing in Royal Belum area where the energy of the waterfall was intended to be harvested for our project. The project budget is set at RM500. As SK Sungai Tiang is already utilizing PV-diesel power generation system, this project will fully focus on micro hydro power generation system as a backup system to ensure all day supply for the application of the school and probably for the local community whenever possible. The design of penstock and dam will be not included due to the intended design of run-of-river hydro plant without storage while generators will only be selected but not designed.

As the actual power consumption details are not made available by relevant authorities, the total electricity bills are assumed to be of RM700 per month which is relatively true for an average rural primary school.

CHAPTER 2: LITERATURE REVIEW

2.1 MINI GRIDS

Mini Grid is described as a small, local electrical network which is not tapped to the main grid. (Singh, et al., 2015). For mini grids, normally the users or customers are in close proximity, with no easy road access and linking the community to the main grid is proved to be of high challenge and initial costs. In conventional mini-grids, diesel engine generator sets (or also known as diesel gensets) are used to provide the needed electricity for the customers which the mini-grid serves. Although the diesel gensets are able to fulfil the electricity demand for the local community, it cannot be ignored that the emissions of greenhouse gases is a concern and the high operational costs, especially the high diesel fuel cost and high transportation fees to deliver them. The mini grid technology also demands the willingness and ability to pay for the electricity provided.

Since the loads that are needed to be supplied is relatively small, thus, isolated remote grids are said to be able to attain medium to high level of renewable penetration which is different than the larger scale grid. (Pelland et al., 2012). Renewable energy sources, like solar, hydro and wind energy are identified to be able to help tackle the emisision and high operating cost issues by reducing the operational time for the diesel gensets. Dedicated management system are needed to manage the system when integrating renewable energy sources with diesel gensets in mini-grids as the complexity of the whole system increases.

2.1.1 STANDALONE DIESEL SYSTEM

In Malaysia, there are many rural villages that rely on standalone diesel generators set to provide electricity to the local community. These villages are usually located quite a distance off the national grid and the idea of extending the national grid to these villages has being deemed uneconomical by Tenaga National Berhad (TNB), the biggest electricity provider company in Malaysia (Lau., Yousof., Arshad., Anwari, & Yatim, 2010). In the cases where the villages are deep within the forest and involve hilly conditions, extending the national grid to the region is too costly as the expenses needed for construction and set up is too high to be borne by TNB. Hence, these villages depends on the diesel generators to supply electricity for their daily demands. Due to the fact that the diesel fuel price has risen as the government attempts to reduce its subsidies, the cost of generating electricity using diesel generators alone is also proven to be a tough task to handle. Nevertheless, the prolonged usage of standalone diesel system also give rise to environmental concerns as the diesel generators emissions will harm the air quality in the region.

2.1.2 PV/DIESEL HYBRID SYSTEM

Solar energy is one of the renewable energy source that is inexhaustible and readily available in our country as we experience abundant solar radiation, ranging from 3–6 kWh/m^2 a month throughout the year. By using solar energy, we hope to reduce the dependency on the need of generating electricity using fossil fuels and other non-renewable energy sources. In rural electrification applications, solar panels are introduced to the current standalone diesel generators system with the aim of reducing the reliance of diesel generators to fulfil the daily demands.

This integration of PV cells with diesel generators brought a handful of benefits with the most obvious one being the reduction in carbon emissions as the diesel generators operating time are cut short with the presence of electricity produced by the solar cells during daytime. In addition, peak demands during the day can also be covered by adding battery storage capability to store the energy produced during off-peak hours to cover the peak demands. In a long run, this hybrid system will be economically beneficial as the operating expenditure (OPEX) will be lower as the fuel consumption is highly reduced (Luiz Carlos Guedes Valente et al., 1998).

2.1.3 PICO HYDRO/PV/DIESEL HYBRID SYSTEM

The detailed information on pico hydro/PV/ diesel tri-hybrid system are not widely available due to the limited researches conducted in this area as compared to PV/Tidal or PV/Wind hybrid systems (Zhou et al. 2013). However, in principle, the system only differs from PV/Diesel system in the aspect of the additional pico-scale hydro power added to the hybrid system. Some economic studies has been done to analyse the economic feasibility of PV-Hydro-Diesel and the results are surprisingly promising where the overall costing of the system are lower as compared to PV/Diesel system due to the consistent hydro power output from the hydro source.

2.2 HYDRO POWER

As we know, hydro energy is listed as one of the renewable energy source because it is 100% environmental friendly and cheap (Saket and Kumar, 2006). Up until 2014, the application of hydro energy, in specific, mini hydro power generation accounts for 6% of the total renewable energy installation capacity in Malaysia. This means that, from the total of 243MW generated from renewable energy source, mini hydro only contributed a small 14.58MW.

In Malaysia's Eleventh Plan, the Malaysia government intend to push harder for the energy sector to produced 2080 MW which is about 8.5 times the current renewable energy capacity. The mini hydro is estimated to be able to contribute 24% of the total amount which is around 500MW, more than 34 times the current capability.

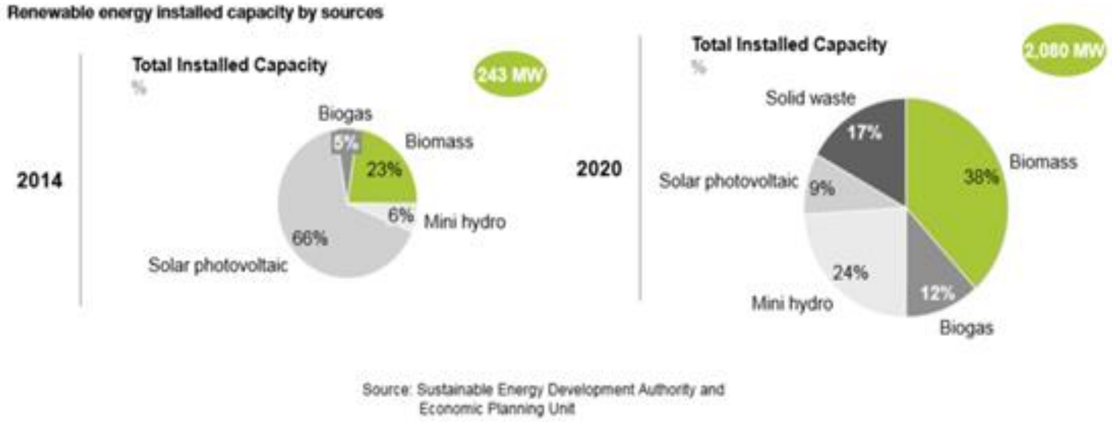


Figure 1: Renewable Energy Installed Capacity by Sources

2.2.1 PARAMETERS OF HYDRO POWER

In order to estimate the power generation potential in a river, it is essential to be able to measure the flow rate and also the head of the river. Flow rate is defined as the amount of water flowing past a certain point in a given period of time. The unit for flow rate is litre per second. Meanwhile, the head of water refers to the vertical height (unit: metres) measured from the turbine level up to the level where water enters the penstock or a stream. The horizontal distance or the penstock length does not contribute to the pressure increments. This head is important as it is needed to compute the current water pressure or the potential water pressure in the river or stream.

2.3 HYDRO POWER PLANT

Hydro power plant can be divided into 3 major types based on their characteristics. The first type is known as pumped storage hydro scheme where off peak electricity are used to power up pumps which pump the water after the tailrace back into the reservoir in order to generate electricity for demand during peak hours and also to ensure grid stability. Meanwhile, the second type of hydro power plant is called reservoir hydro scheme where a huge dam will be constructed as the water reservoir to separate generation from water inflows. The size of the dam however, are very much dependent to the suitability of the site as well as the cost consideration to build the dam. The third type of hydro power plant is the run-of-river hydro power scheme where there will be no water reservoir, i.e. dam and thus, the generation of electricity is relying on the size and water level of the river.

The types of hydro power plant can also be categorized according to their relative capacity. Large-Hydro power plant which is more than 100MW in output are usually being feed into large electricity grid to reduce the dependency of power generation using non-renewable power sources. For rural standalone mini grid, it is normally Run-Of-River (RoR) type where storage capacity is optional depending on the geography of the site as well as the budget constraints.

Table 1: Hydro Power Plant Category Table (Singh, 2009)

Category	Capacity
Large-Hydro	More than 100MW- usually feeding to large electricity grid
Medium-Hydro	15-100MW – usually feeding to grid
Small-Hydro	1-15MW- usually feeding to grid
Mini-Hydro	100kW- 1ME, standalone schemes or feeding into grid
Micro-Hydro	5kW-100kW, standalone schemes for small and rural community in remote locations
Pico-Hydro	From few hundreds Watt (W) to 5kW

2.3.1 RUN-OF-RIVER HYDRO

In all hydro systems, the electricity production is done by harvesting the natural flow and elevation head of the river. In some cases where the system have "pondage" to temporarily store water, it allows the regulation of flow to some level and shift the generation of electricity to meet peak hour demands. On the other hand, when there are no pondage, electricity production timing cannot be scheduled as it follows the river flows and hence, peak demand might not be fulfilled. If there are no damn utilized, a small part of the river flow might be channelled through a penstock where it will be guided into the turbine where electricity will be produced.

