Celtic Sea Floating Offshore Wind – The Next Decade

Matt Hodson, Chief Operations Officer, Celtic Sea Power

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HM Government
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Cronfa Datblygu Rhanbarthol Ewrop
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The next decade will be transformational

……

……2023 will be pivotal

- Celtic Sea Power – A brief Introduction
- Global Pipelines
- UK Pipeline and Ambition
- Celtic Sea Scale and Current Status
- Industrial Ecosystem Requirements

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Celtic
Sea
Power

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Celtic Sea Power

- Strategic regional development of FLOW in the Celtic Sea
  - Accelerate FLOW development
  - Maximise economic benefit for the region and UK
- Autonomous subsidiary of Cornwall Council
- Based in Hayle, Cornwall and Pembroke, Wales
- Staff of 18 with range of experiences and skills
- Key Projects:
  - Cornwall Flow Accelerator (CFA), ERDF Funded.
  - Pembroke Demonstration Zone (PDZ) / Multi-Connector Offshore Sub-Station
- Co-founder and board member of the Celtic Sea Cluster
- Co-founder and member of the Celtic Sea Developers Alliance

HM Government

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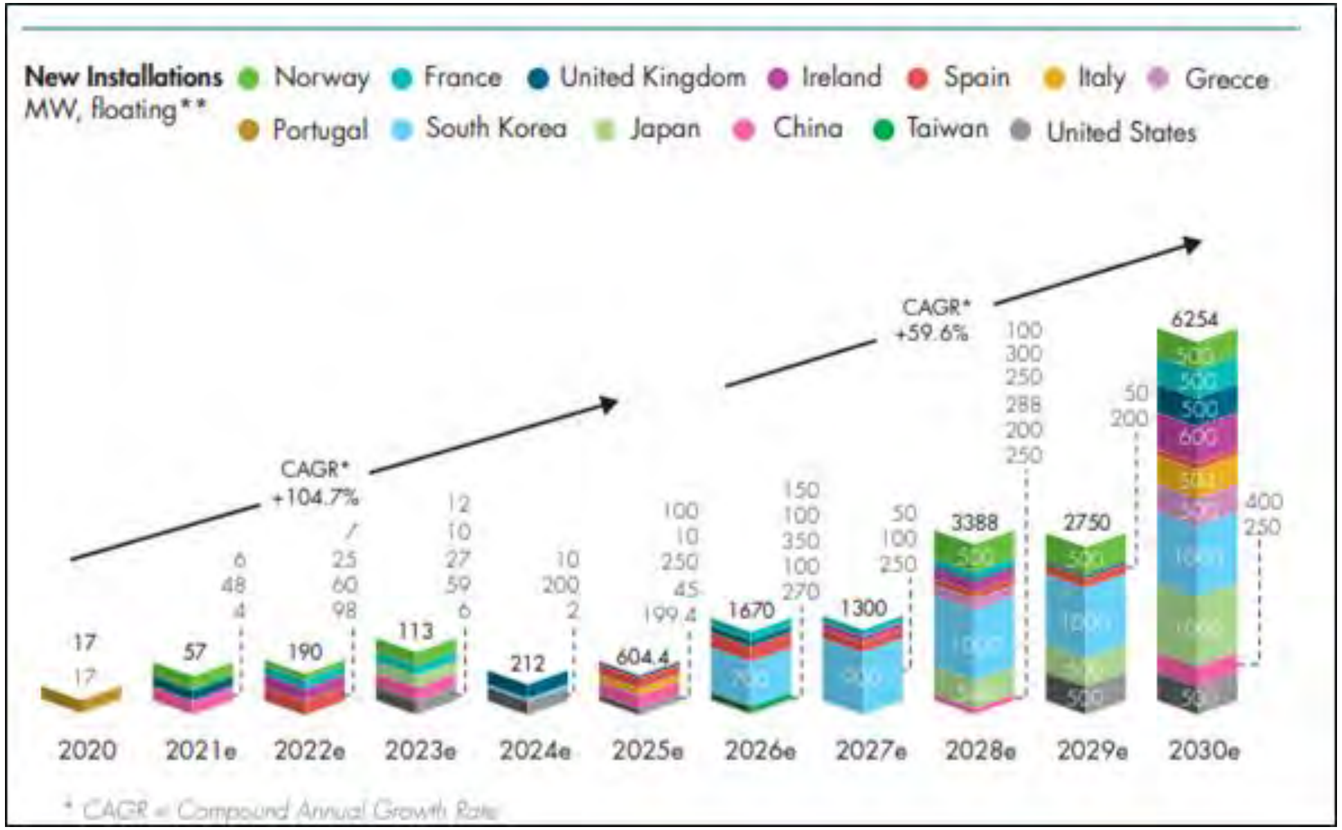
Global Pipeline to 2030 and beyond



