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ENFAIT
ENABLING FUTURE ARRAYS IN TIDAL

D10.9 – AIM: Full Array Operational Report

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Contents

1 Introduction

1.1 Preface

A Funding Grant was awarded, from the European Union's Horizon 2020 research and innovation programme in January 2017 to demonstrate a grid-connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation – Enabling Future Arrays in Tidal (EnFAIT). This was in response to the call LCE-15-2016: Scaling up in the ocean energy sector to arrays to generate significant learning through demonstration of cost-effective tidal arrays.

1.2 Background

The EnFAIT project was carried out to allow for the effects of differing array layouts to be measured, modelled and demonstrated. An increased understanding of the effects of array layouts on performance and loading will help push tidal energy towards commercialisation.

To investigate tidal array effects, three additional turbines were installed in Bluemull Sound, Shetland to expand the existing array of three original turbines. Tidal flow monitoring devices were installed alongside the turbines at various locations across the site. In addition, load and power performance measuring equipment was installed onto the turbines. The combination of the data streams from installed sensors, alongside modelling work, has provided insights into array effects. These insights have influenced the placement of the second set of three turbines in the array and will further inform the layout of future tidal arrays.

The original three turbines in place on the site at the outset of the EnFAIT project were the Nova Innovation M100 turbines, with the additional three installed being a newer model; the M100-D. Both turbine models are rated at 100kW with a 9m and 8.5m rotor diameter respectively. Turbine 4 was installed in 2020, with turbines 5 and 6 being added to the array in 2023.

Figure 1 Nova M100-D turbine (Nova Innovation, 2021)

1.3 Purpose

This document presents the results and emerging findings for the Array Interaction Model (AIM) study from operation of the full six turbine EnFAIT array on the site at Bluemull Sound, Shetland. This report is to be submitted to satisfy deliverable D10.9 of the EnFAIT project and to be also made available for public dissemination.

Array Interaction Model findings are presented and instrument deployments carried out to further develop and validate the model are discussed. The results of deployments carried out since deliverable D10.8 (EnFAIT, 2021) are summarised. These were used to further investigate site behaviour and inform greater understanding of tidal turbine array effects.

Details of the deployment of a blade strain gauging system and analysis of the data are presented, along with the installation of a horizontally facing Acoustic Doppler Current Profiler (ADCP) onto the nacelle of turbine T4 to gather in situ flow measurements. Results of a Vessel Mounted ADCP (VMADCP) survey carried out earlier in the project are also presented, which focus the measurement of turbine wake paths across the Bluemull Sound site. Further array behaviour findings will be discussed in deliverable D10.10.

2 Instrument Deployments

Various instrument deployments were carried out in the latter stages of the EnFAIT project to gather additional datasets to further increase understanding of array interaction behaviours and further validate the Array Interaction Model. The deployments detailed in this section gathered data to compliment that collected in previous measurement campaigns.

2.1 Blade Strain Gauges

2.1.1 Installation and Calibration

A Fibre Bragg Grating (FBG) strain gauging system was installed on the blades of turbine T3 to gather in-situ blade loading measurements during normal operation. The system utilised optical fibre strain gauges with a standalone power source and data acquisition package to gather data at a high enough sampling frequency to observe turbulence features in the flow. The strain gauges installed in the blades were supplied by Smart Fibres.

Figure 2 Smart Fibres FBG sensor (Smart Fibres, 2023)

A SmartScan interrogator unit was utilised to operate the optical fibre system and process the gathered packages of light sent through the fibres.

Figure 3 Smart Fibres Smartscan interrogator (Smart Fibres, 2023)

Prior to the deployment of the strain gauging system on the EnFAIT site, a calibration process was carried out to establish a database of strain responses from the strain sensors under known applied loads. Forces were applied to the blades of T3 in flapwise orientation in the workshop, working up from zero to the maximum applied force in increments. After reaching the maximum applied force, the load was decreased back to zero in the same increments. The resulting response from the strain gauges on one of the blades can be seen in Figure 4. The database established of strains vs loads, can be referenced with operational measurements to assess blade loading during operation on site.

