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Parametric Study of a Flapping blade Hydrokinetic Turbine to harness Renewable energy for Small Communities

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Abstract

1. Introduction

With more than half the global population living closer to 3 km to surface freshwater (Kummu et al., 2011), shallow water bodies such as rivers, canals and estuaries can be a promising source of sustainable energy for local communities. While most contemporary research focused on tidal currents and lift-based axial flow turbines (Laws and Epps, 2016), studies still lack the appropriate technology to harness renewable energy from these resources. Environmental issues and lack of appropriate hydrokinetic turbines to run efficiently at a lower velocity (≤1 m/s) are some challenges for their utilisation. A vertical axis, drag-based turbine (Diameter =0.42m and Height = 0.25m) has been designed and studied for its optimum performance to extract energy from these underutilised flow cases. A parametric study of a modified hydrokinetic Savonius prototype (named CarBine) with multiple flapping blades for seven different models (T1 to T7) is conducted in a hydraulic flume at Cardiff University. The turbine design is altered by varying blade numbers and solidity ratios, where the power coefficient (C_p) measurs their performance to inform the optimum design configuration by blade numbers.

2. Methodology

A bi-directional hydraulic flume driven by an axial flow impeller was used for all the experimental testing of seven model turbines with simple geometry and low-cost flat plate stainless steel blades. The 17 m long flow re-circulating rectangular channel with a cross sectional dimension of 1.2 m wide and 1 m deep provided room to accommodate the model turbine and its mechanical disk brake type power take-off instrumentation. The flow depth at the test flume was set to 500 mm for all turbine models. An acoustic doppler velocimeter (ADV) by Nortek was used to measure the freestream flow condition. The turbine test point was characterised by the measured freestream flow velocity (U_∞) as the resultant of three velocity components (U_x, U_y, U_z). The power on the test turbines was generated by inducing friction on a mechanical disk brake attached to the turbine shaft as a power take-off (PTO) simulator mechanism. The frictional force (F) was measured directly via a load cell to calculate torque (τ) along with the rotational speed (ω) via a coupled encoder on the turbine shaft. The performance of model turbines was characterised by using the non-dimensional power coefficient (C_p) and tip speed ratio (λ) given by equation (1), where ρ = water density, A = turbine swept area.

$$C_p = \frac{\tau\omega}{0.5\rho A {U_\infty}^3} \quad , \lambda = \frac{r\omega}{U_\infty} \tag{1}$$

Similarly, the solidity ratio was defined as follows:

$$\sigma = \frac{cN}{d_0} \tag{2}$$

(where c, N and d_0 are length of the blade chord, the number of blades and the outer diameter of the turbine, respectively).

3. Results and Discussion

The modified vertical axis Savonius hydrokinetic turbine with 7 different models was tested experimentally in a hydraulic flume to provide an optimum design based on their ability to abstract energy from the flow. Among the test cases, the turbine with eight blades in four arms (T1) outperformed all models by achieving $C_{pmax}/\ \lambda_{max}$ = 0.146/0.409 at the solidity ratio of 1.90, as in Figure 1 (left). The same model tested by removing half of the inner blades (T5) still showed notable performance results, with $C_{pmax}/\ \lambda_{max}$ = 0.081/0.378. While a positive correlation is found between the increasing solidity and C_p, it did not follow the same for increasing blade numbers. Unlike that in the fixed blade turbine, this emphasises that a more significant portion of the energy in the flow could have been consumed to rotate the flapping blades with increasing blade numbers. However, with a similar σ ratio, the increased blade numbers in the T4 model helped on reducing the torque ripples, as in figure 1 (right).

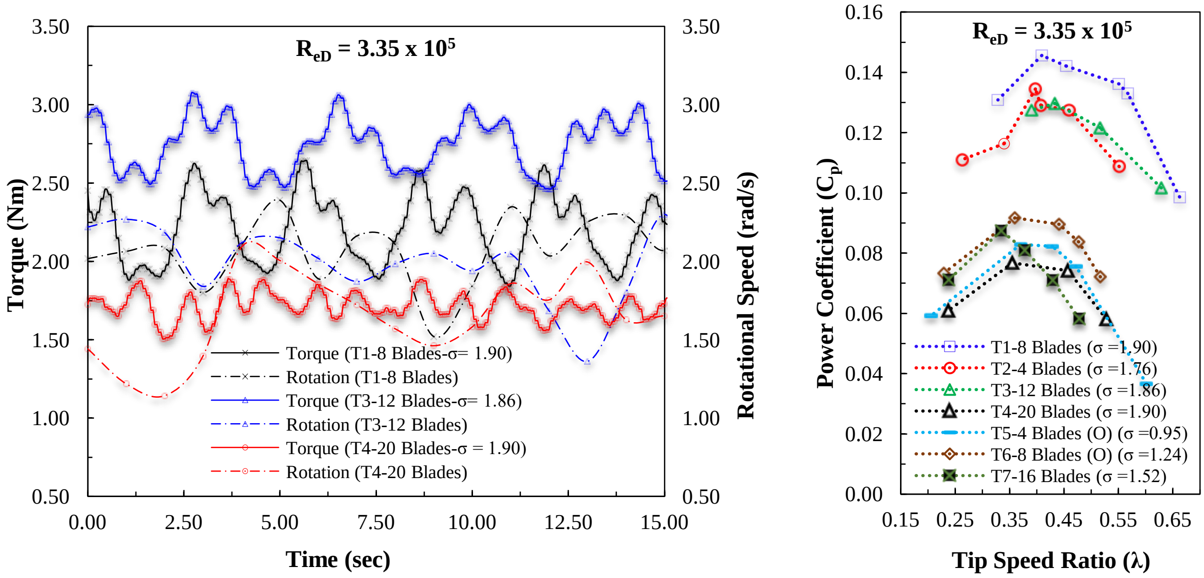

Figure 1: C_p-λ curve for model turbines (left) and torque and rotational speed variation for 3 model turbines with similar σ ratio (right)

4. Conclusion

A turbine with eight flat plate blades in four arms was found to be the best configuration with $C_{pmax}/\ \lambda_{max}$ = 0.146/0.409 at σ ratio of 1.90. The model with 20 blades, characterised by the same σ ratio, performed the least with $C_{pmax}/\ \lambda_{max}$ = 0.077/0.355. Conversely, the temporal torque variation for the most efficient turbine was characterised by high peaks and troughs compared to the least performing model. Additionally, the optimum configuration (T1) showed promising resilient characteristics on performance even when half of the inner blades were removed. Finally, a lower tip speed ratio ($0.15 \leq \lambda \leq 0.70$) characterised this new turbine as a slow-rotating device with its possible application at ecologically sensitive rivers and estuaries.

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References

KUMMU, M., DE MOEL, H., WARD, P. J. & VARIS, O. 2011. How Close Do We Live to Water? A Global Analysis of Population Distance to Freshwater Bodies. PLOS ONE, 6, e20578.
LAWS, N. D. & EPPS, B. P. 2016. Hydrokinetic energy conversion: Technology, research, and outlook. Renewable and Sustainable Energy Reviews, 57, 1245-1259.