A study on the applicability of shallow water equations for predicting tidal turbine wakes

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1 Introduction

Tidal current turbine (TCT) is one type of equipment used for tidal energy extraction, and turbine arrays have been proposed for large scale applications. For a tidal current power farm, both the reduction of total energy and the interaction between turbine wakes will affect the power output. In near-shore shallow water regions where the turbine arrays are to be located, the tidal stream is considered as a sheet flow where the vertical dimension is usually two to three magnitudes smaller than the horizontal dimension (Lin et al., 2015). For practical applications with complex topography, shallow water equation (SWE) based models are the most accepted tools for predicting near-shore hydrodynamic processes including tidal elevation and current velocity.

Meanwhile, the effect of turbines on the flow has been represented by a quadratic drag force, to assess tidal power generation potential and environmental impact (Walters et al., 2013). In more recent studies, the concept of actuator disk has been combined with SWE models to investigate the three dimensional effect of turbine arrays on the hydrodynamic processes in field scale problems (Lin et al., 2015, Roc et al., 2013). However, there is few work that discuss to what extent the fore-mentioned simplifications are proper and the results are reliable. To fill this gap, model turbine experiments were conducted and detailed flow field measurement was carried out to provide sufficient data for validation. The objective of this study is to build a field scaled model that is able to reproduce wake interaction within turbine arrays. Details are given of the development of a combined SWE and profiled actuator disk model.

2 Material and methods

2.1 Physical experiment

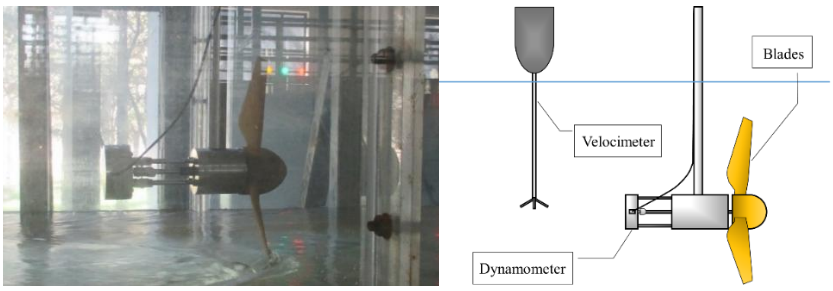

Figure 1 A sketch of the scale turbine and the gauge system

The experiments were carried out in the open channel flume at Tsinghua University, Beijing, which has a test section of 14.4 m long. Both the flow fields with and without a scaled turbine model were measured using an acoustic Doppler velocimeter (ADV). The rotor has a diameter of 300 mm with the blades developed from the foil profiles of NACA series. During the experiments, the thrust force applied on the blades was measured with a specially designed dynamometer (Fig. 1). For each of the measured cross-sections, data were collected at 435 sampling points with 2.5 mm lateral and 3 mm vertical spacing respectively. Velocity and main turbulence characteristics were processed.

2.2 Classical and modified actuator disk method

The most common use of the actuator disc method is to simplify the rotor into a one dimensional permeable disc (Hansen, 2008). However, the pressure distributions on the rotors differ for different designs of hub and blade sections. The resultant thrust profiles thus provide diverse initial conditions for the wake. Compared to a porous plate, the non-uniform geometry and rotation of rotors create more variable profiles, which means that a longer distance is needed to reproduce a fully developed wake that is similar to the case of a uniform thrust. It is clear that the effective extent given by an actuator disk model can be improved by introducing thrust profiles. In the current study, the blade element momentum (BEM) method was adopted to assess the possible profiles, with the blockage correction being included. Figure 2 shows comparisons between simulated and measured velocity deficit distributions.

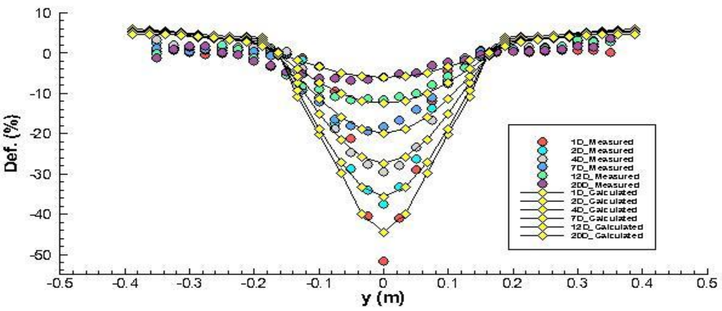

Figure 2 Comparisons of velocity deficit distribution between simulated results and measured data

3 Conclusions

1) The distributed thrust actuator disk method has better performance than the uniform thrust actuator disk method.
2) Based on a coarse grid, it is possible to reproduce turbine wake with SWE model and actuator disk method. However, the accuracy of the predicted flow field is reduced within a small area downstream of the blades.
3) Although the swirling flow cause by the rotating blades cannot be resolved, the tangential effects of rotors on a broader area can be simulated with strengthened momentum exchange.

Reference

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