Effect of Blade Inclination Angle on the Efficiency of Hydrokinetic Turbine in an Undershoot Zero Head System

Ibrahim Abubakar Masud and Yoshihide Suwa

***Abstract*—Hydro kinetic water wheel turbines are known to be conventional systems for energy harvesting in rural communities around the globe. Different turbine systems have been analyzed to produce promising energy with a head difference ranging from 1-100's of meters but little has been done to come up with a zero head system for energy harvest mainly due to the fact that their efficiencies have not being studied well and optimized. The concept of this research concentrates on the angle of inclination of this turbine with respect to the water flow in an undershoot zero head system. In this research, series of experiments were conducted on 3 different turbines with equal width and diameter of 220(mm) each. Angle of inclination of this turbines varies in to 30°, 60° and 90° with respect to the water flow. Performance of these turbines is studied and the output power, torque, and efficiencies are compared to ascertain the best in such condition. Each turbine was designed using a plastic plate of 2(mm) thickness. Potential of this type of turbine is displayed to be used in a zero head flow to harness the loss energy of free flowing waters in irrigation canals and water streams.**

***Index Terms*—Turbine, water wheel, zero head, undershoot.**

I. Introduction

Hydropower offers a merit over fossil fuels because it uses water as a renewable source of energy and its continuous energy supply while still serving as base power. However, most of this micro and small hydro sites are unexplored [1]. Water is a clean source of energy and does not release any pollution into the air. Hydrokinetic technology has the potential to generate a great amount of electricity for us with a minimum impact to the environment; hydrokinetic power resource evaluation has been done across the globe but little effort is being put to ascertain a zero head system of energy harvest. Around the world, there are many renewable energy sources such as small hydropower in micro or pico form but a zero head potential of this source has not being fully harnessed. Small hydropower projects have low impact levels an easy to implement, prevent, modify and rely on local manufacturing technology which can promote the knowledge of hydropower domestically [2].

Small hydropower (SHP) with low head differences have not been exploited due to their negative effects on the ecology and that conventional turbines are not really economical. Stream wheels have not been on production for more than 80years possibly because of low efficiency which caused demotivation in exploring the knowledge of stream wheels [3]. Currently, stream wheels could be of interest as energy converters for fast surface flows in large rivers or tidal currents.

Hydrokinetic water wheels have a very good advantage over other conventional turbines as they require no civil structure, require low installation cost and are designed to have harmless effect to the aquatic flora and fauna. Hydrokinetic technology has the potential to generate a great amount of electricity with minimum impact to the environment. This emerging kind of renewable energy source are considered unique as they are converters made without changing natural pathway of the water stream [4].

Research in this field regarding the impact of design parameters in a low head axial flow turbines like blade height, blade profiles, and number of blades for micro-hydro application continue to be deficient, although there is a need and potential for such type of turbines application [5].

This particular turbine is meant to be used in irrigation canals especially during farming process, where the water has velocity to be converted into useful energy by this proposed open type system [6]. Due to such need, the number of researchers in designing suitable turbine for this applications has increased and much of their work has focused on designing and developing turbines with various patterns in order to catch more energy and generate maximum electricity [7]. The idea of this experiment entails the flow of water around a model pool driven by a pump and harnessed by a turbine in a zero head manner where the kinetic energy of water flow is converted into useful energy as illustrated in Fig. 1 below.

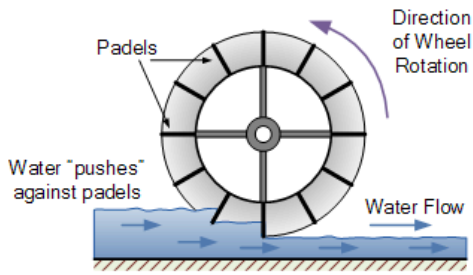

Fig. 1. Undershoot water turbine concept.
Source: http://www.alternative-energy-tutorials.com/hydro

II. Equipment and Methodology

A. Turbine Design

In this research, 3-type of turbines were designed with difference in angle of blade inclination at 30°, 60° and 90° with respect to the water flow in the experimental model pool. The turbines were designed using a 2(mm) thickness plastic plate. The actual diameter and width of the turbines are 0.22(m) × 0.22(m). Each turbine has 12-numer of blades having a blade depth of 0.037(m) as shown in Fig. 2A, 2B

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and 2C. All the dimensions were determined at one full rotation of the turbine. This is when the best turbine torque and efficiency are possible [4].