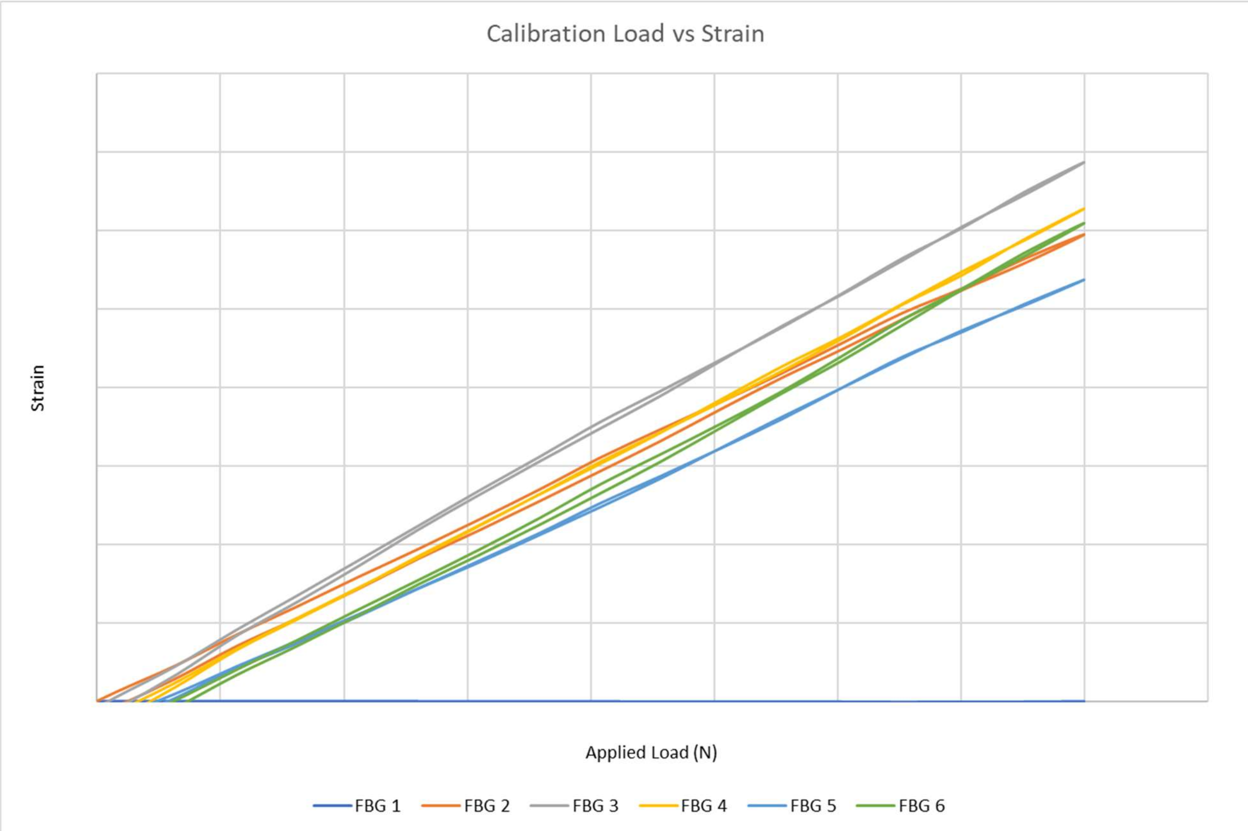

Figure 4 Calibration results for blade strain gauges

2.1.2 Operational Measurements

The final installation and deployment of the system on T3 took place in November 2020. After a period of in situ operation on the turbine, the data storage device used to capture the strain gauge measurements was recovered and the recorded data analysed.

Figure 5 shows the strain relationship with time for one side of one of the blades. FBG 2 lies closest to the blade root, working outwards chronologically to the blade tip. FBG 1 is a temperature sensor, so its reading remains fairly constant with time compared to the other sensors.