Run of River (RoR) hydro schemes are more favourable in some cases where environmental impacts are of big concerns. This is because comparing to bigger scale hydro projects where dam will need to be built, the RoR type only has a small barrage, usually just a weir, where there are minimal or no water stored. (Paish, 2002). RoR hydro schemes are also more conservative towards the environment as marine life are less interfered, less risk towards sedimentation issues and costs lesser than the larger plants with dam. (Goodland, 1994). Egre and Milewski (2002) also stated than in RoR hydro projects, the social and environment implications are also considerably low as there is no need for big reservoir which might transform a river into a lake as pondage for the hydro generation purpose. This statement is also backed by (Bakis, Demirbas,

2004) which said that regardless of the size of the RoR projects, its impacts towards the ecosystem of the natural river flow will be lower compared to those of large dams.

Figure 2: Crossflow Turbine with no intended storage capacity

2.4 TURBINE

A turbine is a device that extracts the potential energy of running water, stream or river and converts into mechanical energy in the form of rotating shaft power. All turbines have its own power-speed characteristic and its efficiency-speed characteristic. They will operate most efficiently in a certain head, flow and speed. A generator will then be used to convert these mechanical energy and turn them into electrical energy.

Different turbines are chosen for different heads as the shaft speed for electricity generation is needed to be as close to 1500 rpm in order to reduce the speed change between the generator and also the turbine. The speed of all turbines will decrease with proportion to the square-root of head, hence, low-head sites needs turbines which is relatively fast under given operating condition.

2.4.1 IMPULSE TURBINE

For impulse turbine, there are 3 types of turbines, namely Pelton turbine, Turgo turbine and also Crossflow turbine (Banki turbine). Pelton turbine is made up of a circular wheel with multiple split buckets around its rim. The Pelton turbine rotates when a high velocity water jet apply high force to the tangent of the wheel, where the water jet will split into two based on the shape of the buckets and deflected following the path of the buckets (roughly around 180^o) and fall down in the discharge channel below the Pelton wheel.

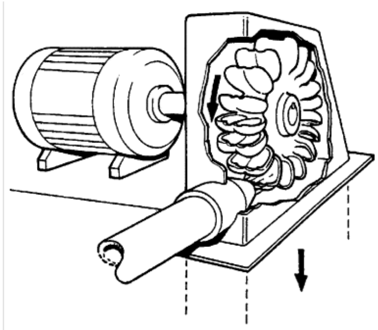


Figure 3: Pelton Turbine

As for Turgo turbine, the working principle is identical to Pelton turbine, however, the water jet is direct at a specific angle (normally it is 20^o) to the runner plate instead of tangentially manner. The water will enter the left side of the runner and leave the runner on the other side. Due to this geometry of the Turgo runner, the flow rate of the water jet does not interfere with the flow of the discharging fluid, making the Turgo turbine to be able to have a smaller runner diameter compared to Pelton turbine.

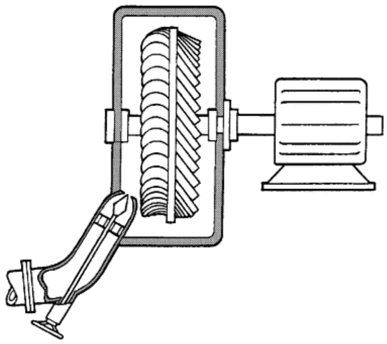


Figure 4: Turgo Turbine

As for Crossflow turbine (which is also known as the Banki turbine), the setup involves a drum-like cylindrical rotor with solid disk from end to end and gutter-shaped 'slats' which join the disks. Water jet will then hit the top side of the rotor through the blades which is curved (normally at the angle of 16^o), the water will then drops at another blade on the far side of the rotor due to gravity. The second pass will still have some minimal residual energy.

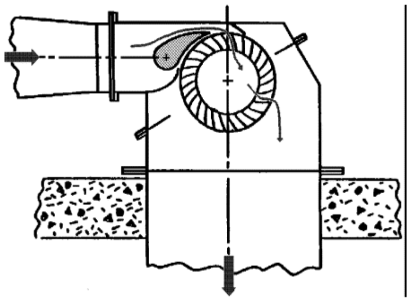


Figure 5: Crossflow Turbine

2.4.2 REACTION TURBINE

Reaction turbines harvest the flow of water to generate hydrodynamic lifting force to help propel the runner blades. The difference of reaction turbine with respect to impulse turbine is that the reaction turbine is always operating within a water-filled enclosure. All reaction turbines contain a diffuser (or also known as draft tube) below the runner where the discharge of water occurs. This diffuser or draft tube will slow down the speed of the discharging water and reduces the static pressure below the runner, and hence, increase the effective head.

The two types of reaction turbine are Kaplan turbine and Francis turbine. Kaplan turbine is like a reversed ship propeller-type of turbine where the turbine runner benefits from the swirl of the incoming water and the water then flows into the draft tube with its leftover momentum. The thing that makes Kaplan different from propeller-type turbines is that it has adjustable vanes that can be positioned according to the available flow. The mechanics of adjusting and positioning the turbine blades and vanes can improve the efficiency of the system over a range of flows.

As for Francis turbine, it is a modified propeller turbine where water flows in radially towards runner and turned to emerge axially.

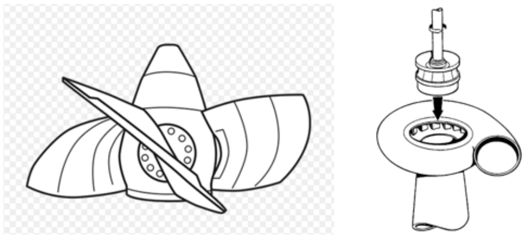


Figure 6: Kaplan Turbine (left) & Francis Turbine (right)

2.4.3 TURBINE EFFICIENCY

Turbine efficiency is defined as the measurement of effectiveness of turbine in converting its input energy to output force or movement. It is also known as the ratio of the output over the input as shown in the formula below:

$$Efficiency, \eta\ (\%) = \frac{Output\ Power}{Input\ Power}\ x\ 100\% \tag{1}$$

Turbine efficiency will always be lesser than 100% as the actual system will experience losses, i.e. power loss during transmission and also head losses in the penstock.

From the study carried out to compare the efficiency of major turbine, it was found that there are no turbine that supercedes the others as the turbine efficiency is dependent on the flow rate of the water source. Pelton and Kaplan turbines operates at very high efficiency levels when operating below design flow. In contrary, the efficiency of the Cross Flow and Francis turbines reduces a lot if operate at below at half of the normal flow that they were designed for. (British Hydropower Association, 2005).

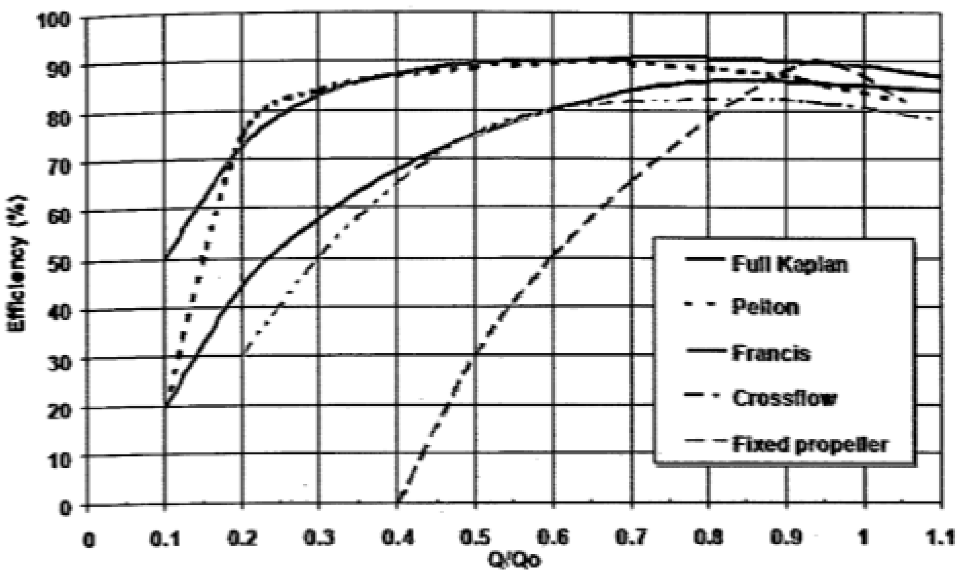


Figure 7: Turbine Efficiency Grapoh of Turbine Types

In average, the turbine efficiency can be noted according to the values from the table below:

Table 2: Turbine Efficiency Value

Turbine	η
Pelton	0.90
Banki-Mitchell	0.87
Turgo	0.85
Francis	0.90
Kaplan	0.90

2.4.4 TURBINE SELECTION

Preliminary turbine selection is depending on the head and also the flow rate of the river selected as the water source. At different net head and flow rate, there is a different turbine that is suitable for the application. Typical river with high head will utilize Pelton turbine whereas Banki and Kaplan turbines are suitable for river with low head.