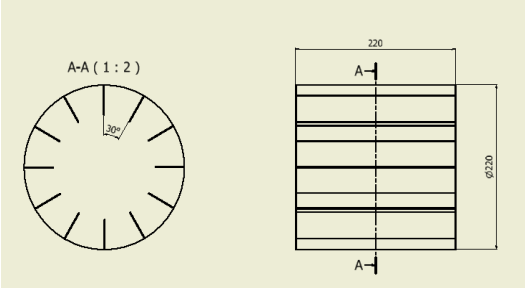

Fig. 2A. 90° inclination turbine layout.

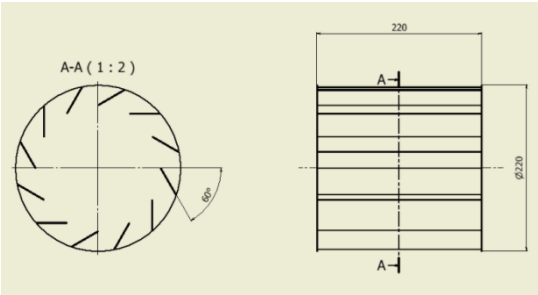

Fig. 2B. 60° inclination turbine layout.

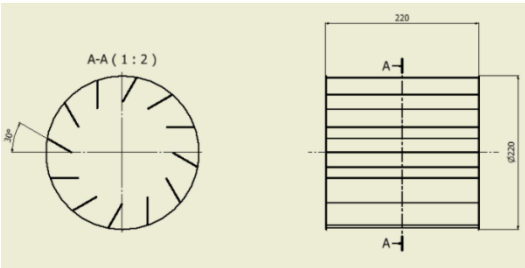

Fig. 2C. 30° inclination turbine layout.

B. Water Pool

Fig. 3 illustrates the concept of the experiment which is achieved by fabricating an experimental model water pool to harness the kinetic energy of the water flow in the laboratory. The pool is 0.6(m) width, 0.6(m) depth and 1.8(m) length. The turbine is fixed at one side of the model and pump at the opposite side. The water circulation was fulfilled by fixing a curve using a flexible plastic plate at both ends of the model. A relatively stable laminar flow was achieved by designing a throat at the point of water inlet to the turbine. These eliminates the negative effect of vortex and maximizes energy harvest by allowing almost all the targeted water to pass through the turbine.

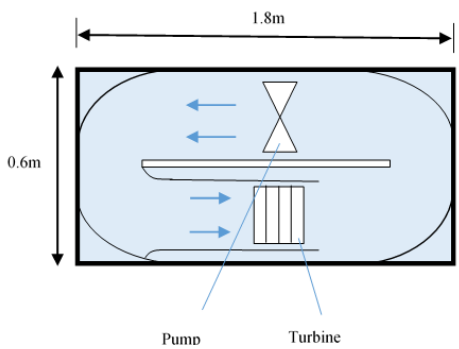

Fig. 3. Model pool.

C. Water Pump

To achieve the continuous flow of water in the system, a fixed waterproof 300W dual speed underwater propeller diving pool scooter model BM1207 was used. The pump is controlled using 4- number AD-8724D model power supplies to match the power rating. The pump is able to control the water flow of 0.4(m/s) at 10.0(v) and 0.6(m/s) at 12.2(v). The difference in this velocities is quite small as such 0.6(m/s) velocity was adopted for this experiment as shown in Fig. 4.

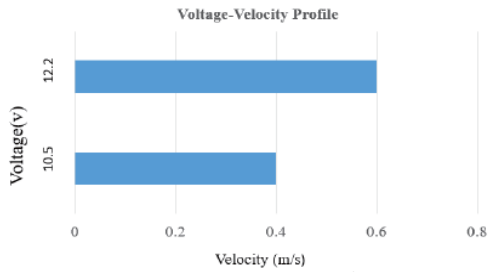

Fig. 4. Voltage-velocity profile.

D. Arduino rpm Sensor

Data acquisition in this experiment is tapped using a programmed arduino rpm sensor which serve as an optical tachometer. The logic entails the action of rotation of the turbine attached to a hub having 4-bades that passes through the arduino at equal interval. The performance of the turbine is recorded directly in the database which is established in form of time and rational speed recorded at each point.

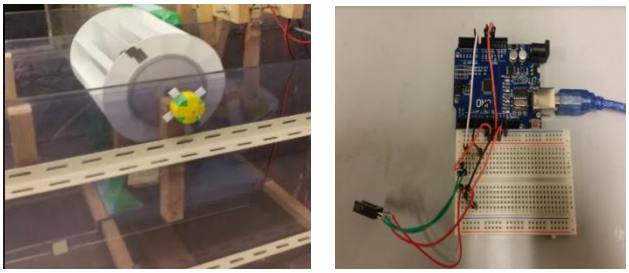

Fig. 5. Turbine with Hub and Arduino rpm sensor.

