Performance prediction of zero head turbine at different water levels

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Abstract. Hydropower technology has been focusing on conventional water turbines with performance and efficiency depending on water head without really paying much attention to the energy in flowing waters. Such energy can be harnessed by integrating zero head turbines in possibly undershoot system. The turbines are modelled to be alternative systems in renewable energy. In this research, performance of this turbines in form of a conventional water wheel is studied using both programming prediction and experimental methods. Various type of turbines was designed by altering the blade inclination angle and testing the performance at 4- water levels. The maximum and minimum efficiencies were predicted in this study at this water levels. Based on the result, the viability of this turbines are positive and can be used to harness loss potential of flowing waters in canals and rivers which can be easily installed.

1. Introduction

Hydrokinetic zero head turbines share the same mode of operation with wind turbines, and the design principles are quite similar. Both wind and hydrokinetic turbines are renewable energy sustainable systems gathering attention from researchers across the globe. [1]. Scientists have developed much interest on this type of turbines recently because it allows the use of small low-head hydro resources thereby avoiding some of the environmental, social, and economic problems associated with development of earth dams. Hydrokinetic is an alternative and a cheaper solution to remote and off-grid areas having nearby flowing streams of water [2]. Flowing water streams with little or zero head can be found in rural communities. Installation of the typical hydroelectric system is not viable in such river or water flow [3]. Developing nations can use this technique to provide electricity to remote places where transmission line cannot be connected easily or the cost becomes very high [4]. Micro hydro as a form of small hydropower is one of the most economical and environmentally friendly renewable energy technologies to be considered for powering rural communities [5]. It is often classified by the power generation potential based on head of water and discharge of water flow. A typical micro hydropower needs a substantial amount of water to be diverted from the stream/river and brought to the turbines power house without compromising the elevation which is the head. A typical micro-hydro is characterized to have high initial project capital cost and very low running costs over time [6]. In Hydrokinetic system, the turbine is placed in the water stream and flowing water enables the turbine to rotate producing electricity [7]. Hydrokinetic zero head turbine system is a new category
of hydropower energy that generates electricity by extracting kinetic energy of flowing water instead of potential energy of falling. It generates electricity without dam’s storage thereby saving costs [8]. In a flowing stream, th turbines go one step further. This type of turbine has an upper hand by simply utilizing the energy in the velocity of the water in the stream [9]. Energy can be extracted from the river currents by using submerged hydrokinetic turbines, capturing energy through the processes of hydrodynamic, rather than aerodynamic, lift or drag [10]. However, the dimerit of using typical small-scale hydropower is that, in most cases it is obtained from run-of-river plants that lack storage [11]. In all this research conducted by scientists, there is no any attempt to study and optimise these type of turbine performance with respect to water levels. Our reasearch has focused on this issue which predicts the suitable water level for best performance using modelling, experimetal and simulatiion methodologies.

2. Modelling  
A model was designed to study the behaviour of this turbine. In this model, a method for calculating the torque was adopted by critically studying the geometric shape. First of all, it was assumed that the water energy is completely harnessed by the upstream blades thereby shielding the downstream blades. Now suppose the flow is uniform and the blades are rotating at regular intervals. By calculating the uniform flow velocity, it seems likely that the tendency will be obtained depending on the area and angle of the blades during rotation when looking at the turbine from the upstream side. As such we have an idea of the acting force on the blades.

2.1. Modelling calculation  
The force applied perpendicularly on each blade is given by equation (1) below

\[ F = \frac{1}{2} \rho (v \sin \alpha)^2 \times A \]  

(1)

Since there are multiple blades during rotation, the force received by the front blade is not received by the blade at the back. Since only the one whose projected area of the blade is obtained as seen from the upstream side contributes to torque, we assume the behaviour in Fig. 1 which describes the cross-sectional view of the turbine model with the direction of the flow velocity coming from the left side.

![Figure 1. Turbine Cross-sectional View.](image)

3. Experiments  
In order to create a continuous flow of water around the system for the experiment, a water pool of depth 600[mm], width 600[mm] and length 1800[mm] was developed. Flow of water is influenced by a fixed waterproof 300[W] dual propeller diving pool scooter pump model BM1207 and diverted by a design curve in the pool. The turbine is located in the convergent throat of the pool at opposite side to the pump allowing it to harness energy from the relatively stable flow of water thereby rotating the turbine using free kinetic energy. The turbine 220[mm] x 220[mm] has 8 number of blades and was designed using a 1[mm]thickness plastic plate. Water level was kept at different height of the turbine blade to study the condition at different water levels.

The data targeted for this experiment is the angular velocity, time and power potential of the system. Angular velocity and time were determined using an Arduino sensor. The experiment was conducted...
at 0.6m/s flow velocity determined by controlling the pump using a voltage regulator. The pump was regulated at maximum voltage of 12.2 [V]. The velocity of the system that corresponds to the voltages is 0.6[m/s] as earlier stated. The value of the output power of the turbine was determined using the principles of applied mechanics. The concept entails adding mass loads to the turbine by transferring it through a rope pulley system until the maximum power was determined at the point of no-rotation of the system turbine. The rotational speed n [rpm] and time [T] at that time were measured. The power is determined using the below expressions.

\[ P_t = T \times W \] \hspace{1cm} (2)

\[ P_{in} = \frac{1}{2} \rho A V^3 \] \hspace{1cm} (3)

Equation (2) defines the output power of the rotating turbine (Pt) and equation (2) defines the input water flow kinetic energy of the system (Pin). The efficiency of the system is determined using the two equations.

