Development of Model System for Cost-Effective Pico-Hydro Turbine

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Abstract— **One of the main obstacles of rural electrification programme is to find an alternative energy to replace power generated by generator. The ever increasing fuel price and its cost of transportation to the remote location limited the availability of electricity to certain time of the day. Since the rural settlement usually located near water source, renewable energy based on hydro is suggested. This paper will discuss about the development of model system for cost-effective pico-hydro turbine. The size of the turbine will be based on low flow and low head application. Two types of turbine, propeller or also known as axial-flow and cross-flow, are evaluated under these conditions. Both of the turbines were installed in one model system equipped with storage tanks and piping system. Centrifugal pump is used to ensure the circulation of the water between main storage tank into the flowing tank simulating the run-of river application for pico hydro system. The head of the model system is fixed with variable parameter of water flow rate is controlled by using controller valve and flow meter for power data collection for each turbine. The performance of both turbines were also simulated and evaluated by using CFD's software. Techno-economics evaluations are done so that the model of the system will be able to select the optimum size of the turbine based on the flow rate for a cheap efficient and cost-effective hydro turbine.**

Keywords— **Pico hydro turbine, propeller, cross-flow, model system, cost effective.**

I. INTRODUCTION

Pico-hydro turbine is one of the alternative renewable energy to replace the existing power supply sources in the remote settlement. Most of the houses of off-grid areas are still using conventional generator which are generally costly to maintain and operate as their main power supply. Based on the scenario in our country, the price increased of fuel recently had major impact on the usage of the generator. To overcome this burden, other alternative solution must be considered in order to replace the usage of the existing generator. Since the rural settlements are located near to the water supply due for

the daily needs and activities, therefore, the implementation of pico-hydro turbine as one of the alternative way to replace the generator is the compatible choice. Furthermore, pico-hydro turbine has less installation set-up which no involvement of dam or reservoir. It also involve with less maintenance and replacement cost as well as environmental friendly for long-term application.

Hydro turbine can be classified into three categories such as high head, medium head, and low head turbines. The classification are based on the power output generate by the turbine as well as the value of head and flow rate of water. Pico-hydro turbine falls under low head categories with high flow rate of water and generate power output up to 5 kW. The pico-hydro turbine has been widely used in countries with high renewable energy resources such as water. Nepal and India are some of the examples countries which are still practicing this hydro concept for those people who live in remote locations. Some of the electrification programs contribute high benefits as well as improve the living conditions of the remote communities. For example, the development of electrification program such as RIDS-Nepal (Rural Integrated Development Service) project in Humla, Nepal, contributed a very huge impact to the target end users. Some of the evidence showed that the program has improved health conditions, increased the indoor cleanliness and personal hygiene as well as increased the social gathering among the communities [1].

This paper discuss about the development of test-rig for pico-hydro turbine. The model system consists of propeller turbine and cross-flow turbine in order to make a comparison of power output generate by both type of the turbines. A. A. Williams [2], has developed a test rig for pico pelton turbine where runners with different buckets shapes which were fabricated and produced by various countries such as Europe, South Asia, North and South America were tested in laboratory [3]. Test-rig of pico-hydro system by using house

water supply for residential use has been developed by H. Zainuddin [4]. Once again the project has focused on the pelton wheel of pico-hydro. A group of researchers from Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia (UKM) [5], has done an investigation about power output produced for low head and low flow rate of water. The head has been fixed with 1.5 m in height and the water flow rate was about 24 l/s. The head of the proposed test-rig is fixed at 2 m, while the water flow rate is varied by using a control-valve.

II. METHODOLOGY

The proposed test-rig consists of axial-flow turbine and cross-flow turbine. The axial-flow turbine is out-sourced while the cross-flow turbine is fabricated in-house. Figure 1 shows the proposed model system of the test rig.
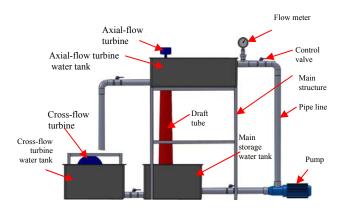

Fig. 1 Schematic diagram of test-rig

The model system of the test rig consists of few main componenets. The components are the main supporting structure, axial-flow turbine water tank, cross-flow water tank, main storage water tank, pump, pipeline system, pressure gauge, flow meter, control valves, electrical module and water level sensor. The water source is tapped from the domestic water supply.

