Aerodynamic response of a vertical axis wind turbine under prescribed floating motions

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Introduction

The development of floating offshore wind turbines has broadened the capability of the wind industry to new levels. Vertical axis wind turbines (VAWTs), although not as widely used as horizontal axis wind turbines (HAWTs), show promising feasibility in floating conditions. The classical reasoning for favouring VAWTs is that they are not sensible to wind direction and that the heaviest mechanical parts, such as the generator, may rest at the bottom. Because of this, the centre of gravity is located lower on the turbine, providing better turbine stability. This can lead to a design that has simplified and relatively cheaper maintenance than a HAWT.

In a moving environment, do VAWTs make sense? Is the aerodynamic behaviour on these conditions as sensitive as that of a HAWT?

The main objective of this work is to study the aerodynamic response of the turbine under a one degree-of-freedom prescribed harmonic motion at operational conditions, by evaluating the effects each of the motions have on the VAWT power production.

Methodology

We focus on the aerodynamic performance of an H-type VAWT design. All simulations are done in QBlade using the Lifting Line Free Vortex Wake method (LLFVW). This model calculates the blade forces using two-dimensional sectional airfoil polar data and the rotor wake shed from the blades is explicitly resolved.

Two simulated sea states are used. The first state is a motionless system, which serves as a control, while the other sea state is a scaled representative of a possible site used for the OC5 project, as shown below. It is achieved by subjecting the turbine to prescribed sinusoidal motions for each of the six degrees of freedom present in a floating environment. All simulations are done for normal operating conditions at a uniform rated speed.

Turbine characteristics:

- Capacity: 10 kW
- Radius: 5.56 m
- Blade length: 6 m
- Chord: 0.30 m
- NACA 0018 airfoil

Simulation conditions:

- Wind speed: 9 m/s
- TSR: 3.6
- Wave height: 0.168 m
- Period: 1.84 s

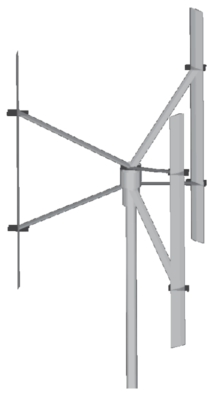

Figure 1. VAWT configuration.

Results

The figures in this section show the power coefficient over one wave period. VAWTs' power output oscillates due to the rotation of the blades and clear distinctions showcase the interaction of the tower shadow and the blade directly behind it. The simulation of the turbine under each motion is shown in blue, while the red line in every case represents the fixed bottom turbine or static case.

In Fig.1a the surge motion shows significant impact of the relative wind velocity at the rotor, while the pitch motion in Fig.1e also sees an effect from the skew angle of the rotor which induces aerodynamic stiffness. The skew angle alters the induction, it creates unsteadiness that may affect the solver's accuracy. Table 1 points to a general increase in Cp under every motion, with pitch being the most influential.

We evaluated the efficiency of the turbine as the ratio between the power coefficient and the thrust coefficient (see eq.1), as the former characterises the gain of the system while the latter relates to a cost. In Tab.1 we observe that the thrust is not as affected by the motions, given that the efficiency as well as Cp increases for every case.

$$\varepsilon = \frac{C_P}{C_F} \qquad (1)$$

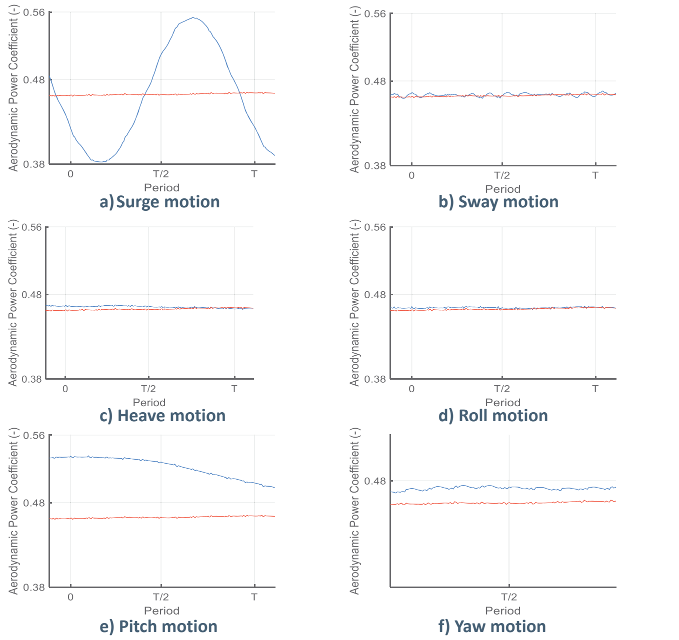

Figure 3. Average power coefficient of turbine under rotational motions, over 10 wave periods. Blue shows motion case, red shows static case.

Table 1. Comparison of power production and efficiency of motion cases against static case.

Motion	Static	Surge	Sway	Heave	Roll	Pitch	Yaw
Mean Cp	0.4607	0.4645	0.4651	0.4654	0.4628	0.4660	0.4686
Difference (%)	-	0.83	0.95	1.01	0.46	1.16	1.02
ε	0.4790	0.4821	0.4817	0.4815	0.4805	0.4827	0.4827

Conclusions

The six motions occurring in a floating VAWT were studied individually in this work. The aerodynamic response was measured by the variation in aerodynamic power. The efficiency of the turbine was considered as the ratio between power and thrust. From this, we conclude that:

- The pitch motion increases the aerodynamic fluctuations which may compromise the turbine structurally.
- Advanced controllers are needed to keep a stable output. This is a known challenge even for bottom-fixed VAWTs.
- More realistic and complex motions of the system must be analysed to gain further understanding of the aerodynamic response of a VAWT in floating conditions.

References

- G. Bedon, U. S. Paulsen, H. A. Madsen, F. Belloni, M. R. Castelli, and E. Benini. *Aerodynamic benchmarking of the deepwind design*. Energy Procedia, 2015.
- M. Borg and M. Collu. *A comparison on the dynamics of a floating vertical axis wind turbine on three different floating support structures*. Energy Procedia, 2014.
- V. Leroy, J.-C. Gilloteaux, A. Combourieu, A. Babarit, and P. Ferrant. *Impact of the aerodynamic model on the modelling of the behaviour of a floating vertical axis wind turbine*. Journal of Physics: Conference Series, 2018.
- D. Marten. QBlade*: A Modern Tool for the Aeroelastic Simulation of Wind Turbines*. PhD thesis, TU Berlin, 2019.
- I. Paraschivoiu. *Wind turbine design: With emphasis on darrieus concept*. Presses Internationales Polytechnique, 2009.
- M. S. Sakib and D. T. Griffith. *Parked and operating load analysis in the aerodynamic design of multi-megawatt-scale floating vertical-axis wind turbines*. Wind Energy Science, 2022.
- K. Wang, T. Moan, and M. O. Hansen. *Stochastic dynamic response analysis of a floating vertical-axis wind turbine with a semi-submersible floater*. Wind Energy, 2016.
- T. Wen, K. Wang, Z. Cheng, and M. Ong. *Spar-type vertical-axis wind turbines in moderate water depth: A feasibility study*. Energies, 2018.