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ENFAIT

ENABLING FUTURE ARRAYS IN TIDAL

T1-3 Operations Report:

Performance and Progress of the Shetland Tidal Array



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Executive Summary

This report summarises the results and key achievements of the three original Nova M100 turbines on the Shetland Tidal Array (STA), now operated under the Enabling Future Arrays in Tidal (EnFAIT) project. Turbines T1, T2 and T3 (Ailsa, Betty and Charlotte) were deployed in 2016 and 2017. The EnFAIT project began in July 2017, with the development of a programme to identify a package of upgrades based on the initial operation of the turbines in the array. The upgrades were fully implemented and have significantly improved the performance of the turbines. This analysis covers the performance of the turbines up to May 2020. Key achievements include:

Record-breaking performance	The Shetland Tidal Array has had its best performing year to date, setting new records for availability, generating hours and output. For the 12 months from June 2019 to May 2020, Nova's three turbines clocked up more than 14,000 operating hours and generated 469 MWh of electricity. Performance will continue to show big improvements as Nova's new direct drive turbines are deployed in Shetland and the enhanced technology is installed in more energetic sites.
Reduced operation & maintenance costs	For the first time, Nova undertook annual maintenance on all three of the turbines at the same time. The three turbines were removed from the sea, serviced at Nova's Edinburgh workshop, and redeployed in the array within a three-week period in May 2019. This has slashed operational costs by 50%.
Extended Service Intervals	The array achieved and exceeded its annual service target, running for more than 12 months since the previous service in May 2019. With this strong performance, Nova has now extended the interval between scheduled maintenance interventions on this, the world's first tidal array. The longer the turbines are able to operate without the need for servicing, the lower the cost of tidal energy.
Improved capacity factors	Bluemull Sound is a moderately energetic 'Tier 2' site. The capacity factors of the original three M100 turbines have improved year on year during the EnFAIT project and now consistently exceed 20%. Nova has used the learnings from EnFAIT to design a new direct drive turbine, the M100-D. This new turbine (T4) is forecast to achieve a capacity factor greater than 30% at Bluemull Sound. The new turbine will achieve even higher capacity factors at more energetic "Tier 1" sites: a capacity factor greater than 50% is forecast at Petit Passage in Canada. This is substantially higher than solar and onshore wind.
Ability to retrieve in all conditions	Operations to recover and redeploy the turbines have been carried out in spring tides, the strongest tides in the tidal cycle. This shows that operations to retrieve turbines can be undertaken any day of the year. This is believed to be a first for the tidal sector. Bluemull Sound (like many other tidal sites) is also relatively sheltered from the wind, meaning weather downtime is reduced compared to offshore wind.
Anti-fouling coatings	New anti-fouling blade coatings have improved the performance of the rotor. Further research is being undertaken to apply coatings to other areas.

These achievements demonstrate the significant impact the EnFAIT project is having on improving turbine performance and reducing costs. This landmark project is clearly helping to make tidal energy mainstream.

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I The Project

1.1 Introduction

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 call *LCE-15-2016: Scaling up in the ocean energy sector to arrays* to generate significant learning through demonstration of cost-effective tidal arrays.

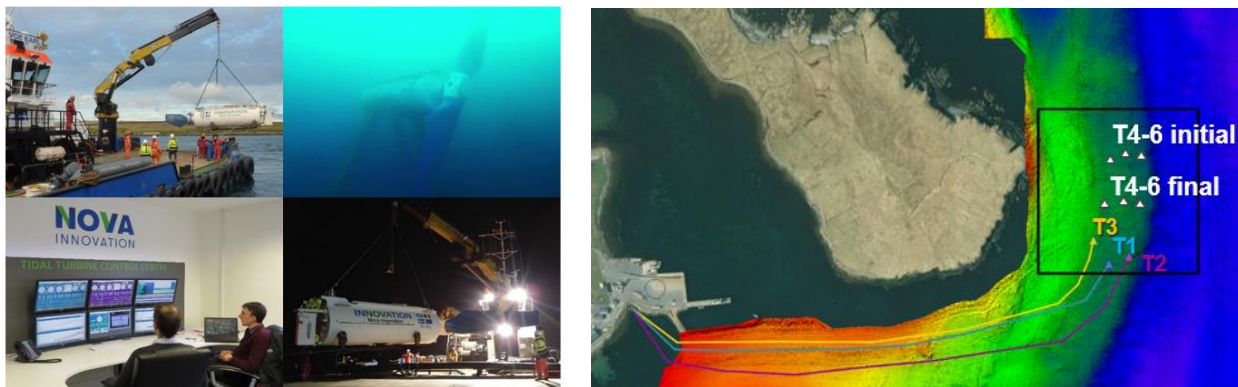


Figure 1-1: STA Operations and indicative site layout

EnFAIT is a 5-year, €20m project to lower the cost of tidal energy through learning and by doubling the capacity of Nova Innovation's Shetland Tidal Array, from three to six turbines. The turbines will also subsequently be repositioned in the array, to study wake impacts on generation and cyclic loadings downstream, validating an Array Interaction Model.

This document reports on operation of the T1-3 Shetland Tidal Array turbines prior to T4 deployment, based on analysis of data collected in two earlier activities – T6.2 (Operate two of the original turbines) and T6.5 (Operate the upgraded turbines). This document is related to deliverable D6.4 of the EnFAIT project and is made available for public dissemination. See Figure 1-2.

	2017				2018				2019				2020				2021				2022		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	
	Initial operations				Operation of upgraded turbines								Operate expanded array		Operate full array								
	D6.4 T1-T3 Operations Report												D6.5 T1-T4 Ops Report		D6.6 T1-6 Initial Report		D6.7-Interim D6.8-Final						
T1					Implement upgrades																		
T2																							
T3																							
T4																							
T5																							
T6																							

Figure 1-2: High level overview of EnFAIT project phases

1.2 The Shetland Tidal Array (STA)

The three Nova M100 tidal turbines (T1-3) each have a horizontal axis two-bladed rotor with a gearbox and medium voltage induction generator (Figure 1-3). The nacelle and rotor are mounted on top of a steel tripod substructure with additional concrete ballast. The whole assembly rests on the seabed under its own weight (no drilling is required) and each turbine is connected to a shoreside transformer by a subsea electrical cable. To give an idea of scale, the rotor diameter from tip to tip is 9m, the length of the nacelle is approx. 7m and the nacelle sits approx. 9m above the sea-bed. Nova Innovation began operating this, the world's first fully operational and grid connected tidal energy array, in 2016. Since then, the company has gained a wealth of world-leading operational experience through array operations and EnFAIT-related research and development work.

