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Improved Tidal Turbine Performance through Optimised Support Structure Design

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Abstract

Experimental testing of scale tidal turbines reveals the importance of the turbine support structure on device performance. Previous work suggests that this may be related to a highly turbulent region around the support structure. Experimental work using 1:72 scale commercial support structure models supports this, with up to 50% differences in power output observed using the same turbine mounted on different support structures. Computational modelling of the same cases is ongoing, which it is hoped will allow identification of specific geometrical features of support structure design that lead to reduced turbine output, and allow the proposal of optimal structure designs. These designs will then be tested experimentally.

Keywords Computational Fluid Dynamics; Performance measurement; Scale modelling; Tidal turbine; Water Channel.

1. INTRODUCTION

Tidal stream energy offers the potential to replace fossil-fuel electricity generation systems with renewable energy, as due to the predictability of the tide, the intermittency issues associated with other renewable sources are avoided. Suitable sites for the technology exist in many countries around the world, and the UK is a world leader in the development of this technology. Tidal stream turbines are designed with the eventual aim of installation in arrays of 50 – 200MW, with single devices commonly around 50m tall and rated at 1-2MW. Most are visually similar to a wind turbine, comprising a blade unit and nacelle mounted on a support structure.

It is hypothesised that the support structure may affect the turbine blade hydrodynamics and therefore performance. The aim of this work is to study turbine power output over a range of support structures, with the future aim of designing an optimal support with minimal performance influence. 1:72 scale tidal stream turbine models were tested experimentally at the University of Florence wave-current channel as part of a MARINET-funded project [1].

2. SUPPORT STRUCTURE DESIGNS

Most tidal stream turbine designs are broadly similar, but each developer favours a slightly different design of support structure. The support structure designs of four commercial devices [2] were studied. Three used rigid seabed-mounted support structures attached to pile foundations (S1: beam structure, S2: tripod, S3: angled post) and the fourth a catenary cable mooring system (S4).

Scale models were manufactured from Duralin polymer. A scale of 1:72 was used, giving a blade diameter of D=250mm. A single nacelle and turbine unit was manufactured using an off-the-shelf blade (since all power data analysis would be comparative it was not necessary to expend resources on the development of a high-performance blade unit). The blade was fitted to a right-angle gearbox, through two sets of nylon bearings fitted inside the nacelle body to a driveshaft passing vertically through the top of the nacelle. The completed support structure models are each shown with the turbine unit in place in Figure 1.

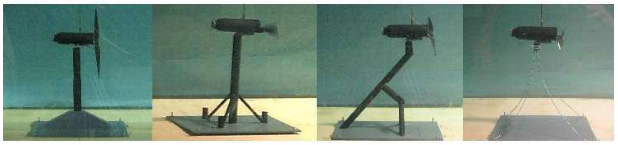

Figure 1. 1:72 scale support structure models (l-r: S1, S2, S3, S4).

3. EXPERIMENTAL FLOW AND POWER MEASUREMENT

Turbine models were installed in the 40m CRIACIV water channel. Flow velocity was measured using acoustic (ADV) and ultrasonic (UDV) Doppler velocimetry. The UDV system was positioned at 1D (250mm) downstream of the turbine, and recorded 75 instantaneous profiles at a frequency of 2.27Hz, ensuring that at least one complete blade rotation was captured in every experimental case. Each vertical velocity plot comprised 204 points at an approximate spacing of 2.9mm. The ADV system was positioned 10D downstream of the turbine. A sampling frequency of 25Hz was used over a total recording period of 90 seconds per experiment. Volumetric flow rate was also measured using a magnetic flow meter, and water flow height was measured using ultrasonic depth gauges positioned at 3.8m, 18.5m and 38.5m downstream from the inlet of the channel.

Turbine models were driven using an electric motor attached to the vertical driveshaft partially visible in Figure 1. Blade-generated power was calculated from rotational speed ω and motor power P_{app}. ω was recorded using an optical encoder mounted on the turbine drive shaft, and P_{app} was measured using an ultra-sensitive current measurement module. Both were connected to a data acquisition module recording at 50Hz for 90 seconds per experiment. To calculate blade generated power, each experiment was conducted with blades in place (power applied $P_{app}B$) and with turbine blades removed ($P_{app}NB$). Since the power required to drive the turbine at constant ω with blades was less than that without blades due to the power generated by the blades themselves, the difference between the two cases yields the blade-generated power, P_B (1):

$$P_B = P_{app}NB - P_{app}B \qquad (1)$$

From P_B, turbine power coefficient (C_P) was calculated. C_P gives the ratio of generated power to available power in the undisturbed flow. The water channel, turbine model, drive system, and flow and power measurement equipment described previously is illustrated in Figure 2.

