Resource Assessment of Large Marine Current Turbine Arrays

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Arrays, wakes and Near Field Effects

Introduction

Tidal energy has the potential to provide a predictable supply of renewable energy in different locations around the world, where there are significant amplitudes of tidal elevations and currents.

To implement this, methods of resource assessment must be developed to understand with confidence the potential a resource has to provide energy from large tidal turbine arrays. Only then will large arrays be deployed.

The aim of this work is to investigate the flow field inside large tidal turbine arrays, to adapt 2D depth averaged models to incorporate this detail and hence improve the accuracy of power predictions.

This work first reviews the main challenges faced in modelling large marine current turbine arrays using 2D depth averaged models, namely the scaling issues that lead to uncertainties in defining the flow field inside large arrays, and uncertainties in the shear velocity profile of the flow over a tidal cycle.

Currently, a 2D depth averaged model of the British Isles is being built using Telemac 2D. Section 2 gives information on this and the work that is planned using this model.

Section 3 gives an overview of future work, which focuses on investigating the flow field inside large arrays, and the equilibrium flow speed that forms downstream of the arrays' leading edge. This is of value as it can give an indication into how 2D models can be adapted to incorporate the turbine scale flow affects when modelling large arrays to better predict power generation.

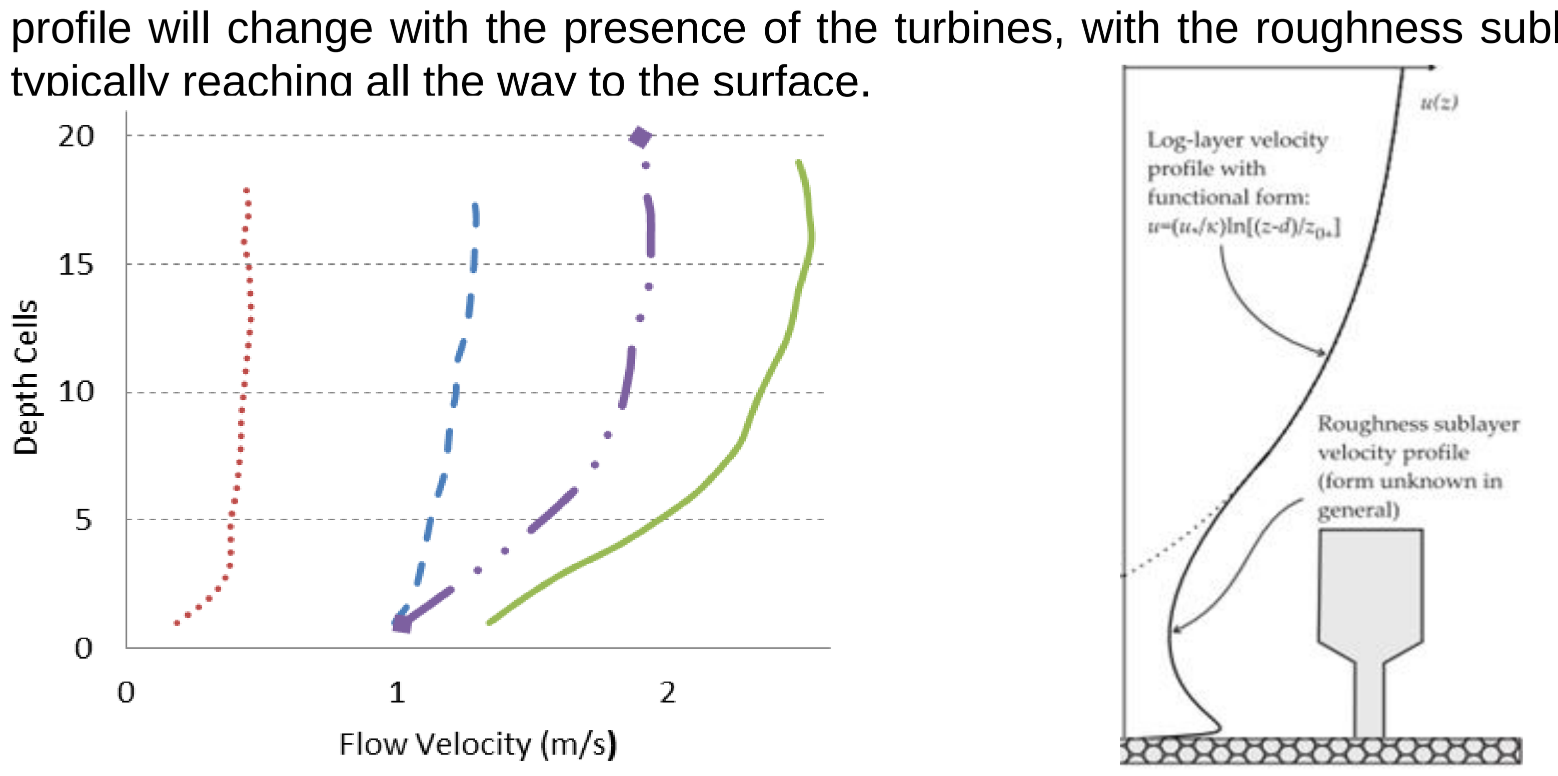
1. Challenges

A.Defining the flow field inside an array