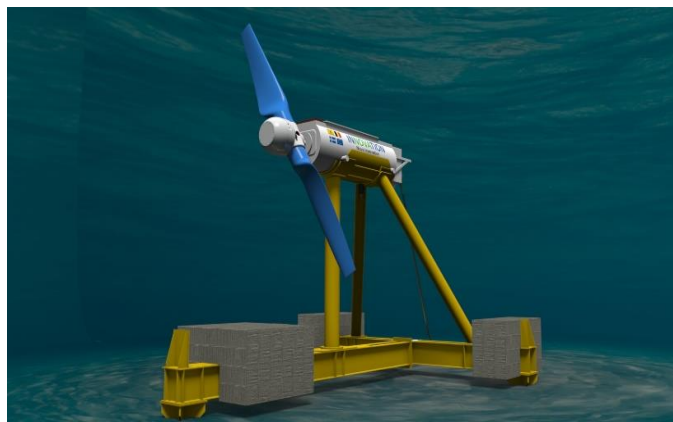


Figure 1-3: Nova M100 Basic Architecture

Three Nova M100 turbines have been installed and operated in the Shetland Tidal Array (STA), powering local homes and businesses in Shetland for more than four years. The array is in Bluemull Sound, which lies between the islands of Yell and Unst in Shetland (Figure 3). Bluemull Sound is an excellent location for a tidal energy project, with characteristic maximum current speeds of 2.5m/s, good shelter from the prevailing wave and wind directions and a good quality pier at Cullivoe harbour on Yell, within one kilometre of where the turbines are deployed.

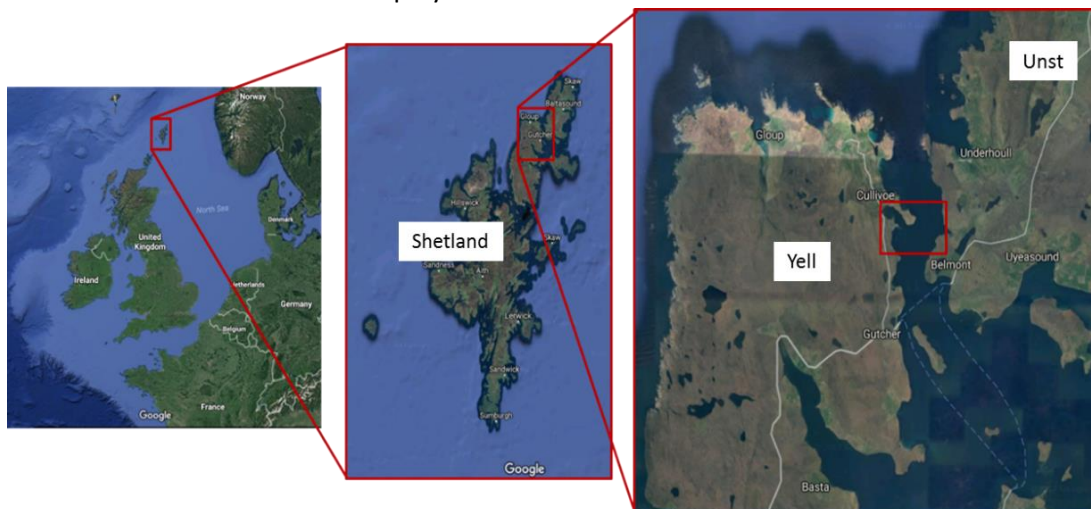


Figure 1-4: Bluemull Sound Location

1.3 Scope of this report

The purpose of this document is to report on the operation of the T1-3 turbines prior to T4 deployment, based on analysis of data collected in T6.2 and T6.5. These tasks are listed below for reference.

- **T6.2 Operate two of the original turbines**

Collect operational data and report key performance indicators to provide a baseline for comparison with the improvements delivered through the project. Co-ordinate with WP10 (Validate array modelling tools) to ensure quality data are provided for resource assessment and turbine wake measurement purposes. Provide information to WP9 (Optimise array reliability, maintainability & availability) to inform the array spares strategy based on operational learning. Recover one nacelle and deliver its drivetrain components to WP9 for forensic analysis.

- **T6.5 Operate the upgraded turbines**

Install and operate turbines T1-3 at Bluemull Sound and collect data from the new instrumentation. Continue to record and report key performance indicators for the turbines and the array. Co-ordinate with WP10 to ensure quality data are provided for wake modelling and performance assessment purposes, including the installation of any stand-alone instrument packages on the seabed. Recover and redeploy turbines for maintenance in accordance with the test plan and in response to any unplanned failures. Capture learning from operational experiences which can be used to optimise array design and layout.

2 T1-3 Operations Overview

Turbines T1, T2 and T3 (Ailsa, Betty and Charlotte) were deployed on the Shetland Tidal Array (STA) in 2016 and 2017. The EnFAIT project began in July 2017 and as per the EnFAIT test plan, initial array operations informed the development of a range of upgrades, which were implemented in 2018. Following the completion of the EnFAIT turbine upgrades, the three upgraded Nova M100 turbines (T1–T3) were redeployed and installed on the seabed. The turbines were then retrieved for their annual scheduled maintenance intervention in May 2019 and then redeployed. See Figure 2-1.

