Tidal resource, turbine wake and performance modelling on the EnFAIT project

Alasdair Macleod, Andrew Watson, David Quantrell, Sam Porteous and Tom Wills

The Project

Enabling Future Arrays in Tidal (EnFAIT) is an EU Horizon 2020 flagship tidal energy project. It aims to demonstrate the development, operation and decommissioning of the world's largest tidal array (six turbines), over a five-year period, to prove a cost reduction pathway for tidal energy and that it can be cost competitive with other forms of renewable energy.

The Site

The Nova Innovation EnFAIT tidal turbine array is located in Bluemull Sound, Figure 1. Bluemull Sound is between the islands of Yell and Unst in Shetland, Scotland. The tidal array is located just off the Cullivoe headland.

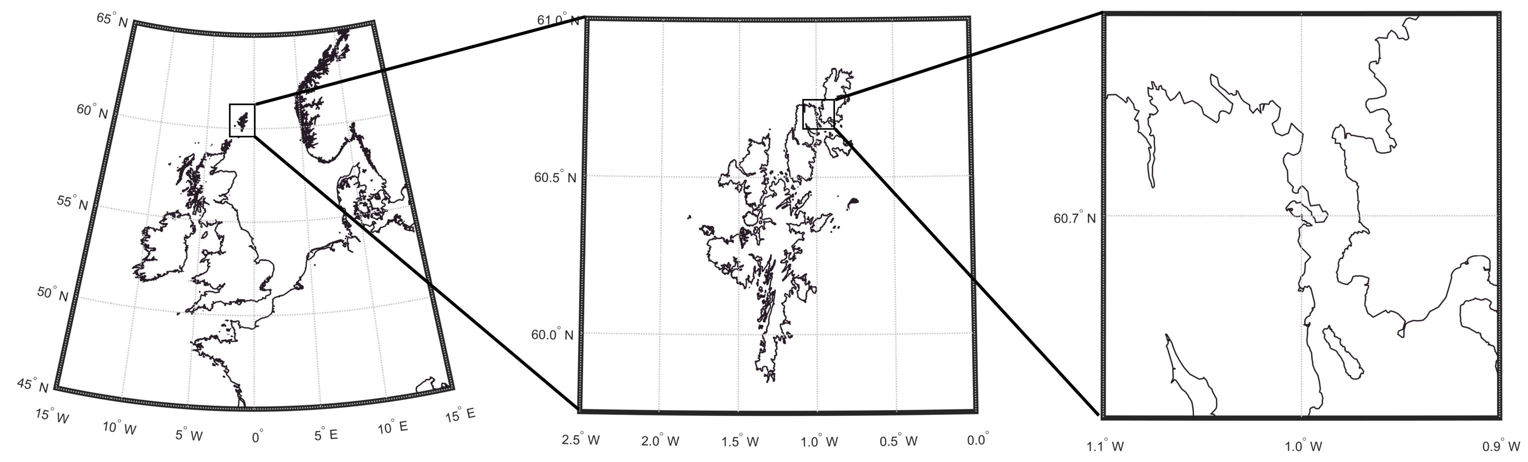

Figure 1. EnFAIT site location. The Site is located off the Cullivoe headland, between the isalnds of Yell and Unst, in Shetalnd, Scotland.

The Plan

One of the greatest strengths of the EnFait project, in relation to array layout understanding, is the plan to restructure the array layout throughout the project duration, this is shown in Figure 2. While final array positions are yet to be investigated, the high-level plan is to first install the Nova M100 turbines, Figure 3, in a simple line array of three. This has been achieved and the turbines are operational with no wake effects impacting turbine performance.

Next, three further turbines will be installed to the north of the existing three turbines making an array of 6 turbines in two rows of three. These three turbines will be installed approximately 20 diameters to the north of the existing three. This spacing will mean there is minimal array interaction between the rows of turbines. The flow around the turbines and the loading on the turbines will be recorded. This data will act as a benchmark which array interaction can be observed against.

Once data has been collected the array will be reconfigured. The streamwise spacing will be reduced to between five and ten diameters. By targeting wake and turbine interaction on one of the devices, but aiming to avoid on the others, the project will directly measure the effect of array spacing and wake interactions. This data will be used to validate modelling work.

This plan is illustrated in Figure 2.

This poster lays out some of the data collected and the analysis done on the road to delivering an Array Interaction Modelling (AIM) tool for the EnFAIT site. It also describes the plan to develop the array modelling tool.