Floating wind outlook 2020's - GWEC market intelligence 2021

- By 2026 annual installation >1GW/yr
- 2030 FLOW forecast 3GW - 19GW
- The global pipeline of floating offshore wind projects is 185GW over 230 projects, (RUK EnergyPulse insight report Nov 2022)
- Of the 185GW, 121MW are fully commissioned over nine projects in seven countries: 96MW are under construction; 288MW are consented or in the pre-construction phase; 31GW are in planning or have a lease agreement; and 153GW are in early development or the leasing process.

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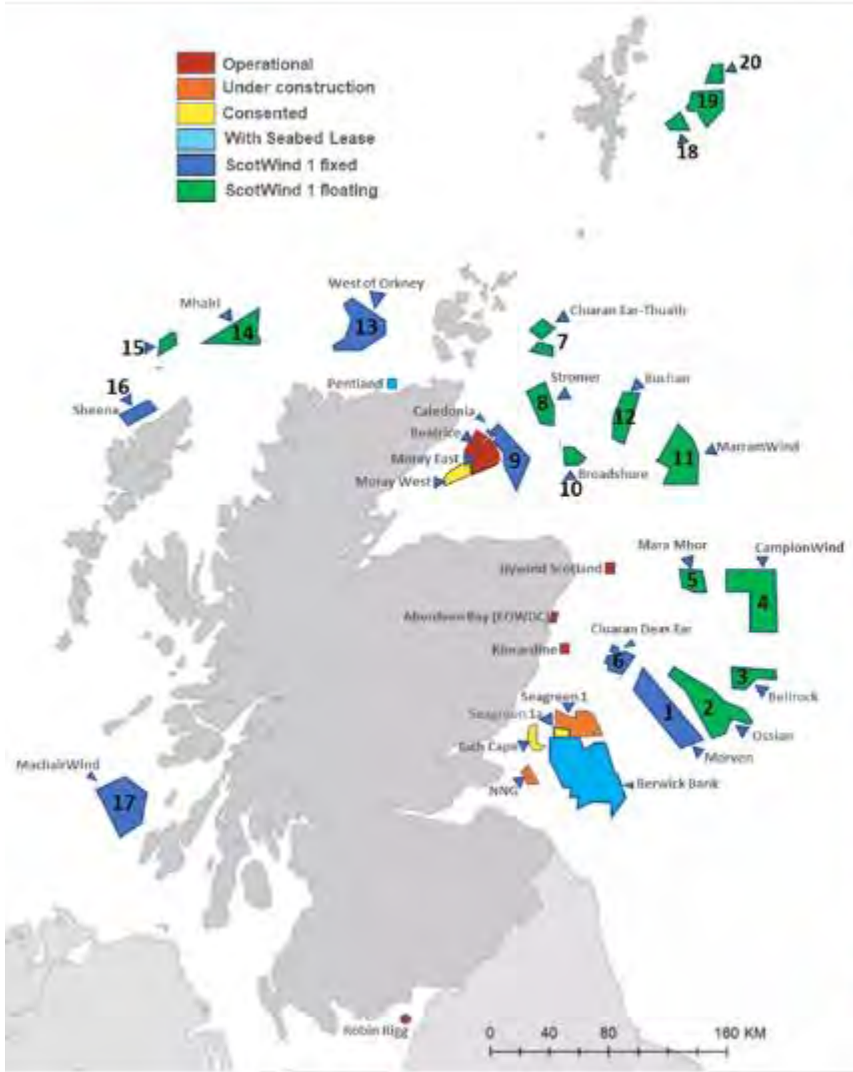
UK - Scotland



ScotWind Round

Total = 27,626MW

Floating Wind = 17,871MW (65%)