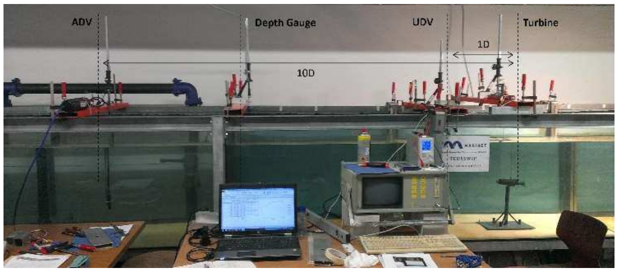

Figure 2. Measurement equipment in central region of CRIACIV water channel. Depth gauges at 3.8m and 38.5m are not shown.

3.1. EXPERIMENTAL CASES AND RESULTS

All experiments were carried out using a water depth of 600mm and a flow rate of 73l/s, yielding a bulk flow velocity of 0.152m/s through the channel. Experiments were conducted at Tip Speed Ratios (TSR) of λ = 2, 3, 4 and 5, controlled by turbine rotational speed, which ranged from ω=2.5rad/s to 8.6rad/s. C_P-λ plots for the three rigid support structure cases are given below. Due to vibrations in the structure during testing, results from the cable moored support structure (S4) case were not usable.

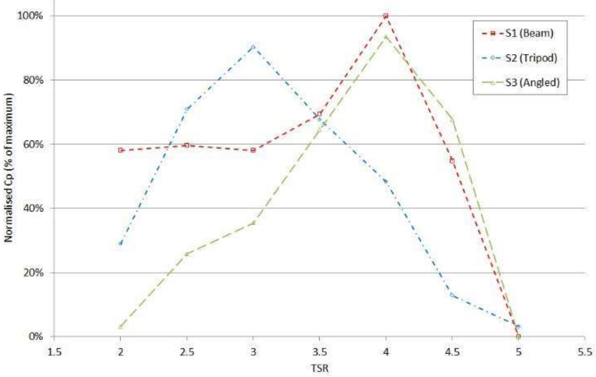

Figure 3. C_P-λ plots for S1, S2 and S3 support structure designs. C_P normalised by overall maximum (as generated by S1 at λ=4).

Results (Fig. 3) appear to illustrate a significant influence of support structure on turbine performance, with maximum C_P generated at λ=4 using the beam and angled (S1 and S3) designs, but at λ=3 in the tripod (S2) case, where the peak C_P value is around 10% lower. It is noted that S2 incorporates smaller geometrical features than S1 and S3. C_P curves between λ=3.5 and λ=5 are similar in the S1 and S3 cases, but below this range the S1 C_P is significantly higher.

Previous experimental work at 1:143 scale [3] suggested that support structures may influence performance due to the presence of a highly turbulent region upstream of the support structure. This was found to yield regions of relatively high and low blade performance in inverse correlation with turbulent kinetic energy. The results of the present study suggest that this effect is also observed using commercial structure designs. It has not been possible to record upstream turbulent kinetic energy experimentally, hence a computational "virtual laboratory" will now be used to study this effect, and ultimately for the development of optimal support structure designs, which will subsequently be tested under identical experimental conditions.

4. FUTURE WORK

Numerical replication of the aforementioned experimental study is currently ongoing. Computational Fluid Dynamics models have been solved using the Large Eddy Simulation method. A steady state model of the full water channel has been used to generate boundary conditions for subsequent transient models of each support structure. Using these, numerical results will be calculated at the same flow cases tested experimentally (λ = 2, 3, 4, and 5).

5. CONCLUSIONS AND CONTINUATION

It has been demonstrated experimentally that the support structure of a tidal stream turbine can have a significant influence on the performance of the turbine blades. Results from this study reveal that a different turbine support structure changes the C_P-λ curve of an identical turbine, resulting in different performance characteristics over a range of flow and rotational speeds. This suggests that the design of support structure may be used to tune the performance of a turbine to a given set of conditions, and that support structure optimisation may be able to yield performance improvement. Computational replication will now be used to help explain the observed performance differences, and to develop support structure designs with reduced performance influence, which will subsequently be manufactured at 1:72 scale and studied experimentally.

REFERENCES

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