Design and Site Implementation of Hydro-electrifier

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

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(AP Dr Hussain H. Al-Kayiem)

UNIVERSITI TEKNOLOGI PETRONAS, TRONOH, PERAK

September 2013

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.

RAEZ EDRIEZAL BIN ABDUL MALEK

ABSTRACT

The energy production and transportation represents challenge to the decision maker and the designers of the rural areas. This challenge created an interest to produce electricity from any possible source available in the rural areas. One of the adopted and proven techniques is the pico hydro power generation. This project is mainly about a pico hydro power generation, in which a modified water turbine is installed in the new pico hydro power generation that will be deployed at UTP solar research site to partially accommodate the night lighting electrical supply at that site. This project is done to reduce the dependency on the networks electrical supply. The idea is to utilize the water stream of the drain system located near to the solar research site and used it to produce electricity. There are three basic things of deploying any hydroelectric site which are dam, turbine and generator. Suitable dam was deployed at the drainage system to increase the head of the water. The turbine holder was fabricated so that the turbine can be placed at the stream. Generator is connected to the turbine to get the mechanical work to produce electricity. Suitable generator was selected as generators depend on the speed and torque provided to the shaft that connected generator and turbine. With estimated head of the water about 0.5 meters, the speed of the turbine was about 80 rpm. The speed was very fast and with a small torque provided at the generator. Induction generator was looked as the best generator to be used. But due to low water head, automotive alternator is used instead. The concrete dam structure is already designed and built at the site.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, this final year project is in the right route of completion within the time period of two semesters.

My highest appreciation goes to my supervisor AP Dr. Hussain H. Al-Kayyiem. He has been very dedicated to help and train me throughout the project. Also for his willingness to share his valuable experience with me, support and guide me from the very beginning up until now.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Hydroelectricity is type of power generation that used water as the working fluid in producing electricity. Energy from the hydroelectric power is renewable and can be found almost all around the world. Hydroelectricity is generated by using hydro power which is through the use of gravitational force of flowing water. Depending on the head of water, which mean the different of height of the water, the amount of energy that can be converted is based on the value of the head. In other words, the higher the head of water, the higher the potential energy of the water thus higher energy can be converted into electrical energy. Following are the energy conversion flow:

How the energy is converted? The potential energy is based on the water head that is available at certain places. By building the dam at that place, the amount of water head can be increased. This means that the amounts of the potential energy will also increasing. The potential energy is then converted into the kinetic energy when the water arrived at the turbine. The turbine is used to utilize the water flow and energy and converted the flow and energy into kinetic energy. The water that arrive at the turbine will rotate the turbine and will produce mechanical works. The turbine is rotate as the result of water flowing into the turbine blades. If the amount of water rotated the turbine is increase, the amount of energy converted is also increases. Same cases with the water flow rate. If the water flow rate that arrived at the turbine blade is fast, the rotational of the turbine is also increased. Turbine convert kinetic energy into mechanical energy and the mechanical energy is then used by the generator to produce electricity.

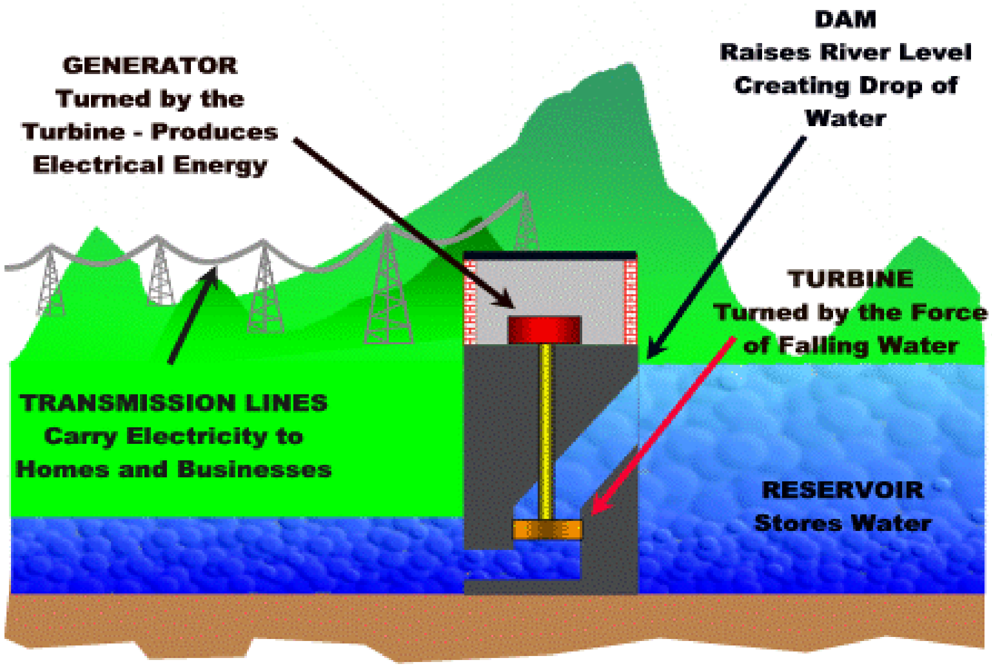


Figure 1: Typical hydro power generation plant

Type of Hydro electric

Hydroelectric plant is classified based on the power output or generated by the plant. Large hydro power generation produces electricity more than 30MW. Small hydro power generation can produce electricity from 0.1MW up to 30MW. Micro hydro power however produce smaller amount of electricity which is in the range of 5kW to 100kW. Finally, pico hydro power produces electricity less than 5kW. This is a final year project that uses the concept of pico hydro power generation to generate electricity for night lighting in the solar research site.

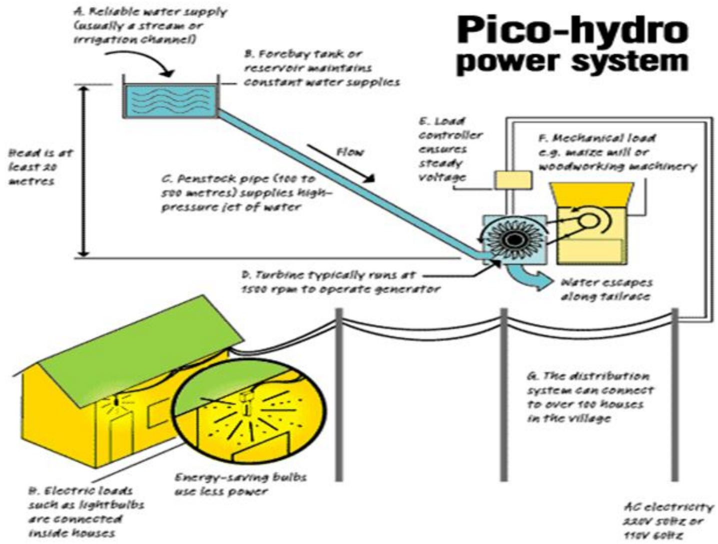


Figure 2: Application of Pico-hydro power system

Demonstration of small scale hydro power generation is growing application to reduce the independency on the national networks. The development of water turbines is on-going in many related research labs and institutes. In UTP, a modified water turbine is designed and fabricated. It is aimed in this project to integrate the water turbine with power generation and energy storage system for night lighting in the solar research site.