To predict the power that can be produced by large tidal turbine arrays, 2D depth averaged models are used to simulate large domains at an acceptable computational expense in comparison with 3D models. Tidal turbines are modelled by applying an added roughness term averaged over the whole plan area of the array. This method lacks detail as it does not consider the turbine scale flow around individual turbines [1], so the variation in flow velocity inside the array is not accurately captured. Analysis from wind farms indicates that the flow velocity reaches a steady speed based on an equilibrium velocity deficit, where the longitudinal pressure gradient is balanced by the drag from the tidal devices and seabed friction. This equilibrium flow velocity is reached as more rows are added to the array, however there is little understanding of where this equilibrium flow velocity forms and how it is affected by independent variables such as array density.

B.Uncertainty in the shear flow velocity profile

Figure 1 shows how the 1 hour average shear flow velocity profile can change throughout a tidal cycle. The variability on a wide range of temporal and spatial scales make it very difficult to incorporate into 2D models. Furthermore, this shear profile will change with the presence of the turbines, with the roughness sublayer typically reaching all the way to the surface.



(a) (b)

Figure 1. (a) ADCP data showing flow speed profile at different times in the tidal cycle using data source [2]. Red = 14:45-15:45, Green = 17:45-18:45, Purple = 19:45 – 20:45, Blue = 01:45-02:45 (b) Shear velocity profile in the water column

2. British Isles Model

Telemac 2D is a depth averaged hydrodynamic software package for modelling free surface flows that solves the shallow water equations, also known as the Saint Venant equations. Currently a model of the British Isles is being built that will allow large arrays to be modelled at different locations, including the Channel Islands and the Pentland Firth.