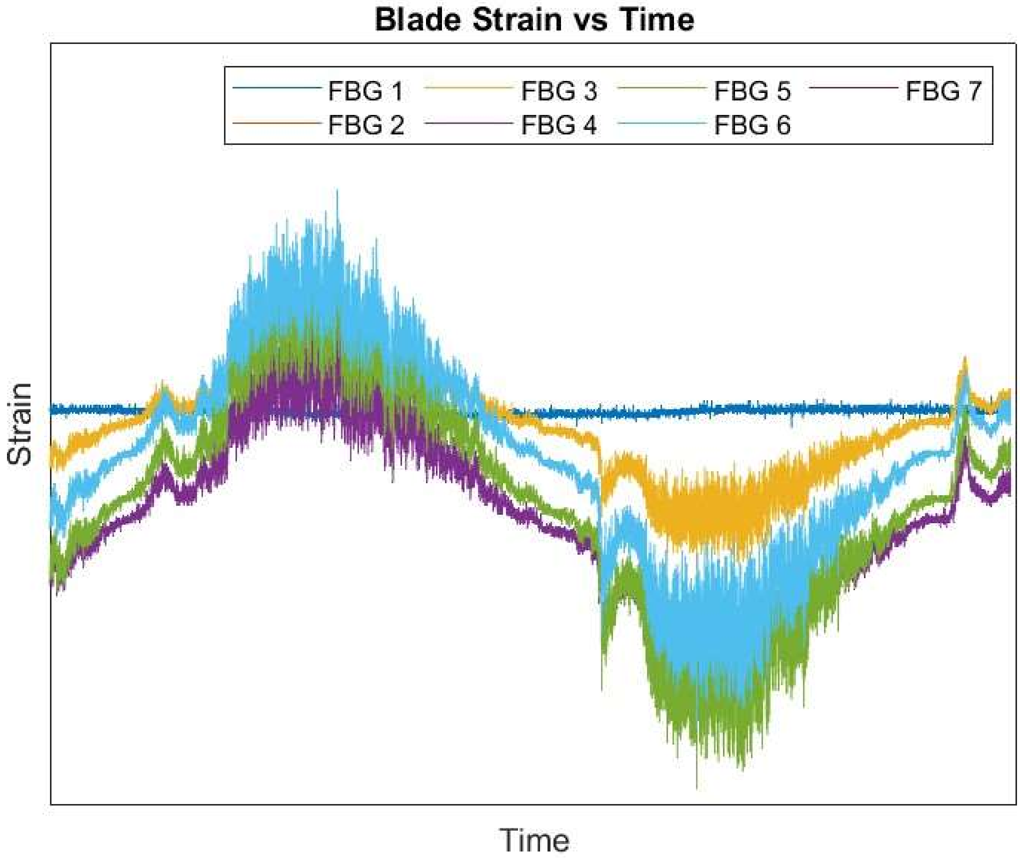

Figure 5 Blain strain with time for 12-hour period

Over the 12-hour period shown the strain follows a sinusoidal pattern which is to be expected, with one full flood and ebb tide occurring across the time window. Another clear pattern that can be seen is the unusual bumps in the signals that happen as the strain gradually increases, before decreasing and increasing again up to the maximum strain. This pattern is one which closely matches that observed in the flow speed measurements in the site, where the flow speed gradually increases from slack tide, before decreasing and then increasing again up to the maximum flow speed. It has been postulated that this behaviour occurs due to the emptying of a nearby bay during the movement of the tide, causing an increase and decrease in flow speed through the Bluemull Sound channel over a short period of time whilst the tide builds to its peak flow speed. The observation of this behaviour in the strain signals indicates that the dataset gathered by the strain gauges is representative of the loading on the blades during operation.

Another observation of the data is that there appears to be a lot of noise in the strain signals. This could be influenced by various factors, including the strain gauging system itself, vibrations from the turbine, or most likely fluctuating forces induced by turbulent flow over the blades. Further work is to be carried out to investigate the cause of this noise. A spectral analysis will be performed to identify primary frequencies at which this noise is present. This should help in identifying the sources of the noise, which will allow the signal to be cleaned and a clearer picture of the true magnitude blade loading with time to be painted. This in turn will allow a deeper understanding of turbine loading to be developed, which will feed into future turbine design and component lifetime predictions.

2.2 Nacelle mounted ADCP

2.2.1 Installation Details

A Nortek Signature 500 ADCP was installed onto turbine T4, with the instrument facing southwards to measure inflow during ebb tides and the wake of T4 during flood tidal flow. The deployment of the ADCP aimed to measure three main things:

- T4 inflow during ebb tides to further validate the tidal flow speed predictions across the site and confirm that the flow speeds used in the Array Interaction Model are representative of real site conditions.
- The wake of T4 during flood tides. Directly measuring the wake of T4 will allow for an increased understanding of turbine wake characteristics immediately downstream of the turbine. During the deployment, the turbine was also powered off and on during a maximum flow speed period to allow the observation of the effects of turbine operation on the wakes produced.
- The wake of the T3 turbine during ebb tides. It was hoped that the wake of T3 could be observed in the measurements, allowing increased understanding of array wake behaviours.

The ADCP was deployed in February 2022 and subsequently recovered during the Autumn of 2022 after a period of operation.

Figure 6 shows the Nortek Signature 500 ADCP mounted to the rear of the T4 nacelle prior to turbine deployment.

Figure 6 Nacelle ADCP mounted on rear of nacelle prior to deployment

The area of measurement south of T4 captured by the nacelle ADCP is shown in Figure 7.

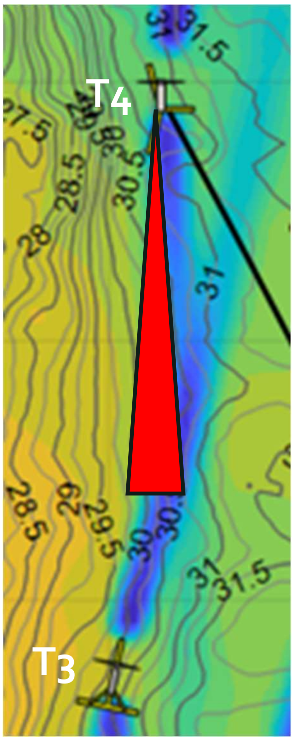

Figure 7 Nacelle ADCP flow measurement area

2.2.2 Measurement Observations

Figure 8 shows turbines 1-6 in the array with depth and flow speed overlaid from the numerical model. The northernmost turbine, T4, has lines plotted indicating the positions of three of the five ADCP beams from nacelle mounted ADCP.