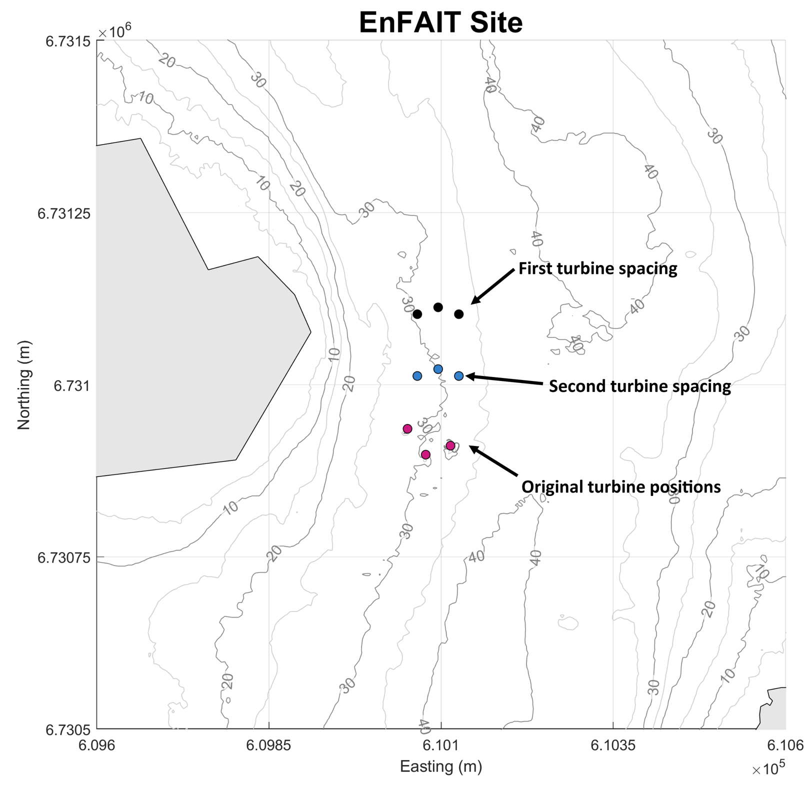

Figure 2. The EnFAIT site showing current and planned turbine locations

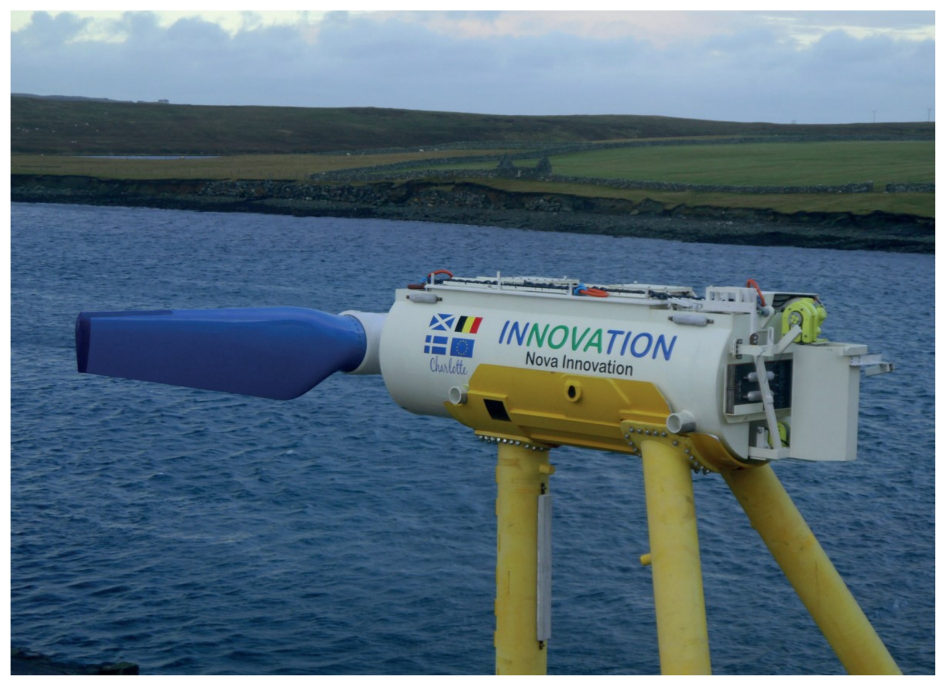

Figure 3. The Nova Innovation M100 turbine on site in Shetland

Figure 4. ADCP measurement equipment

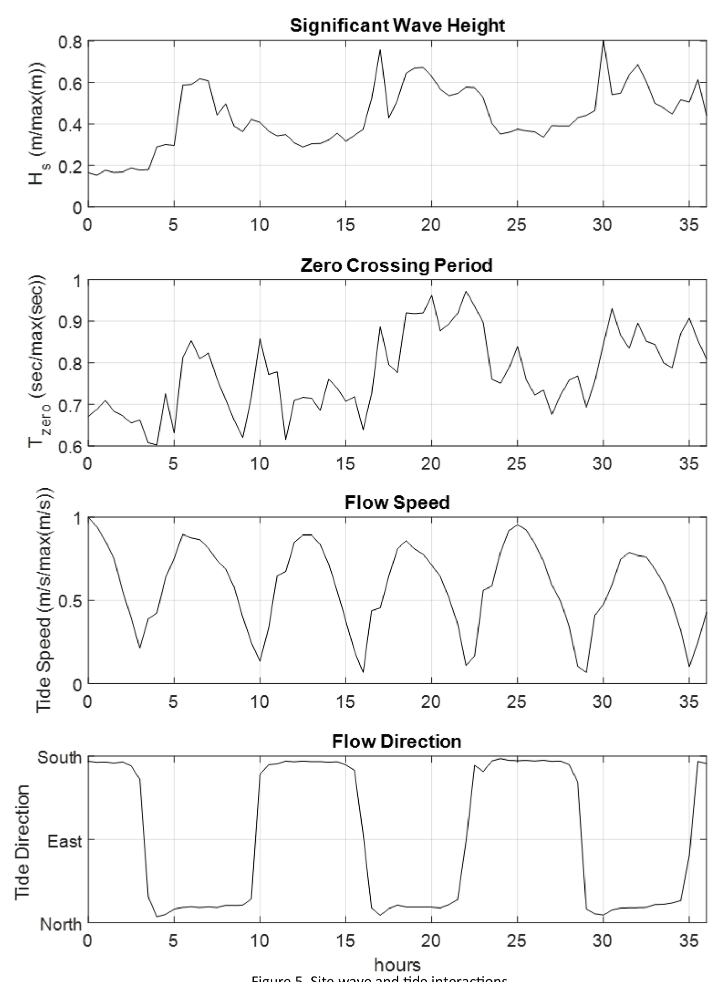

Figure 5. Site wave and tide interactions

Measurement Activities

The 3 ADCP positions were selected to best understand the flow around of the existing 3 turbines. The flow to the North is of most interest as it is here the next 3 turbines in the array, will be installed. ADCPs in this position will also give a good data spread across the consented site area.

The Data

The data recorded by the site installed ADCPs (Figure 4), shows complex flow behaviours. There is asymmetry between ebb (flow going from south to north) and flood (flow going from north to south) flow, there is complex wave and current interactions and there is a range of turbulence features displayed.

Shear Profile

The ebb profile shows continued flow speed increase towards the surface, Figure 6. This is in line with a typical power law governed profile. The flood profile, however, reaches peak flow speed around the middle of the water column and this is maintained up to the surface. This asymmetry in current speed profile is due to the difference in route to site the flow takes in ebb and flood.

Turbulence

Turbulence has been characterised by turbulence intensity. For a measured point in the velocity field, turbulence intensity, Iu, is defined as the root mean square of the time series velocity fluctuations, u', divided by the mean velocity flow, ū .