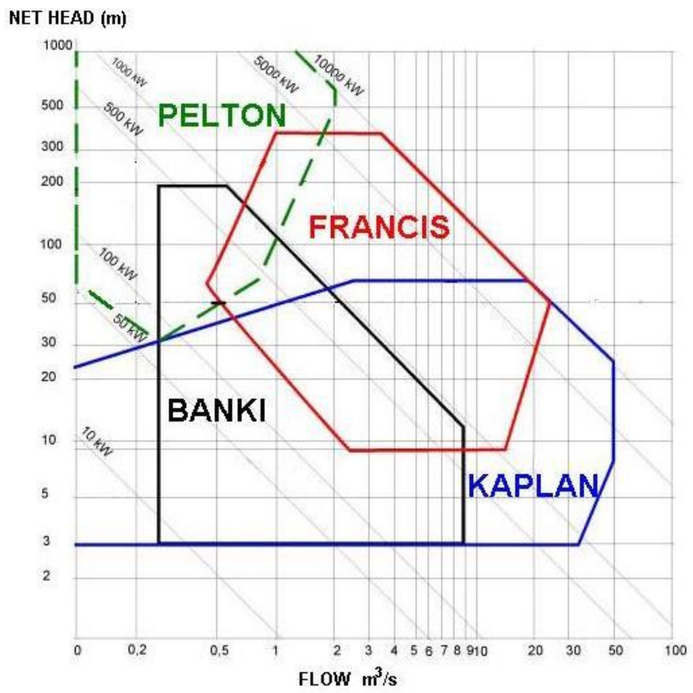


Figure 8: Turbine Application Range Graph (Source : International Network for Sustainable Energy, 2008).

It is also possible to select the suitable turbine types by calculating the specific speed of turbine, N_{st}.

Table 3: Turbine Head Range (Nasir, 2014).

Turbine Type	Head (m)
Kaplan, Propeller	2-40
Francis	10-350
Pelton	50-1300
Crossflow(Banki)	3-200

Table 4: Turbine Specific Speed Range (Nasir, 2014).

Turbine Type	Specific Speed Range (r.p.m.)
Pelton One Nozzle	5-25
Pelton Two Nozzle	7-35
Pelton Four Nozzle	10-50
Crossflow (Banki)	20-200
Francis	50-350
Kaplan, Propeller	200-1550

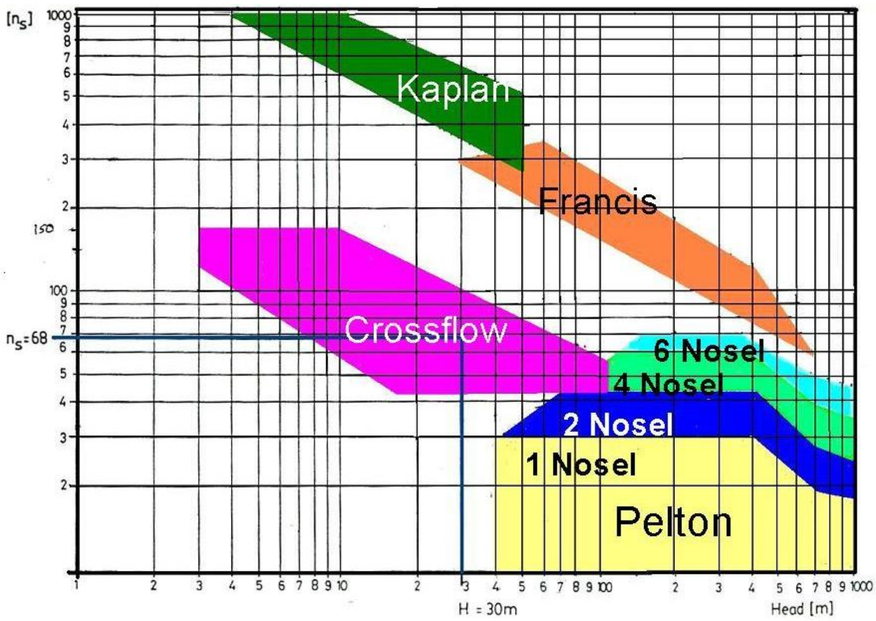


Figure 9: Turbine Application Chart based on specific speed (Source: Indonesian Renewable Energy Community, 2009).

Other criteria which includes: overall system cost, overall System Size, environmental considerations (regulatory, weather, location suitability), unit portability, unit reliability, required civil works, design modularity, and also maintenance & serviceability were also considered.

2.5 POWER ESTIMATION

Theoretical power for a hydro power plant:

$$P_{theoetical} = Q * \rho * h * g \quad (2)$$

Where:

$P_{theoretical}$ = Power (kW)
Q = Flow Rate (m^3/s)
ρ = Density of water (1000 kg/m^3)
H = Head (m)
G = Gravitational acceleration (9.8 m^2/s)

The turbine efficiency obtained has to be included in the actual power calculation formula where the new formula will be:

$$P_{actual} = \eta * Q * \rho * h * g \quad (3)$$

Where:

P_{actual} = Actual Power (kW)
H = Efficiency (%)
Q = Flow Rate (m^3/s)
ρ = Density of water (1000 kg/m^3)
H = Head (m)
G = Gravitational acceleration (9.8 m^2/s)

2.6 TNB ELECTRICITY TARIFF RATE (DOMESTIC)

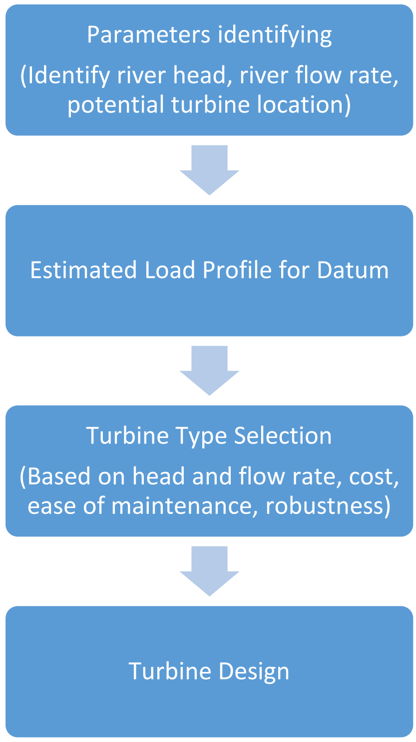
Table 5: TNB Electricity Tariff Rate for Domestic Usage

Tariff Category	Unit	Current Rate (01.01.2014)
First 200 kWh (0-200 kWh per month)	sen/kWh	21.80
Next 100 kWh (201-300 kWh)	sen/kWh	33.40
Next 300 kWh (301-600 kWh)	sen/kWh	51.60
Next 300 kWh (601-900 kWh)	sen/kWh	54.60
For the next kWh (901 kWh onwards)	sen/kWh	57.10
Minimum monthly charge of RM3.00		

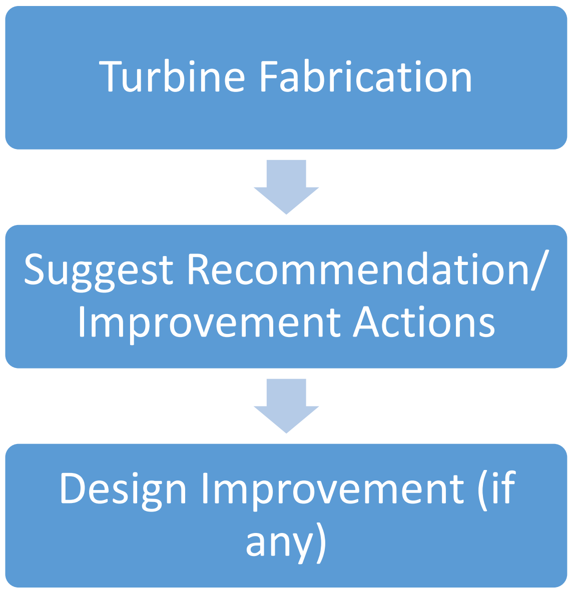
CHAPTER 3: METHODOLOGY

3.1 ACTION PLAN

<u>Final Year Project I</u>



<u>Final Year Project II</u>



3.2 PROJECT ACTIVITIES

1. **Site Assessment (Suitable Turbine Location)**
   In our case, the location of Royal Belum has been identified as our datum. However, we need to assess any nearby waterfall or river that meets our requirement for mini hydro plant suitability. For instance, we need water source that has constant flow and does not dry up during the dry season; we need water source that is close to the target population to reduce the need for power transmission line; we need to have suitable turbine installation location where the nature of the reserve will not be disturbed.

2. **Maximum Hydro Power Potential Calculation**
   The maximum amount energy that can be harvested from a mini hydro system can be estimated by calculation using the values of head and flow rate obtained from the water source.

3. **Power Demand Estimation & Current PV/Diesel System Contribution**
   To understand the amount of electricity needed, we have to estimate the power load needed by the each household in the area. Since we are targeting the local community near SK Sungai Tiang for this project, we have to estimate the power consumption by the community and also the breakdown of the current power generation system supplied to them.

4. **Turbine Type Identification**
   After considering the available head and the flow of water source, the suitable turbine shape can be selected using the relevant chart or graphs. Estimated operating efficiency can also be determined.

5. **Turbine Designing & Fabrication**
   Since the turbine type that is to be utilized is determined, the turbine can now be designed by using the appropriate formulae. The 2D and 3D drawing will be presented by using Solidworks software for latter fabrication process. Details like the guide vanes angle, overall dimensions, number of blades has to be taken into account.

6. **Site Testing & Data Gathering**

   After fabrication of turbine is done, the turbine would have to be brought to designated site for testing to observe the turbine capability as well as to gather live data. The data will then be processed to determine the efficiency of the turbine so that recommendations can be made to improve the design in the future.

3.3 SITE ASSESSMENT

Flow Rate Obtaining Procedure:

For ease, the measurement of flow rate can be done by using a stopwatch and a 10 litre water bucket. The flow rate (unit: litre per second) can be obtained by dividing the 10 litre bucket volume by the amount of time needed to fill the bucket completely. The method is only applicable when the opening of the river is narrow or through a weir of pipe when the flow is at a maximum rate.

