7MW Levenmouth Demonstration Turbine - Managing data and the asset to develop research and demonstration projects during turbine operation

16 January 2020

Paul McKeever – Head of Electrical Research

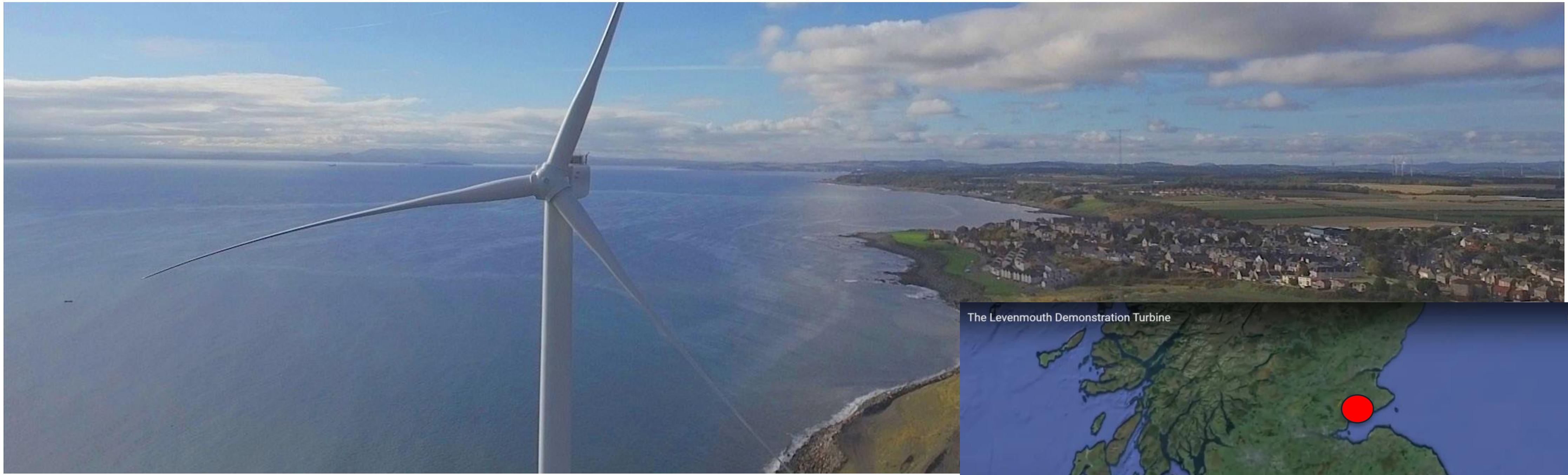
CATAPULT
Offshore Renewable Energy

Agenda

- 7MW Levenmouth Demonstration Turbine (LDT) Summary
  - The LDT in numbers
  - Operation of the LDT - Challenges
- LDT Asset Usage
  - Management & Utilisation of Data
    - The Platform for Operational Data (POD) Service
  - Developing a Turbine Model
    - The LDT Model
  - LDT as a Demonstration Platform
    - Case Studies
      - Non-intrusive demonstrations
      - Offshore Demonstration Blade (ODB) and TotalControl Projects
- Conclusions

7MW Levenmouth Demonstration Turbine (LDT) Summary

- Short Video - https://youtu.be/-j3hZvQIEWI



- Located in Fife, Scotland
- Acquired by ORE Catapult in November, 2015
- One of the world's most advanced open access offshore wind turbines
    - Dedicated to research and product validation/demonstration

The LDT in numbers

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Features

Wind class
IEC Class I_A/ S_B

Rotor dia.
171.2m

Capacity
7MW at grid side

Hub height
110.6m

Blade length
83.5m

Total height
196m blade tip to sea level

Generator
Medium voltage PMG (3.3kV)

Converter
Full power conversion

Drive train
Medium speed (400rpm)

Rated frequency
50Hz

Rotor speed
5.9 ~ 10.6rpm

Wind speed
3.5 ~ 25m/s

Temp. range
Survival
-20°C to +50°C
Operating
-10°C to +25°C

Lightning protection level
Level 1 (IEC 62305-1)

Corrosion category (ISO 12944-5)
Inside : C4
Outside : C5-M

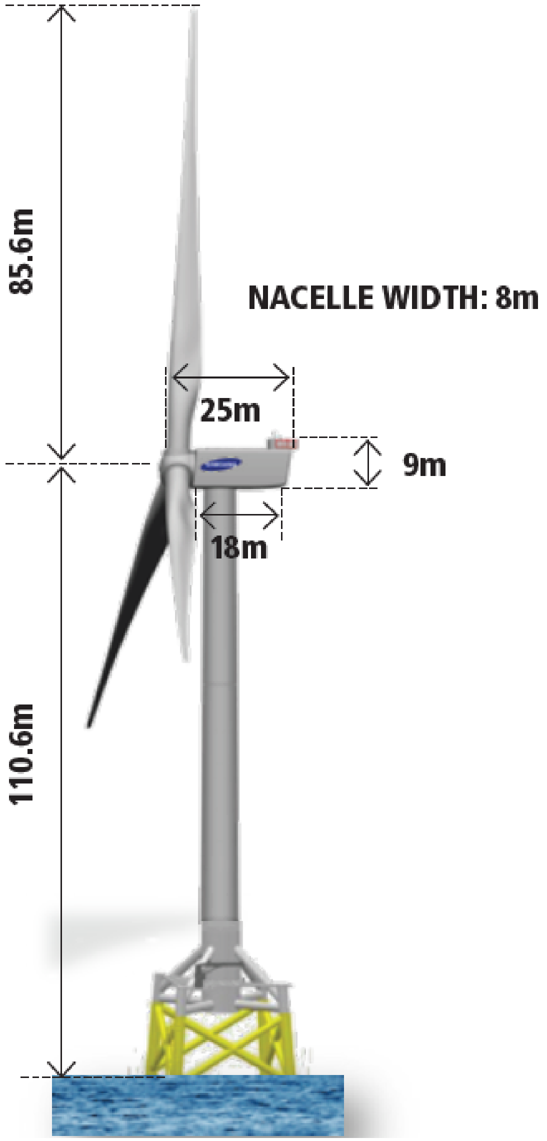
Design life
25 years

Control system features

- Independent and collective pitch control modes
- Active drivetrain damping
- Active load control
- Blade load monitoring

Complementary measurement opportunities

- Access hatches on roof
- Land-side flat locations for lidar installation (including 1 pad with electrical connections)
- On-site IEC met mast with cup anemometry currently installed
- Deck space on transition piece for small instruments



Operation of the LDT

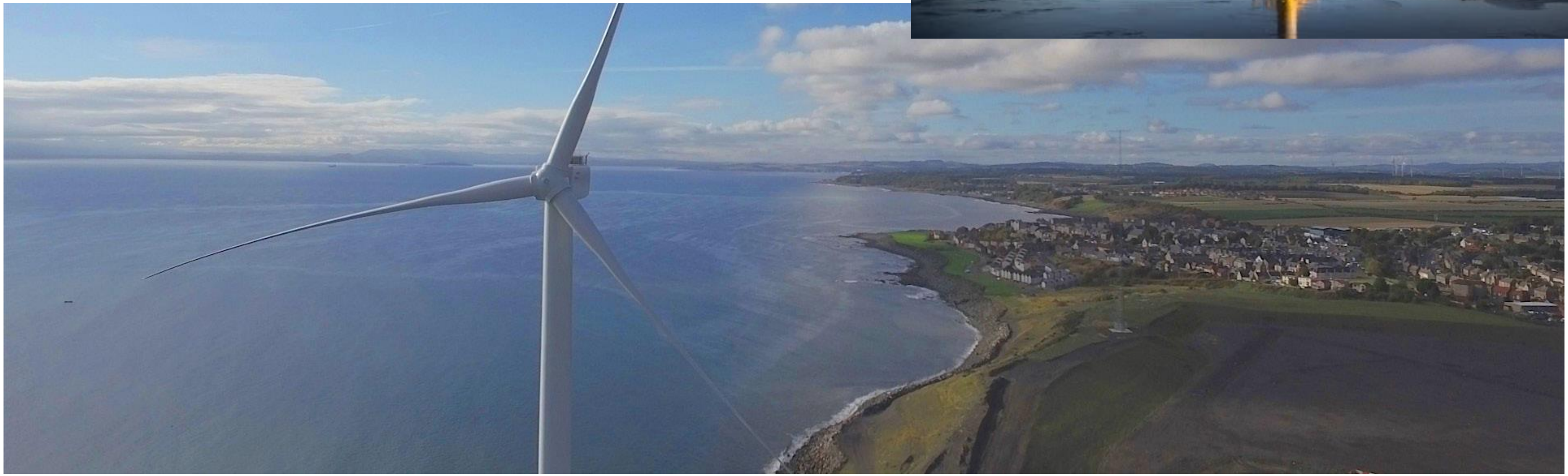
List of Activities (non-exhaustive)