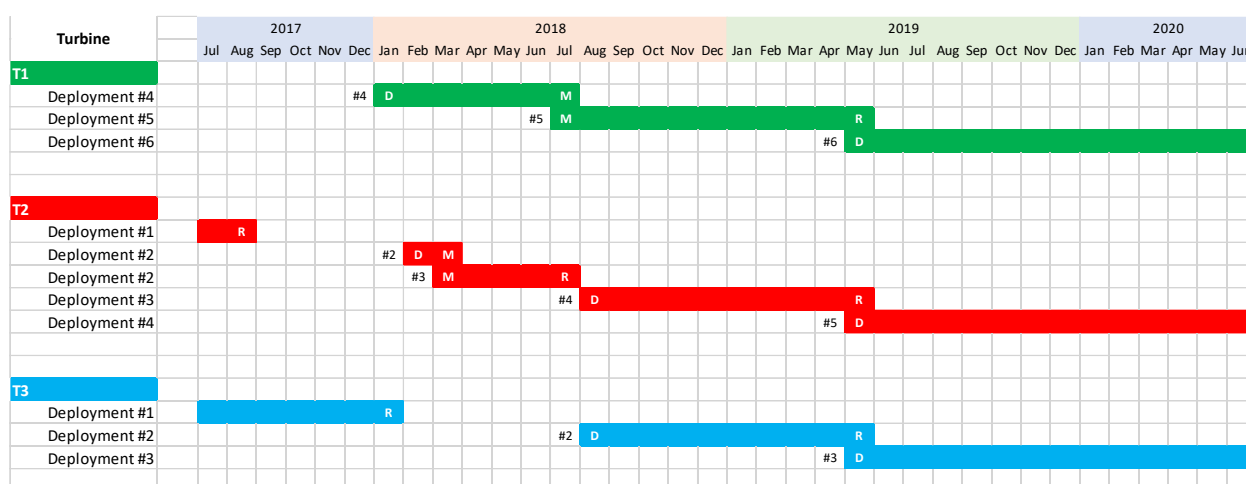


Figure 2-1: T1-3 turbine deployments during the EnFAIT project, prior to T4 installation

Over this period the key achievements have been:

- Record performance since EnFAIT upgrades:
 - Total annual power production from the Shetland Tidal Array has more than doubled compared to performance before the EnFAIT upgrades.
 - Turbine availabilities are now consistently over 85%
 - The time between offshore maintenance intervals has increased by 50% compared to the first EnFAIT deployments
- These figures demonstrate that tidal energy has now moved beyond the prototype stage towards becoming an investable asset class.
- M100 (T1-3) turbine capacity factors of >20%, with the M100D (T4) model expected to achieve >30% in Bluemull Sound ("Tier 2" site) and capacity factors >50% in "Tier 1" commercial locations such as Petit Passage in Canada. These high capacity factors demonstrate great advantage over solar and onshore wind in terms of energy delivery versus installed capacity.
- The M100 (T1-3) turbines are each supplying power for around 40 homes on average, with the M100D model expected to supply >60 homes when deployed in Bluemull and >100 in more energetic "Tier 1" locations currently being developed worldwide. This demonstrates the potential for Nova's modular and scalable technology to be power communities across the world.
- A comprehensive programme of data gathering and modelling by EnFAIT partners means that the STA is likely now the world's best characterised tidal array. With the installation of an additional three turbines (T4-6), Nova will become the first company to operate an optimised tidal array.

- In May 2019, Nova carried out a three-turbine “pit stop” in record time, reducing operational costs by 50% by completing workshop maintenance and significant planned EnFAIT upgrades on three turbines, then redeploying. Required service intervals are rapidly decreasing as reliability increases: driving down the cost of energy.
- Offshore operations to recover and redeploy the turbines were carried out in spring tides, expanding the window of workable conditions and therefore reducing downtime: turbine recovery during spring tides is believed to be a first for the tidal sector and is an important component of reducing the cost of energy.
- Load and performance data were continuously recorded and informed improvements to the Nova turbines and array architecture, as well as to the development of design tools such as ORE Catapult’s Array Interaction Model (AIM), which characterises turbine wakes and their impact on downstream devices in order to optimise tidal array design.
- Physical modelling and data driven analyses were used to evaluate the effectiveness of Condition Monitoring System (CMS) upgrades and to develop new variables to use as CMS performance indicators, enabling early identification and prevention of fault modes that reduce production.
- The impact of biofouling on turbine performance has been studied in more detail than ever before, and specialist materials have already been proven to reduce these issues to zero between maintenance periods of >2 years: a further operational cost saving, coupled with improved blade performance to reduce cost of energy further.
- Many positive and negative hazard observations and best practice suggestions have been (and continue to be) recorded on Nova’s Safety Management System. There have been zero lost time or RIDDOR-reportable safety incidents associated with EnFAIT and the STA.

3 Key Performance Indicators (KPIs)

This section outlines the EnFAIT approach to reporting KPIs from the Shetland Tidal Array.

Through work with ORE Catapult's data team, the WP6 KPIs have been defined and systems created to report KPIs automatically from operations data, adapting principles from a wind industry standard (IEC TS 61400-26-1:2011) for use on tidal arrays.

3.1 Data sources

KPIs for the operation of the EnFAIT turbines on the Shetland Tidal Array utilise a range of different data sources, as shown below.

	Production	Reliability	Logistics	Overheads
	<ul style="list-style-type: none"> - Power generated - Operating hours - Capacity factor - Availability 	<ul style="list-style-type: none"> - Number of failures - Type of failures - Downtime - Restricted generation - Cost to repair - Resolved remotely / required offshore intervention 	<ul style="list-style-type: none"> - Marine ops mobilisations per year - Marine ops days per year - Cost per mobilisation - Vessel day rates 	<ul style="list-style-type: none"> - General ops spend - Insurance costs
SCADA system	✓	✓		
Quality observations log	✓	✓		
Health and Safety observations log	✓	✓		
Procurement system / ERP		✓	✓	✓
Marine operations log		✓	✓	
Control centre log	✓	✓		

Nova optimised three new cloud-based logging systems to digitise information from the following areas:

- **Quality observations** – e.g. component failures
- **Control centre operations** – e.g. operator interventions for fault-finding, software updates, etc.
- **Marine operations** – an overview of offshore maintenance interventions

Combining information from these three data sources and the Shetland Tidal Array SCADA allows Turbine KPIs to be analysed and reported: this includes all aforementioned metrics such as generating hours, capacity factor, number of failures requiring marine operations to resolve, etc.

3.2 Operative states

3.2.1 Definitions

Operating states were defined by adapting guidance from IEC TS 61400-26-1:2011 (Time-based availability for wind turbine generating systems) for tidal energy. See definitions below.