Mean velocity flow has been taken over 10 minute intervals. Velocity fluctuations have also been taken over 10 minute intervals, mean velocity fluctuations squared is defined by $\langle u'^2 \rangle$. Signal noise is removed to improve the estimate of turbulence intensity. For simplicity, in early analysis, noise has been defined as the square of velocity fluctuations at slack tide. Turbulence intensity through depth is shown in Figure 7.

$$I_u = \sqrt{\frac{\langle u'^2 \rangle - noise}{\bar{u}}}$$

Waves

There is an observable difference in the waves coming from the north on an ebb to a flood tide, Figure 5. On an ebb tide, with the flow heading to the north and waves coming from the north (opposing wave and tide directions), wave heights tend to be larger and wave periods tend to be longer than on a flood tide.

The waves recorded show a variation in spectral content depending on significant wave height and tidal flow direction. Considering the recorded wave spectra it can be seen that on an ebb or a flood tide, with waves coming from the north (going south) and a significant wave height greater than two meters the wave spectra matches well to a theoretical JONSWAP spectra of matching peak period and significant wave height. As significant wave height is reduced the wave spectra becomes less peaky and more closely matches a Bretschneider spectra. With waves heading north, the available data shows good correlation with a JONSWAP spectra. Further work is required to understand the phenomena which cause these observations.

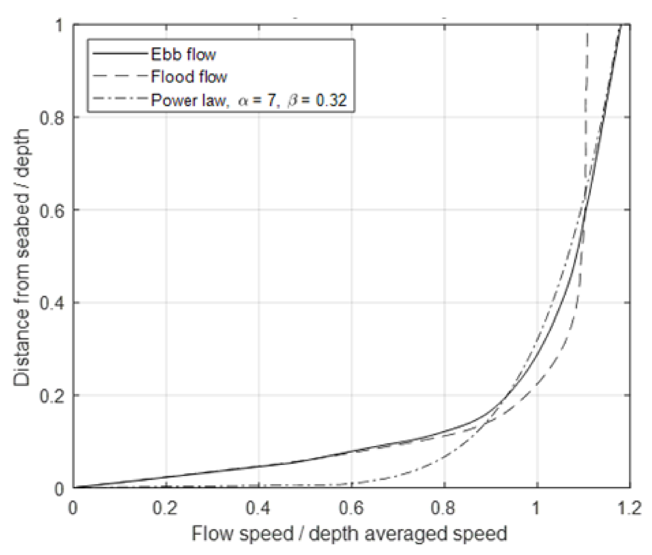

Figure 6. Site shear profiles in ebb and flood power law profile shown for comparison