- Product validation of new concepts and technology (including power performance measurements)
  - Demonstrate remote inspection methods and technologies
- Improve wind resource estimation and standardisation
- Holistic control system development, including control algorithm optimisation
- Prognostic condition monitoring system (CMS) development
- Measurement system development (DAQ, sensors)
- Measure and compare real-life data against a controlled test programme
- Structural mechanics
- Aeroelastic modelling
- Aerodynamic modelling
- Design and analysis tool evaluation
- Evaluate environmental conditions, data and/or impact

Enables vital testing, verification and validation of remote sensing and other innovative technologies in order to prove reliability and performance (and facilitate data availability) for next generation offshore wind turbine technologies.

Operation of the LDT - Challenges

1. Proximity to land
    1. Great for turbine access
    2. Still provides offshore environment
    3. Care regarding interaction with local community
    4. Effects on wind resource assessment



Operation of the LDT - Challenges

1. Spare parts
2. Major alterations
    1. Logistics
    2. Turbine Financial Model
    3. Consenting
3. Mother nature

LDT Asset Usage

Management & Utilisation of Data

In addition to standard SCADA controller signals and existing condition monitoring systems (see summary table below), ORE Catapult has been working on the CLOWT (Clone of the Levenmouth Offshore Wind Turbine) Project.

- Project ultimately aims to develop a validated virtual model of the Levenmouth Demonstration Turbine (LDT)
- Validated using measurement campaign data from a comprehensive package of instrumentation

Component	High-Level Measurement Description
Hub	Temperature, rotational speed, azimuth
Pitch	Pitch position, pitch rate, pitch demand, motor current, motor temperature
Nacelle	Yaw position, wind direction, wind speed, yaw error, yaw speed, temperature (inside and outside), vibrations (accelerations)
Drive-train	Oil pressure, oil temperature, vibrations (accelerations), gearbox temperature
Main bearing	Temperature
Tower	Vibrations (accelerations)
Electrical	IGCT temperature, current (generator, grid), voltage (grid, generator), temperature (generator), reactive power (generator, grid), torque, generator speed, active power (grid, generator), grid frequency, grid phase, power factor
Protective relay (IPR)	Line current, frequency, power (real, reactive and apparent)

CLOWT Project Sensors

Component	Sensor	Location	Qtty
Blade	Strain Gauge	Blade root	4 x 3 blades
		¼ Blade length	4
		.4 Blade length	4
		½ Blade length	4
		.6 Blade length	4
		¾ Blade length	4

Component	Sensor	Location	Qtty
Tower	Strain Gauge	Tower top	2
		Tower base	2
		Tower middle	2
	Accelerometer	Tower top	1
		1/3 from top	1

Component	Sensor	Location	Qtty
Transition Piece	Strain Gauge	Diagonal Leg (side 1)	2
		Horizontal Leg (side 1)	2
		Tower	3
		Diagonal Leg (Side 2)	2
		Horizontal Leg (Side 2)	2

Component	Equipment	Location	Qtty
Wind Resource	ZephIR Lidar	Nacelle (Forward Facing)	1

Component	Sensor	Location	Qtty
Power Train	Speed	Various	Multiple
	Torque		
	Temperature		
	Current		
	Voltage		
	Humidity		
Pitch System	Temperature		
	Current		
	Voltage		
	Humidity		

Component	Sensors	Location	Qtty
Jacket	Strain Gauge	Jacket Brace 1	2
		Jacket Brace 2	2
		Jacket Leg	2
		Jacket Brace 1 (alternate side)	2
		Jacket Brace 2 (alternate side)	2

The Platform for Operational Data (POD) Service

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What is POD?

- POD enables you to access and request data sets for the LDT

How does it work?

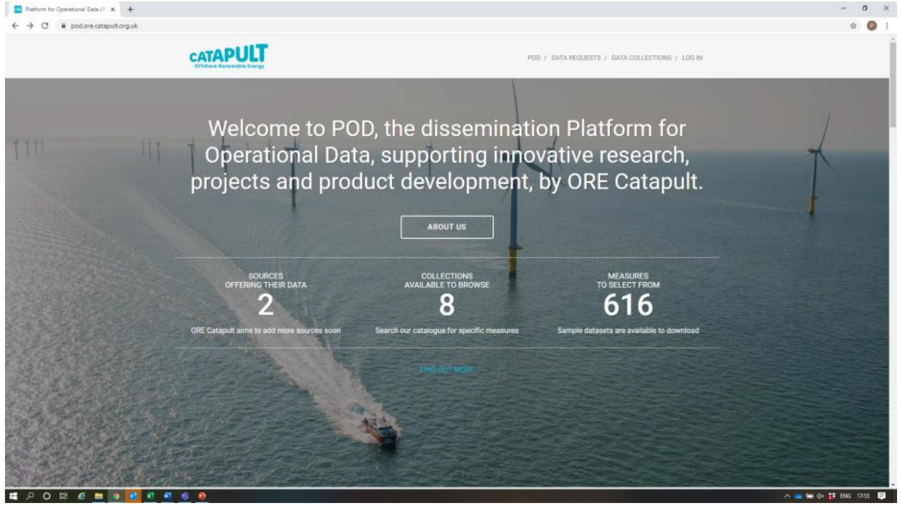
- Browse the [POD catalogue] and request your required datasets
    - Samples of each data collection are available for you to view
- Choose the data collections/time periods you are interested in
- Briefly describe your intended use of the data

*There is a small charge to cover the data retrieval, depending on the size or complexity of the request, and this will be calculated after receipt of the request and discussion around an appropriate solution.

Data Storage & Availability

Data Set	Frequency of Capture
LDT Met Mast SCADA	1 sec & 10 min
LDT Substation SCADA	1 sec & 10 min
LDT Turbine SCADA	1 sec & 10 min
LDT Alarm Log	

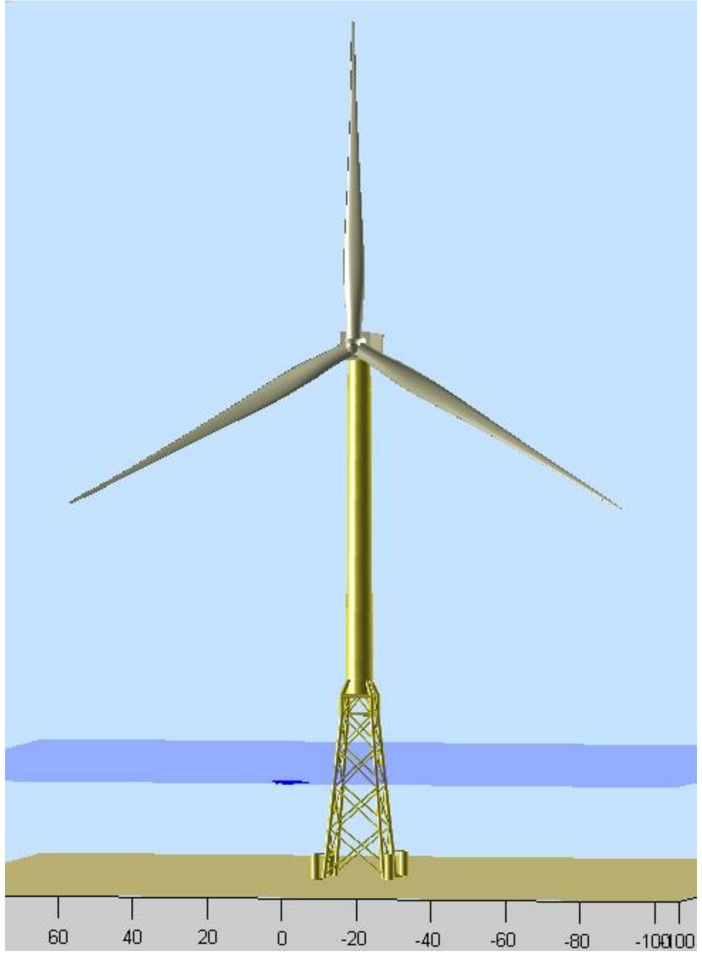
All data sources are collected in a bespoke Data Acquisition System (DAQ) and are stored on a local server at the LDT site. Data transfer to remote users can be provided where appropriate.