In the case where the bucket method cannot be applied, the flow rate can be obtained by using a float or a buoy. The speed at which the float travels is equivalent to the river flow rate. The average speed of the river however, can be calculated by multiplying the speed of the float by a certain factor:

$$Q\left(\frac{Litre}{sec}\right) = A * S\left(\frac{m}{\sec}\right) * 1000 \quad (4)$$

Where:

Q = Flow rate (litre per second)

A = Correction Factor (0.8 for a concrete channel, 0.7 for earth channel, 0.5 for rough hill stream)

S = Speed of float (metre per second)

As for streams which has average depth of less than 15 centimetres, the following formula is used to estimate the flow rate up to an accuracy of 80 %:

$$Q\left(\frac{litre}{\sec}\right) = \frac{D_{float}(m) * Avg\ Depth(m) * Avg\ Width\ (m)}{Time\ taken\ by\ float\ (s)}\ x\ 1000 \qquad (5)$$

Where:

Q	= Flow rate (litre per second)
D	= Distance travel by float (m)
Avg Depth	= Average depth of stream (m)
Avg Width	= Average width of stream (m)

Head Obtaining Procedure:

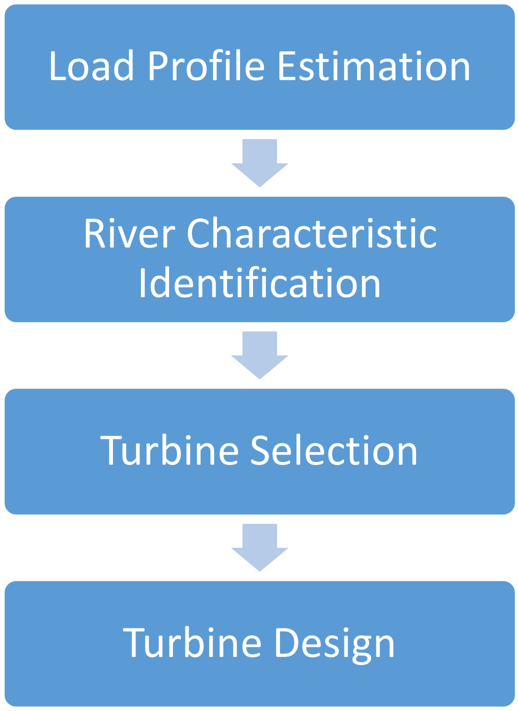
There are several methods at which the head can be obtained:

1. Using pressure gauge: Connecting a pipe from the water intake location to the potential turbine location and attach a suitable range pressure gauge at the end of the hose.

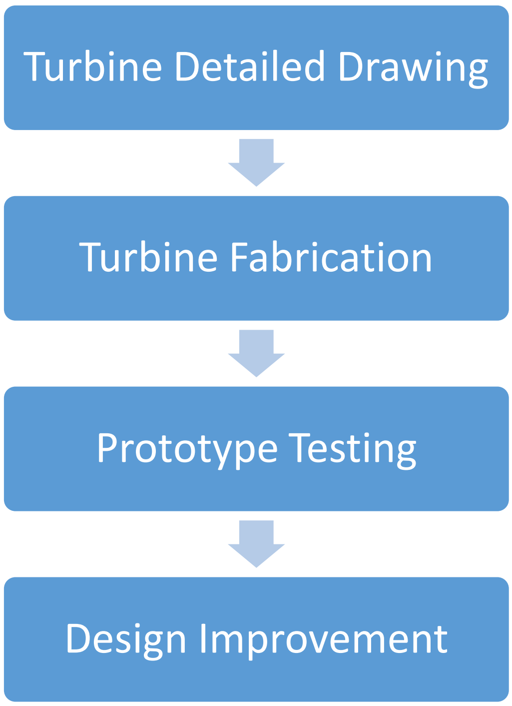
2. Using contour map: The head can be identify by comparing the height of the water source and also the potential site at which the hydro scheme will be set up from the contour map.

3.4 KEY MILESTONES

FINAL YEAR PROJECT I (FYP I)



FINAL YEAR PROJECT II (FYP II)



3.5 GANTT CHART

FYP I

Table 6: Gantt Chart for FYP I

Key Task/ Major Event	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Background Study														
Load Profile Estimation														
Turbine Type Identification														
Turbine Designing														

FYP II

Table 7: Gantt Chart for FYP II

Key Task/ Major Event	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Turbine Technical Drawing														
Drawing Approval														
Materials Procurement														
Fabrication														
Prototype Testing														

CHAPTER 4: RESULTS

4.1 LOAD IDENTIFICATION

Following TNB's electricity tariff rates for domestic users, the estimated average monthly load for SK Sungai Tiang are calculated following the estimated price of RM700 per month for an average rural primary school.

Power Consumption (kWh/month)	**Price per unit (sen/kWh)**	**Cumulative Price (MYR)**
1-200	21.80	RM43.60
201-300	33.40	RM78.00
301-600	51.60	RM231.80
601-900	54.60	RM395.60
900 ++	57.10	RM395.60-RM697.00

$$\frac{(RM697-RM395.60\,)*100sen/1RM}{57.10\;sen/kWh} = 533.10 \text{ kWh}$$

Total power consumption will be 900kWh +527.85kWh= 1427.85 kWh/ month (47.55kWh per day).

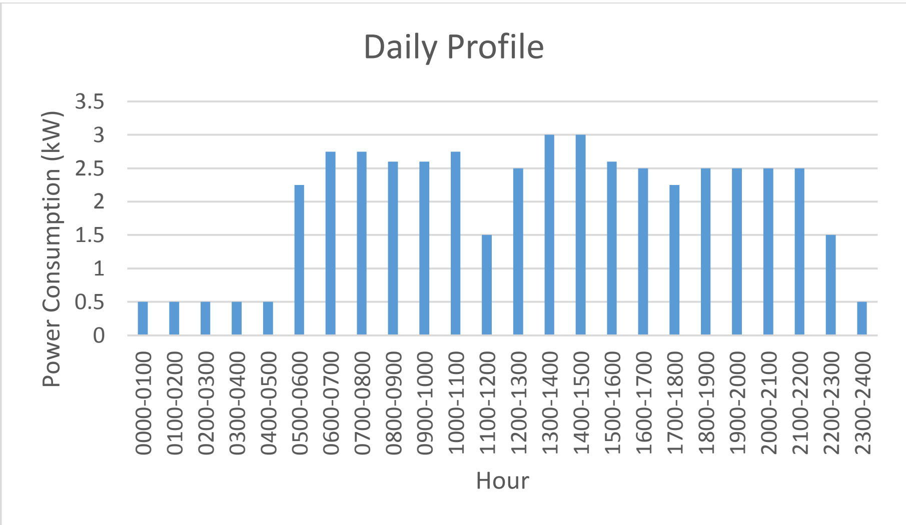


Figure 10: Estimated Daily Profile For Power Usage in datum

Table 8: Estimated Daily Profile

Time	Power	(Unit)
0000-0100	0.5	kWh
0100-0200	0.5	kWh
0200-0300	0.5	kWh
0300-0400	0.5	kWh
0400-0500	0.5	kWh
0500-0600	2.25	kWh
0600-0700	2.75	kWh
0700-0800	2.75	kWh
0800-0900	2.6	kWh
0900-1000	2.6	kWh
1000-1100	2.75	kWh
1100-1200	1.5	kWh
1200-1300	2.5	kWh
1300-1400	3	kWh
1400-1500	3	kWh
1500-1600	2.6	kWh
1600-1700	2.5	kWh
1700-1800	2.25	kWh
1800-1900	2.5	kWh
1900-2000	2.5	kWh
2000-2100	2.5	kWh
2100-2200	2.5	kWh
2200-2300	1.5	kWh
2300-2400	0.5	kWh
Daily Electricity Consumption	47.55 kWh	

4.2 POWER POTENTIAL ESTIMATION

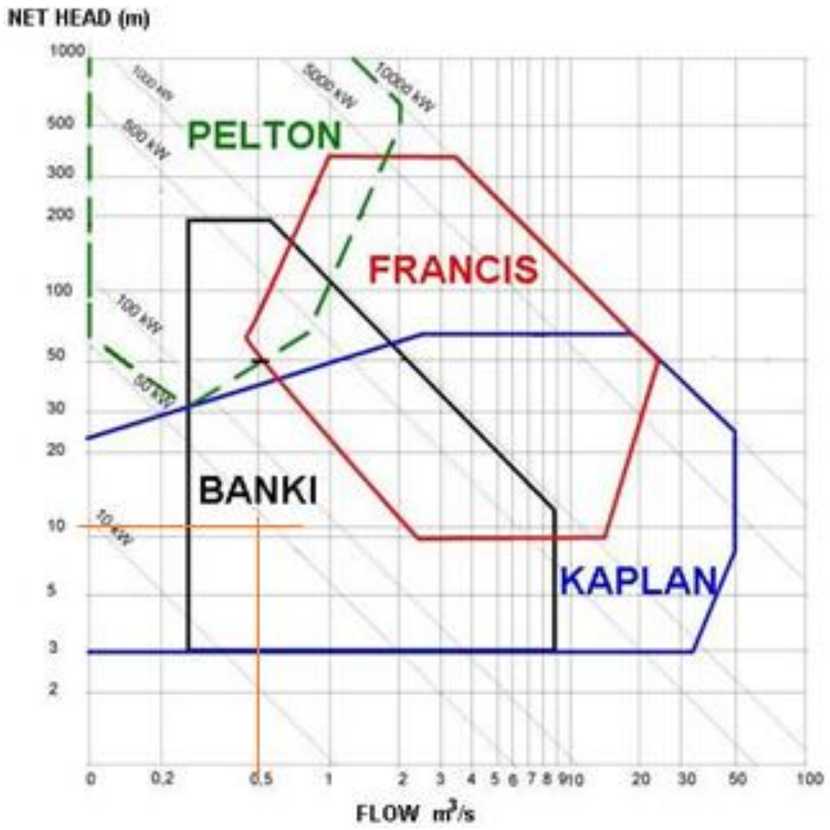
Given that in our case, flow rate, Q= 0.5 m^3/s and the head, H= 10 m, the theoretical system power potential without taking into the efficiency of the whole system and the head losses along the penstock will be:

$$P_{theoretical} = (Q * \rho * h * g)$$
$$= (0.5*1000*10*9.81)$$
$$= (49.05kW)$$