SITE	DEVELOPERS	CAPACITY
1	BP and EnBW	2,907MW
2	SSE Renewables, CIP and Marubeni	2,610MW
3	Falck Renewables and BlueFloat Energy	1,200MW
4	ScottishPower Renewables and Shell	2,000MW
5	Vattenfall and Fred Olsen Renewables	798MW
6	Thistle Wind Partners	1,008MW
7	Thistle Wind Partners	1,008MW
8	Falck Renewables, Orsted and BlueFloat Energy	1,000MW
9	Ocean Winds	1,000MW
10	Falck Renewables and BlueFloat Energy	500MW
11	ScottishPower Renewables and Shell	3,000MW
12	Floating Energy Allyance	960MW
13	RIDG, Corio Generation and TotalEnergies	2,000MW
14	Northland Power	1,500MW
15	Magnora Offshore Wind	495MW
16	Northland Power	840MW
17	ScottishPower Renewables	2,000MW
18	Ocean Winds	500MW
19	Mainstream RP and Ocean Winds	1,800MW
20	ESB Asset Management	500MW

ScotWind Round - Offshore wind Scotland 2023

- £700 million spend on option fees

Celtic Sea Pipeline, Ambition and Timelines

432MW of Test and Demo Projects in Train

Test and Demo Sites - Celtic Sea

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Contracts for Difference: Auction Round 4 & 5

- Hexicon's TwinHub announced as successful bid July 2022
- 32MW demonstration FLOW to be built out on the old WaveHub site
- Initiates real activity to help Cornwall and the region get ready and scale up for FLOW.

- Blue Gem Wind's 100MW Erebus aiming for AR5 in 2023
- When built, it will be the world's largest FLOW farm

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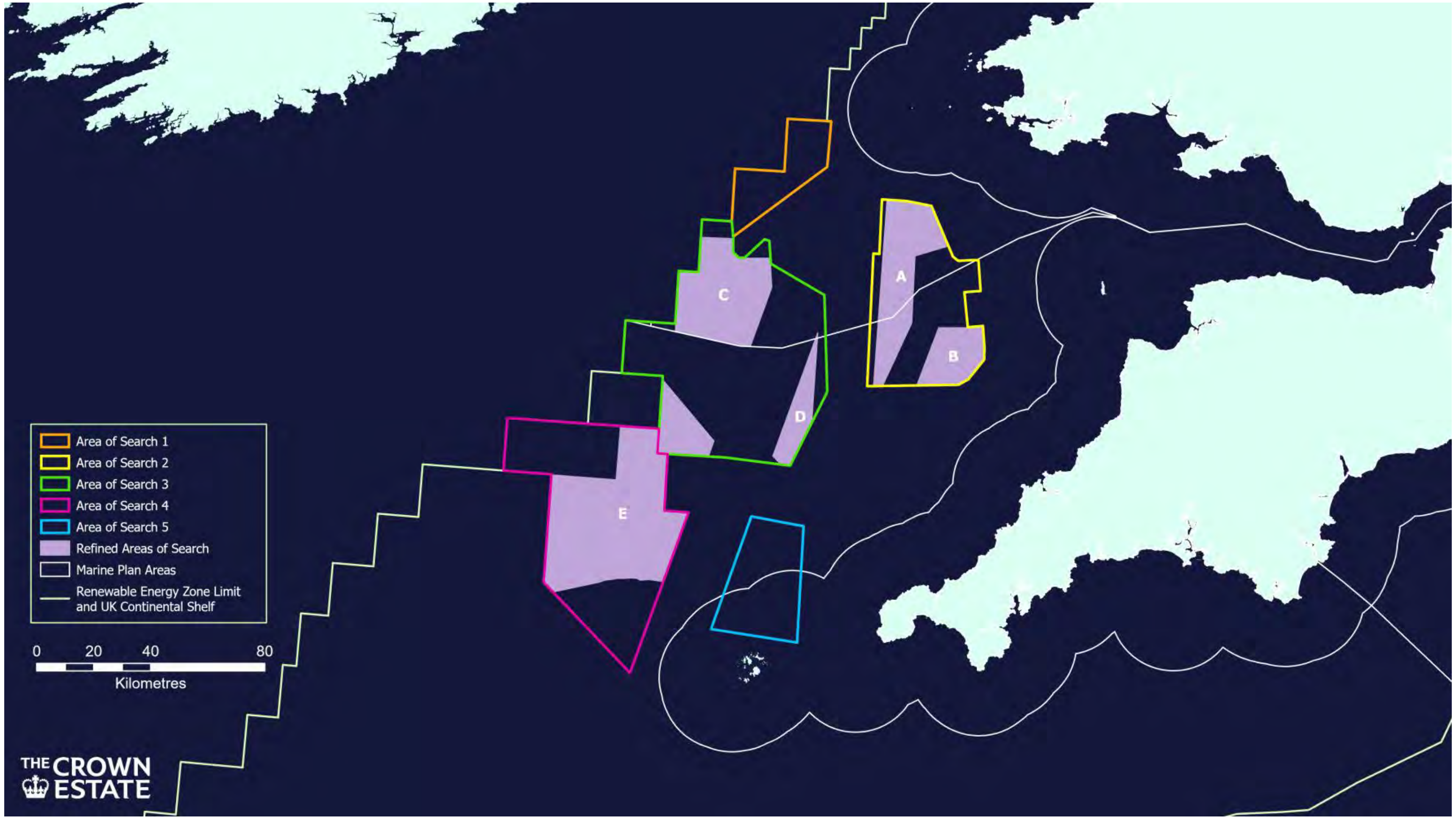
FLOW is set to be a key part of UK's energy transition