1.2 PROBLEM STATEMENT

Utilization of water streams is practical approach for small scale power generation. In UTP, a modified water turbine is designed, fabricated, but not utilized for power generation. Fabrication of power generation system needs to be done so that the modified water turbine can be applied to real power generation system.

1.3 OBJECTIVES

1. To select and fabricate suitable power generation unit for integration with modified water turbine.
2. To install the hydropower system in suitable water stream in the selected water stream at UTP and utilize the generated power for night lighting in the solar research site

1.4 SCOPE OF STUDY

Scope of study is focusing on what is need to be focused on in order for the project to flow in the right ways. Following are the scope of study that is done in making this project:

- Renewable energy – Pico hydro electric
- Selection and fabrication of suitable power generation to be used with modified water turbine
- Installation of hydropower system in UTP drain system to generate power for night lighting
- Electric component and transmission
- Proving that this modified water turbine can be used for real life power generation application (full scale).

CHAPTER 2
LITERATURE REVIEW

Pico hydro power generation has being used to reduce the independency on the national networks electrical supply. Although it is only produce small electrical generation, pico hydro generation is very useful as it a source of renewable energy that benefit for the long time in term of electrical sources. Research has being done to find the suitable tools and equipment for deploying pico hydro electrifier at Universiti Teknologi Petronas (UTP). By using an existent drain system at UTP's solar research site, a pico hydro power generation is being deployed by utilizing the water stream to produce electricity. Hydro electrifier is powered by using the potential energy of the water to rotate the turbine of the hydro electrifier. The work from the turbine is then applied to rotate generate rotor to produce electricity.

Some modifications need to be done in order to produce more electricity. This situation can be solved by increasing the potential energy of the water with the deployment of dam system. By building a dam at the end of the drain system, the head of the water will increase therefore increase the potential energy. Modified water turbine will be used to convert the potential energy of the water into kinetic energy and mechanical energy. This modified water turbine applied the mix concept of savonius-pelton rotor that have extra blade inside the rotor to optimize the potential energy from the water to rotate the turbine rotor. The turbine will rotate the generator to produce electricity. But what is the most suitable generator that can be used in optimizing the mechanical work of the water turbine for this hydro electrifier?

2.1 PICO HYDRO POWER GENERATION

Pico hydro is a small water power which is used for hydro electricity generation up to 5kW. It was named "pico" by Nigel Smith (2005) because to differentiate with micro, mini and larger hydro power. [23] Widely used in rural communities, pico hydro is the lowest-cost technology for electrical generation. The main parts of the system consist of intake from stream or river, pipe, water turbine, electrical generator, electronic controller and electrical distribution system. [23]

Many places like Vietnam, Indonesia and Kenya already used this technology to generate small scale electricity for local used. A very small 'pico-hydro' power system had been installed in Central Province, Kenya by The Eastern Africa office of the Intermediate Technology Development Group (ITDG-Ed) to accommodate two remote communities on the slopes of Mount Kenya. [7] Over 200 homes provided with light and power points from this project. This project has won Ashden Awards for Sustainable Energy. [7]

Figure 3: Power house for a pico-hydro power generation in Kenya (Photo from Martin Wright/Ashden Awards, 2004)

Figure 4: Clearing the canal for pico hydro power generation (Photo from Martin Wright/Ashden Awards, 2004)

In Vietnam, pico hydro system is sold on the markets in Hanoi and other northern province cities by local electrical shop. These pico hydro systems which are brought from China seem to be exported with formal paper. [8]

Table 1: Pico hydro system and it costs [8]

Size	Head (m)	Discharge (l/s)	Lifetime (yrs)	Costs in US$
100W, 220V, 50Hz	1 or 5 to 10	25 (at 1 m)	5	18
500W, 220V, 50Hz	1 or 5 to 10	125 (at 1 m)	5	90

2.2 GENERATOR SELECTION

There are a number of generators that being consider suitable for mini hydro power generation. Through some research, the most suitable generator that can be used is induction generator. Induction generator or asynchronous generator is an AC electrical generator that applied the principles of induction motors to produce power. It works by mechanically turn their rotor faster that he synchronous speed, giving negative slip. Most of AC asynchronous motor can be used as a generator without any internal modification. It is useful in application such as mini hydro power plants, wind turbine and in reducing high-pressure gas streams to lower pressure as it can recover energy with relatively simple control. [22] However, it needs to be excited with a leading voltage to operate. Usually it can be done by connected to an electrical grid or self-excited by using phase correcting capacitors. Among the advantage of using induction generator is the simplicity of the control systems and inherent ruggedness of the squirrel cage design. [25]

Other advantage of induction generator is frequency regulation. The output frequency and volts are regulated by the power system in the Induction Generators and are independent of speed variations. The self-regulation effect minimizes control system complexity. [25] It is also simple and robust construction and can be run independently. It is also inexpensive and requires minimal maintenance. [3] For disadvantage of induction generator, it will not work without capacitors of a suitable value being fitted.

Besides that, induction motor with a capacity that is large compared to the generator rating can cause voltage dips or even loss of excitation when started from induction generators. [4] The induction generators inject active power but require reactive power from the substation. The power loss reduction due to active power generation can only compensate the power loss increase due to reactive power consumption to certain extend. [3]

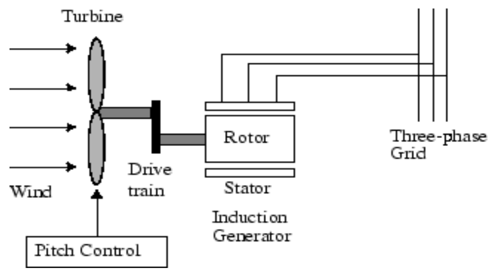


Figure 5: Schematic diagram of Induction Generator used in wind turbine [5]

Although induction generator is agreed to be the best generator for pico hydro power generation, there are some concern about the generator to be used in this project. Due to the very small water head, which is less than 1 meter, induction generator is found to be not suitable to use. This is because induction generator needs to be excited by using external electricity. This means that we need to supply electricity at the generator to start it. Electricity only needs to be used when started. If the generator is operating, external electricity is no longer required. Due to the very small water head, it is not very suitable to use this type of generator as there is a potential that the generator will not produce electricity as the work supply is not enough. Other type of generator is being considered and finally car alternator is used as the generator. Car generator is the cheapest option and it can produce a suitable amount of electricity as the project only required to power night lighting at the solar research site which means that the amount of electricity needed is not so much.