However, since we know that the efficiency of a mini hydro system is estimated to be around 0.6, the actual power that we can expect from the system will be:

$$P_{expected} = (\eta * Q * \rho * h * g)$$
$$= (0.6*0.5*1000*10*9.81)$$
$$= (29.43kW)$$

4.3 TURBINE SELECTION



By plotting the flow and head in figure 8, we can see that the available head and flow of the river limit us to the only option that we can use, which is **Banki turbine (or Crossflow Turbine).**

Table 3: Turbine Head Range (Nasir,2014)

Turbine Type	Head (m)
Kaplan, Propeller	2-40
Francis	10-350
Pelton	50-1300
Crossflow(Banki)	3-200

Table 4: Turbine Specific Speed Range (Nasir,2014)

Turbine Type	Specific Speed Range (r.p.m.)
Pelton One Nozzle	5-25
Pelton Two Nozzle	7-35
Pelton Four Nozzle	10-50
Crossflow (Banki)	20-200
Francis	50-350
Kaplan, Propeller	200-1550

4.4 SYSTEM COMPONENT

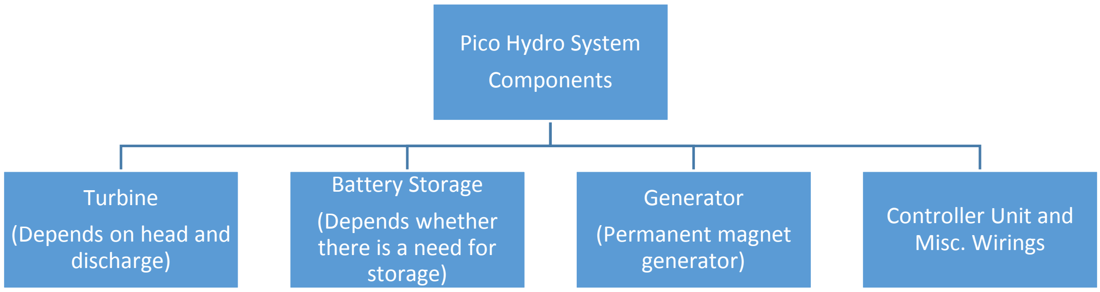


Figure 11: System Components proposed

1. Turbine

   All turbines have its own power-speed characteristic and its efficiency-speed characteristic. They will operate most efficiently in a certain head, flow and speed. Different turbines are chosen for different heads as the shaft speed for electricity generation is needed to be as close to 1500 rpm in order to reduce the speed change between the generator and also the turbine. The speed of all turbines will decrease with proportion to the square-root of head, hence, low-head sites needs turbines which is relatively fast under given operating condition.

2. Battery Storage

   In order to ensure continuity of supply of electricity, a battery storage is normally used. It also functions as a storage bank for the excess electricity generated by the PV module when the load demand is not that high. Typically, deep cycle batteries are used. Deep cycle batteries are designed to be able to handle regular charging and discharging without affecting their lifetime. The capacities of these batteries normally ranged from 2V to 12 V DC.

3. Generator

   A generator will be used to convert these mechanical energy generated from the turbine unit and turn them into electrical energy. Typically permanent magnet generators are used. Permanent Magnet Generators (PMG) normally does not need a gearbox like what the generators required as PMG are designed to be directly coupled with the turbine and are capable of producing high power output at low RPM.

4. Controller Unit and Misc. Wirings

   A controller unit is a logic controller used to control the flow of the electricity generated. When there are demand higher than the amount of power generated, the controller will utilise the power available in the battery storage. In the case where the storage is empty, the controller acts to initiate the diesel generators to generate power to cover the excess demand.

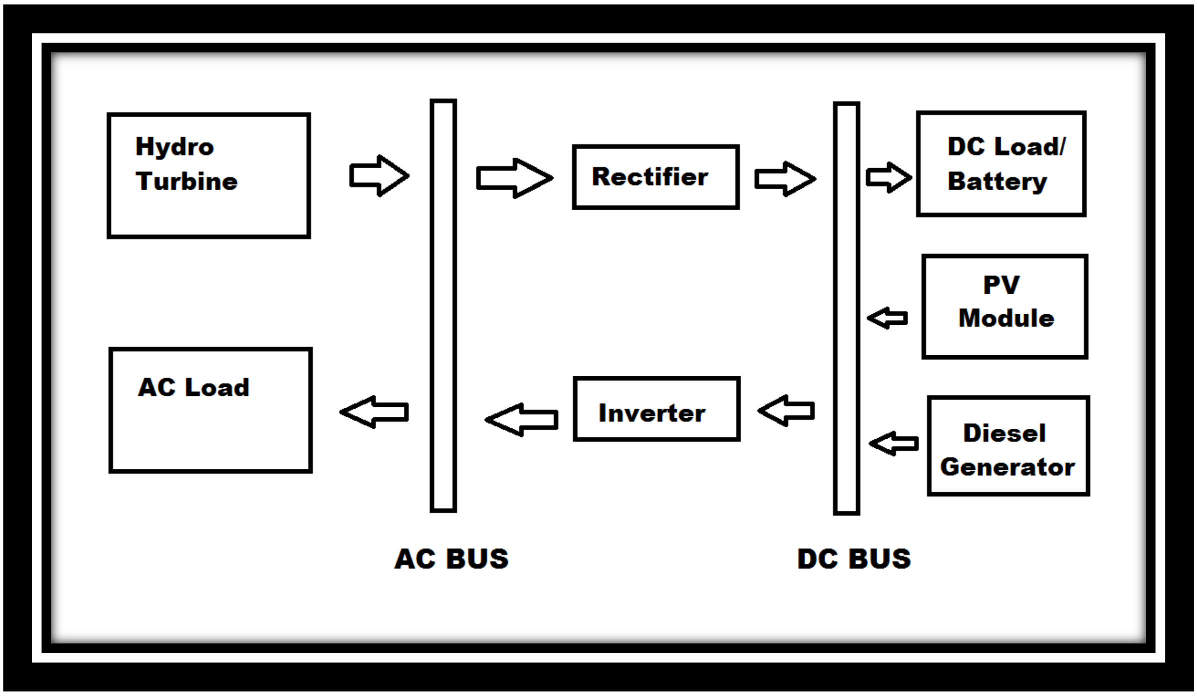


Figure 12: Suggested Layout for the Overall System

4.5 TURBINE DESIGN

According to (Bilal, 2013), the design of crossflow turbine can be done by using the following governing equations:

1. Net head, $H_n = H_g - H_{tl}$ (Assumed to be 10m)
2. Water flow rate, $Q = V_r * A_r$ (Assumed to be 0.5m^3/s)
3. Turbine efficiency, $\eta_t = \frac{1}{2} * C^2 * (1 + \varphi) * cos^2(\alpha)$
4. Turbine power, $P_t = \eta_t * Q * \rho * H_n * g$
5. Turbine specific speed, $N_s = \frac{N * \sqrt{P_t}}{H_n^{\frac{5}{4}}}$
6. Turbine speed, $N = \frac{513.25 * H_n^{0.745}}{\sqrt{P_t}}$
7. Runner outer diameter, $D_0 = 40 * \frac{\sqrt{H_n}}{N}$
8. Thickness of jet entrance, $t_e = K * D_0$
9. Tangential blade spacing, $t_b = 0.174 * D_0$
10. Radial rim width, $a = t_b = 0.174 * D_0$
11. Runner blade number, $n = \frac{\pi * D_0}{t_b}$
12. Runner length, $L = \frac{Q * N}{50 * H_n}$
13. Water jet thickness, $t_j = \frac{0.233 * Q}{L * \sqrt{H_n}}$
14. Distance between water jet to centre of shaft, $y_1 = 0.116 * D_0$
15. Distance between water jet to inner periphery of shaft, $y_2 = 0.05 * D_0$
16. Runner internal diameter, $D_i = D_0$-2a
17. Radius blade curvature, $r_c = 0.163 * D_0$
18. Blade inlet angle= Blade exit angle, $\beta_1 = \beta_2$

NOMENCLATURE:

H_n	Net head	N_s	Turbine specific speed
H_g	Gross head	N	Turbine speed
H_{tl}	Total head losses (6% of gross head)	D_0	Runner outer diameter
Q	Water flow rate	t_j	Water jet thickness
V_r	River flow velocity	K	Constant (0.087)
A_r	River cross-sectional area	t_b	Tangential blade spacing
η_t	Turbine efficiency	a	Radial rim width
C	Nozzle roughness coefficient (0.98)	n	Runner blade number
φ	Blade roughness coefficient (0.98)	y_1	Distance between water jet to centre of shaft
α	Angle of attack	y_2	Distance between water jet to inner periphery of shaft
P_t	Turbine power	D_i	Runner internal diameter
ρ	Density of fluid	r_c	Radius blade curvature
g	Gravitational acceleration	L	Runner length

RESULTS

Table 9: Result from calculations based on the design formula

Given conditions: H=10m, Q=0.5m^3/s		
$P_t = 43.2\ kW$	$L = 0.434m$	$t_j = 0.085m$
N=434 rpm	$D_0 = 0.291m$	$y_1 = 0.034m$
$\eta_t = 88\%$	$D_i = 0.189m$	$y_2 = 0.015m$
$N_s = 160.5$	$t_b = 0.051m$	$r_c = 0.047m$
$\alpha = 16°$	$\beta_1 = 90°$	$\beta_2 = 90°$

4.6 COST ANALYSIS

CASE STUDY: SK PENONTOMON, SABAH

In SK Penontomon, Sabah, a PV/Diesel hybrid system of 15.23kW rating was installed. The load usage is estimated over a 24 hours load profile where the peak load during the day was identified. With daytime considered to be between 0600 hours to 1800 hours, the energy consumption is 35.96 kWh during the day and 15.72kWh during the night respectively. (Mahmud, A.M., 2011).