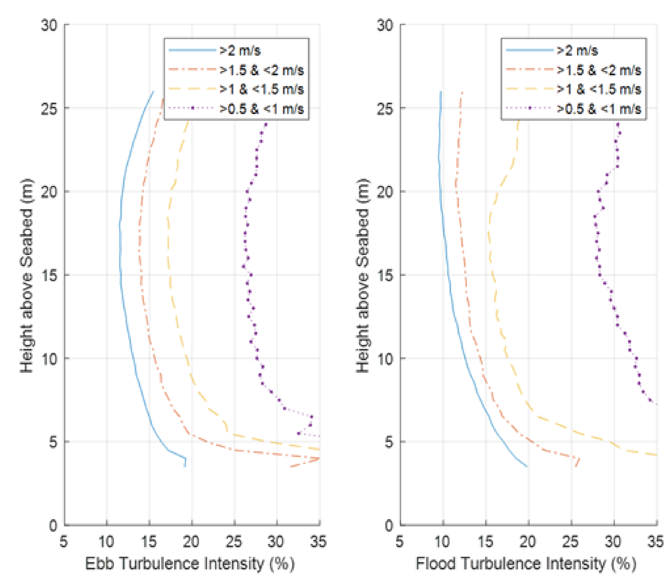

Figure 7. Site turbulence intensity profiles through depth

The Model

The array modelling technique presented is based around 3 modelling methods: a site resource model, a wake model built using Computational Fluid Dynamics (CFD) and a Blade Element Momentum (BEM) model. The results from these three models are brought together in MATLAB to produce a tool to inform array design.

The modelling approach has been selected to offer a balance between complexity and computational efficiency. The tool to be created aims to be physically accurate, and useful for modelling array loading and power effects, while remaining practical to execute. The approach is semi empirical and is built upon high fidelity site and turbine data and numerical simulations.

The array interaction model will be built around 3 detailed numerical models, site flow data and turbine data. A flow diagram illustrating the modelling approach is shown Figure 8.

The site flow models, wake CFD models and turbine BEM model shall be combined to produce an Array Interaction Model (AIM). The AIM will be a tool that allows quick and computationally cheap site assessment. Using a semi-empirical approach, based on the 3 models run and validated by site recorded data, the tool will assess array designs for performance and loading.

The tool, while not modelling complex flow physics, will be robust and fast. It will allow multiple array designs to be assessed. The AIM tool will be validated against site recorded data and the complex LES-ALM model. The LES-ALM model will run a reduced number of array designs as proof cases.

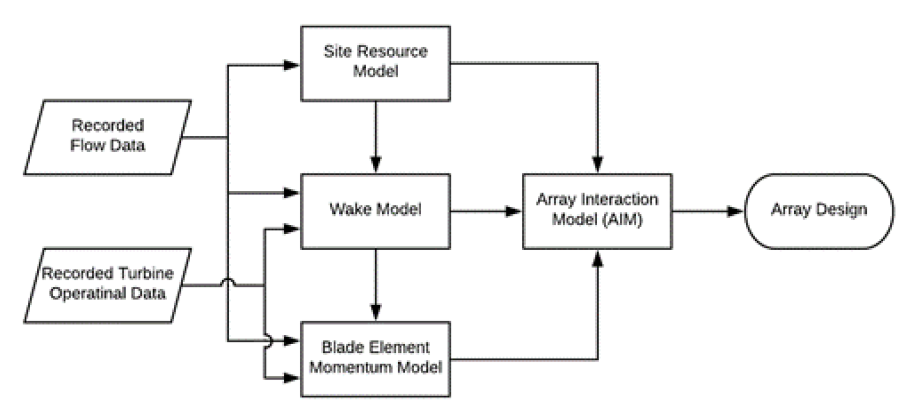

Figure 8. Modelling approach flow diagram

A. Macleod & S. Porteous are at Offshore Renewable Energy Catapult, Glasgow, G1 1RD, (e-mail: alasdair.macleod@ore.catapult.org.uk, sam.porteous@ore.catapult.org.uk).
D. Quantrell & A. Watson are at MetOceanWorks, London, E8 3DL, (email: info@metoceanworks.com).
T. Wills is at Nova Innovation, Edinburgh, UK, EH6 6HQ (e-mail: tom.wills@novainnovation.com).

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