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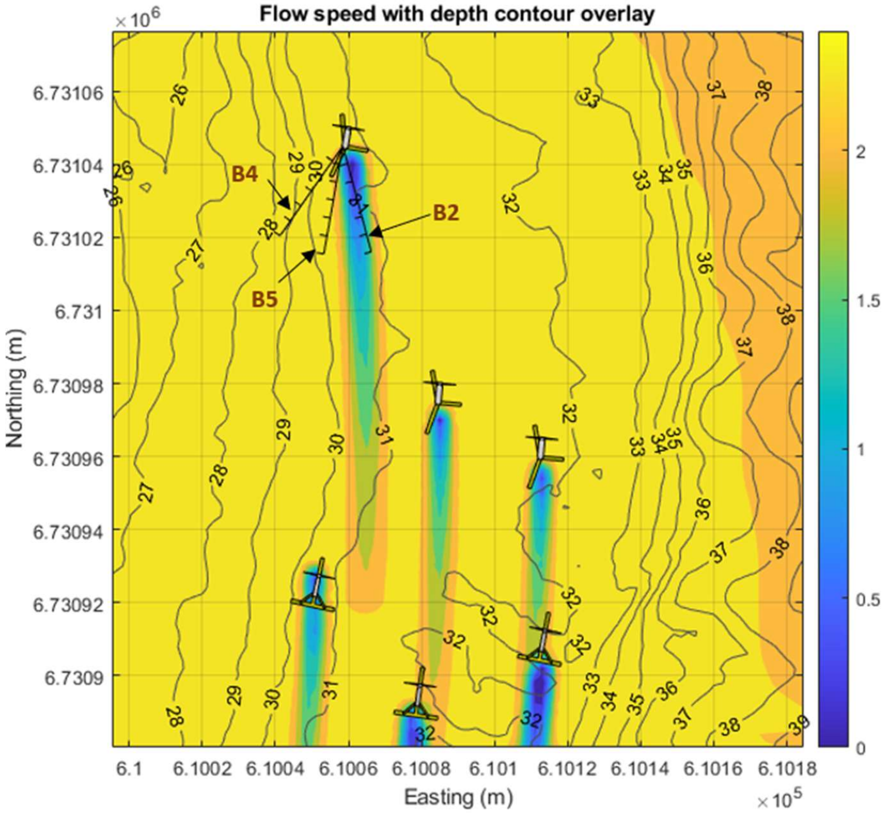

Figure 8 Beams from T4 nacelle ADCP. Turbine array with depth and flow speed from numerical model

Of all of the beams, beam 2 points most directly into the wake of T4 during flood. Velocities along the beam paths were plotted, shown in Figure 9, and compared to velocities predicted for the same locations in the numerical model.