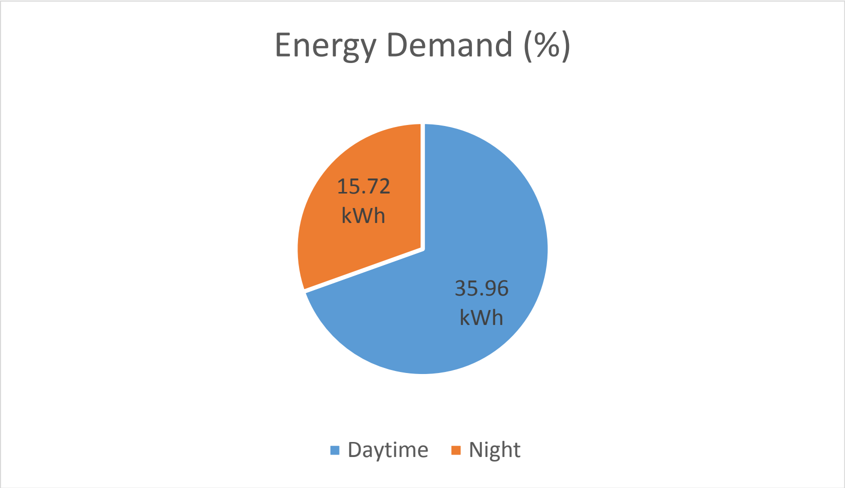


Figure 13: Energy Demand in % for SK Penontomon, Sabah (51.68kWh)

Table 10: Cost Estimated for SK Penontomon Standalone Diesel vs PV/Diesel systems

Parameters	SK Penontomon	
	Standalone Diesel (USD $)	PV/Diesel Hybrid (USD $)
Investment cost	153,183.00	647,670.00
Cost of Energy (cost/kWh)	4.37/kWh	6.68/kWh
Operating Cost	68,157.00/year	56,333.00/year
Diesel Generator Power Contribution	29.36 MWh/year	2.06 MWh/year
Diesel Consumption	12,514.00 L/ year	778.00 L/year
Cost of Diesel	18,771.00/ year	1,167.00/ year

* Assumed EUR= 1.14 USD
* Assumed Cost of Diesel = USD1.50/ litre, due to logistic cost to rural area.
* Assumed project lifetime = 25 years

Since Pico Hydro will have zero replacement cost due to its high reliability as well as zero Operational & Maintenance (O&M) costs. (Arith, F. et al., n.d.), its incurred cost towards PV/Diesel to establish PV/Pico Hydro/ Diesel hybrid is only its initial cost.

Table 11: Cost Estimated for Pico Hydro Implementation

Cost	**Pico Hydro (USD $)**
Investment Cost/ Capital	Depends on manufacturer (USD 10,000-100,000)
Replacement Cost	0
Operational Cost	0
Maintenance Cost	0

Assuming that the investment price is USD50,000; total power output from the Pico Hydro scheme is 29kW;

Parameters	SK Penontomon	
	PV/Diesel Hybrid (USD $)	PV/Diesel/Pico Hydro Hybrid (USD $)
Investment cost	647,670.00	697,670.00
Cost of Energy (cost/kWh)	6.68/kWh	6.688/kWh
Operating Cost	56,333.00/year	56,333.00/year
Diesel Generator Power Contribution	2.06 MWh/year	2.06 MWh/year
Diesel Consumption	778.00 L/year	778.00 L/year
Cost of Diesel	1,167.00/ year	1,167.00/ year
Total Power Generated (kW)	131,587.2	6,395,587.2

Total power from Pico Hydro for 25 years

= 29 kW *24 hours * 30 days * 12 months

= 6,264,000 kWh

Cost of energy for Pico Hydro

= Cost/ Total Power Generated

= USD50,000 / (6264000)

= USD 0.00798/kWh

New cost of energy

= USD 6.68/kWh + USD 0.00798/kWh

= USD 6.688/kWh

4.7 TURBINE FABRICATION

Table 12: Bill of Materials for Prototype

No	Items	Desc.	Quantity	Price
1	PVC Pipe	15mm	1 m	RM 2
2	Pillow Bearing (OD 19.05mm)	SKF SY3/4"TF	2 units	RM 85
3	Perspex Plates	Custom (DPC)	2 units	RM 52
4	Aluminium Sheet (Block 21)	0.5mx 0.5mx 1mm	1 unit	-
5	Steel Rod	20mm Dia x 20cm	1 unit	-
6	Bolt and Nut	M8	12 pairs	RM 8
7	L frame	10ft/ piece	3 units	RM 45
8	Epoxy	3 tonnes cap.	2 units	RM 24
			TOTAL	RM216

Figure 14: Cross Flow Turbine Prototype (Image 1)

Figure 15: Cross Flow Turbine Prototype (Image 2)

Figure 16: Cross Flow Turbine Prototype (Image 3)

CHAPTER 5: RECOMMENDATIONS

5.1 HOMER Pro Simulation

HOMER PRO is a robust microgrid simulation software developed by HOMER Energy for identifying optimum configuration for microgrid of various sectos, ranging from village power microgrid to grid-connected university campuses. HOMER is able to carry out **simulation** of operation of a hybrid microgrid for the timeframe for a year in multiple time steps ranging from one minute up to an hour. HOMER is also carry out **optimization** of the microgrid design by looking into all possible combinations of system types in a single run, and sorting the systems by optimization variable. **Sensitivity analysis** is also another feature of the software where user is able to change different variable of the system to compare all the possibilities. (Homer Pro, 2014).

HOMER Pro should be used to identify the suitable pico hydro sizing that is to be integrated into the PV/ Diesel hybrid system while carrying out the economic analysis to identify the Rate of Return (RoR) from the project.

5.2 Actual Village Load Profile

By understanding the village load profile, the electricity usage pattern during the whole 24 hour period can be identified along with the peak load during the day. This can help the microgrid designer in selecting the suitable battery storage capability for the microgrid. If battery storage is smaller than what is needed, then the diesel fuel consumption will be higher to cover the load difference. Inversely, the cost of capital will be too high if battery storage capability is in excess. Actual load profile can be traced by identifying the kilowatt rating of electrical appliances available in each household (kW) and also the duration of usage over the day (h). The sum of all the kWh of all electrical usage over the year shows the load profile.

5.3 Actual Water Source Flow Profile

The river source flow profile should also be obtained to understand the flow rate and water level of the river across the year. This will help in designing the water intake towards the turbine and make necessary design changes to anticipate the period when the flow is the highest and the lowest throughout the year.

CHAPTER 6: CONCLUSION

With the power output expected to be around 706.3 kWh, the waterfall identified is a good source of hydro energy. However, the waterfall site has to be further assessed in other aspect such as whether the location is easily accessible for transportation and maintenance purposes, etc. If all the criteria are fulfilled, the waterfall will bring significant hydro power from the pico hydro system to help achieve the aim of reducing the time needed for diesel generators operating to fulfill the electricity demand, thus, reducing the diesel fuel consumption and carbon emissions from the generator sets.

Crossflow Turbine which is popular for application in hydro power generation for head ranging from 2m-100m and a varieties of flow rate is identified as the type of turbine to be used in this study. Since the Crossflow turbine operates with a runner which rotates when the water hit the surface of the turbine blades, the centrifugal force generated helps the runner to wash away any unwanted particles such as sand, grass, leaves and etc. This helps to reduce the likeliness of cavitation losses within the runner and hence, its efficiency is considered higher as compared to other types of hydro turbine. Not to mentioned, Crossflow turbine is relatively easier to be designed and manufactured as its overall structure involved less number of parts.

In our case, the turbine is designed to harvest the vertical fall of the water flow from the waterfall without any nozzle or intake jet to direct the water properly into the turbine vanes. This is to reduce the relative cost of having extra components (top nozzle section and penstock) which may incur extra material cost, maintenance fee and etc. In the case where output of the turbine largely differs from the expected output, then the weakness or imperfections in the systems has to be looked into and provide recommendations to the system so that future improvements can be made to similar case.