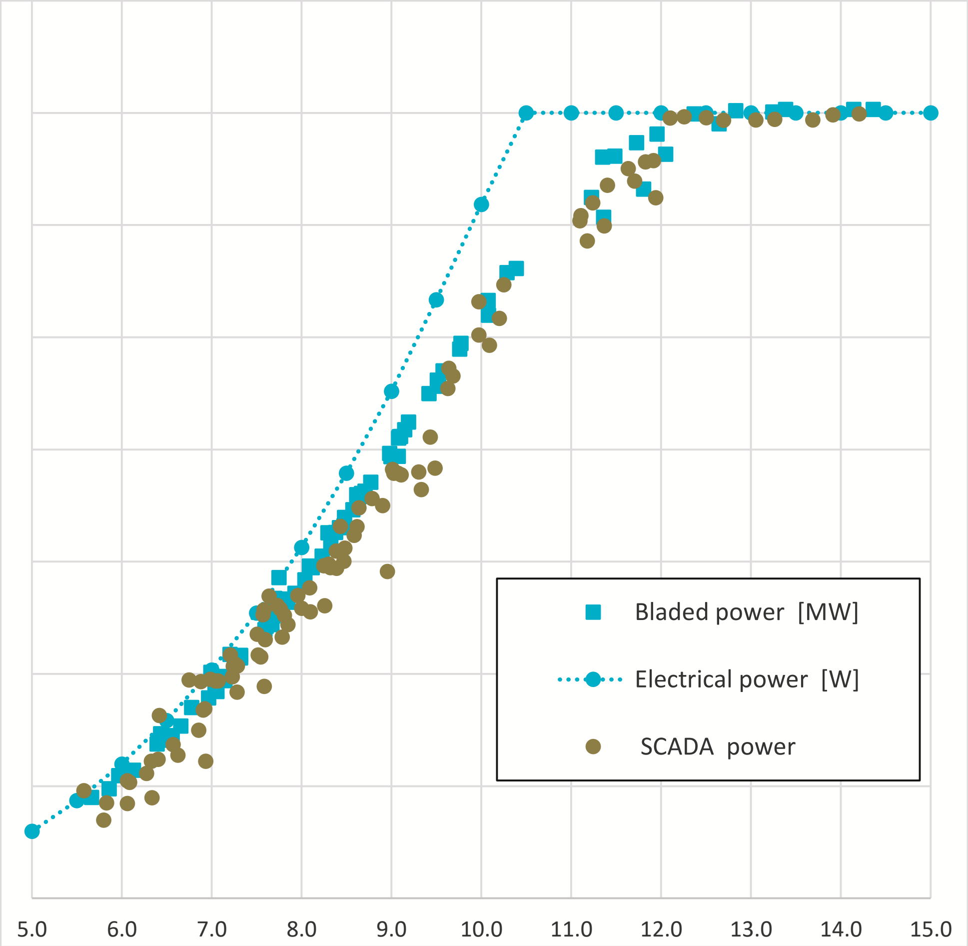
Developing a Turbine Model

Developing the LDT Digital Twin

Enhancing Modelling (using real data)



Power Curve now matches real measurements



Started with aeroelastic model, but this is being expanded to powertrain and grid connection modelling

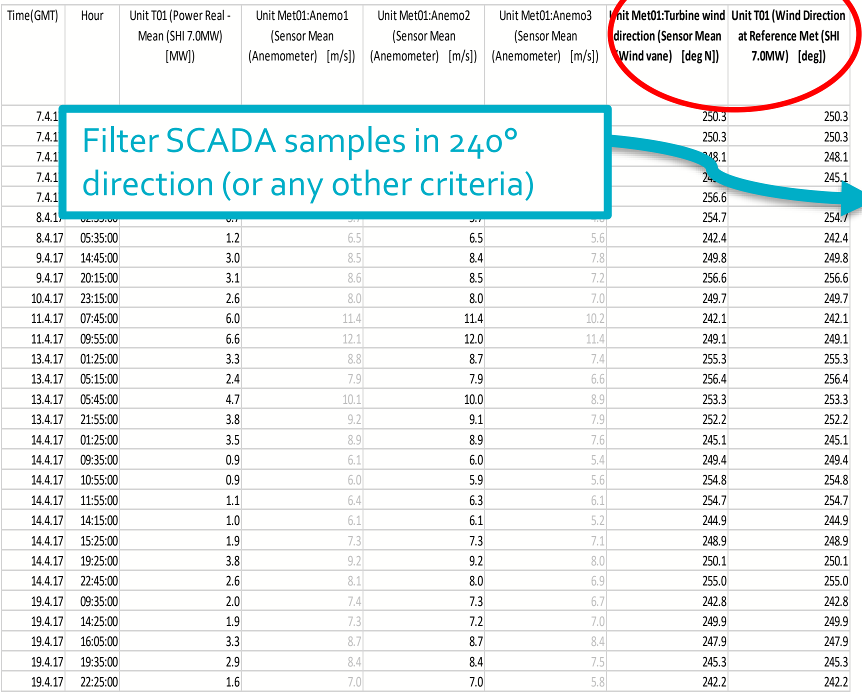
Managing Data on the Project

- **1st step in process: choose your data**

- We have filtered SCADA samples where wind direction is aligned with the met mast
    - Using only samples where all wind measurements (met mast, WT) coincide

Managing Data on the Project

- **2nd step: run some simulations**
- Used a bespoke python script - wind measurements are being easily translated into simulations:



Time(GMT)	Hour	Unit T01 (Power Real - Mean (SHI 7.0MW) [MW])	Unit Met01:Anemo1 (Sensor Mean (Anemometer) [m/s])	Unit Met01:Anemo2 (Sensor Mean (Anemometer) [m/s])	Unit Met01:Anemo3 (Sensor Mean (Anemometer) [m/s])	Unit Met01:Turbine wind direction (Sensor Mean (Wind vane) [deg N])	Unit T01 (Wind Direction at Reference Met (SHI 7.0MW) [deg])
7.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	250.3	250.3
7.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	250.3	250.3
7.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	248.1
7.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	245.1
7.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	256.6	256.6
8.4.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	254.7	254.7
8.4.17	05:35:00	1.2	6.5	6.5	5.6	242.4	242.4
9.4.17	14:45:00	3.0	8.5	8.4	7.8	249.8	249.8
9.4.17	20:15:00	3.1	8.6	8.5	7.2	256.6	256.6
10.4.17	23:15:00	2.6	8.0	8.0	7.0	249.7	249.7
11.4.17	07:45:00	6.0	11.4	11.4	10.2	242.1	242.1
11.4.17	09:55:00	6.6	12.1	12.0	11.4	249.1	249.1
13.4.17	01:25:00	3.3	8.8	8.7	7.4	255.3	255.3
13.4.17	05:15:00	2.4	7.9	7.9	6.6	256.4	256.4
13.4.17	05:45:00	4.7	10.1	10.0	8.9	253.3	253.3
13.4.17	21:55:00	3.8	9.2	9.1	7.9	252.2	252.2
14.4.17	01:25:00	3.5	8.9	8.9	7.6	245.1	245.1
14.4.17	09:35:00	0.9	6.1	6.0	5.4	249.4	249.4
14.4.17	10:55:00	0.9	6.0	5.9	5.6	254.8	254.8
14.4.17	11:55:00	1.1	6.4	6.3	6.1	254.7	254.7
14.4.17	14:15:00	1.0	6.1	6.1	5.2	244.9	244.9
14.4.17	15:25:00	1.9	7.3	7.3	7.1	248.9	248.9
14.4.17	19:25:00	3.8	9.2	9.2	8.0	250.1	250.1
14.4.17	22:45:00	2.6	8.1	8.0	6.9	255.0	255.0
19.4.17	09:35:00	2.0	7.4	7.3	6.7	242.8	242.8
19.4.17	14:25:00	1.9	7.3	7.2	7.0	249.9	249.9
19.4.17	16:05:00	3.3	8.7	8.7	8.4	247.9	247.9
19.4.17	19:35:00	2.9	8.4	8.4	7.5	245.3	245.3
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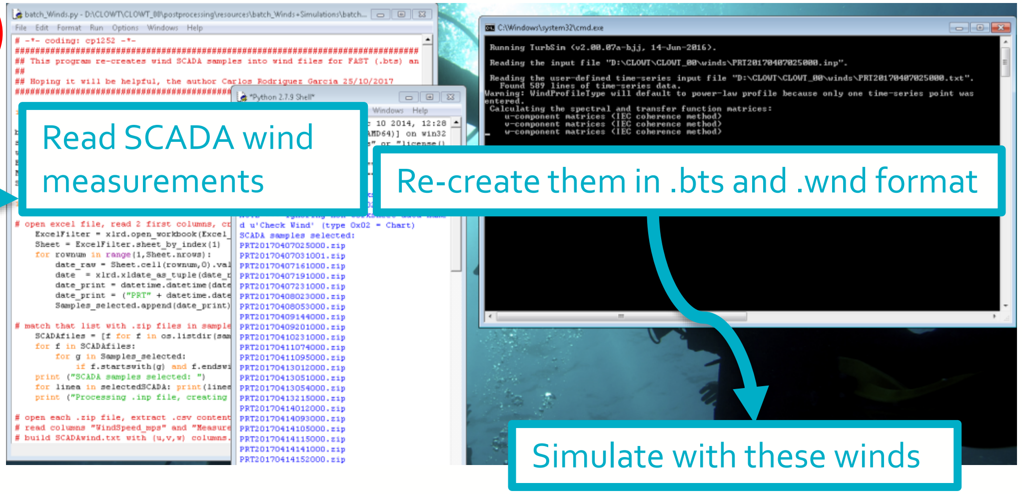
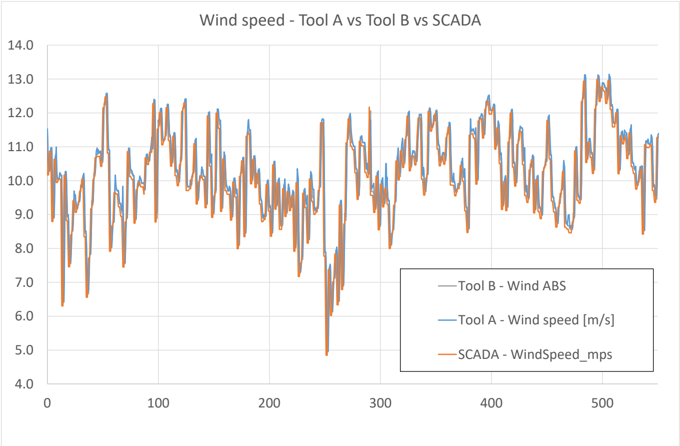
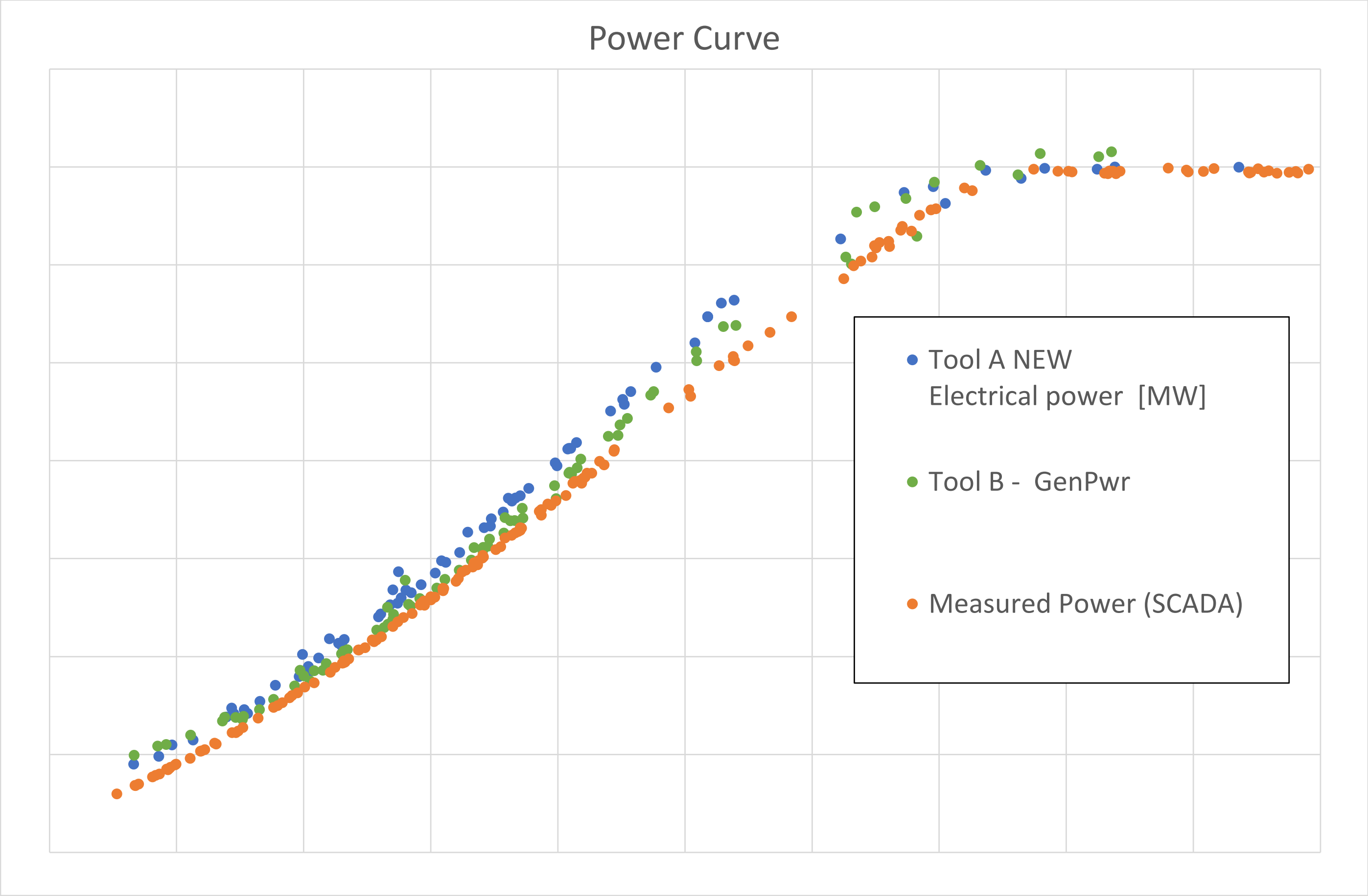