Figure 6: Car altenator

2.3 MODIFIED TURBINE

The turbine uses the concept of the Savonius rotor that was based on the principle developed by German aircraft engineer Anton Flettner in the 1920s. [26] Savonius used a rotor that was formed by cutting the Flettner cylinder into two halves along the central plane and then moving the two semi-cylindrical surfaces sideway along the cutting plane so that from the top view it resembled the letter “S”. [10] The advantage of this rotor are it simple and cheap construction, acceptance of wind from any direction thus eliminating the need for reorientation, high starting torque and relatively low operating speed (rpm). [10]

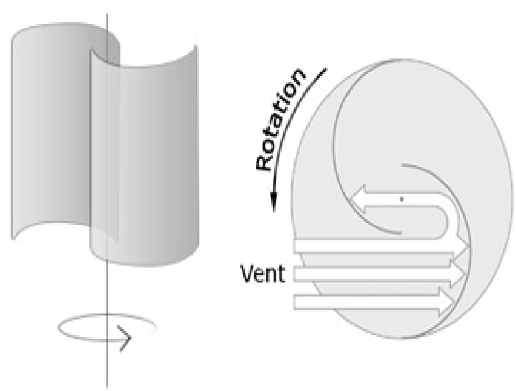


Figure 7: Savonius Rotor [11]

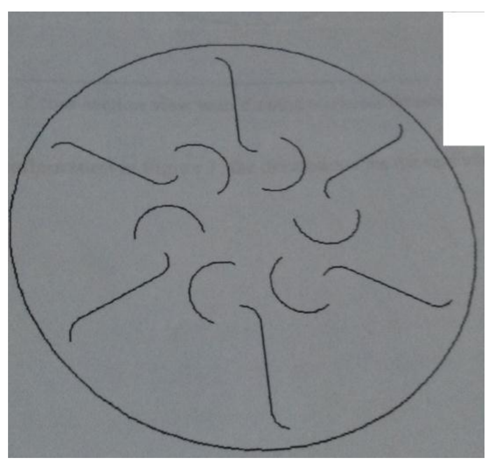


Figure 8: Modified turbine design

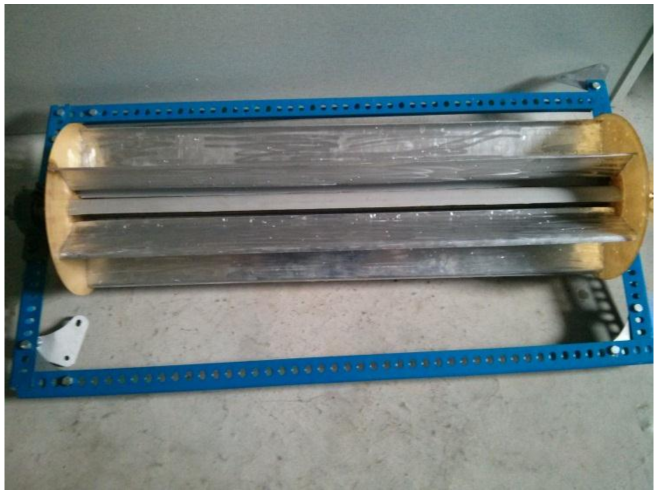


Figure 9: Modified turbine

CHAPTER 3
METHODOLOGY

This chapter presents the solution procedure of the problem under consideration. The setbacks in the potential parameters are: low level water stream, high rpm with low torque, and low efficiency power generation unit. To overcome the setbacks and produce successful prototype of Pico hydro generation, the following methodology is adopted.

3.1 Project activities

I. Information gathering:
   - Previous study in pico hydro generation
   - Research on suitable generator and specification

II. Main components in the pico hydro power generation consist of:
   - Generator
   - Modified turbine
   - Dam

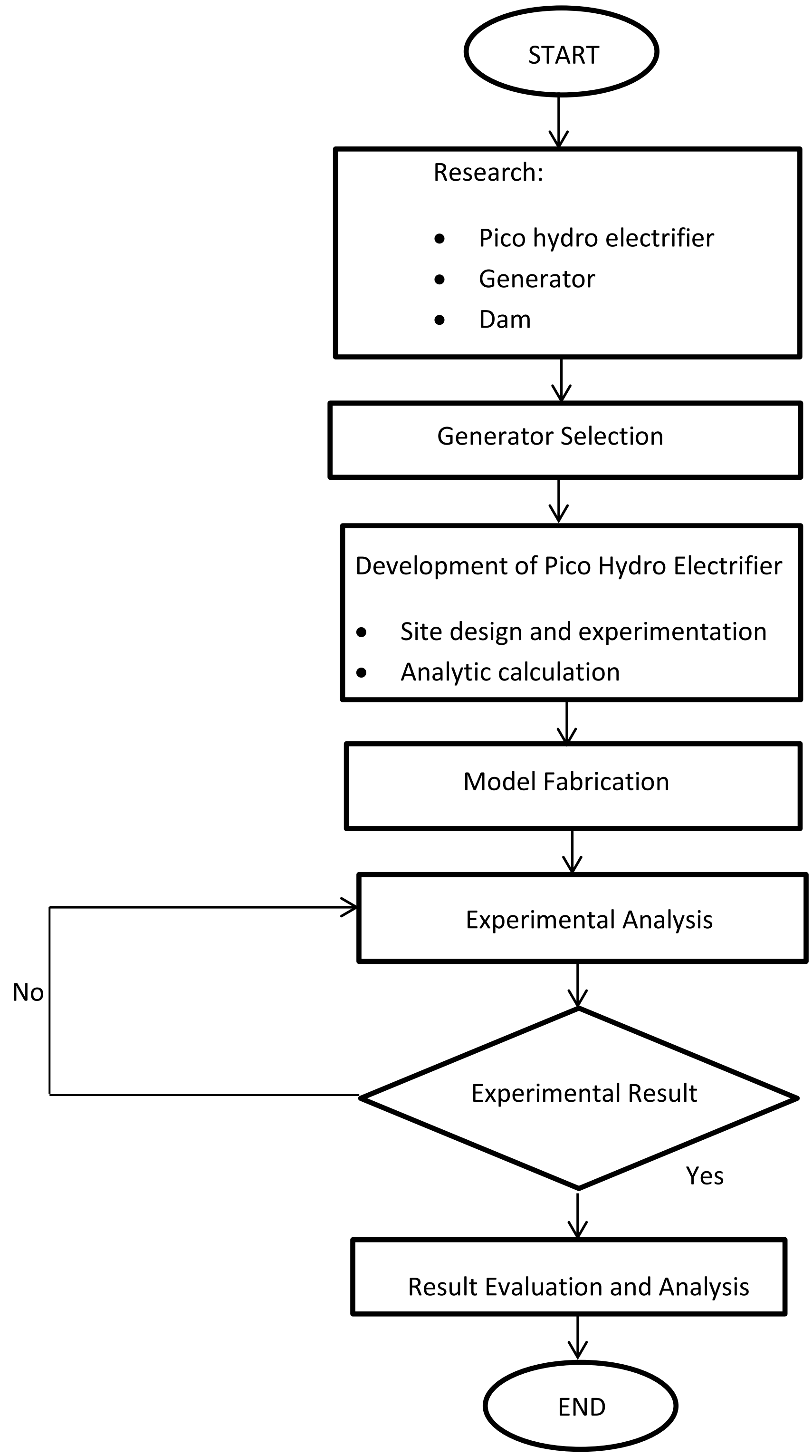
III. Project development
   - Find suitable connector for connection between modified turbine and generator (belts, gears, coupling shaft, etc.)
   - Calculation of power produce