UK Target of 5GW by 2030 (BESS)



4GW Leasing round in mid-2023. GW scale projects by 2035.

20GW of additional capacity by 2045.

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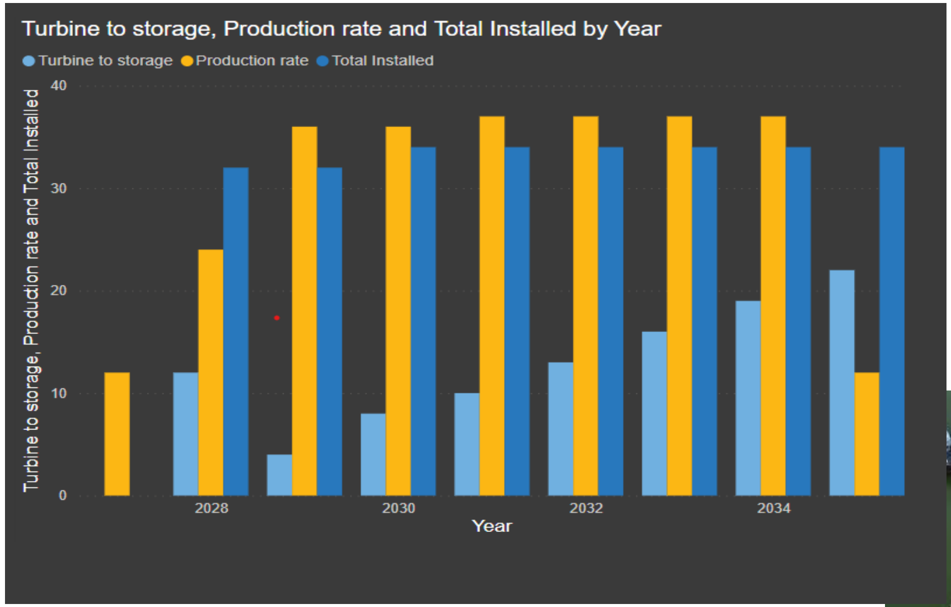
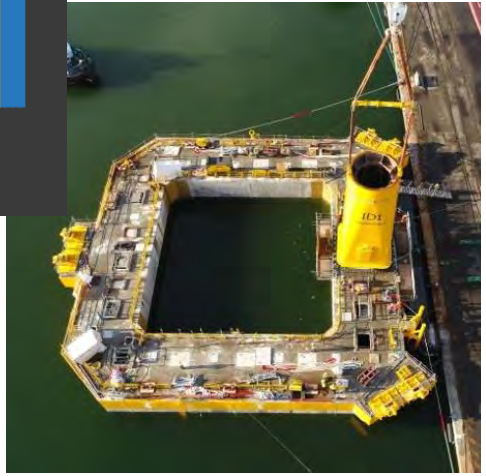
The Celtic Sea Industrial ecosystem – What do we HAVE to do?

AVERAGE PRODUCTION RATE REQUIRED 2030 on = 1 INSTALLED TURBINE EVERY 1.5 WEEKS FOR 6 YEARS

Smooth ramp up of production to deliver 4GW of FLOW in Celtic Sea by 2035 and maintain same until 2060





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Thank you
matt.hodson@celticseapower.co.uk

MORWIND

Dynamic Array Cables - A Developer Perspective

28th March 2023

vF

About Morwind

Morwind is a Cornish development company, driven by a commitment to accelerate decarbonisation, whilst promoting maximum local, regional and national opportunities.