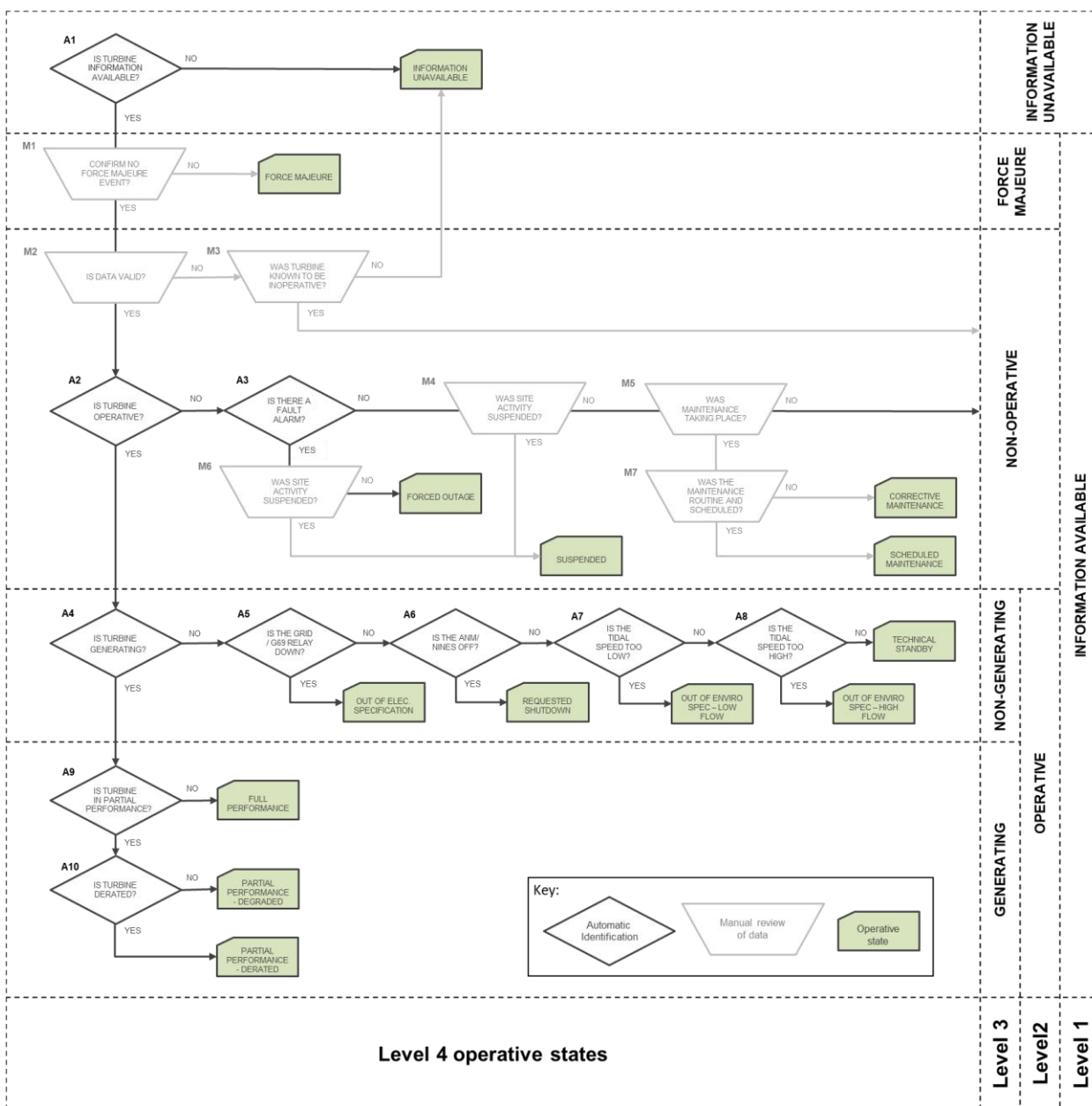
Level 1	Level 2	Level 3	Level 4	Example
INFO AVAILABLE (IA)	OPERATIVE (IAO)	GENERATING (IAOG)	FULL PERFORMANCE (IAOGFP)	
			PARTIAL PERFORMANCE – DERATED (IAOGPPDR)	Commissioning / throttling due to grid curtailment
			PARTIAL PERFORMANCE – DEGRADED (IAOGPPDG)	Throttling to reduce loads
		NON-GENERATING (IAONG)	TECHNICAL STANDBY (IAONGTS)	
			OUT OF ENVIRONMENTAL SPEC - LOW FLOW (IAONGENLF)	Tidal flow insufficient for turbine cut-in
			OUT OF ENVIRONMENTAL SPEC - HIGH FLOW (IAONGENHF)	Tidal flow beyond turbine cut-out
			REQUESTED SHUTDOWN (IAONGRS)	Marine ops Software reboot Onshore site visit
			OUT OF ELECTRICAL SPECIFICATION (IAONGEL)	NINES / grid loss
	NON-OPERATIVE (IANO)	SCHEDULED MAINTENANCE (IANOSM)		
		PLANNED CORRECTIVE MAINTENANCE (IANOPCA)		Retrofit / upgrade / other
		FORCED OUTAGE (IANOFO)		Response / diagnostic
		SUSPENDED (IANOS)		
	FORCE MAJEURE (IAFM)			
INFORMATION UNAVAILABLE (IU)				

Both types of production-based availability were estimated in accordance with IEC TS 61400-26-2:2014 (BSI, 2017).

These operative states can then be used to calculate KPIs such as downtime, generation hours and production-based availability. As can be seen from the flow chart above, there are some operative states that require manual review of data to identify. While this is likely to remain the case for the T1-3 turbines, the operating software for turbines T4 onwards has been designed so that the need for data to be reviewed manually can be reduced and, where possible, eliminated.

3.2.2 Identification

Operative states were identified using the following logic developed by Nova, which contains a mix of automatic and manually generated inputs.