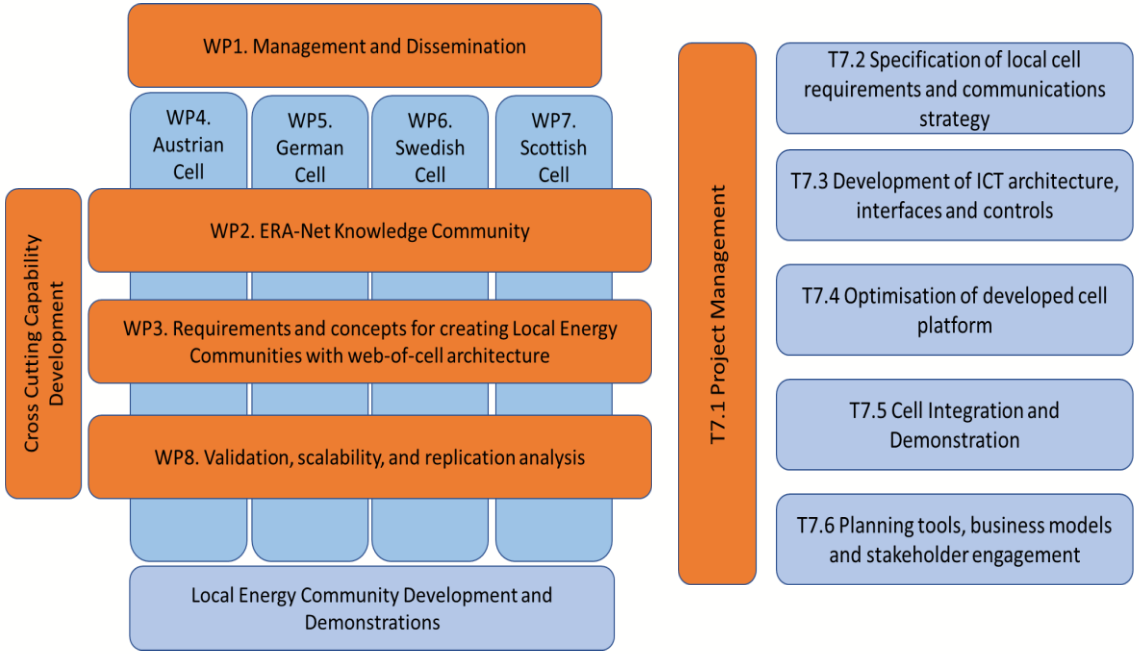
Managing Data on the Project

- **3rd step: compare simulations to reality – power curve (also compared pitch, rotor speed & torque)**
- Re-created wind fields measured on the nacelle, and using original controller, we have more reliably evaluated aero-elastic code performance. In this graphic, Tool A vs. Tool B vs. SCADA

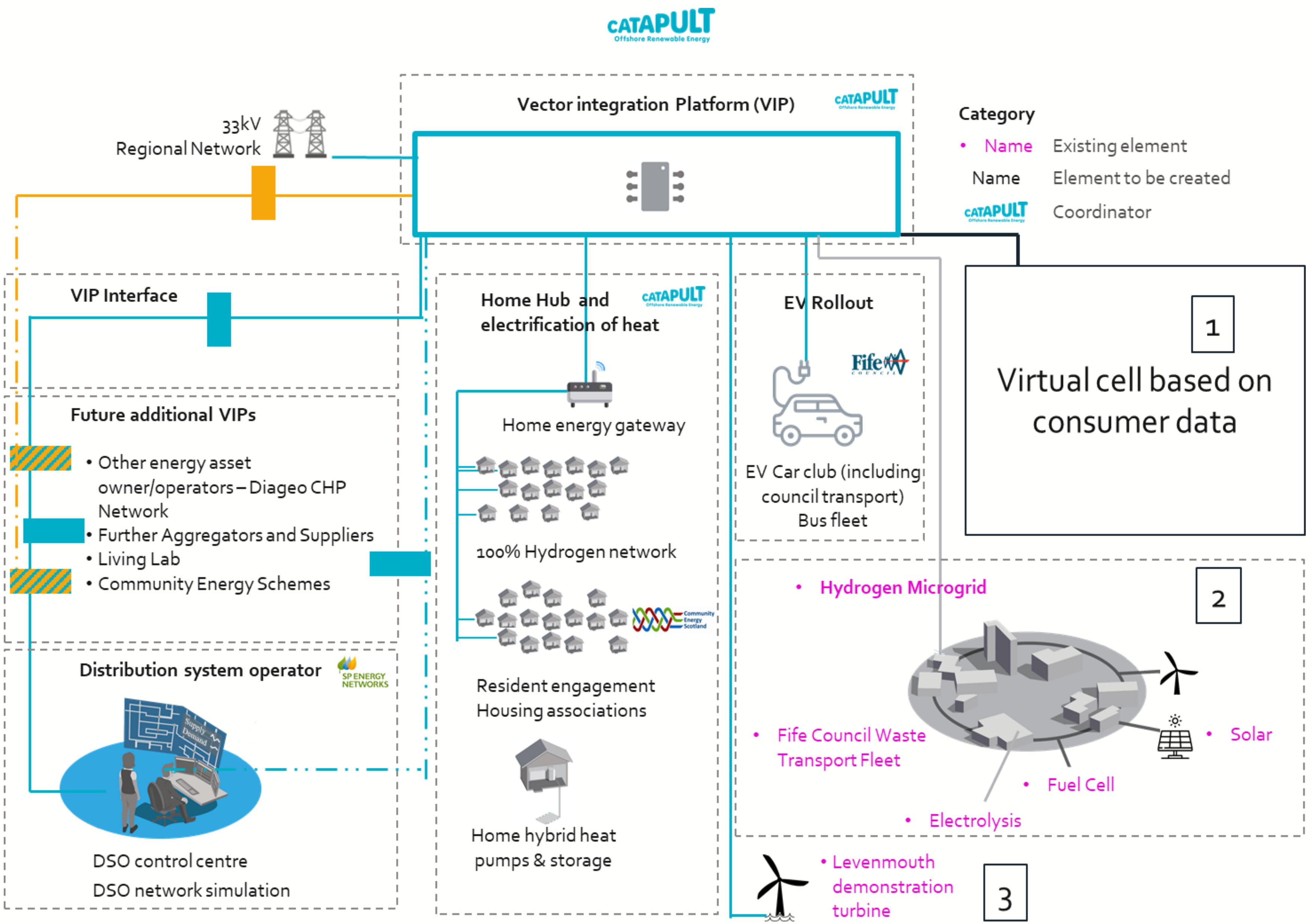


Future Use of the LDT

- **CLOWT Sensors –** Additional sensors recently fitted to the LDT will enable a number of new R&D projects
- **Expansion into Energy Systems Research – Project CLUE**
- Concepts, Planning, Demonstration and Replication of Local User-friendly Energy Communities (CLUE) - €7million project delivered over 3 years from December 2019
- CLUE will develop and validate a tool kit supporting the implementation of sustainable local energy systems and will close the gap of missing control and monitoring tools
- The different types of Local Energy Community (LEC) stakeholders (cooperatives, project developers, DSOs, owners, operators of LECs, utilities, supplier) will participate in CLUE



Project CLUE



LDT as a Demonstration Platform

Non-Intrusive Demonstrations

List of Activities (non-exhaustive)

- Product validation of new concepts and technology (including power performance measurements)
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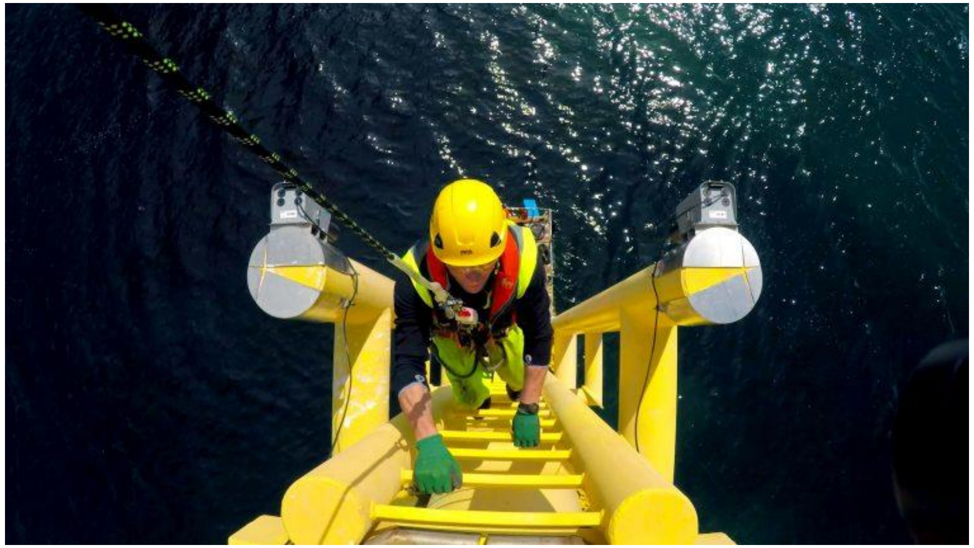
Enables vital testing, verification and validation of remote sensing and other innovative technologies in order to prove reliability and performance (and facilitate data availability) for next generation offshore wind turbine technologies.