- Exclusive agreement with Corio to develop FLOW in Celtic Sea

Experience

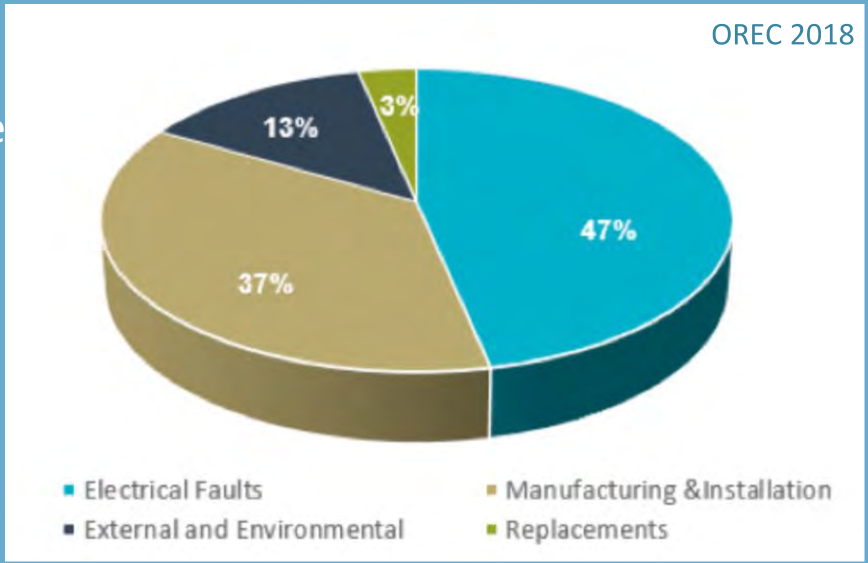
- >100 years of cumulative offshore wind development experience
- Originated London Array, the world's first 1,000 MW offshore wind project
- Provided consenting support to over 26 GW of offshore wind worldwide

Corio is a portfolio company of Macquarie's Green Investment Group, operating on a standalone basis. Launched in April 2022, Corio today has one of the world's largest offshore wind development portfolios, at over 20 GW, including projects in England and Scotland

The cable journey so far...

Incidents relating to the installation and operation of subsea power cables are found to be the most costly cause of financial losses in offshore wind industry

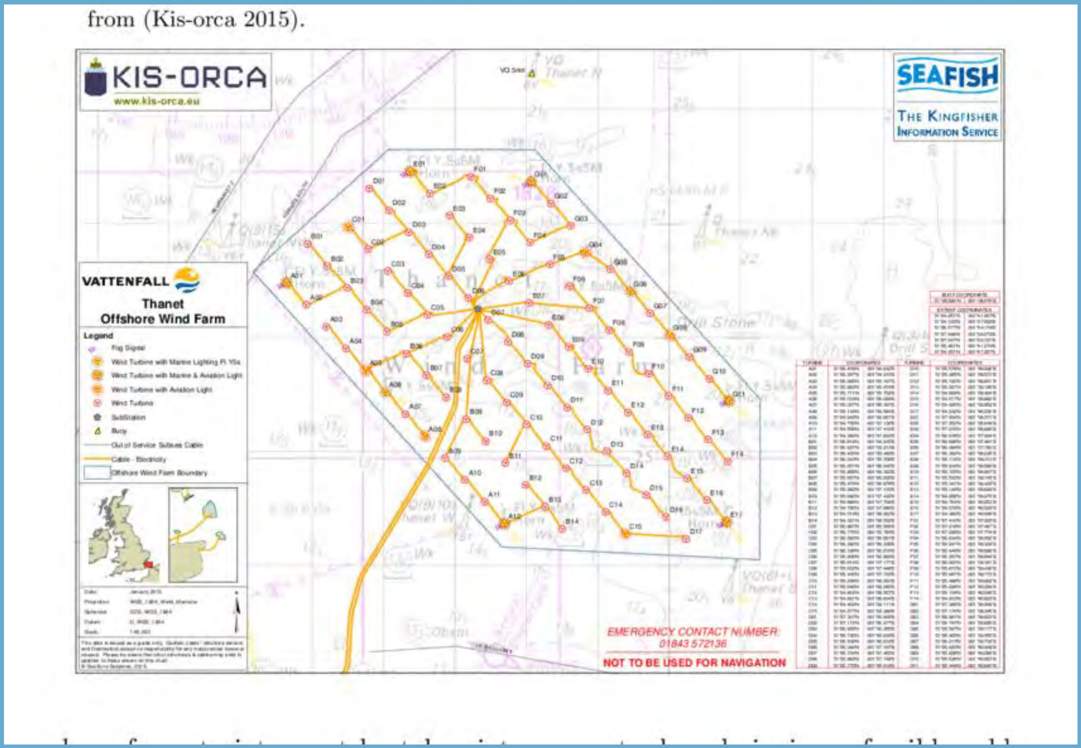
- 55% of insurance claims and 75% of claim value in offshore wind farms are related to inter-array cable faults (GCube 2019)
- a total of 43 array and export cable failures have been reported since 2007 (OREC 2018)
- Issues associated with manufacturing and / or installation are reported to be the most common cause of cable failure