A. Main Supporting Structure

Main supporting structure plays very important role in order to support the load of the axial-flow turbine water tank which is located on top of the main structure itself. The structure must be durable enough to be able to support the tank together with propeller turbine and water. A structure analysis has been done by COSMOS, and the result shows that hollow bar mild-steel 3" x 3" is the optimum requirement to build a safe supporting structure for this particular purposes.

B. Axial-flow Turbine Water Tank

This tank is one of the main three tanks. It is located 2 m in height from the ground. The tank is made from mild steel with 1 mm thickness and it is fabricated in house due to there is no standard size in the market to purchase. This tank will be filled with water and the propeller turbine together with its chamber will locate at a proper location inside this tank. This

particular tank will only be used when the experiments on the axial-flow turbine is carried out.

C. Cross-flow turbine water tank

The tank is located on the ground beside the main storage water tank whereby both of these tanks will be linked to each other using PVC pipe. The cross-flow turbine will be placed in this tank at a particular position. This tank will only be used when the experiments on the cross-flow turbine is carried out. Unlike propeller turbine water tank, this type of tank is a standard tank which is available in the market.

D. Main storage water tank

This tank is located exactly at the bottom of the propeller turbine water tank. It is a main tank to supply water which circulating through the tanks during experiments. There should be enough water supplies and no disturbance of water flow occurs during the experiments in order to get the best of data collection.

E. Pump

The main function of centrifugal pump is to transmit the water through the pipeline from main storage water tank into propeller turbine water tank. The pump will ensure the continuous circulation of water so that there will be enough water provided during the experiments.

F. Pipeline System

The only purpose of having the pipeline system is to channel the water from each tanks involved especially during the experiments. In this case, the PVC piping line will be used because it is cheap and less maintenance required.

G. Pressure gauge

Pressure gauge will be installed to determine the difference of pressure occurs between atmospheric and water pressure inside the pipelines.

H. Flow Meter

Since the variable parameter for the experiment is flow rate of the water, therefore it is necessary to have this equipment installed in the model system. This equipment will provide the variation of the water flow rate for the experiments. Basically, a flow meter is an instrument used to measure linear, nonlinear, mass or volumetric flow rate of a liquid or gas.

I. Control Valves

The variable parameter in this research is water flow rate. Therefore, in order to control the water flow rate, control valves is used.

J. Methodology/Process Flow of the Model System/'Test-Rig'

Once when the model system of the test-rig is ready, the related experiments can be implemented. The first experiment involves propeller turbine. In this experiment, two valves which are connected to the cross-flow turbine water tank are closed to avoid water from enter into this tank. Water will be supplied to fill the main storage water tank. Once the tank is

full, the pump will start operating by transmitting the water from the main storage water tank into the top tank which is known as axial-flow turbine water tank. Before entering this tank, a flow meter will indicate the value of the water flow rate. The amount of water flow rate can be controlled by using control valves which is located before the flow meter on the pipelines. The flow which is in laminar form will enter the water chamber and guide the water to the guide vanes inlet and next to the runners. The water will exit from runners and pass through the draft tube before filled back into the main storage water tank to have a complete cycle of water flow. The cycles will keep repeated until the experiments are completely done and all the data has been collected.