IV. Model fabrication
   - Fabrication of dam, connector and turbine holder

V. Testing and implementation

3.2 Project Planning

The execution procedure of the project is outlined as in the flow chart below:



3.3 System modelling and prototyping

The project analysis includes the theoretical calculation and experimental measurement.

1. Theoretical model and calculations

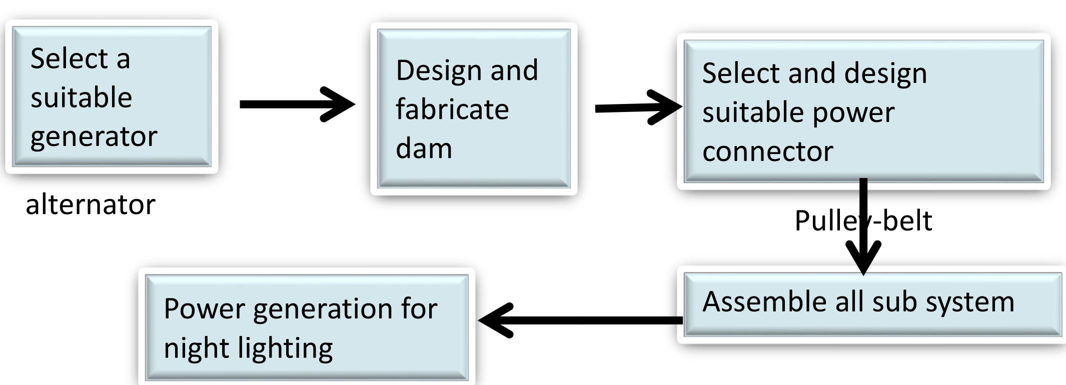
   Theoretical analysis focus on the study related to equation such as Faraday's Equation and Bernoulli's Equation. Bernoulli's equation is done to identify the work that is supplied by the turbine based on the head of water. Faraday's equation is done for electrical produce by generator. The theoretical water flow rate, water head, torque and rotational speed of turbine and power generated by the generator can be calculated.

2. Experimental prototype and measurements

   Testing and experimentation is conducted in order to get the actual speed of turbine, power generated by the turbine and generator. The experimental data will be used to compare with the theoretical value that has been calculated.

3.4 Conceptual Design

Design is done in two steps which is prototype creation and design implementation. Prototype is done after the research and analysis of the previous studies has been done. The objective of the model so that experimentation can be done near to the actual design so that the data collected is correct. Implementation is where the actual system being installed and testing can be done. Turbine performance can be identified based on the water flow from the drain system at the solar research. Following are the system timeline:



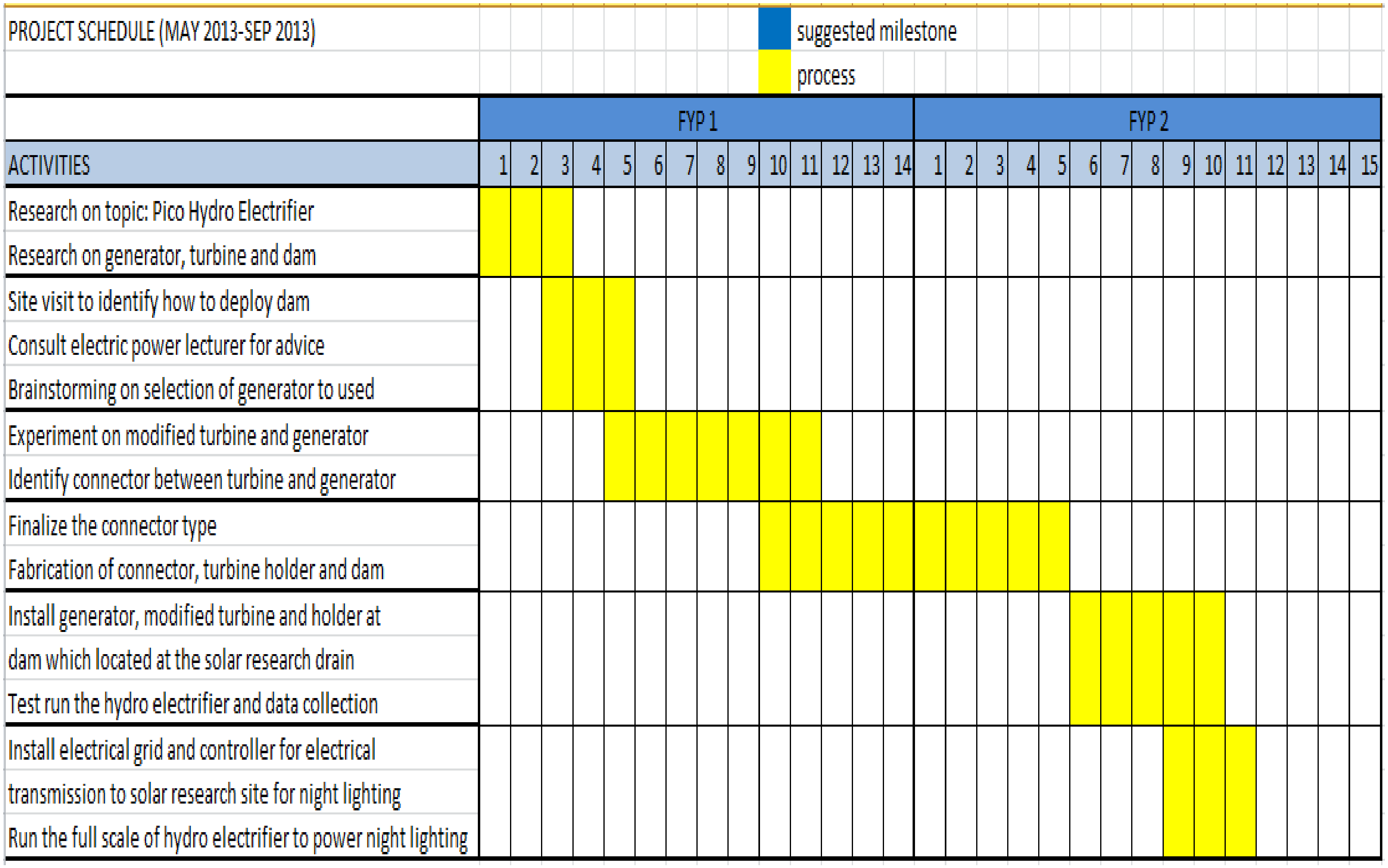
3.5 **Material Selection**

The material to be used is based on several criteria such as water resistant characteristic of the equipment as the system will be deployed at the site involving water as the working fluid. Part that need to be fabricate includes dam, generator – turbine connector, generator and electrical component.

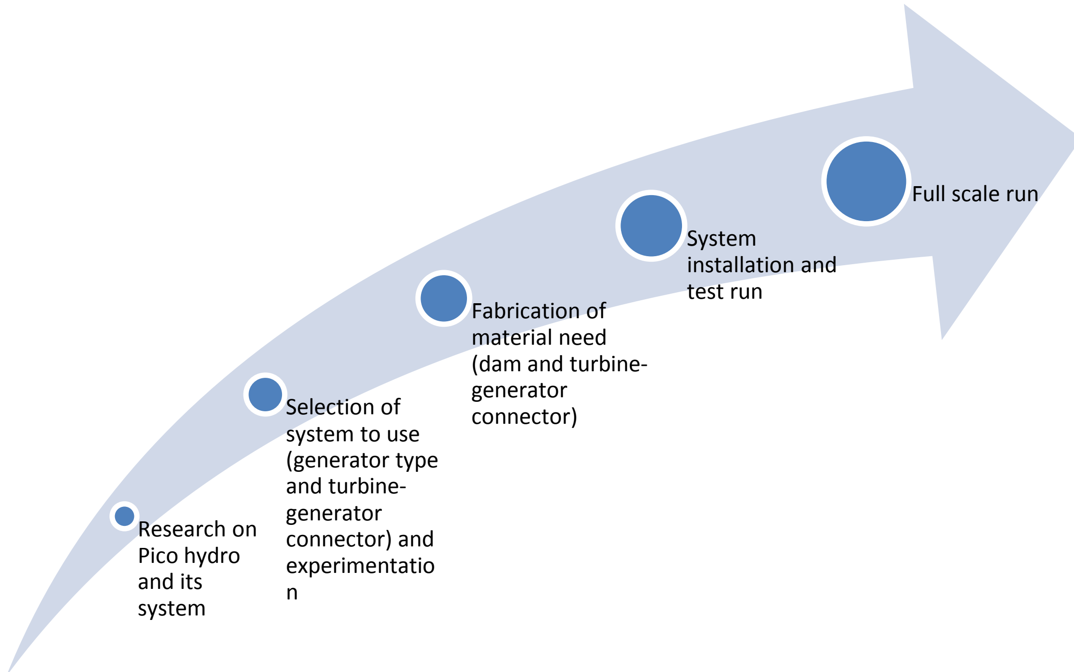
Table 2: Material Selection

Item	Material	Description
Dam	Concrete	Concrete is known as the best material to be used for dam as it has high strength. This characteristic can avoid the dam from breaking as the result of water force and flow rate.
Generator-turbine connector	Pulley and belts	Pulley and belts is found to be the best connector to be used as it is easy to be placed and the maintenance is also easy to be done. Besides, the connector can fix easily into the connection as the belt is flexible
Generator	Car alternator	Alternator is widely used as generator in pico hydro power generation with a very small head as asynchronies generator is not very suitable. Also because of it price which is affordable and can produce suitable amount of electricity

Gantt chart


PROJECT SCHEDULE (MAY 2013-SEP 2013)
suggested milestone
process
FYP 1
FYP 2
ACTIVITIES
1 2 3 4 5 6 7 8 9 10 11 12 13 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Research on topic: Pico Hydro Electrifier
Research on generator, turbine and dam
Site visit to identify how to deploy dam
Consult electric power lecturer for advice
Brainstorming on selection of generator to used
Experiment on modified turbine and generator
Identify connector between turbine and generator
Finalize the connector type
Fabrication of connector, turbine holder and dam
Install generator, modified turbine and holder at
dam which located at the solar research drain
Test run the hydro electrifier and data collection
Install electrical grid and controller for electrical
transmission to solar research site for night lighting
Run the full scale of hydro electrifier to power night lighting

Key Milestone



FYP1	Weeks 1-3	Weeks 4-11	Weeks 12-14		
FYP2			Week 1-5	Weeks 6-10	Weeks 11-12

CHAPTER 4
RESULT AND DISCUSSION

In this section, the author is explaining the result of the project conducted by discussing what the impact of the result to the project. The implementation of the design is made at the drain located near solar research site at Block B, Universiti Teknologi PETRONAS. The water stream is available throughout the year as there is a huge pond-like reservoir located at the top of the drain.

Figure 10: Picture of the hydro electrifier site before the dam is placed

4.1 DAM DESIGN

The main function of dam is to elevate the different in the height of water or water head. By increasing the head of water, the potential energy from the water will increase thus will increase the amount of electricity produced. The dam also designed to control the f low rate of water as the faster the flow rate, the higher the kinetic energy of the water. Following are the design of the dam with its dimension.