- from 2014 to the end of 2017, recorded cable failures at UK offshore wind projects have led to a cumulative loss of power generation of approximately 1,970 GWh (OREC 2018)
- Cable failures relate to electrical AND fibre optic faults, which cause impact to the wind farms performance and output

Site Design

Cables are the arteries to the farms’ beating heart



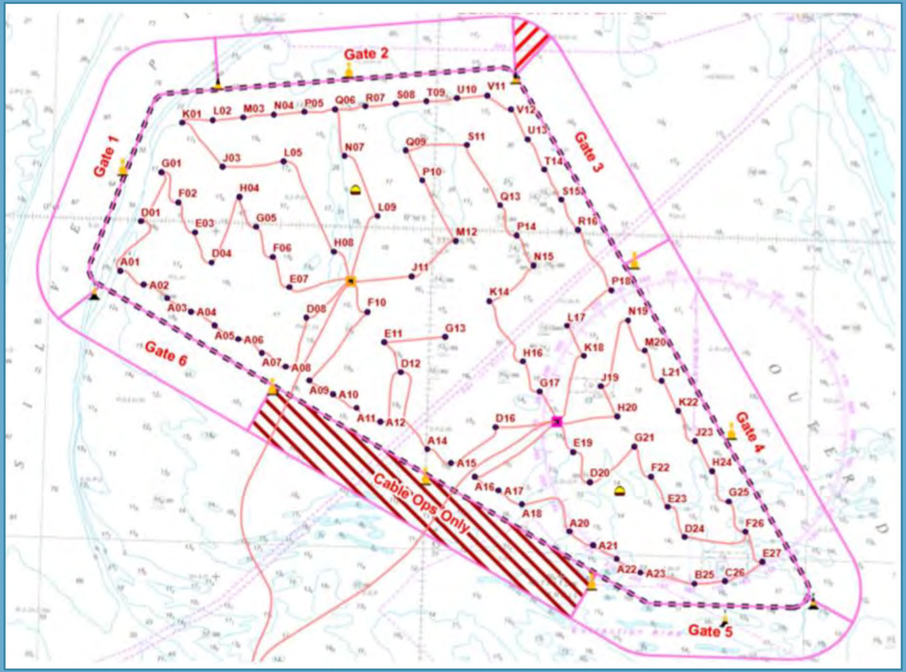
Thanet, 2010 – 100 WTG’s (300MW)

- water column exposure
- moorings conflict and integration
- Impact to other users

Operational questions

- maintenance – disconnection for tow to shore...
- fault rectification

Triton Knoll, 2022 – 95 WTG’s (857MW)