III. Experiment

A. Energy Conversion Technique

Kinetic energy of the flowing water in the pool is converted by the turbine using this technique. The model setup does not allow us to use a generator to measure the energy but rather we used the principles of applied mechanics to add load to the system via a pulley mechanism. The turbine is attached to a winding mechanism and load added directly to the system via it. This resulted in an established value of the torque, and power.

From the above adopted principle, the following 3 equations were used to calculate the parameters involved.

$$\text{Power output } Pt = T\omega \tag{1}$$

$$P_t = \frac{1}{2}\text{rmg} \times \frac{2\pi n}{60} \times 10^{-3} \tag{2}$$

$$\text{Pinput} = ½\,\rho A V^3 \tag{3}$$

where Pt is the turbine output power, Pin turbine input power, T turbine torque, ω is the angular velocity, r is the turbine

radius, m mass load, g acceleration due to gravity, n is the rotational velocity (rpm), ρ is density of water 1000kg/m^3 and V is the water velocity (0.6m/s).

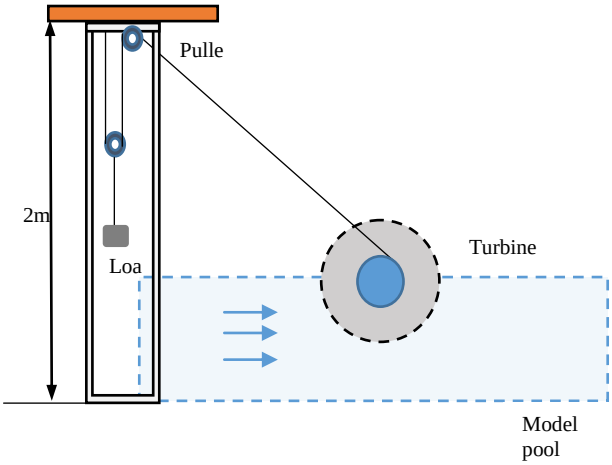

Fig. 6. Schematic load input model.

B. Data Acquisition

The velocity of water in the system was measured using a flow meter which is inserted at the throat close to the turbine water inlet at a value of 0.6(m/s) average.

The experiment was divided into two. The first experiment is to establish the blade performance and the second experiment was conducted to come up with the turbine efficiency and torque. At first, water level was kept at maximum height of the blade to harness maximum kinetic energy of the flowing water. As the turbine was inserted, water was made to flow at the established velocity and the arduino sensor with hub were set where the turbine performance was ascertained by recording the average value of the rotational speed and time as seen in Fig. 7.

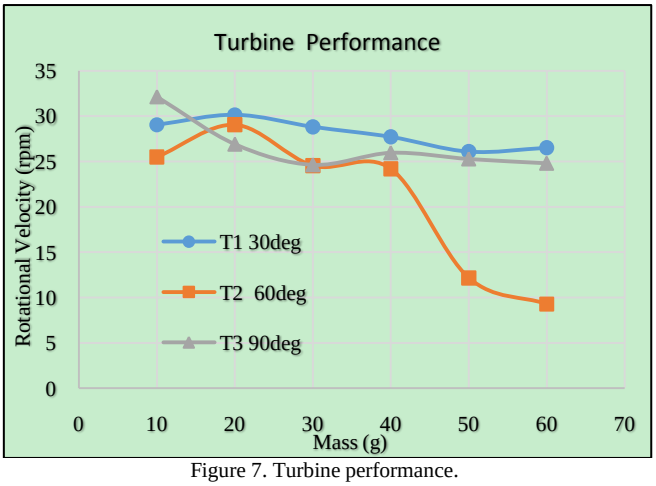

Figure 7. Turbine performance.

Second part of the experiment involves, adding load to the system using the pulley mechanism from 10g minimum load, and increasing the load up till maximum load to a point where the turbine was not able to rotate.

IV. Results and Discussion

From the above, all the 3 types of turbines were set to undergo this two experimental process and the graphs below were established. Fig. 7 defines the turbine performance of the 3- turbines. The graphs show the rotational velocity (rpm) vs the load(g). We observed that, the 30-degrees inclination turbine has a very high performance tendency with an average rotational velocity of about 28(rpm) compared to 90-degree inclination which is relatively stable at about 23(rpm). The 60-degree inclination turbine has a rough tendency displaying instability at a mass of about 40g which shows that the turbine angle of inclination could not resist and convert the onward tide of water current at the established speed of 0.6(m/s).