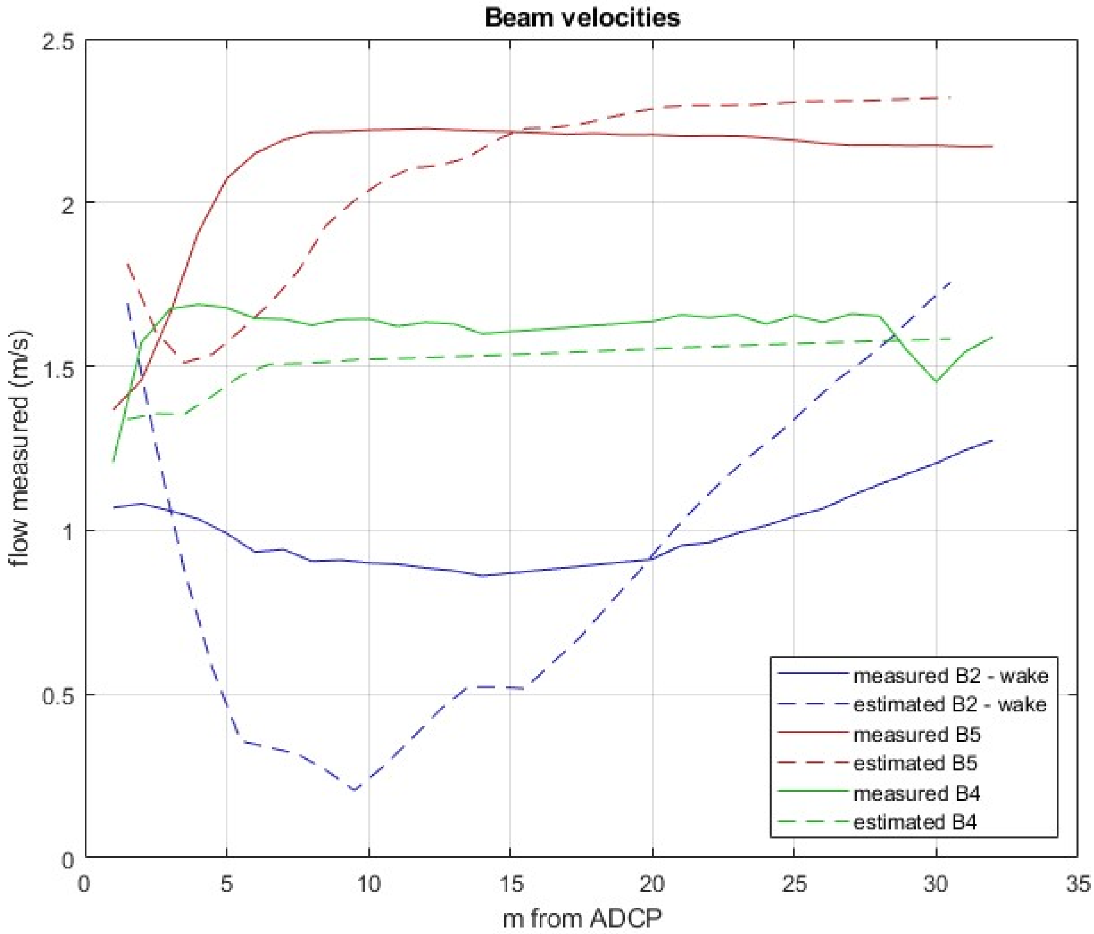

Figure 9 Along beam velocities plotted against numerical model velocity estimates

For tidal flow that passes around the sides of the turbine, good correlation can be seen between the measured and predicted flow speeds. However, the current wake model overestimates near turbine wake deficit and underestimates far field wake deficit, as show in the beam 2 blue lines. The next iteration of the Array Interaction Model will be adjusted and fine-tuned to address this disparity.

2.3 VMADCP Survey

2.3.1 Survey Equipment

In February 2021 a vessel mounted ADCP survey was carried out on the EnFAIT site to observe turbine wake behaviours and characteristics during array operation. The Nortek VMADCP Coastal system used comprised of a GNSS unit, data storage and processing system, and Signature 1000 ADCP to gather water column flow measurements across the site. The system was mounted onboard a survey vessel, with the ADCP suspended over the side of the vessel on the end of an extendable pole. The pole was extended during survey runs to place the ADCP in the water over the side of the vessel, facing downwards through the water column.

Figure 10 Nortek vessel mounted current profiler - Signature VM Coastal (Nortek Group, 2023)

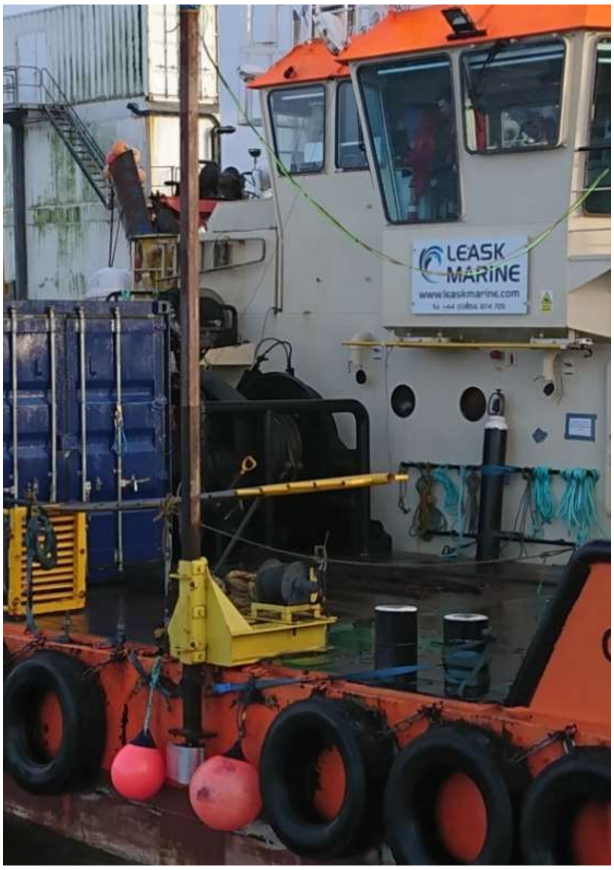

Figure 11 Signature VM Coastal system mounted onboard the survey vessel

The survey campaign took place over a period of five days from 21st to 25th February 2021 and across that period, various survey runs were carried out to gather flow measurements during flood and ebb tides. Two different techniques were employed to gather measurements across the site, both focussed on capturing measurements of specific wake behaviours. Drifting runs were carried out where the survey vessel was allowed to drift across the site from upstream of the turbines to far downstream to capture wake measurements along their length. These runs were utilised to observe wake recovery downstream of the turbines and to capture wake paths on the site. Drifting with the tide rather that actively powering across the site minimised the noise interference of the vessel motor with the ADCP acoustic measurements, minimising interference and maximising the quality of the data measured. On other survey runs, the vessel was kept in place by mooring lines to gather measurements at single points over periods of time. This technique focussed on capturing single point wake measurements over a longer period.