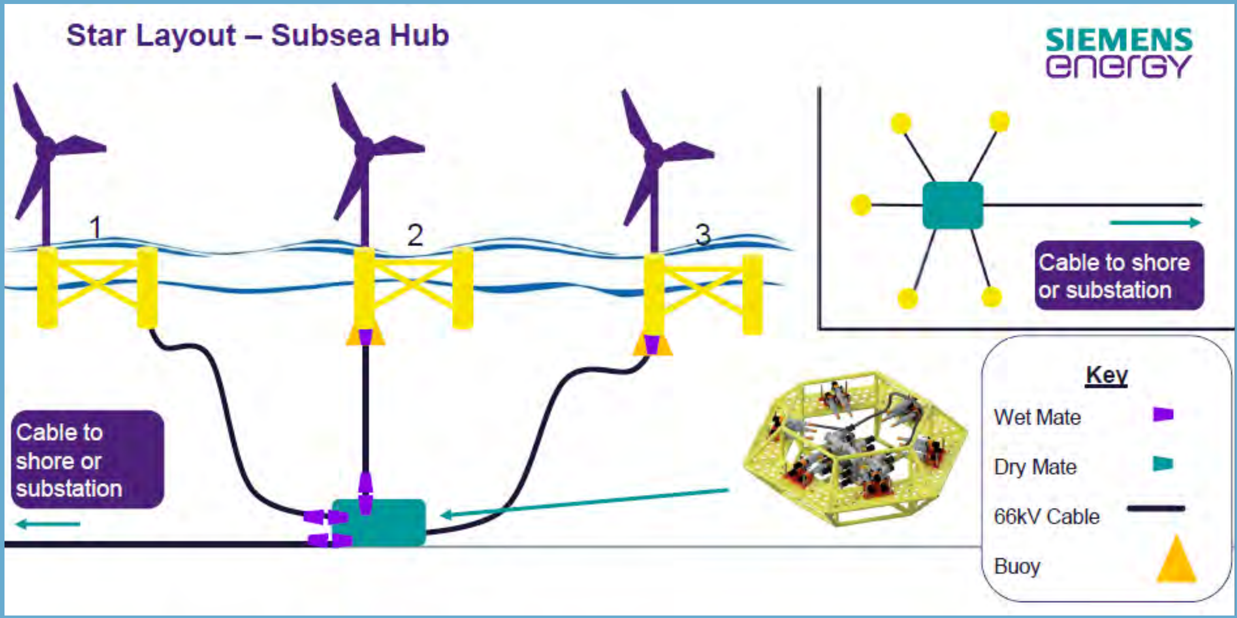


Manufacture, Supply & Installation

MORWIND

Robust electrical design, manufacture and installation is critical for long term investment

- **Industrialisation:** 65+ WTG arrays (largest operating array = 11 turbines, Tampen, 2022)
- **Innovation:** 11-33-66-132 kV; dynamic environment; wet connectors
- **Configuration / connector hubs**
- **Manufacture:** quality / defects; supplier constraints; roadmaps
- T&I: vessels; hookup
- Design questions
  - ❑ increased lengths
  - ❑ more complex
  - ❑ losses / performance