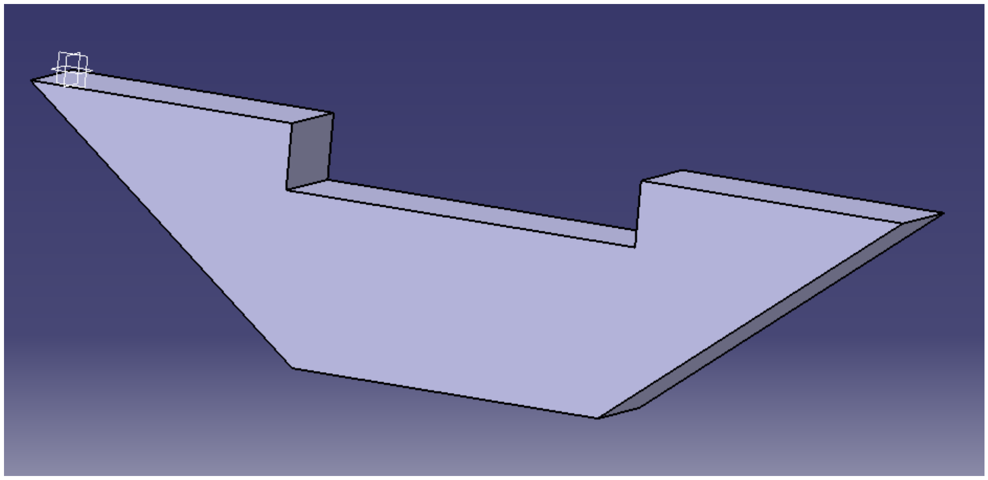


Figure 11: Dam design

Figure 10 shows the design of the dam that is planning to be built. The dam design is adapted by the size and dimension of the drain system where I plan to build the dam. By building this dam, the head of the water increase from 0.3m to 0.5-0.6m.

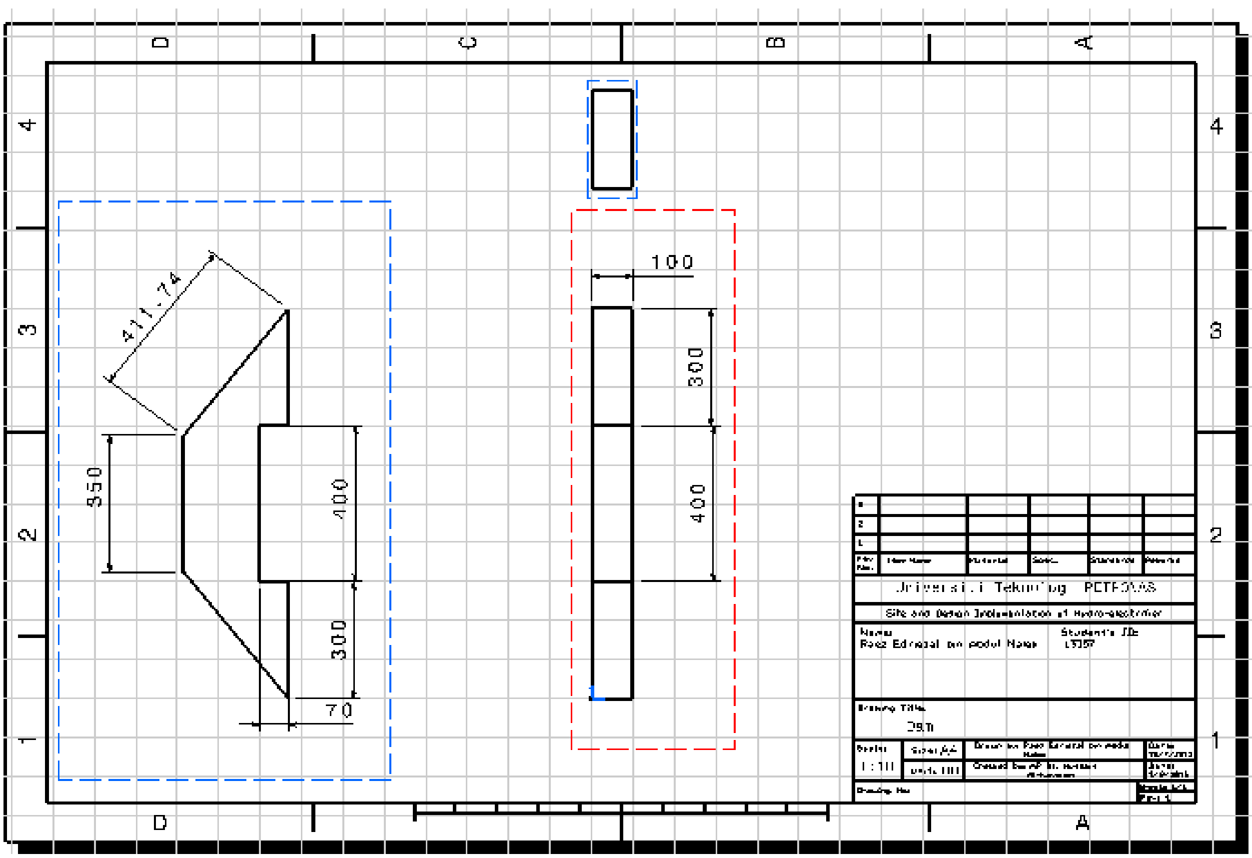


Figure 12: Dam Dimension

After designing part, fabrication part takes place. The dam is fabricated by me with help of fellow civil engineering friends and civil lab technician so that the dam meets the standard for concrete work. First of all, a contractor is hired to do the foam work of the dam. Foam work is a casing of concrete based on dimension from the design. Foam work is done so that concrete can be shaped easily based on our desired.

Figure 13: Foam work of the dam

After the foam work is done, concrete is then made based on the volume of the dam that is designed. Total volume of the dam is 0.014264 m^3. Concrete mixture must be made based on the following ratio:

- Cement = 540V
- Water = 205V
- Sand = 550V
- Stone = 1115V

where V is the total volume of the foam work. After calculation, the amount of material used to make concrete are 7.7kg of cement, 2.9kg of water, 7.9kg of sand and 15.9kg of stone. To avoid the concrete from insufficient due to spill during the mixture of concrete, extra mass of above materials are used but with the same ratio.

Figure 14: Concrete mixture is placed inside the foam work to shape the concrete

Reinforcement bar is also place inside the concrete so that the strength of the concrete is higher so that it can withstand continues pressure and force from water flow. The dam is placed at the drain to increase the water head at the drain. Water level is not consistent and based on whether it is raining or not. When hot season when rarely raining, the water level is very low. This problem is improved by placing bricks at the bottom of the drain floor. By shallowing the drain, the water will move above the bricks thus making the water level seems high. This is important as we want to use the water to rotate the turbine blades for power generation.