Limpet – Height Safety and Access Systems



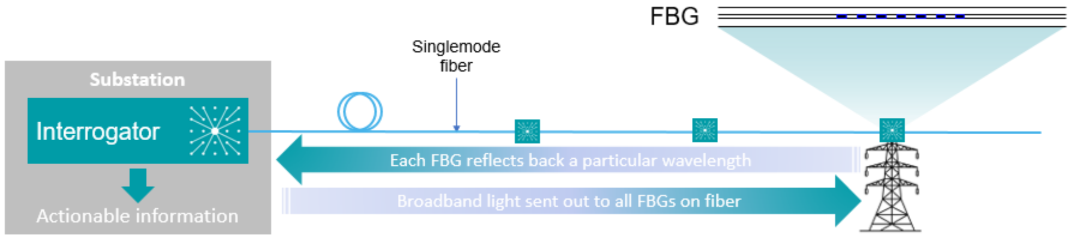
- Getting onto and off the turbines from a boat is among the most stressful and dangerous parts of offshore turbine maintenance
    - When waves are higher than 1.5 metres, transfers are considered too risky
- Failed transfers and lost energy production are hugely expensive for operators
    - Problem is set to become worse as the industry pushes into sites that are further from shore
- Limpet Technology has developed an offshore personnel transfer system aimed at alleviating this problem
    - Dynamic hoist and fall arrest system uses in-built lasers to track the vessel's deck, adjusting the height of the hoist in real time
    - Compensates for the motion of the vessel and allows the technician to clip in and transfer onto the turbine more easily
- Limpet's system can make safe transfers possible in 3m waves
    - Aims to increase access to far offshore turbines from 50% of the year to 80%

Synaptec – Cable Monitoring Utilising Existing Cable Optical Fibres

Synaptec's technology

Novel application of fibre Bragg gratings (FBGs) to enable distributed sensing of electrical parameters through standard single-mode optical fibre.

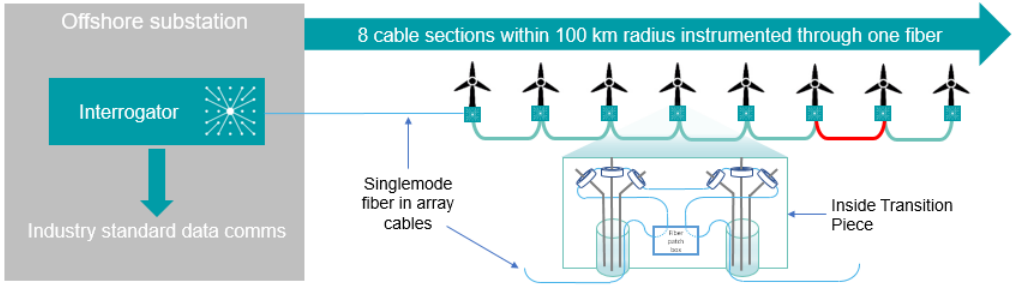
- Multiple FBGs can be 'daisy-chained' along a single optical fibre up to 100 km from the substation
- Each FBG reflects a different wavelength
- One Interrogator processes data from all sensors in parallel



Synaptec's technology

Proposition for offshore renewables sector:

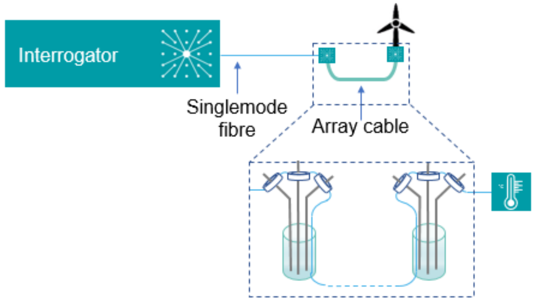
- Existing methods of fault location are crude and slow
- Faults in array cables result in significant downtime, loss of generation and financial penalties
- One fault per 400km cable per year costs £2.2M & 27 days to fix
- Synaptec's technology would enable 'differential protection' of each individual cable section at low cost and requiring no non-standard or intrusive engineering works to install
- Concept now requires trialling in a live environment to demonstrate proposition to operators



* OREC fault database, UK 2017

REACTION

- **R**enewable **E**nergy **A**rray **C**able and **T**ermination **I**nstrumentation using **O**ptical sensor **N**etworks
- Trial of Synaptec's sensing platform on OREC's 7MW Levenmouth Demonstration Turbine



- Enabling differential current protection of array cables, significantly improving robustness and locating of faulted asset compared to existing methods
- Exploring scope for better analytics;
  - additional, integrated **temperature monitoring** of cable terminations
  - live power quality monitoring and analysis
  - cable failure prognostics and predictive maintenance

REACTION

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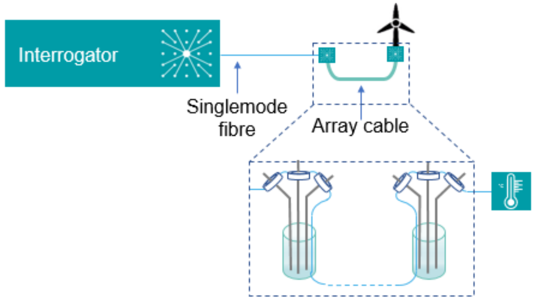


The project will consist of three core technical aims:

1. **Development and characterisation of sensor platform hardware**
2. **Live trial at OREC 7MW test turbine**
3. **Exploitation of leveraged data**

Intrusive Demonstrations - Offshore Demonstration Blade (ODB)

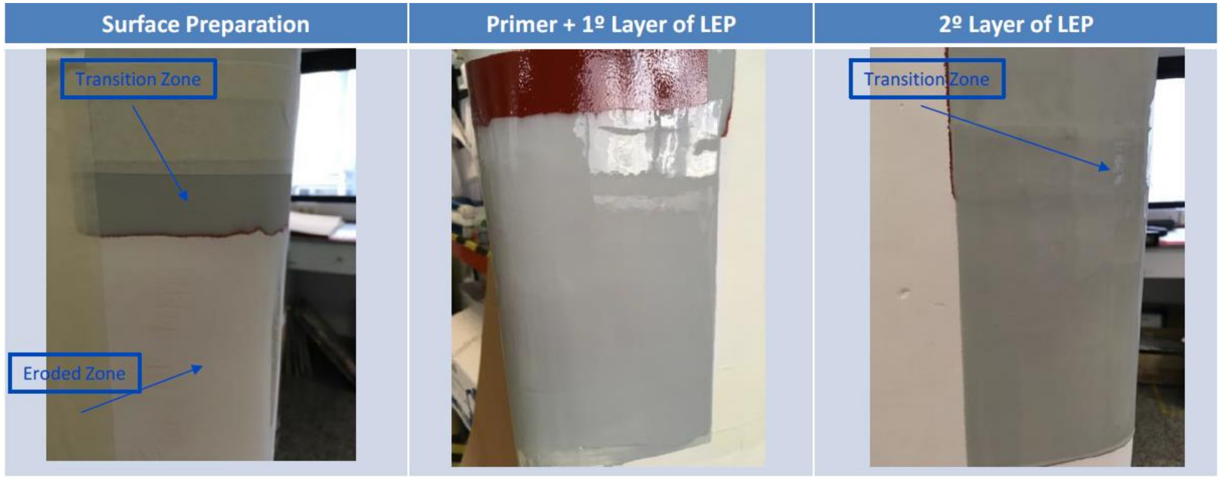
- 2-year DemoWind-funded project forming a €4 million research collaboration between 10 European partners
    - Coordinated by the ORE Catapult commercial arm (ODSL)
- Led the development of seven novel offshore wind turbine blade technologies, which collectively could lower the levelised cost of energy (LCOE) of offshore wind by as much as 4.7%.
- The Offshore Demonstration Blade (ODB) project supported the research, development and demonstration of wind turbine blade innovations, including aerodynamic and structural enhancements, blade monitoring systems and blade erosion protection solutions
    - A number of these innovations were demonstrated on the Levenmouth Demonstration Turbine