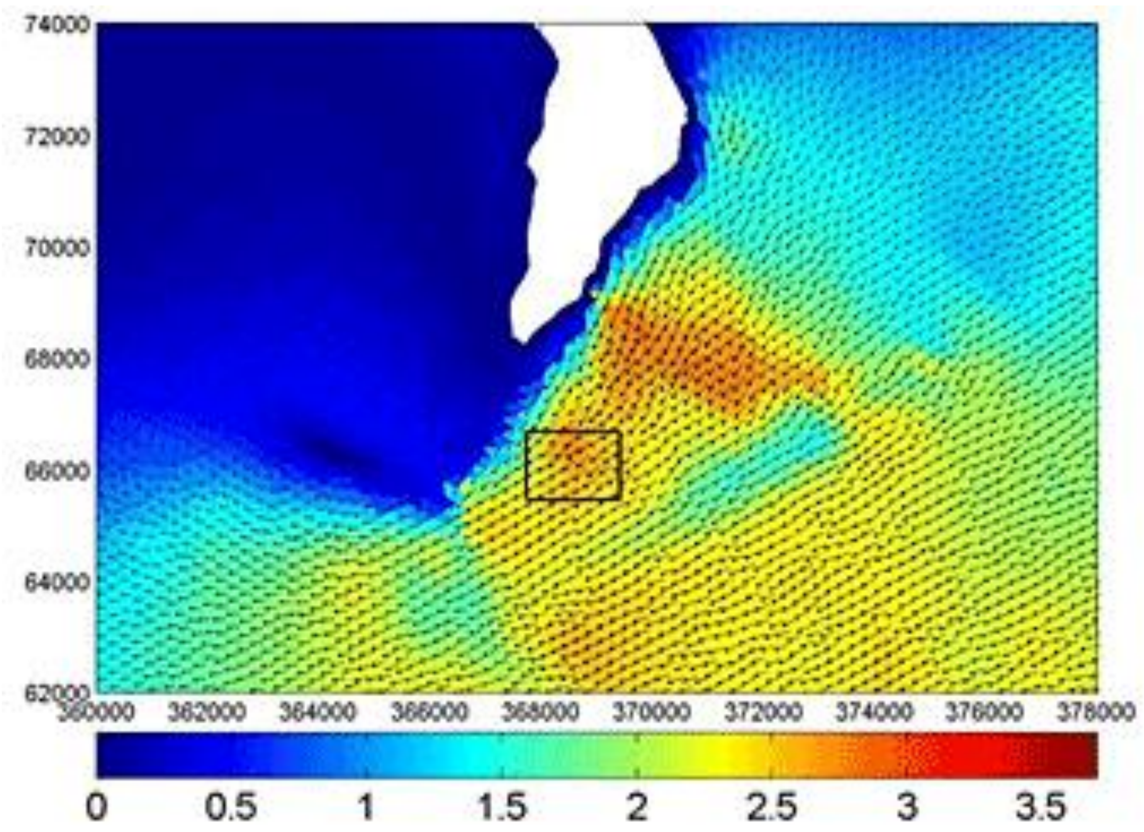


Figure 2. Tidal flows around a headland from Telemac 2D. Colour scale in m/s. Rectangle shows area with highest mean cube speed. [3]

Eleven tidal constituents will be used to drive flow at a liquid boundary that runs parallel with the continental shelf in order to minimize the impact of reflections at the boundary on the simulation.

3. Future Work

A. Equilibrium flow velocity deficit

An important element of this work that requires better understanding is the occurrence of an equilibrium flow velocity, which forms some distance downstream of the leading edge of an array. Future work will focus on quantifying the equilibrium velocity, the distance it forms from the leading edge of the array, and its dependence upon dimensionless groups such as array density. (Array density is defined as the total swept area, A_T in an array divided by the plot area, A_a of the array, given in m^2/km^2). Findings can be used to adapt 2D models to account for the flow field inside an array, and at its boundaries, a feature they currently lack.

Experimental work completed by the Sustainable Energy Research Group (www.energy.soton.ac.uk) at the University of Southampton will be used to compare against 2D models. One experiment used 10 porous disks, positioned in a staggered array of 7 rows. A second experiment used porous fences to physically simulate a four-row array [4]. These results will be compared against Telemac 2D models to get an understanding into the difference in flow field that is obtained and how this affects power calculations.

New experimental work will look at how the flow velocity field develops as rows are added to an array using tidal fences in a flume. This will further the work of Blunden et al [4], who used a flume to investigate the velocity deficit in multiple row tidal fences in comparison with a CFD simulation. This work is key to validate any modifications made to the Telemac 2D modelling process.

B.British Isles Model

Once the Telemac 2D model of the British Isles has been built, resource assessment at various locations , for example the Channel Islands and the Pentland Firth will be conducted to better understand the potential these sites have for generating electricity.

It is intended to develop the work already completed in locations with high resource potential by incorporating any flow field findings to more accurately predict the power generation at specific sites.

References

1. C. R. Vogel, R. Wilden, G.T. Houlsby, A correction for depth-averaged simulations of tidal turbine arrays, EWTEC conference paper, 2013 .
2. UKCMER DTP – Tidal Energy Queen's Marine Laboratory(QML), Portaferry, Northern Ireland, 29th May 2013.
3.http://www.energy.soton.ac.uk/modelling-of-tidal-currents-phase-1/
4.L.S.Blunden, W.M.J.Batten, M.E.Harrison, A.S.Bahaj, Comparison of boundary-layer and field models for simulation of flow through multiple-row tidal fences, 2009.