Another wake survey was carried out in mid-April 2023 to study array wakes with T5 and T6 installed. This survey focussed on turbine wakes in the area between T1-3 and T5 and T6 to investigate wake interactions with the turbines deliberately closely spaced. The locations of T1-6 relative to each other across the EnFAIT site are shown in Figure 12. The data gathered from this survey will be analysed in the remaining months of the project to gather insights into array interactions with close turbine spacing.

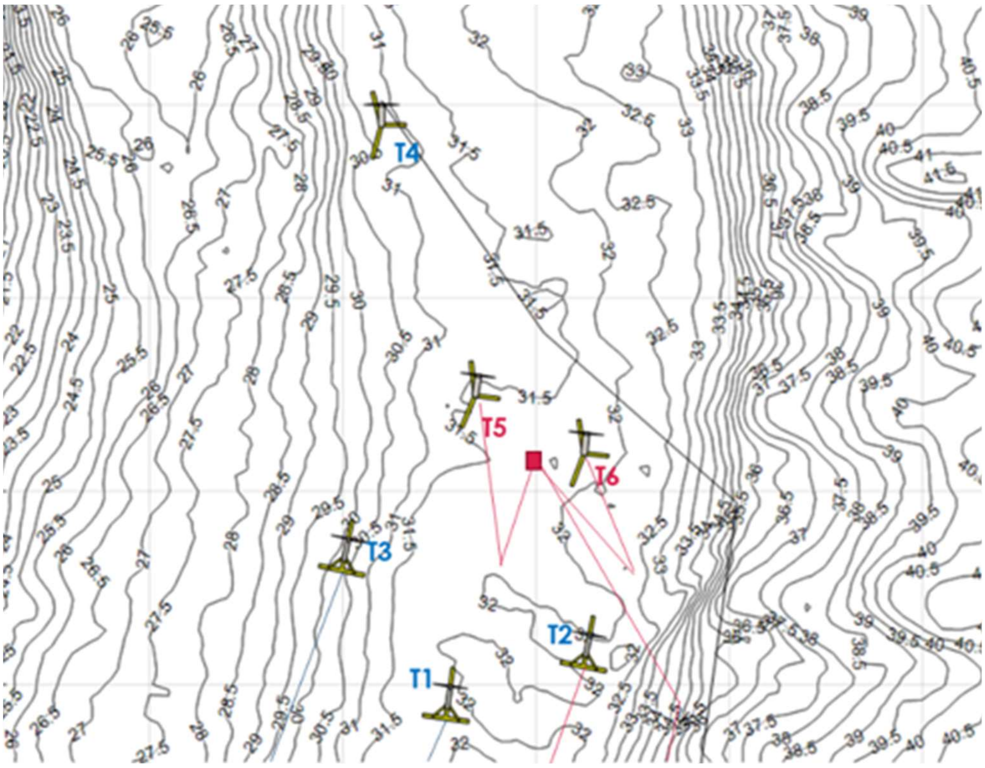

Figure 12 T1-6 locations on EnFAIT site

2.3.2 Observations

A visualization of the data gathered from the VMADCP survey can be seen in Figure 13. Wakes can be seen on the left side of the image, with the blue colour indicating slower flow speeds than the yellow. The deficit can be seen on multiple transects during the survey.