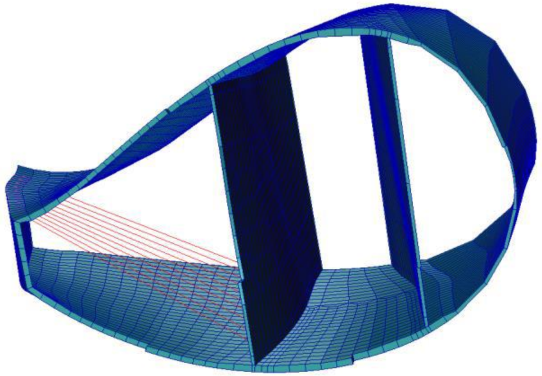
The Impact

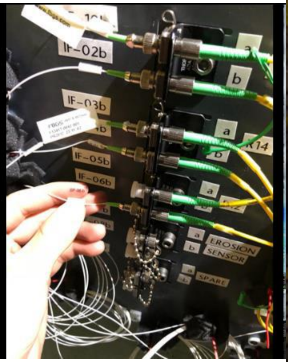
- O&M costs represent almost a quarter of the total LCOE of an offshore wind turbine
    - Rotor O&M (specifically blade erosion and blade structural integrity) represents a large share of these costs
- Improving the performance and operational lifetime of turbine blades is therefore a key factor in lowering LCOE.

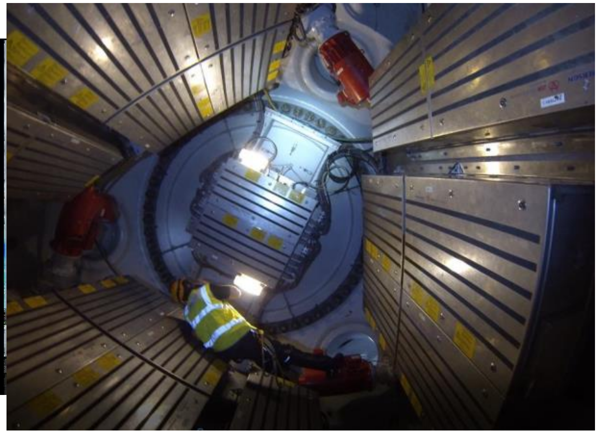
ODB Demonstrations at Levenmouth (LDT)

- Aerox Advanced Polymers - Leading Edge Protection Coating
  - Installed on LDT in May 2019
  - Applied successfully to blade area that had previously had a repair due to some minor lightning damage
  - Performance of the coating continues to be monitored
- GEV Windpower – X-Stiffener
  - Installed on LDT in May 2019 with support from Bladena
  - Explain where fitted inside the blade
- TNO – Cross Sectional Shear Distortion Sensor (CSSDS)
  - Installed on LDT in May 2019 with support from GEV Windpower
  - Designed to monitor X-Stiffener performance
  - X-Stiffener and the CSSDS were decommissioned in late 2019 after a few months of trial









Intrusive Demonstrations - The TotalControl Project

- TotalControl is a project within the Horizon 2020 framework funded by the European Union (Project Number 727680)
- The project runs for four years, from 1 January 2018 to 31 December 2021
- The total project budget is EUR 4 876 482,50

- The ambition of the TotalControl project is to develop the next generation of wind power plant (WPP) control tools, improving both WPP control itself and the link between wind turbine (WT) and WPP control
- TotalControl uses high-fidelity simulation and design environments including time resolved flow field modelling, nonlinear flexible multi-body representations of turbines, and detailed power grid models

TotalControl – Use of LDT

List of Activities (non-exhaustive)

- Product validation of new concepts and technology (including power performance measurements)
    - Demonstrate remote inspection methods and technologies
- Improve wind resource estimation and standardisation
- Holistic control system development, including control algorithm optimisation
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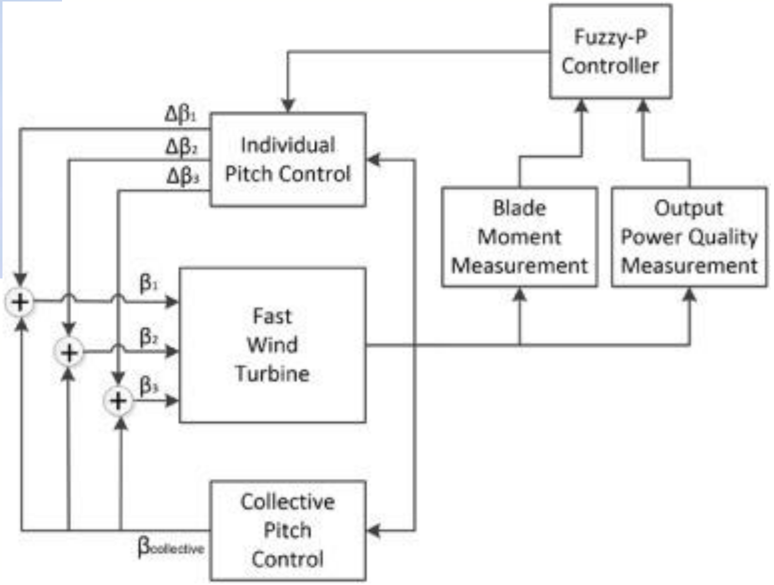
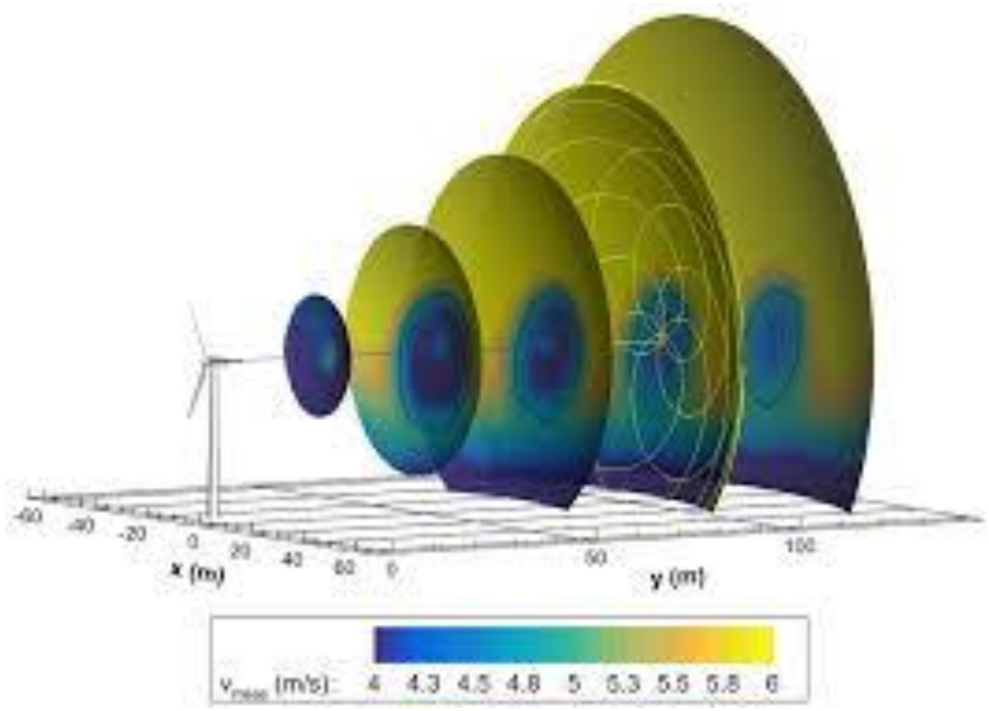
Developing/Demonstrating Improved Wind Turbine/Farm Control