3.3 Turbine KPIs

The following KPIs can be reported for individual turbines:

- Turbine KPI 1: Generating hours
- Turbine KPI 2: Downtime
- Turbine KPI 3: Production
- Turbine KPI 4: Technical time-based availability
- Turbine KPI 5: Operational Time-based Availability
- Turbine KPI 6: Technical Production-based Availability
- Turbine KPI 7: Operational Production-based Availability
- Turbine KPI 8: Actual capacity factor
- Turbine KPI 9: Potential capacity factor
- Turbine KPI 10: Number of failures (total operations impact)
- Turbine KPI 11: Number of failures (partial operations impact)
- Turbine KPI 12: Number of failures requiring marine operations to resolve
- Turbine KPI 13: Number of forced outages
- Turbine KPI 14: Lost Production due to Major System Repairs
- Turbine KPI 15: Lost Production due to Major System Repairs
- Turbine KPI 16: Grid curtailment operational hours

3.4 EnFAIT array-level KPIs

Turbine KPIs can then be aggregated to report the following array level KPIs:

- EnFAIT KPI 1: Aggregated turbine generating hours
- EnFAIT KPI 2: Average turbine generating hours
- EnFAIT KPI 3: Aggregated turbine downtime
- EnFAIT KPI 4: Average turbine downtime
- EnFAIT KPI 5: Grid loss hours
- EnFAIT KPI 6: Production
- EnFAIT KPI 7: Technical Time-based availability
- EnFAIT KPI 8: Operational Time-based availability
- EnFAIT KPI 9: Technical Production-based availability
- EnFAIT KPI 10: Operational Production-based availability
- EnFAIT KPI 11: Actual capacity factor
- EnFAIT KPI 12: Potential capacity factor
- EnFAIT KPI 13: Total number of failures (total operations impact)
- EnFAIT KPI 14: Total number of failures (partial operations impact)
- EnFAIT KPI 15: Average number of failures per turbine (total operations impact)
- EnFAIT KPI 16: Average number of failures per turbine (partial operations impact)
- EnFAIT KPI 17: Total number of forced outages
- EnFAIT KPI 18: Average number of forced outages per turbine
- EnFAIT KPI 19: Lost Production due to Major System Repairs
- EnFAIT KPI 20: Lost Production due to Major System Repairs
- EnFAIT KPI 21: Number of offshore interventions
- EnFAIT KPI 22: Number of onshore interventions

- EnFAIT KPI 23: Number of manual restarts
- EnFAIT KPI 24: Vessel contract days
- EnFAIT KPI 25: Vessel mobilisation/transit days
- EnFAIT KPI 26: Vessel working days
- EnFAIT KPI 27: Vessel weather standby days
- EnFAIT KPI 28: Vessel technical standby
- EnFAIT KPI 29: Number of tidal slacks used for marine operations
- EnFAIT KPI 30: Number of dive team hire days
- EnFAIT KPI 31: Number of dives completed
- EnFAIT KPI 32: Number of Non-access Days Due to Weather
- EnFAIT KPI 33: Mean Time to Successful Remote Restarts

This detailed set of turbine and array-level metrics goes beyond what is required for evaluating strategic KPIs but should help identify performance and operational improvements. The practicalities and value of reporting each KPI are being evaluated as the project progresses.

3.5 Example results

The full set of KPIs are confidential and commercially sensitive. Some example results are shown below.

3.5.1 Operative states analysis

Figure 3-1 shows an example operative state analysis for an individual turbine.

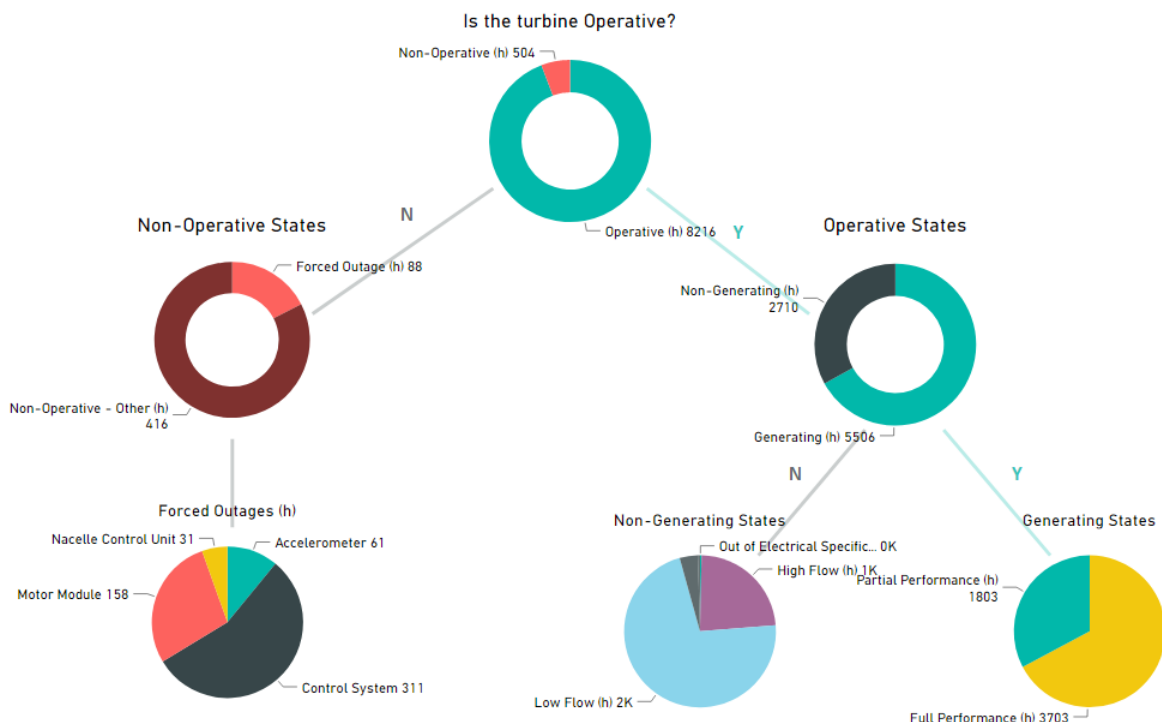


Figure 3-1: Operative states analysis for an STA turbine over a representative operational period

In this example period, the turbine has spent 6,009 hours in an operative state (where it was able to generate) and 572 hours in a non-operative state, which is to say that turbine availability was 91.3%. Of

the generation time, most hours are spent in full performance mode, with the turbine operating to its design power curve. The hours relating to partial performance are due to the turbine being throttled due to grid constraints or other factors. Non-operative time relates to grid loss events (forced outages) and a combination of control and component faults. The identification of operative states in this way has helped Nova to better understand performance and identify priority areas for improvement. On future commercial arrays, this sort of easily interpretable information will be invaluable to operators.