The turbine was fabricated based on the design formula according to the high efficiency crossflow turbine design journal by Bilal, 2014. Turbine testing was not completed within the short time frame, hence, the validity of the turbine design could not be proven. Moreover, Homer simulation was not carried out due to software complication and inefficient technical support to solve the software launching issue in time to complete this project.

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APPENDICES

Figure 17: Google Maps image on the exact location of SK Sungai Tiang (Royal Belum)

Figure 18: Google Maps image showing the distance between SK Sungai Tiang (Royal Belum) and the nearest town which is Gerik, Perak (Source: wikimapia.org)

Figure 19: Malaysia National Grid

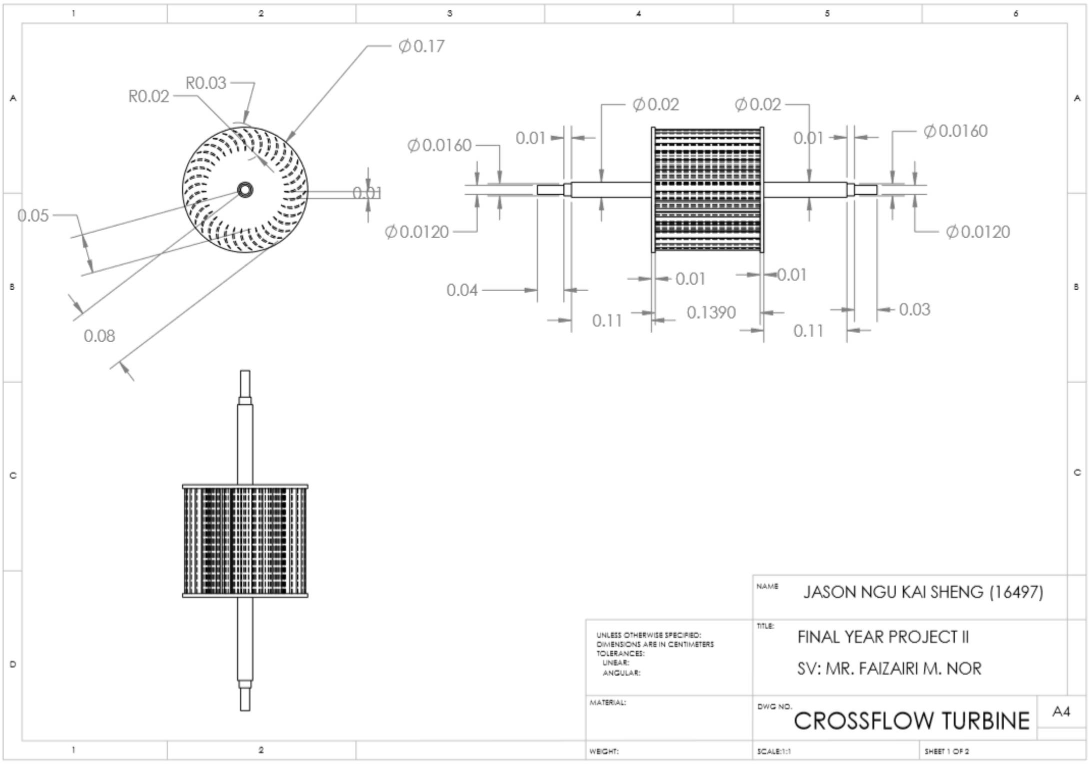

Figure 20: Draft 1 of Cross-Flow Turbine (using Solidworks)

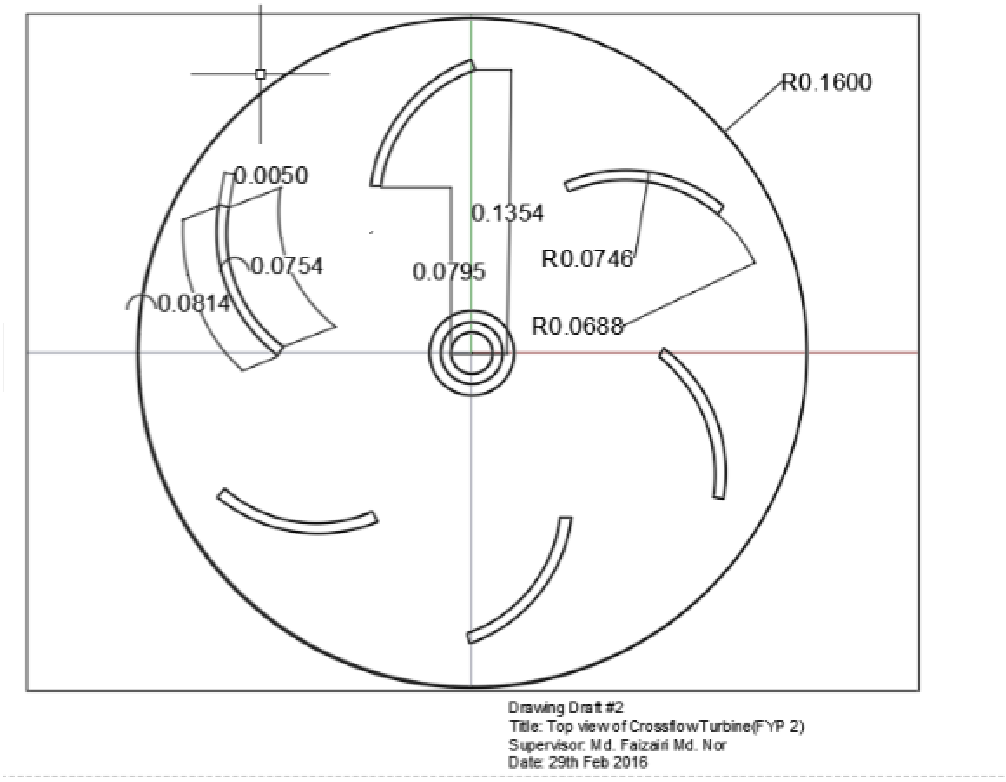

Figure 21: Draft 2 of Cross-Flow Turbine- Top View (using AutoCAD)

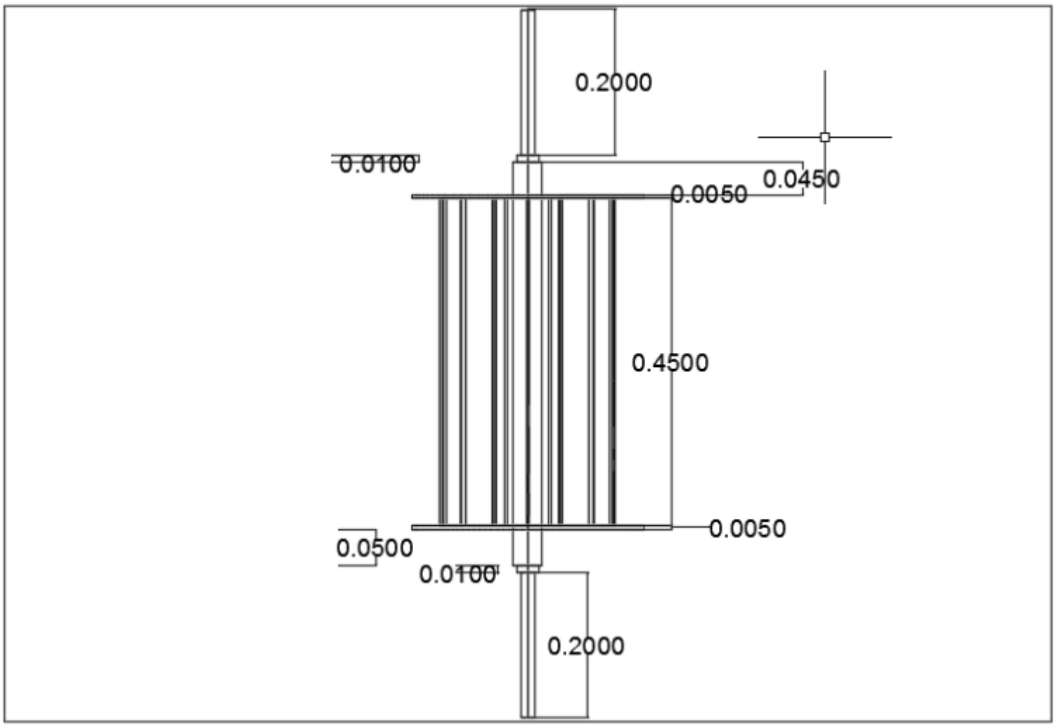

Figure 22: Draft 2 of Cross-Flow Turbine-Side View (using AutoCAD)