The second experiment involves the cross-flow turbine. All valves should be in the open position to allow the water flows through the related channels. Besides that the axial-flow turbine will be removed from the system, and the draft tube's hole are also will be covered. The steps of the first experiment will be repeated, but this time the water from top tank (axial-flow turbine water tank) will straight away be channeled into the cross-flow turbine water tank in order to turn the blades of the cross-flow turbine. Figure 2 and Figure 3 shows the schematic diagram of water flows (arrow with yellow colour) during both of the experiments.
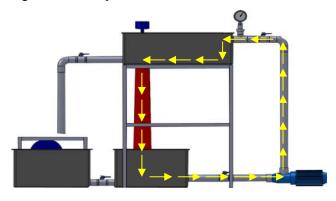

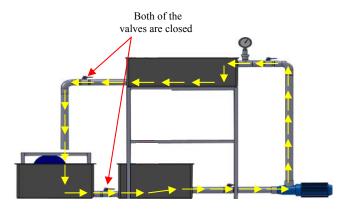Fig. 2 Direction of water flows for experiment 1

Fig. 3 Direction of water flows for experiment 2

K. Power output generate by the turbines

In order to derive the power output produced by the turbines, a general calculation can be used to compare with the data from the experiments. In this situation, to calculate the power, head and flow rate of the water of the stream or river should be considered.

$$\text{Power} = \text{Head } (H) \times \text{Flow rate } (Q) \times \text{Gravity } (g) \qquad (1)$$

Where: Power is measure in watts, head in meters, flow rate is a water flow rate measure in l/s, and gravity value which is 9.81 m/s.

In this case, flow rate can be determined by using the equation:

$$Q = AV \qquad (2)$$

Where: $A = (\pi/4)(D)^2$; D = diameter of pipe

It is expected that, the efficiency is around 60% of the hydraulic energy of water flows is converted into mechanical energy to spin the shaft to generate the generator. On the other hand, another 40% is lost. Assumptions can be made that, the 40% lost of energy is due to converting from mechanical energy to electrical energy.

III. RESULTS

At the initial stage, analysis will be conducted using CFD simulation software in order to find out the flow velocity, V, of the water. Later, the comparison between the two types of turbines will be evaluated based on the power output produced. The water mass flow rates have been set to identify the amount of power output produced by both of the turbines. Low water flow rate means the rate of water flow is less than 50 l/s. Since the study involved with low water flow rate, the values will be used for the experiments are 30 l/s, 40 l/s, and 50 l/s. The experiments will start with 30 kgm/s, because based from the results which have been done by a group of researchers from SERI, UKM, with 24 l/s of flow rate, the result indicated that very little power output produced by the axial-flow turbine which can be neglected [4]. Therefore based from their results, it is concluded that, the flow rate which is below than 30 l/s will give no significant to the results. In these experiments, the height of the head is fixed with 2 m.

The analysis for axial flow turbine has been conducted by using ANSYS simulation software. The existing blade of axial-flow turbine with angle 41^0 and diameter from tip to tip blade is 162mm is used as shown in Figure 4, 5, and 6. Based from the analysis results, the flow velocity, V, for each value of mass flow rate and the power output produced are given in the Table 1.

Analysis is also simulated for cross-flow turbine. As for axial-flow turbine, the mass flow rate has been set to 30 l/s, 40 l/s and 50 l/s. Figure 7, 8 and 9 shown the analysis results of the flow velocity, V, of the cross flow turbine.
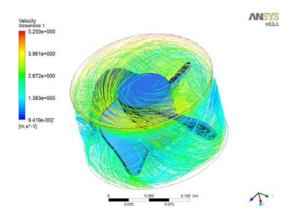
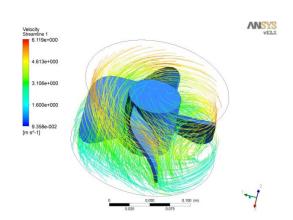Fig. 4 CFD data for mass flow rate of 50 l/s under axial-flow turbine

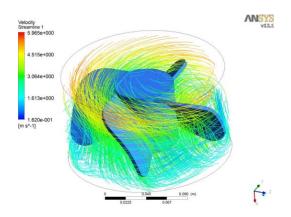Fig. 5 CFD data for mass flow rate of 40 l/s under axial-flow turbine