3.5.2 Turbine Production and KPI reporting

Figure 3-2 shows the production from an individual turbine over a 12-month period. Monthly totals for energy produced are shown in yellow, with lost production arising from partial performance shown in turquoise (note on the Shetland tidal array this is largely due to current local grid constraints), potential production from higher flow speeds shown in purple and forced outages and fault modes shown in light and dark red respectively. The grey band (Modelled vs. Real World Variance) arises from a) deviations between the modelled tidal data and the actual tidal conditions and b) averaging errors in the classification of operative states - primarily due to the fact that 5-minute averaged data is used in the analysis.

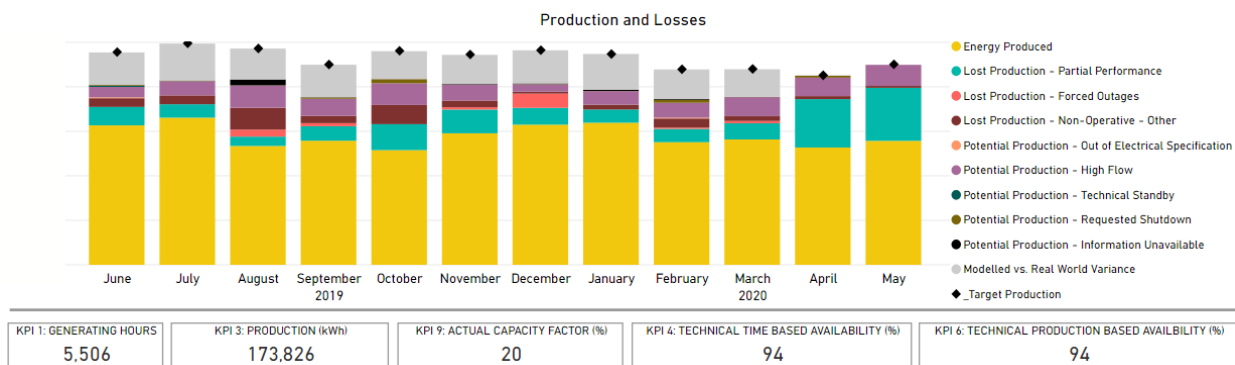


Figure 3-2: Example turbine production and KPI reporting

Bluemull Sound is a moderately energetic ‘Tier 2’ site. The capacity factors of the original three M100 turbines have improved year on year during the EnFAIT project and now consistently exceed 20%. Nova has used the learnings from EnFAIT to design a new direct drive turbine, the M100-D. This new turbine (T4) is forecast to achieve a capacity factor greater than 30% at Bluemull Sound. The new turbine will achieve even higher capacity factors at more energetic ‘Tier 1’ sites: a capacity factor greater than 50% is forecast at Petit Passage in Canada. This is substantially higher than solar and onshore wind.

4 Maintenance and additional upgrades

One of the major upgrades trialled on the T3 machine involved replacing a third-party dry-mate subsea cable connector with a new dry-mate connector designed by Nova, the “Nova-Can”. The period of array operations over the winter of 2018/2019 confirmed that the new connector was robust in operation and a success. Nova took advantage of a scheduled maintenance window in May 2019 to significantly upgrade the electrical connections on the two other turbines in a recovery and redeployment “pit stop” for all three turbines.



Figure 4-1: Turbine recoveries and redeployments, May 2019

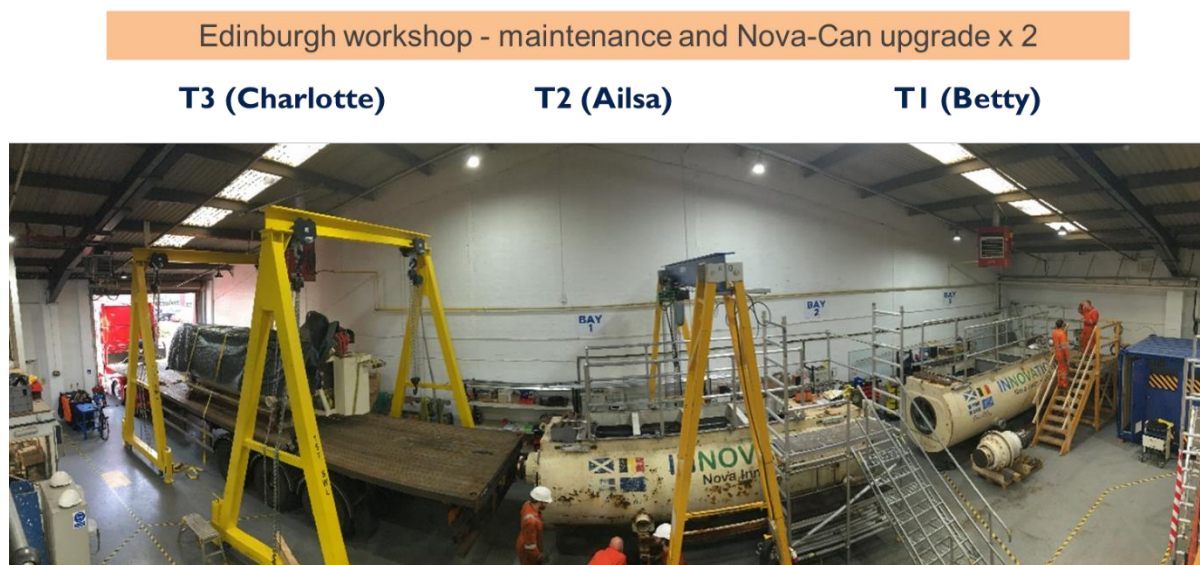


Figure 4-2: Three-turbine pit stop in Nova workshop, May 2019

Nova employed an Engineering Doctorate student to develop condition monitoring algorithms and system improvements, in partnership with SKF and the WP6 activities. This was based on a methodology that balances risk and cost reduction in condition monitoring system design and considered:

- Improved gearbox heat rejection prediction with measured efficiency.
- Development of algorithms, using data from upgraded EnFAIT instrumentation, to model quasi-static heat transfer using an empirical model of heat exchangers and a derived heat transfer coefficient as a condition indicator.
- Relationships between temperature and pressure data observed over time, with data divided into 3 sets corresponding to control system activity, resulting in an indicator of degradation based on the Root Mean Square Error of Cumulative Density Function of Kernel Density distributions

As a result of this work, one of the EnFAIT turbines was fitted with a package of additional sensors to better understand the performance of the turbine cooling system. Monitoring of the data from these sensors is ongoing.