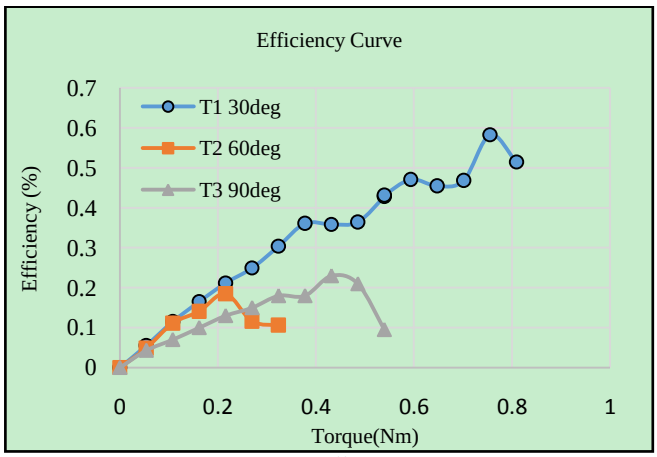

Fig. 8. Turbine efficiency curves.

TABLE I: Summary

Parameter	Turbine Blade Inclination Angle		
	30°	60°	90°
Average Flow Velocity (m/s)	0.6m/s	0.6m/s	0.6m/s
Maximum Torque (Nm)	0.8	0.35	0.55
Average Rotational velocity (rpm)	28	19	23
Efficicrncy (%)	58	19	27
Maximum Power (W)	1.83	0.58	0.74

Fig. 8 illustrates the turbine conversion efficiency (%) vs the torque (Nm). Comparatively, it can be observed that the efficiencies vary with respect to the angle of inclination. 30-degress inclination turbine has a convincing result displaying a high efficiency of 58% at 0.78(Nm) torque. 90-degree inclination turbine has a maximum efficiency of 27% at 0.48(Nm) torque. We observed that that the 60-degree inclination turbine has the least efficiency of about 19% showing less conversion efficiency tendency for a zero head undershoot system. The variations were observed due to difference in angle of blade inclination.

V. Conclusion

In the experiment, 3- prototypes with different angle of inclination were designed in an undershoot zero head system. The result of the systems shows that the turbines displayed a viable behavior for harnessing energy in such system. But conversion efficiencies vary as it directly depends on the blade angle of inclination. Under the same condition of velocity and design parameters, an inclination angle of 30-degress performs higher than 60degreess and 90degress. This is due to the fact that the blade harness energy as well as accommodate and convert the onward force of tide in such

condition conveniently than the other two type of turbines.

It can be concluded that zero head hydrokinetic turbines efficiency of conversion depends directly on the blade inclination angle under normal flow conditions. The ability of the turbine to assimilate the water force and convert it to useful energy effectively.

Future plan of these researches will focus on improving the efficiency and trying a better blade angle for utilizing such potential. More robust analysis of this zero head systems would be carried out using a computational fluid dynamics analysis to establish a tentative data that can be used for the real design and analysis of such type of turbines.

Final result of the experiment would be used to design a suitable system for energy harvesting in rural areas especially in African sub- Saharan countries where energy is insufficient and there is abundance of flowing river waters.

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REFERENCES

[1] N. P. Jade, S. S. Raut, and G. A. Wadnere, "Performance analysis of parameters related to low head hydro turbines and their effect on efficiency turbines," *International Journal of Emerging Technologies, Management and Aplied Sciences*, vol. 3 issue 4, pp. 30-36, April 2015.

[2] S. Phitaksurachai, P.-A. Rudklao, N. Sritrakul, and Y. Tiaple, "Performance Testing of Low Head Small Hydro Power Development in Thailand," *Energy Procedia 138*, pp. 1140-1146, May 2017.

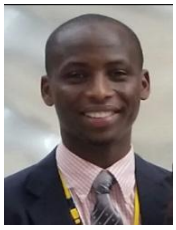
[3] G. Muller, S. Denchfield, R. Marth, B. Shelmerdine, "Stream wheels for Application in Shallow and Deep water," in *Proc. 32nd IAHR Conference 2007*, Jul. 2007.

[4] V. N. Garg and T. S. Rajput, "Efficiency improvement techniques of hydrokinetic turbines a review," *International Journal of Emerging Technology and Advance Engineering*, issue 6, pp. 144-151, June 2015.

[5] A. Arslan, R. Khalid, Z. Hasan, and I. Manarvi, "Design and manufacture of a micro zero head turbine for power generation," *International Journal of Multidisplinary Science and Engineering*, vol. 2, no. 7, October 2011.

[6] G. Nangere, "Power generation by using open type low head turbine," *International Journal of Science and Technology Research*, vol. 3, issue 10, October 2014.

[7] W. Minatrakul and R. Sunutivarakorn, "Effect of blade angle on turbine efficiency of a spiral horizantal axis hydro turbine," *Energy Procedia 138*, pp. 811-816, May 2017.



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