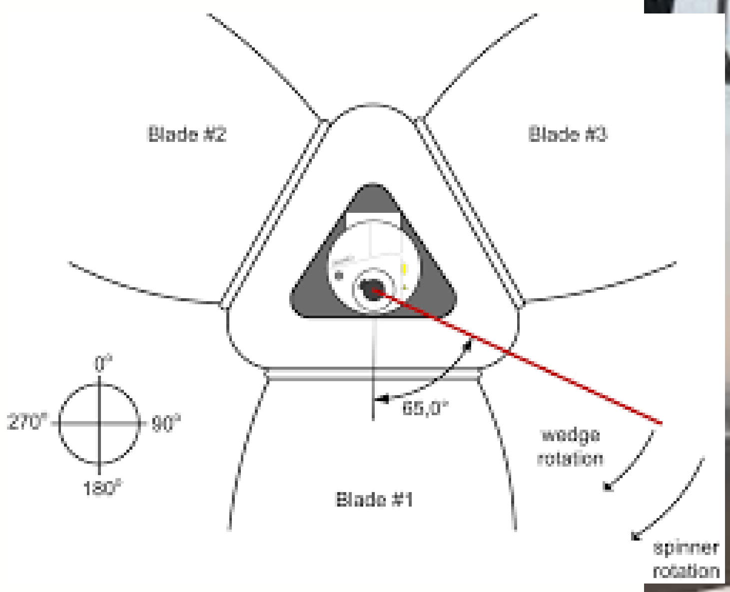
- Controller development
  - Adaptability & operational flexibility (turbulence-based de-rating/up-rating)
  - Ancillary services (active power control)
  - Load reduction and damping (IPC and Lidar assisted control)



Developing/Demonstrating Improved Wind Turbine/Farm Control

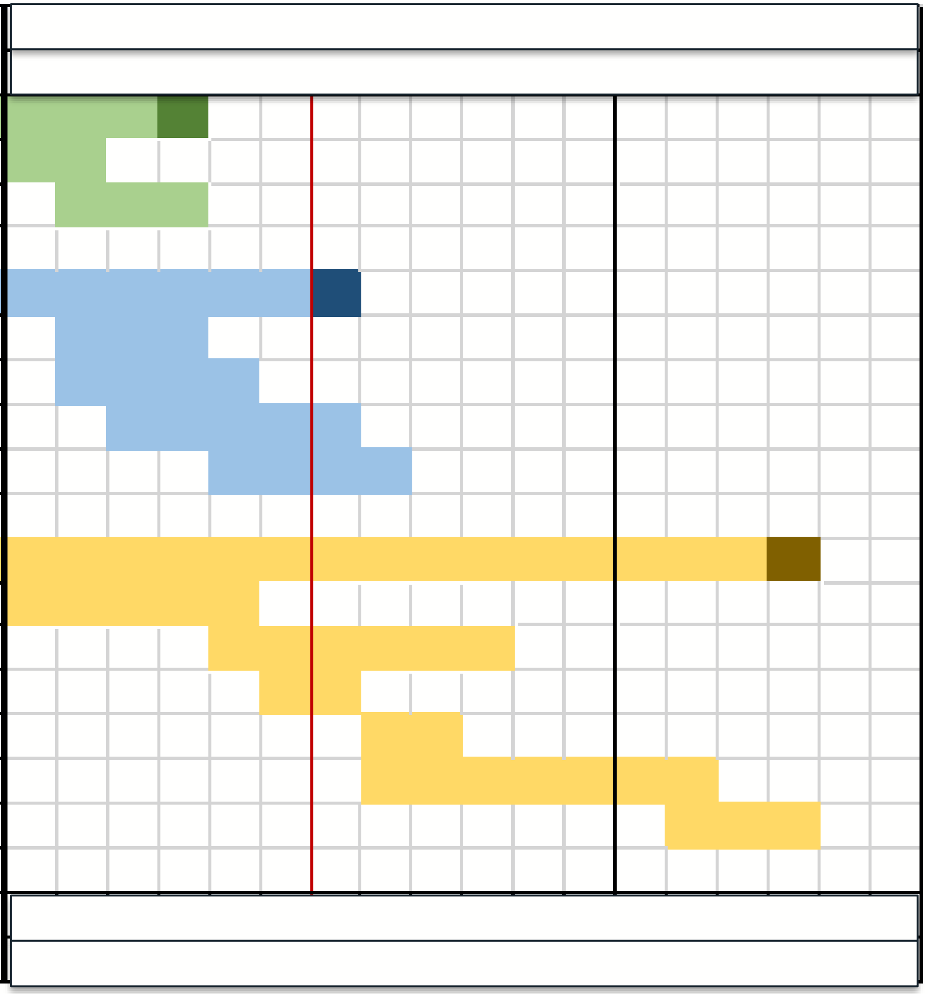
- Lidar Assisted Control
  - Installation of DTU SpinnerLidars planned in early 2020 – One forward and one rear facing
  - Forward facing measures detailed inflow wind conditions
  - Rear facing measures detailed wake dynamics behind the turbine
  - Allows development of feed forward/model predictive controllers and turbine wake controllers





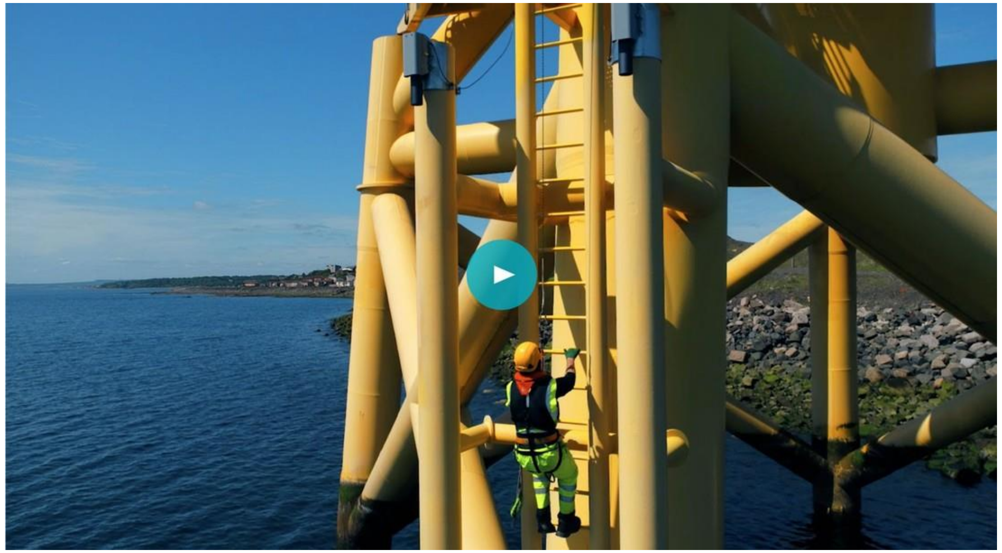
TotalControl Schedule – Activity in 2020/21

Code	Description
D3.6	Wind field measurements using LIDAR (M28)
A	Lidar installation (2 x Lidars simultaneously onto LDT nacelle)
B	LIDAR & LDT instrumentation measurement campaign
D3.9	Predictive wind field model (M31)
A	Turbine DAQ (Measurements)
B	Flow Field Predictive Model
C	Load Estimation (Model) and Validation (Measurements)
D	Reporting
D3.7	Validation of controller adaptations (M40)
A	Pre LDT Implementation Due Diligence and Approval
B	T&V campaing 1 for tests at LDT that DO NOT require Lidar, e.g. yaw - power - IPC
C	Lidar-Bachmann interface implementation - Step 1 Blyth Trials
D	Lidar-Bachmann interface implementation - Step 2 Levenmouth Trials
E	T&V campaing 2 for tests at LDT that REQUIRE Lidar, e.g. predictive control
F	Deliverable D3.7 drafting, final reporting and result dissemination
Code	Description



Conclusions

- 7MW Levenmouth Demonstration Turbine (LDT) Summary
  - Size matters
  - Operating environment and consenting
- LDT Asset Usage
  - Operational data vs. design data
    - Use online POD service or direct contact – paul.mckeever@ore.catapult.org.uk
  - Developing a Turbine Model
    - Model validation, maximising simulation capability, recreating events, pushing boundaries
  - LDT as a Demonstration Platform
    - Case Studies
      - Wide range of projects; flexible asset usage
      - Significant research and demonstration platform – enabling meaningful stakeholder engagement and collaboration



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Email us: info@ore.catapult.org.uk

Visit us: ore.catapult.org.uk

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