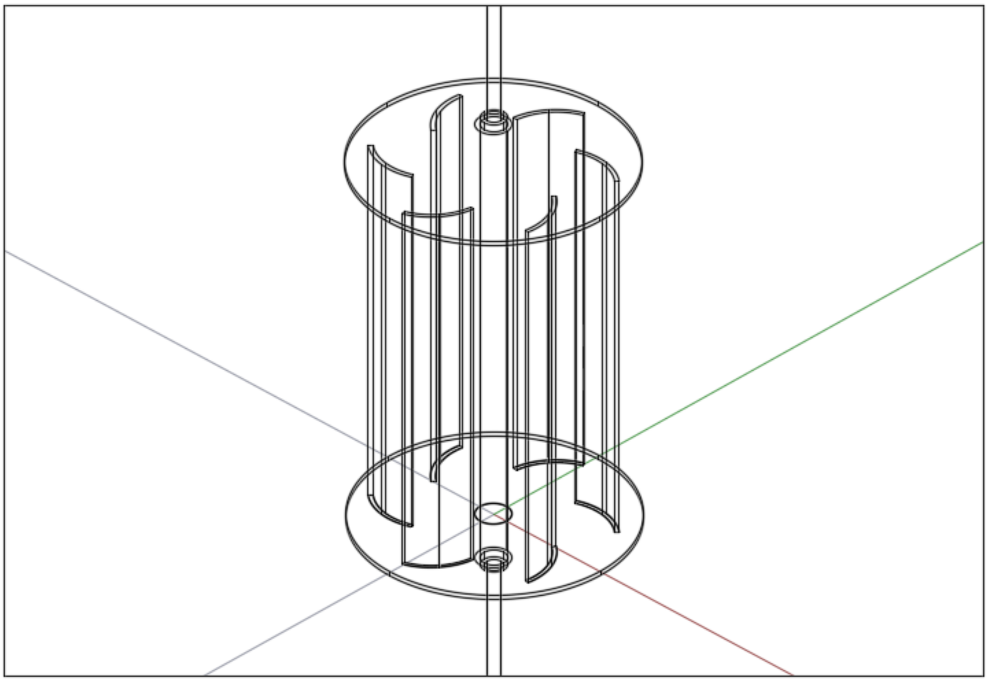

Figure 23: Draft 2 of Cross-Flow Turbine- 3D View (using AutoCAD)

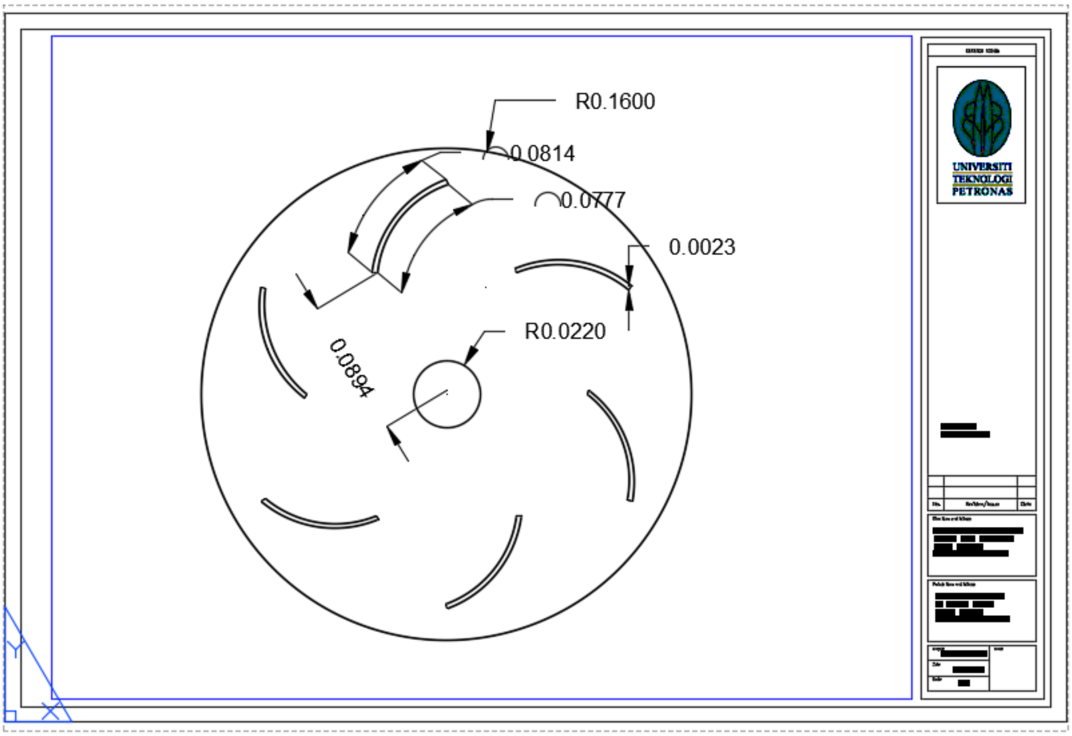

Figure 24: Draft 3 of Cross-Flow Turbine- Top View (using AutoCAD) for DPC Perspex Cutting

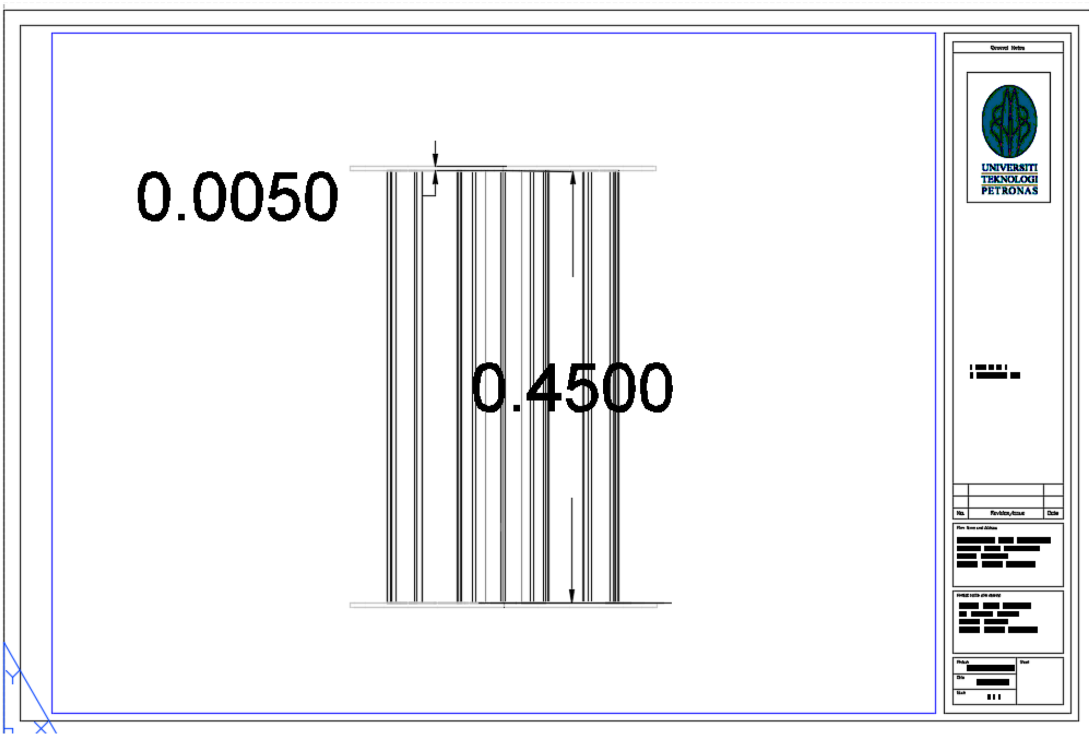

Figure 25: Draft 3 of Cross-Flow Turbine- Side View (using AutoCAD)

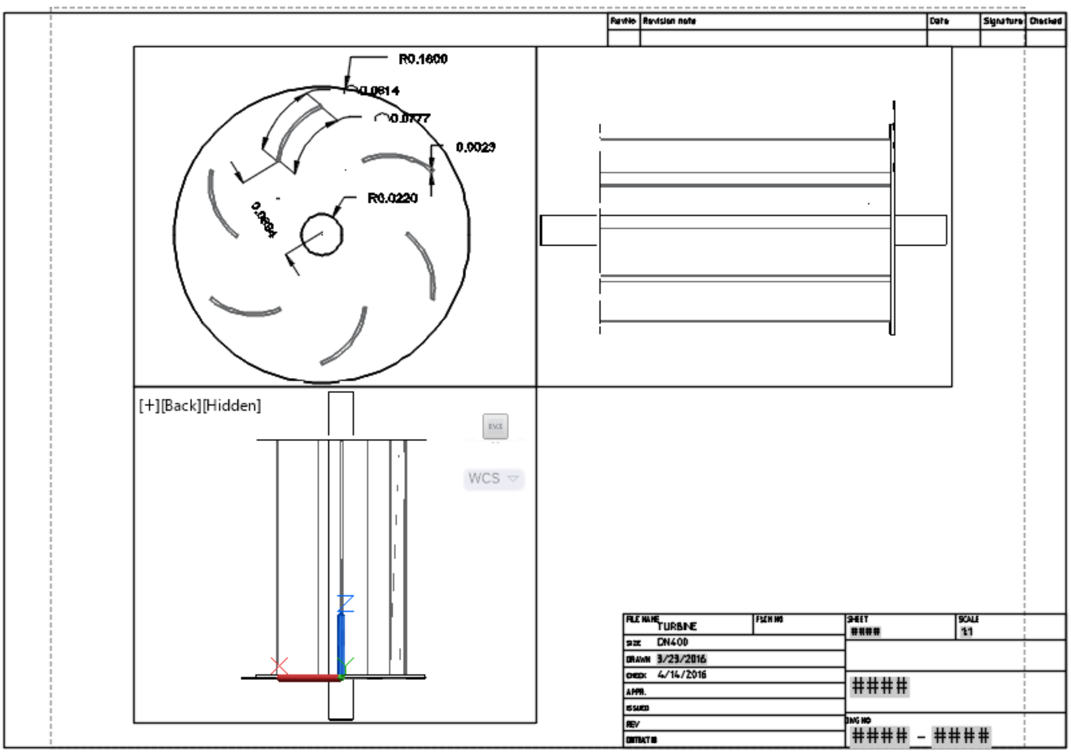

Figure 26: Final Draft for Turbine