4.2 TURBINE-GENERATOR CONNECTOR DESIGN

There are many options that can be used for turbine-generation connector such as gears, pulley and belt and direct connection using coupling. Since the generator that is used is automotive alternator, pulley and belt is chosen as the best connector. This is because car use pulley and belt connector in connecting alternator to the motor. For this case, the motor is replaced with turbine so the same concept can be applied.

In deciding the size of the pulley that can optimize the rotational speed of the turbine, calculation is done to identify the best diameter of pulley to use. The product of diameter and speed of the first pulley is equal to the product of diameter and speed for the second pulley.

$$D_1N_1 = D_2N_2$$

Where,

D = Diameter of pulley

N = Speed of the pulley in RPM

Previous experiment is carrying out on the turbine to identify the speed of the turbine with different water head. The average speed of the turbine for the available water head is 400rpm. Automotive alternator needs rotational about 150rpm to produce electricity. By assuming the diameter of the pulley at the turbine by 100mm, the pulley for alternator is calculated using the above formula. From the calculation, the diameter of the second pulley is 267mm. Design of the pulley is done so that it can be fabricated.

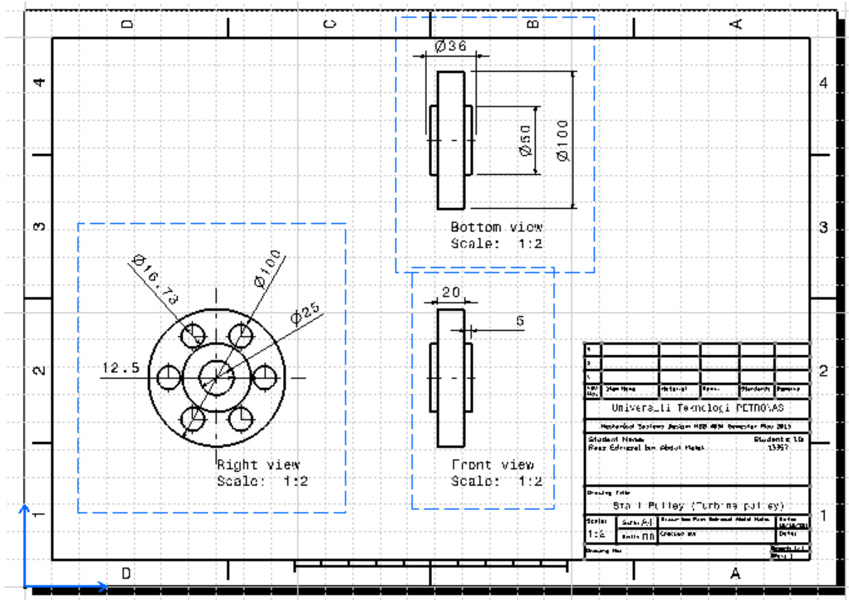


Figure 15: Basic design of turbine pulley

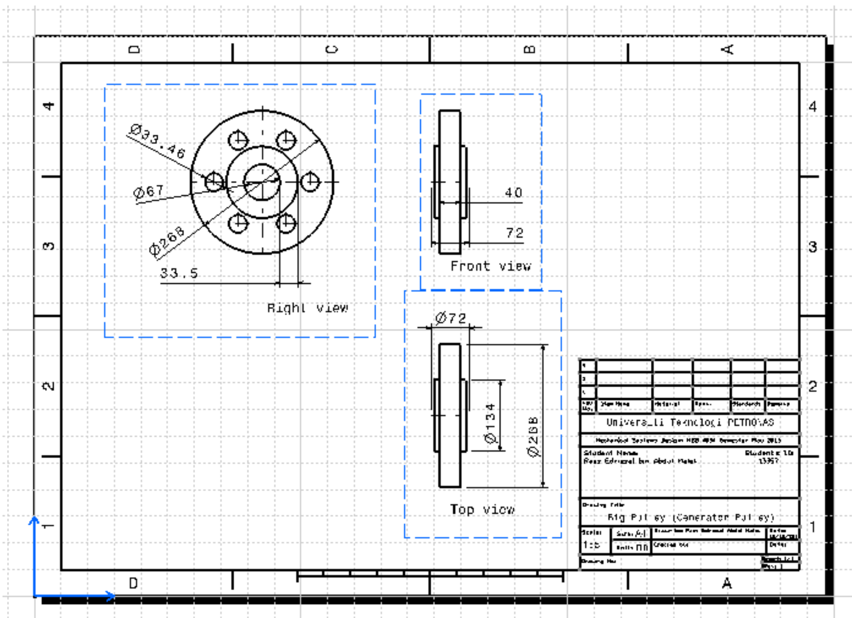


Figure 16: Basic design of alternator pulley

4.3 DESIGN FINALIZATION

After considering many factors such as the drain water level, the water flow rate and the alignment of the subsystem, a design layout is made and finalize as the work to assemble all the subsystem is going to take place. Following are the layout of the hydro-electrifier.

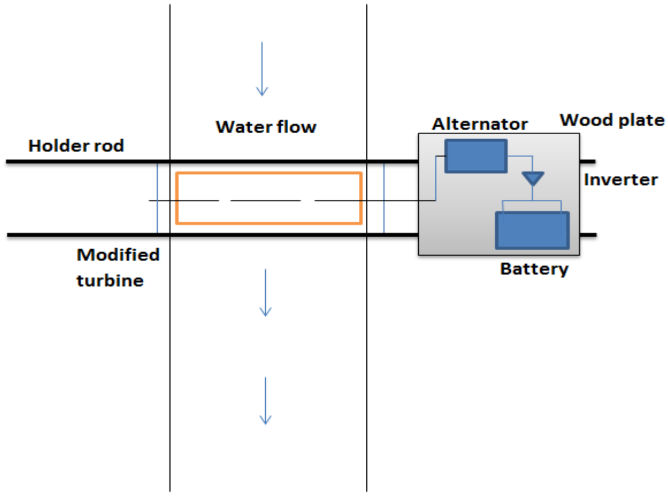


Figure 17: System layout

The layout is made after considering many factors. The holder rods are used to hold and elevate the level of the turbine. This is because the water level at the drain site is quite high during the raining season so to avoid the turbine from being submerge fully by the water, the holder rods is used. Since the landscape of the drain site is the "V" shape, these long rods that touch the wall of the drain make it lift above the drain surface as the rods cannot fit directly at the base of the drain surface due to the rods length exceeding the drain width.