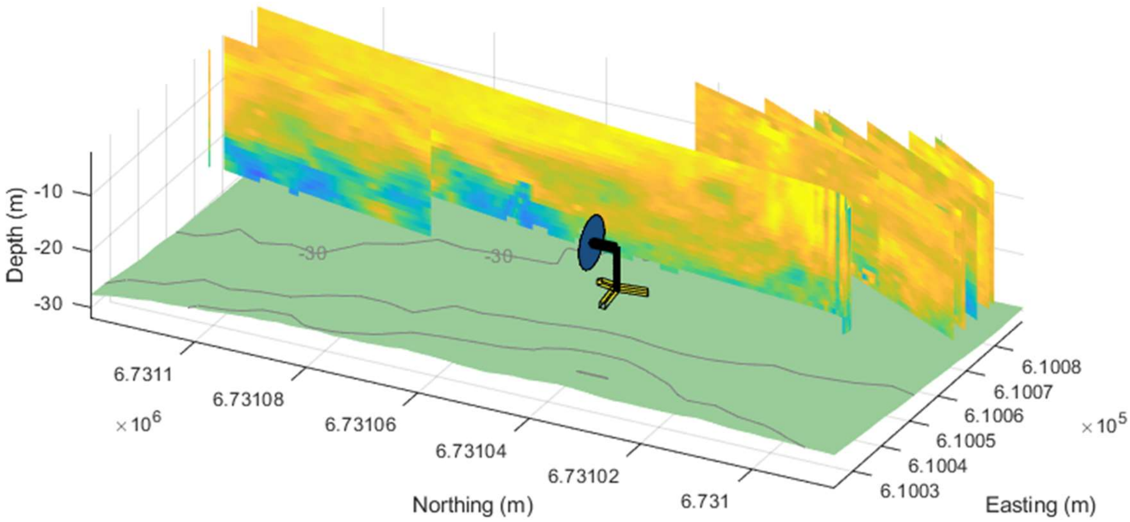

Figure 13 Overview of vessel mounted ADCP survey run

Taking a single transect during the survey where the vessel passed directly over T4, the plot shown in Figure 14 was produced.

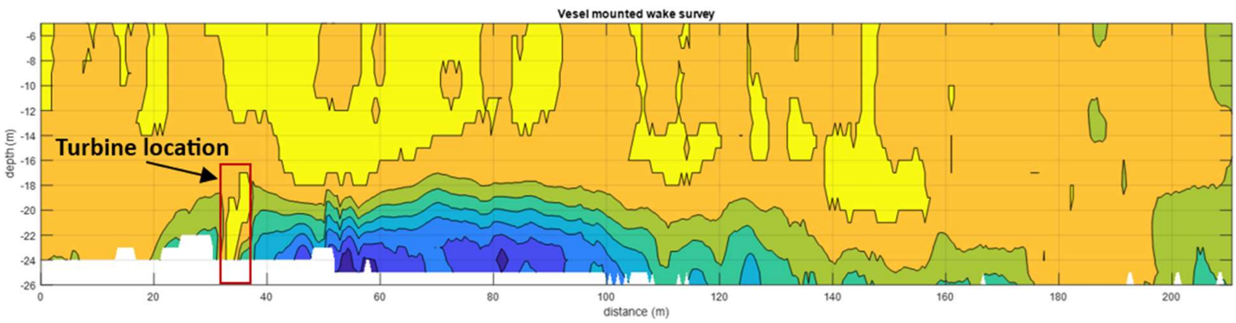

Figure 14 Velocity from single transect during VMADCP survey

With the flow passing from left to right on the plot, the blue velocity deficit, or wake, can clearly be seen behind the turbine. The deficit remains for a distance behind the turbine before gradually mixing with the surrounding flow and recovering to the environmental flow speed.

3 Array Interaction Model

With the Array Interaction Model being further validated using various datasets from site instrument deployments, the model was utilised to inform decisions on turbine placement in the latter stages of the project, as well as being further run and improved to provide accurate array behaviour predictions for the most recent array layout.

3.1 Placement of T5 and T6

The EnFAIT Shetland tidal array was expanded in early 2023 from a four-turbine array to a six-turbine array with the addition of T5 and T6. The location of these additional two turbines was set through the consideration of many different factors, including flow speed and direction, site bathymetry, cable routes and wake paths of the existing turbines. The Array Interaction Model was utilised to inform the placement of these turbines through the wake and flow estimates it provided, showing itself to be a highly valuable tool in optimising tidal array layouts. At this stage in the project, the array spacing between T5 and T6 and the original row of turbines was deliberately made small to enable the observation of close array effects.

The locations of T1-6 in the current array layout are shown in Figure 12 of the previous section.

3.2 Updated Array Wake Predictions

With the addition of T5 and T6 to the array, the Array Interaction Model was re-run to provide updated estimates of wake paths across the site. These predictions will be further assessed and validated through comparison with the flow data gathered in the April 2023 VMADCP survey. Updated velocities and wake path predictions are shown in Figure 15.