3.1 Nomenclature

\( \rho \) = Density of water (kg/m\(^3\))
\( u \) = flow velocity (m/s)
\( A \) = cross sectional area of the blade (m\(^2\))
\( \alpha \) = angle of the blade relative to the flow (°)
\( r \) = Turbine radius (m)
\( T \) = average torque (Nm)
\( W \) = angular velocity in (rpm),
\( V \) = Average Water mode flow velocity (m/s)

4. Simulations

The research simulation was carried out to compare the laboratory experiments results. The average velocity of flow is 0.6m/s around the model. 7- type of turbines with same parameters but different inclination angles were simulated at 4 water levels. The water levels are at 1/4 the turbine radius (0.25r), half the turbine radius (0.5r), 3/4 the turbine radius (0.75r) and equal the radius (h=r). The blades inclinations are at -45°, -30°, -15°, 0°, 60°, 45°, 30°, and 15° with respect to the vertical turbine plane. Fig. 2a & 2b are the simulation of the turbine when inclined at 0° while Fig. 3a & 3b are the simulation of the turbine when inclined at -30°. The simulation was used to determine the pressure impact on the turbine blades and velocity component around the areas of the blades at four water levels on each turbine. As shown in Figure 2 and 3 above. The above results are at water level (h) equal to 0.75 the turbine radius (h=0.75r). Based on the simulation results, the turbines flow velocity was found to be different at all water levels for each type of turbines, henceforth, we have a brighter idea on the reason the disparity between the modelling and experimental approach results. The turbines pressure impact is different for each turbine and the value of pressure depends on the angle of blade inclination and water levels . whereas the vector components was studied at static rotational velocity, the pattern for each turbine varies due to the shape and positioning.
5. Results

Fig. 4 and 5 describe the result of the research. Fig.4 illustrates the comparison between the theoretical and experimental values at 0.75r. We can see that the pattern of performance is fairly symmetrical even though there is a little disparity. The result is equal when the turbine is inclined at -60°. In Fig. 5, various turbine performance are described at different water levels. From the results the turbine inclined at -15° showed a high performance at all levels and is opposite for turbine inclined at 60°.
6. Conclusion

The prototype is designed and we carried out modelling, experiments and simulations for prediction of the performance of the hydrokinetic zero head turbine. The result of the system shows that the turbine displayed a positive performance in harnessing energy in a zero head condition. Water level and blade inclination angle contributes to the efficiency of such type of turbines.

Future plan of these research will focus on improving the efficiency by carrying out a flow visualisation experiment to study the disparity between the theoretical and experimental results even though the pattern seems the same. In conclusion, this turbine has displayed a viable performance and can be used to harness loss potentials in flowing waters.

7. References

[1] M.M. Nunes, R.C.F. Mendes, T. F. Oliveira, and A.C.P. Junior, ‘‘An Experimental Study on the Diffuser-Enhanced Propeller Hydrokinetic Turbines’’, Renewable energy, 133 PP. 840-848 (2019)

[2] G.Saini and R.P.Saini, “A numerical Analysis to Study the Effect of Radius Ratio and Attachment Angle on Hybrid Hydrokinetic Turbine Performance” Energy for Sustainable Development. Volume 47, December, Pages 94-106, (2018)

[3] R.P.Saini, “Performance analysis of a Savonius hydrokinetic turbine having twisted blades”, Renewable Energy, Volume 108, August, Pages 502-522, 2017

[4] M. Tanbhir, U. Nawshad, M. N. Islam, IbneaSina, M. K. Syfullah, and R. Rahman, ‘‘Micro Hydro Power: Promising Solution for Off-grid Renewable Energy Source’’, International Journal of Scientific & Engineering Research, Volume 2, Issue 12, December-2011

[5] Paish O. Small hydro power: technology and current status. Renewable and Sustainable Energy Reviews 2002;6(6):537–56

[6] Ashok S. Optimised model for community-based hybrid energy system. Renewable Energy 2007; 32(7):1155–64.

[7] Tanbhir Hoq, Nawshad UA, Islam N, Sina Ibnea, Syfullah K, Raiyan Rahman. Micro hydro power: promising solution for off-grid renewable energy source. International Journal of Scientific & Engineering Research 2011;2(12).

[8] Herman J. V, Kanzumba K n , Sandile P. K. Status of micro-hydrokinetic river technology in rural applications: A review of literature. Renewable and Sustainable Energy Reviews 29 (2014) 625–633

[9] Vince G, Clayton B. Development and Application of a Water Current Turbine, www.newenergycorp.ca/LinkClick.aspx?fileticket=5%2BtQK3cID%2FY%3D&tabid=84&mid =471; 2010.

[10] Mukrimin S G, Evaluation and measures to increase performance coefficient of hydrokinetic turbines, Renewable and Sustainable Energy Reviews 15 (2011) 3669–3675.

[11] M.J. Khan, G. Bhuyan, M.T. Iqbal, J.E. Quaicoe, Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review, Applied Energy 86 (2009) 1823–1835.

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