The water turbine is placed on top of the rod. Now, only the blades of the turbine touch the water. A wood plate is places at the end of the turbine rotor so that other subsystem can be connected systematically. The wood plate is chosen because it will not react with the metal rod thus avoiding corrosion reaction from take places. Besides, wood plate is not a very good electricity conductor so if the alternator and other electrical component experiencing short circuit, the electricity will not be flowing freely.

At the wood plate, alternator is placed in the same orientation with the turbine rotor. These subsystems are connected by using belts. Pulley is placed at the turbine rotor so that the connection between the turbine and the alternator can be achieved. It is also being used so that the work from the turbine can be transfer to the alternator.

Since alternator producing AC current, an inverter is used to convert the AC current into DC current so that the electricity can be stored into the battery.

4.4 THEORETICAL ANALYSIS

Power – flow rate relationship

$P = \rho g Q H \eta$

Where,

P = power, kW

$\rho = density\ of\ water$, kg/m^3

Q = water flow rate, m^3/s

H = head of water in meter, m

Assume a constant of 0.5m water head with approximately 0.8 turbine-generator efficiency

$P = (9.81)(0.5)(0.8)Q$

$P = 3.924Q$

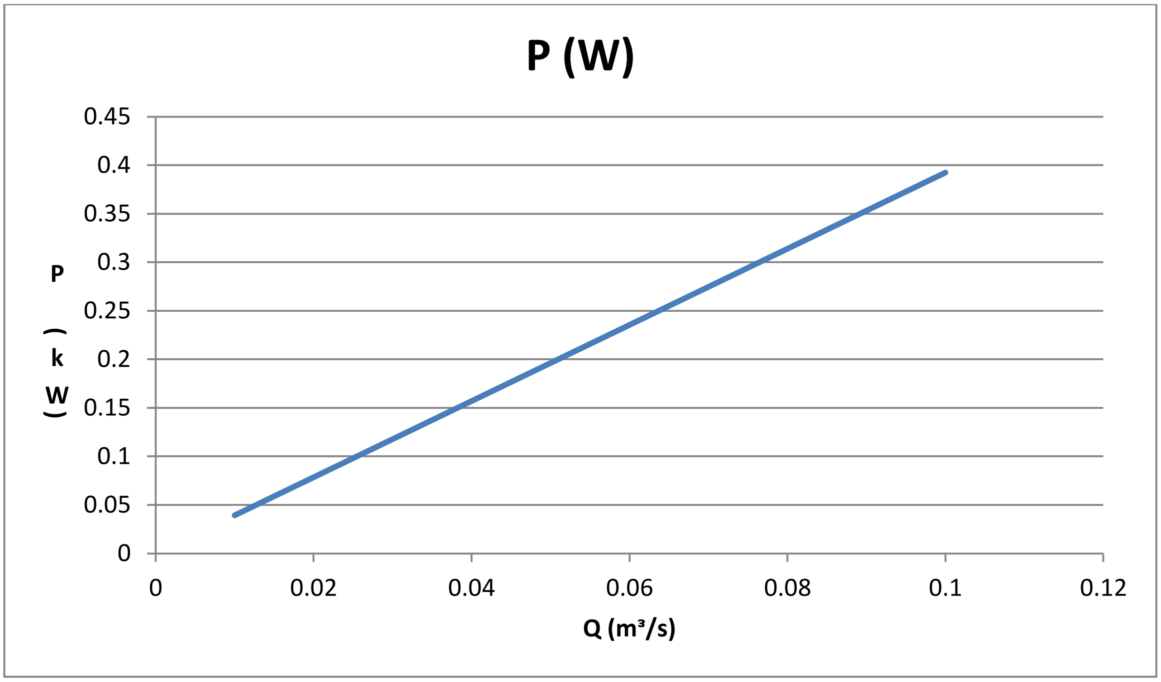


Figure 18: Power – Flow rate graph

CHAPTER 5
CONCLUSION

5.1 CONCLUSION

This project is successfully done and has meets it objective. The suitable power generation system is selected for integration with the modified turbine. The system used alternator as the generator and is connected to the modified turbine using pulley-belt system.

From the system layout, the system frame is works and the alignment and arrangement of the system is in a good manner. Holder rod is placed so that the system can be placed at the top of the water stream and with optimum contact with water. Without the holder rod, the turbine was immersed too deep thus causing the rotational of the turbine disrupted. It also causing the turbine mechanical works to be decreased as the turbine is not rotating smoothly as the result of external water on the blades.

At the ends of the holder rod, a plate is placed so that all the subsystem can be placed there systematically. The subsystem that is placed there includes alternator, inverter for AC/DC current conversion and battery. Battery is used to store generated electricity.

The system is placed in the suitable water stream located near solar research site and Block B in Universiti Teknologi PETRONAS. The stream supplied consistent water since the stream has a reservoir at the top of the stream. Besides the reservoir is a elevated ground which causing water that fall to that ground to flow into the lower ground, which is the reservoir. From the reservoir to the system, there is a different between the heights which means there is a water head. Since water head is a very important aspect for power generation, the site or stream is found to be a very good placed for power generation. The stream's flow rate is very fast as the result of having water head and high water volume during raining season. The flow rate of the water can be used to generate electricity. After the site implementation is done, testing shows that the power generation system is capable providing electricity for night lighting near solar research site.

5.2 RECOMMENDATION

Following are recommendation that can be used for the system to become better:

- The turbine-generator connector need to be tested with different connector so that the efficiency of turbine-generator connected can be increased thus the power output becomes bigger. There are many possible connector including gears and direct connection using coupling. This system should be tested with different connector to see what type of connector has the highest efficiency. The connector with the higher efficiency should be chosen as the best connector for power generation in this case.
- Increasing the water head can improve the power generated by the system so more elevated water stream need to be identified. The current site provides water head and suitable for power generation. But the water head provided is quite low which about 0.5m. Other site with higher water head need to be identified so that the power generated is higher. The site should have the height different at least 1m for the system to consider capable for supplying more power. With a high water head, the water flow rate will also increase. As the result, the power generated by the system is also increase.
- Induction generator is found to be the best generator to use. If we manage to increase the water head more than 1 meter, induction generator should be used instead. Induction generator has higher efficiency compare to car alternator so more power can be produced. It is also more stable and consistent compare to car alternator. But it require to be electrocute first in order for the generator to work so if the water head is low, the torque provided by the water is not enough to supply the sufficient mechanical work needed for the generator to produce electricity thus it is not a suitable choice to use for low water head stream.

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APPENDICES

APPENDIX 1: Turbine 1st testing

Figure A1: Testing turbine rotation at the site

APPENDIX 2: Turbine 2nd testing

Figure A2: Testing to implement turbine at the site