4.1 Spares / consumed components

In order to implement the EnFAIT array spares strategy (as well as to streamline the manufacturing process ready for production quantities), Nova Innovation has moved from an R & D procurement system to a Production System. The work carried out in WP9 to understand spares-holdings and the need for planned-maintenance, has informed this transformation at every stage. The SKF planned-maintenance team have been consulted and informed about the progress within Nova of the ERP system. This supports the WP6 requirement to supply information to WP9 (Optimise array reliability, maintainability & availability) to inform the array spares strategy based on operational learning.

The information arising from EnFAIT forensic inspections and ongoing scheduled maintenance activity are being combined with the data gathered via Nova's quality system, to inform the ongoing development of the array spares strategy.

4.2 Subsea surveys

Subsea surveys have been used to confirm the condition of the deployed substructures, turbines and subsea cables. Surveys of the substructure feet have found some limited local sediment accumulation around the base of the substructures, but no scouring of concern.

Ongoing monitoring of Nova's double armoured cables has revealed that these are stable and robust under their own weight without additional protection.

4.3 HSE

There have been zero RIDDOR-reportable or lost time incidents during EnFAIT operations to date. Hazard observations (which can be positive or negative) and near misses are continually logged on the Nova Safety Management System and reported monthly.

5 Resource and Array Interaction Modelling

5.1 Measurements

Project partners OREC have now made multiple visits to Shetland to coordinate deployments of seabed ADCPs (Acoustic Doppler Current Profilers – see Figure 5-1) and substructure-mounted instrumentation skid deployments (Figure 5-2).

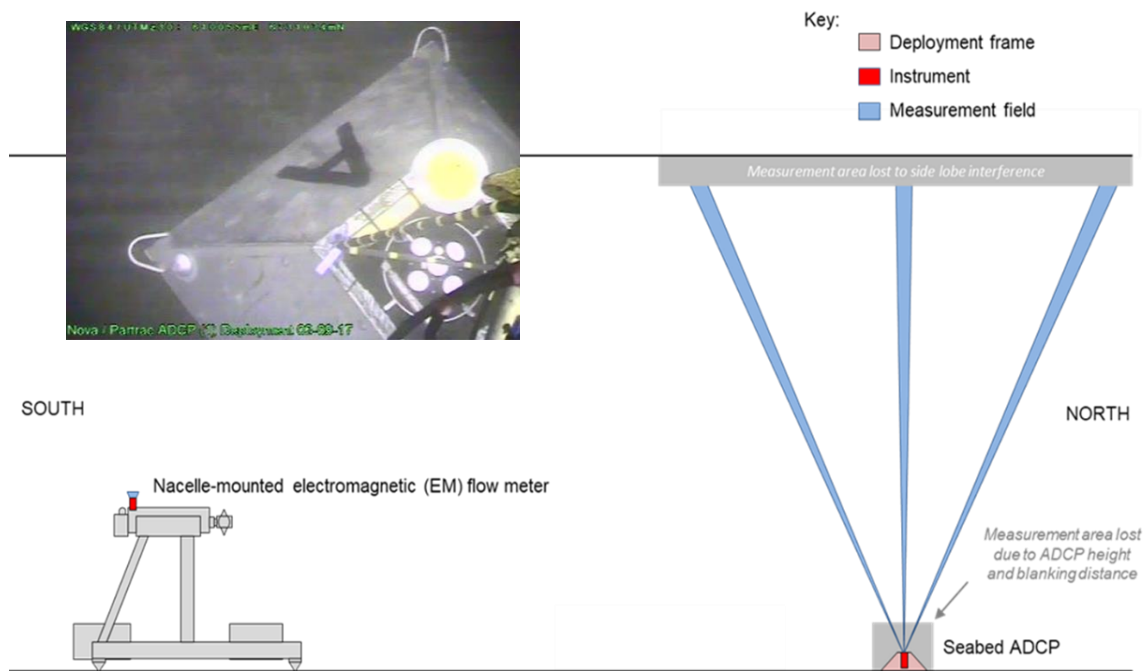


Figure 5-1: Nacelle and seabed mounted instrumentation deployments

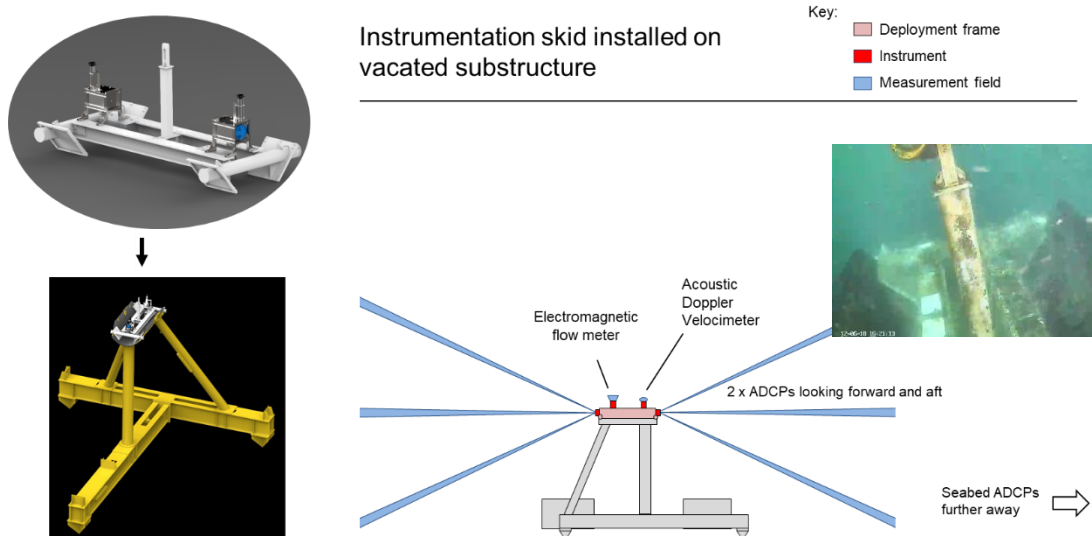


Figure 5-2: Instrumentation skid for stand-alone instrumentation



Figure 5-3: Instrumentation skid recovered

5.2 Performance validation and Array Interaction Modelling

The modelling and flow measurement work on the Shetland Tidal Array have enabled Nova to validate the turbine power curve and to develop a fully validated site resource model, with good alignment between modelled and measured current speeds. Further ADCP deployments are planned around the recently deployed T4 machine.