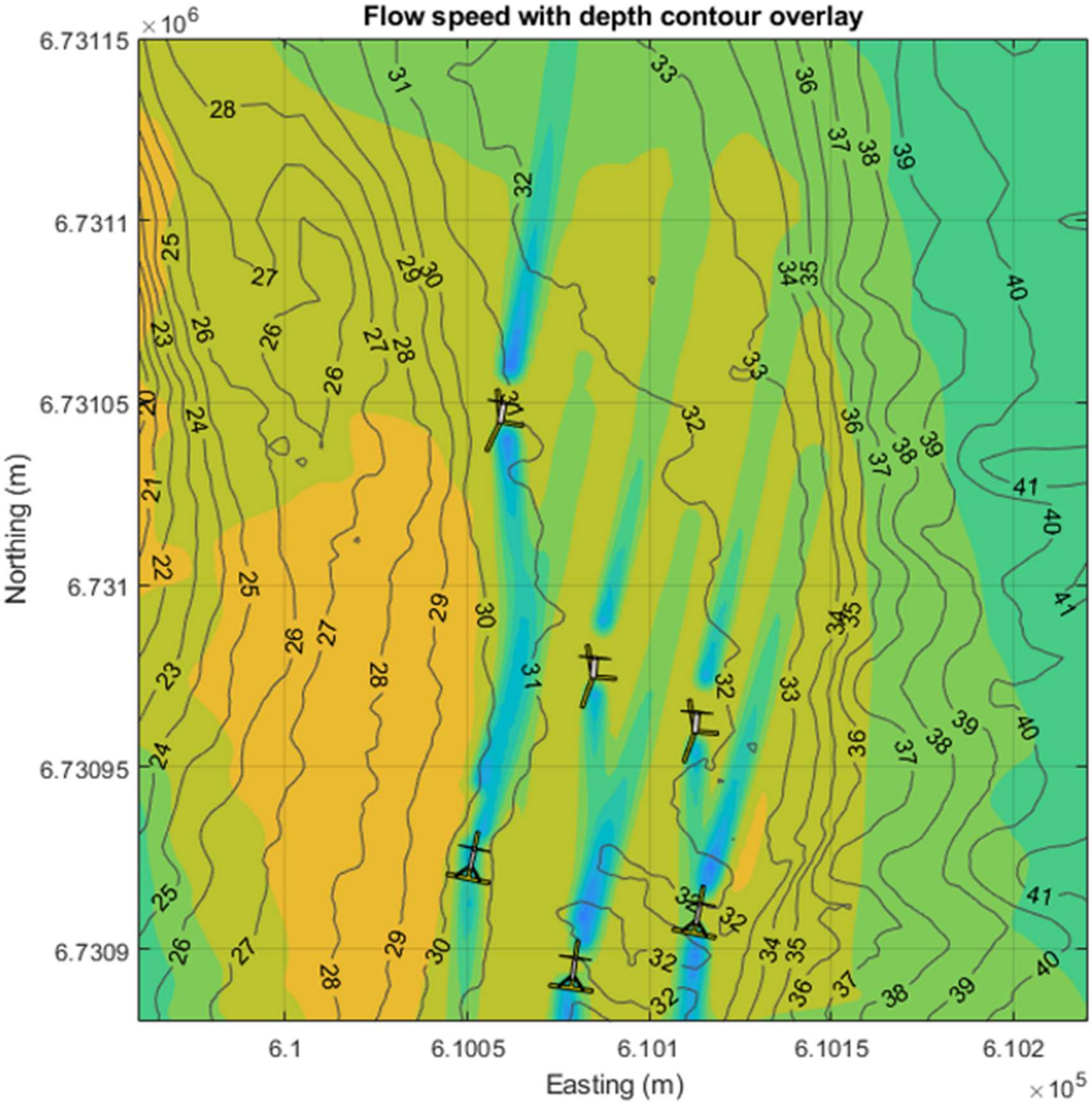

Figure 15 Wake paths and velocities across EnFAIT site with T1-6 installed

4 Further Work

As the close out of the EnFAIT project approaches, various pieces of further analysis work will be carried out to inform the final array interaction observations. These will serve as the concluding array interaction outputs of the projects and will be available to influence the placement of future tidal arrays.

Further analysis work to be carried out includes:

- Spectral analysis of blade strain gauging data to identify turbulent loading frequencies. Cleaning of the strain gauge signals to allow accurate loading observations to be made.
- Comparison of turbine power performance pre and post T4-6 installation to assess array and wake effects on turbine power output.
- Analysis of VMADCP survey results gathered in the April 2023 campaign to observe turbine wakes with the new array layout. These results will be compared against the Array Interaction Model to further validate the model with the now closer turbine placements.
- Updating of Array Interaction Model wake prediction to more closely match wake behaviour observed in the nacelle ADCP wake data.

The outputs of these further analyses, along with key array interaction observations throughout the project, will be presented in deliverable D10.10 at the close out of the project.

5 References

EnFAIT. (2021). *D10.8 - Array Interaction Model (AIM) T1-4 Operational Report.* EnFAIT Enabling Future Arrays in Tidal.

Nortek Group. (2023, 04 18). *VM Coastal (1000/500/250 kHz)*. Retrieved from Nortek Group: https://www.nortekgroup.com/products/signature-vm-coastal

Nova Innovation. (2021, November 25). *Government gives the green light for a blue energy revolution*. Retrieved from Nova Innovation: https://www.novainnovation.com/news/news_/i/government-gives-the-green-light-for-a-blue-energy-revolution/

Smart Fibres. (2023, April 18). Retrieved from https://www.smartfibres.com/products/smartfbg

Smart Fibres. (2023, April 18). Retrieved from https://www.smartfibres.com/products/smartscan

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