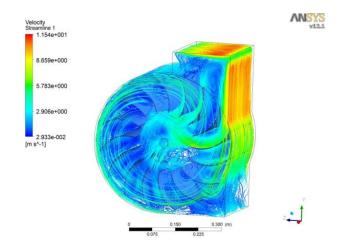Fig. 6 CFD data for mass flow rate of 30 l/s under axial-flow turbine

Fig. 7 CFD data analysis for mass flow rate of 30 l/s under cross-flow turbine
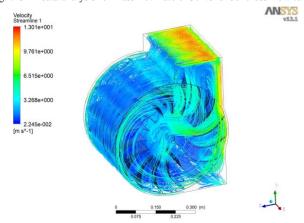

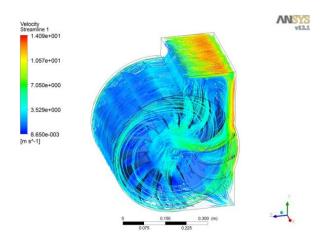Fig. 8 CFD data analysis for mass flow rate of 40 l/s under cross-flow turbine

Fig. 9 CFD data analysis for mass flow rate of 50 l/s under cross-flow turbine

From all the CFD data which shown from Figure 4 to Figure 9, the values of flow velocity, *V*, can be determined. Therefore, by substitute these values in the equation (1) and (2), the power output can be estimated. Table 1 indicated the estimated power output produced by both of the turbines under certain values of mass flow rate.

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TABLE I
MAXIMUM FLOW VELOCITY AND POWER OUTPUT OF
VARIABLE FLOW RATE

	Flow rate (l/s)		
For Axial-flow Turbine	30	40	50
Maximum flow velocity (m/s)	5.965	6.119	5.25
Power output (watt)	725.94	745.56	627.84
For Cross-flow Turbine			
Maximum flow velocity (m/s)	11.54	13.01	14.09
Power output (watt)	1412.64	1589.22	1706.94

From the data analysis which was obtained by using CFD simulation software, it can be simplified by translating it into the form of a graph. Figure 10 shows the power output produced during the analysis for both types of turbines based on 2m head with variable water flow rate.
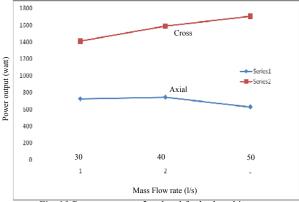

Fig. 10 Power output at 2 m head for both turbines

From Figure 10, clearly shows that even though the water flow rate is low, with a height of 2m, the system is still capable to produce power output as required.

IV. CONCLUSION

Based from the analysis results, conclusion can be made that the power output produced by the cross-flow turbine was much higher (about 50%) if compared to axial-flow turbine for the same values of mass flow rate. However, the results are just based on the simulation analysis which has been done by implementing the ANSYS software. In this study, the implementation of simulation analysis software such as ANSYS can contribute rough idea how the flow of water can be simulated flowing from the inlet, then through the space between the blades and the exit. Once when the model system of the test rig is ready to be used, therefore the field experiments are necessary in order to compare the power output results.

REFERENCES

[1]   Zahnd, A., Kimber, H. M., *Benefits from a renewable energy village electrification system*, Renewable Energy, Vol. 34, 2009, pp. 362-368.
[2]   A.A. William, R. Simpson, *Pico-hydro – Reducing Technical risks for rural electrification*, Renewable Energy, Vol. 34, 2009, pp. 1986-1991.
[3]   Baines J., William A.A., *A test rig for pico hydro Pelton turbines*. Pico Hydro, issue 1. UK: Nottingham Trent University; Oct 1997.
[4]   H. Zainuddin, M.S. Yahaya, J.M. Lazi, M.F.M. Basar, Z. Ibrahim, *Design and Development of Pico-hydro Generation System for Energy Storage Using Consuming Water Distributed to Houses*, Proceeding of World Academy of Science, Engineering and Technology, pp. 154-159.
[5]   Kamaruzzaman Sopian, Juhari Ab. Razak, *Pico Hydro: Clean Power From Small Streams*. Proceedings of the 3rd WSEAS Int. Conf on Renewable Energy, 2009, pp. 414-419.