This resource modelling work has confirmed Bluemull Sound as a “Tier 2” site with moderate resource: an ideal location for proving technology on the world’s first tidal array. However, it should be noted that a large number of more energetic “Tier 1” sites are available across the globe. For example, Nova’s site in Petit Passage in Canada is one such Tier 1 site and learnings from EnFAIT operations are already being transferred to the development of that site.

The in-depth site resource and turbine measurements continue to support WP4 design work, WP9 reliability analysis and WP10 modelling work as shown in the diagram below.

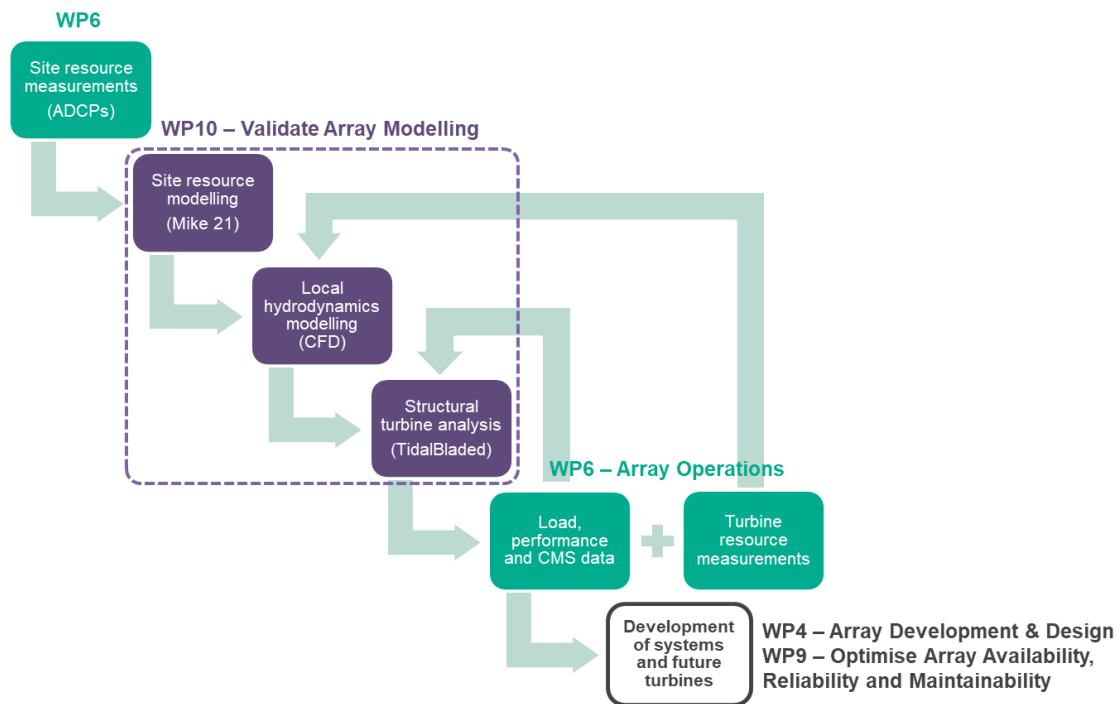


Figure 5-4: Information flows from turbine operations to other EnFAIT work packages

Turbine and resource data continue to feed into OREC Catapult’s CFD model of the flow incident on the turbine (see figure below). In turn, the turbine torque and strain gauge load measurements are used to validate the expected loads generated by this CFD model and the turbine loading analysis generated by Tidal Bladed.

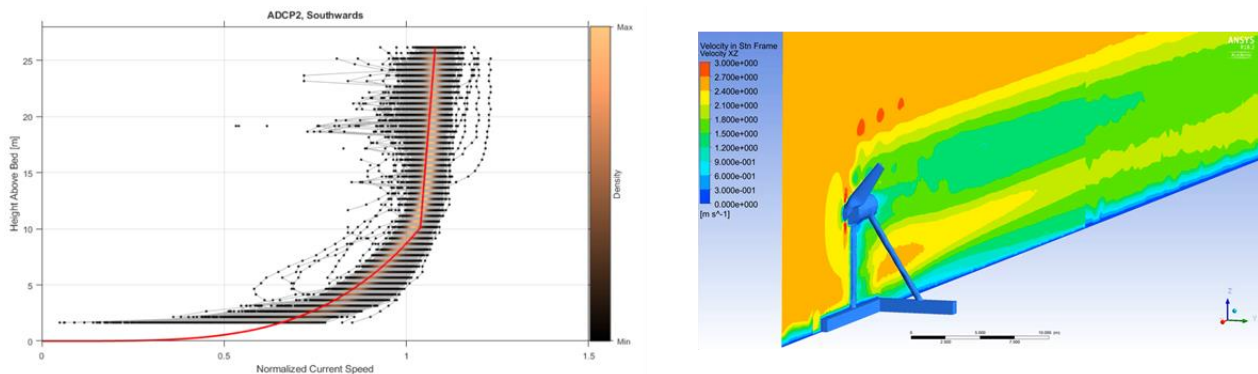


Figure 5-5: ADCP measurement results and screenshot from CFD modelling of turbine wakes

6 Biofouling

Nova continues to monitor the extent and type of biofouling on the deployed turbines. An Engineering Doctorate student was employed to assess biofouling on the EnFAIT turbines. An antifouling strategy for the EnFAIT turbines was developed, including the reduction and the recording of biofouling. The 5 key contributions were:

- The development of a simple visual and weight analysis for settlement panel comparison, allowing non-experts to investigate options and determine a preferred antifouling coating
- The application of image analysis on underwater camera images for estimating biofouling seasonal volumes and thereby preferred deployment times; to reduce uncertainty of maintenance intervals
- The application of 3D photogrammetry on recovered devices allowing operators to record biofouling information within minutes, resulting in fouling prone features being designed out.
- The creation of a biofouling management plan which aims to be a simple, adaptable and globally applicable system to deal with engineering and environmental issues of biofouling.
- The identification of preferred coatings for various biofouling sensitive components, e.g. for the turbine rotor, which is non-toxic and has proven exceptionally effective – see turbine image in Figure 6-1 after >1 year deployed.



Figure 6-1: Negligible marine growth on turbine blades after >1 year of operations; biofouling test pieces

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