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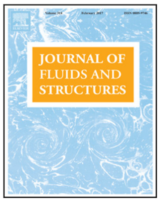

Influence of support structures on tidal turbine power output

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HIGHLIGHTS

- Implementation of fully blade resolved RANS formulation with $k-\omega$ SST turbulence model to study the interaction effects between turbine rotor and two different support structure shapes.
- Integrated rotor force coefficients were higher in the presence of the cylindrical support structure than the elliptical support structure.
- Presence of rotor causes a drop in the mean stream-wise force coefficients of the support structures.
- The velocity deficit just in-front of the support structure is 20% higher for the cylindrical support than the elliptical support.

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ABSTRACT

A fully blade resolved CFD model with a RANS formulation using the $k-\omega$ SST turbulence model was used to study the tidal turbine performance in the presence of two support structures with cylindrical and elliptical cross-sections. The integrated rotor force coefficients were higher in the presence of the cylindrical support structure than the elliptical support due to the higher opposing thrust from the cylinder in the channel increasing the local flow velocity near the top half of the rotor. The angle of attack on the blade decreases as it approaches the support structure due to the reduction in stream-wise flow velocity just ahead of the support structure. This drop is higher for cylindrical support than the elliptical support due to its larger opposing thrust to the flow causing a larger drop in stream-wise velocity. The drop in the angle of attack due to the presence of support structures causes a significant drop in the blade sectional forces as it approaches the support structure. The presence of rotor also causes a drop in the forces on the support structure. The mean stream-wise force coefficients of the cylindrical and elliptical support structures are 0.21 and 0.12 respectively, which are much lower than if they were in open water without a rotor. In case of both the support structures, the stream-wise sectional forces behind the rotor swept area are lower than that in open-water whereas the mean cross-stream forces are higher. The thrust from the rotor and the support structure has a direct influence on the wake velocity. The velocity deficit just in-front of the support structure is 20% higher for the cylindrical support than the elliptical support due to its higher opposing thrust to the flow, and further downstream, the case with cylindrical support has higher velocity deficit followed by elliptical support and then the case with no support structure.

1. Introduction

Tidal energy is one of the emerging forms of renewable energy. There are different types of tidal energy extraction mechanisms but one of the more popular mechanism is using the Horizontal Axis Water Turbine (HAWT). HAWTs are similar

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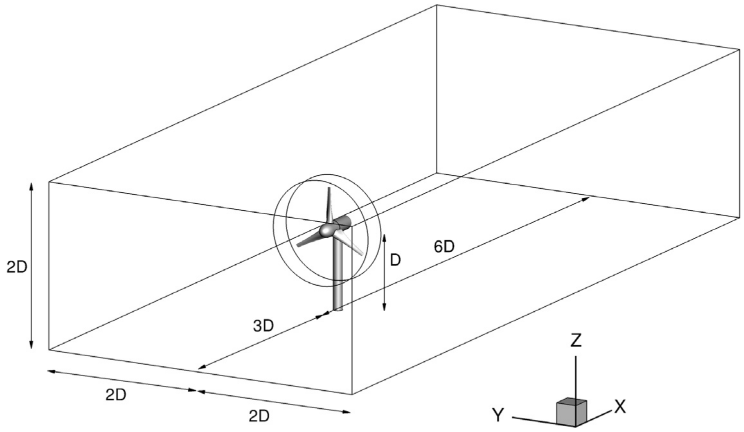

Fig. 1. Dimensions of the computational domain. The flow direction is in the positive *x*-direction.

to wind turbine rotors mounted either on monopiles or different support structures and the influence of the support structure is the main focus of this paper. The influence of support structures on wind turbines have also been studied in the past but mainly about the tower shadow effects (Fruh et al., 2008; Sescu and Andersen, 2011).

In this paper, the influence of support structure cross-section on the turbine rotor forces and its wake is discussed. As a real tidal channel has a sheared velocity profile, all the simulations were performed in a shear flow profile.

Bahaj et al. (2007) conducted towing tank experiments on a model scale turbine for different blade pitch angles and presented the variation in force coefficients with change in pitch angles. The data shows that the force coefficients peak at a particular tip speed ratio for every corresponding blade pitch angle. Vogel (2014) has studied the power capping strategy using Blade Element Momentum (BEM) techniques. In this work, the change in power coefficients with tip speed ratio was studied for different blade pitch angles along with the power-control curve, thus obtaining the data points for the amount by which a blade should pitch at a corresponding tip speed ratio. There have been experimental and BEM studies on the influence of blade pitching but little research on studying the flow physics using blade resolved CFD simulations.

Afgan et al. (2013) simulated a tidal turbine using the RANS model and compared the influence of two different turbulence models, k-ω SST and Reynolds Stress Model, on the prediction of power and thrust coefficients. Mason-Jones et al. (2013) has shown the influence of shear profile and support structures on a tidal turbine using a fully resolved blade model. Since it was a fully resolved model, it was possible to study the interaction effects between the rotor and the support structure, and the variation in force coefficients as a blade completes one rotation is presented to demonstrate this.

McNaughton (2013) implemented a new sliding mesh method with a fully blade resolved turbine inside the sliding mesh. The method was validated by simulating the experiments of Bahaj et al. (2007), which were shown to be in good agreement. Later a full scale rotor was simulated in a sheared flow using the fully resolved blade model to study the influence of shear on the turbine characteristics. Ahmed et al. (2017) simulated a full scale tidal turbine installed in an EMEC site, and compared the fluctuating power and thrust coefficients with real site data.

This paper starts with the description of the domain and the mesh used for the rotor along with the support structure. The influence of the support structure on the rotor is studied by analysing the forces and the angle of attack distribution along the rotor blades. Later the impact of the rotor on the support structure is discussed by investigating the forces on the support structure. The last section presents the effect of rotor and support structure interaction on the downstream wake.

2. Turbine rotor description

2.1. Computational domain

A full-scale turbine rotor of 18 m diameter (D) was used for the current simulations. The turbine blades had a blade twist angle of 15°. The support structure was 18 m (D) in height. The cylindrical support structure considered was 2 m (D/9) in diameter and the front of the support structure was located 2.5 m behind the rotor based on the proprietary design obtained through the PerAWaT project. An elliptical support structure of aspect ratio 2:1 was examined for the other case such that its cross-stream width, the minor axis, is the same as the cylinder diameter, 2 m (D/9) and its major axis length in the flow direction was 4 m.

The computational domain has two sub-domains, the inner domain and the outer domain. The inner domain consists of the rotor and a cylindrical coin, 0.33D long and a diameter of 1.25D, surrounding the rotor excluding the support structure; see Fig. 1. The outer domain consists of the support structure and the remaining computational domain. To simulate turbine rotation, the mesh in the inner domain is physically rotated whereas the outer domain remains stationary and the data transfer occurs through the interface between the two domains. Hence an unsteady simulation is carried out to capture the unsteady nature of the rotor - support structure interaction.