Developer Outlook

MITIGATING RISK, OPTIMISING PERFORMANCE

Site Design / Layout

Early integrated design and mitigation

Performance

Commercial focused

Innovation

Losses

Integrity and reliability

Economics

Cost viability

Insurance

MORWIND

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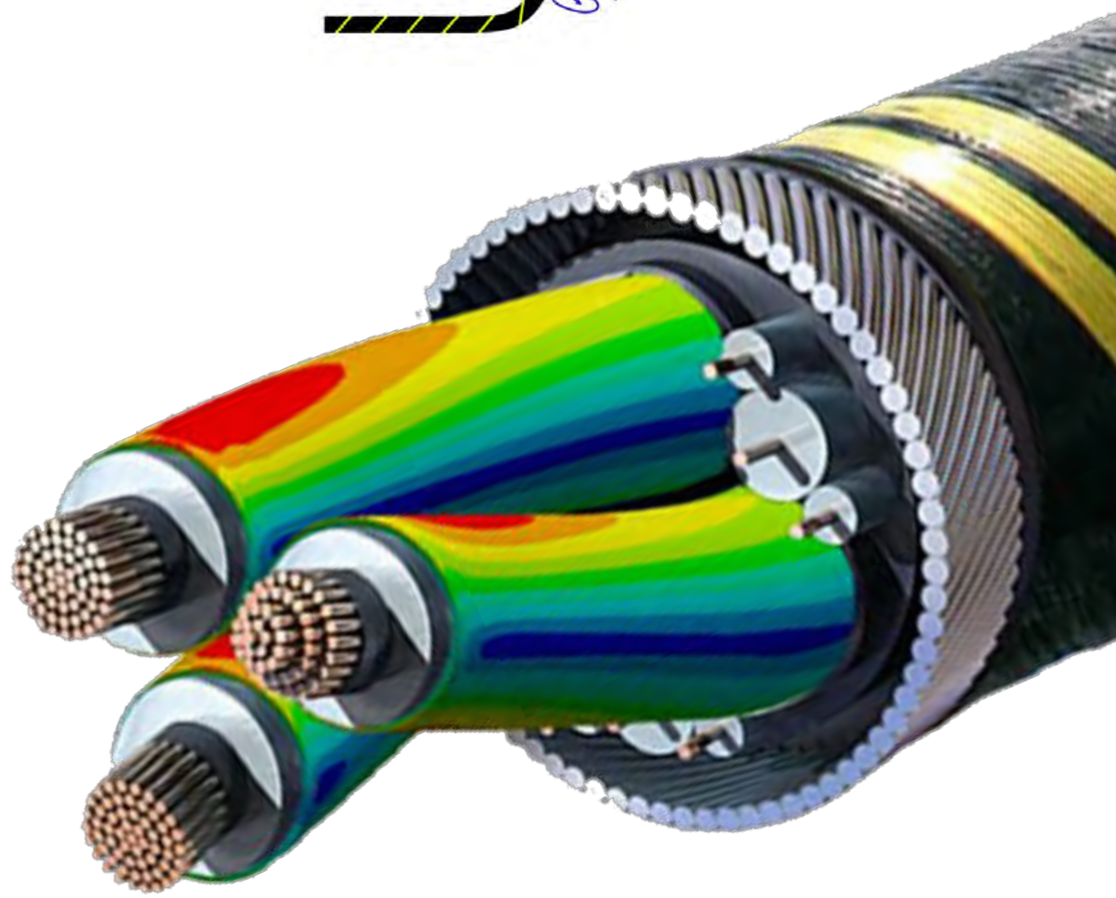
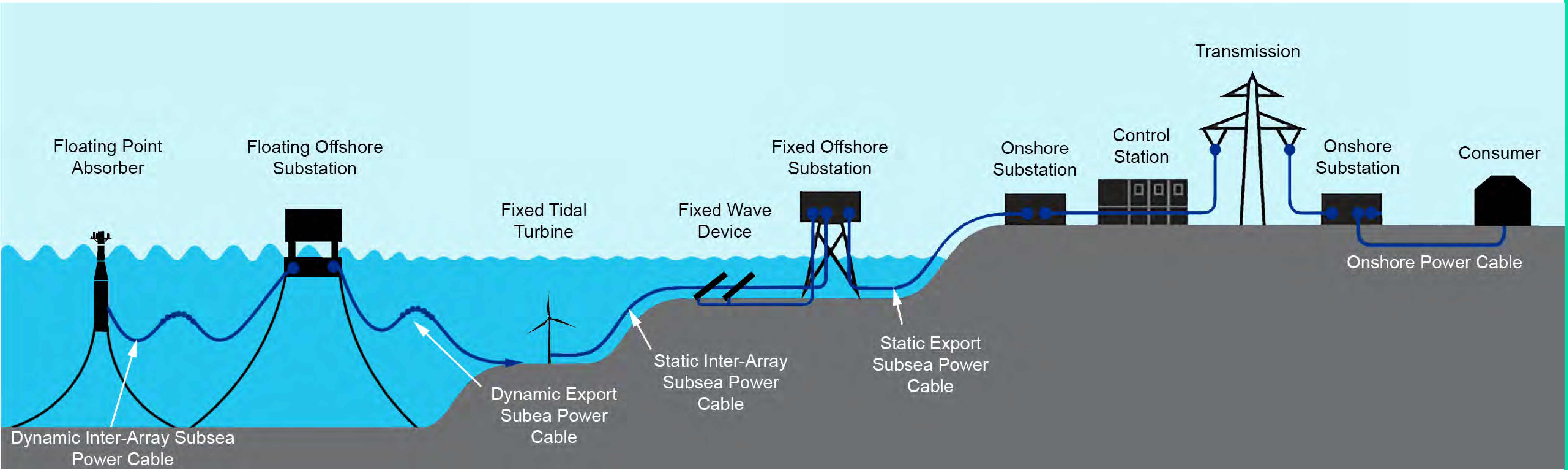
Global and local simulations of DAC systems

Dr Rachel Nicholls-Lee, Prof. Lars Johanning, Prof. Philipp Thies
Renewable energy Group



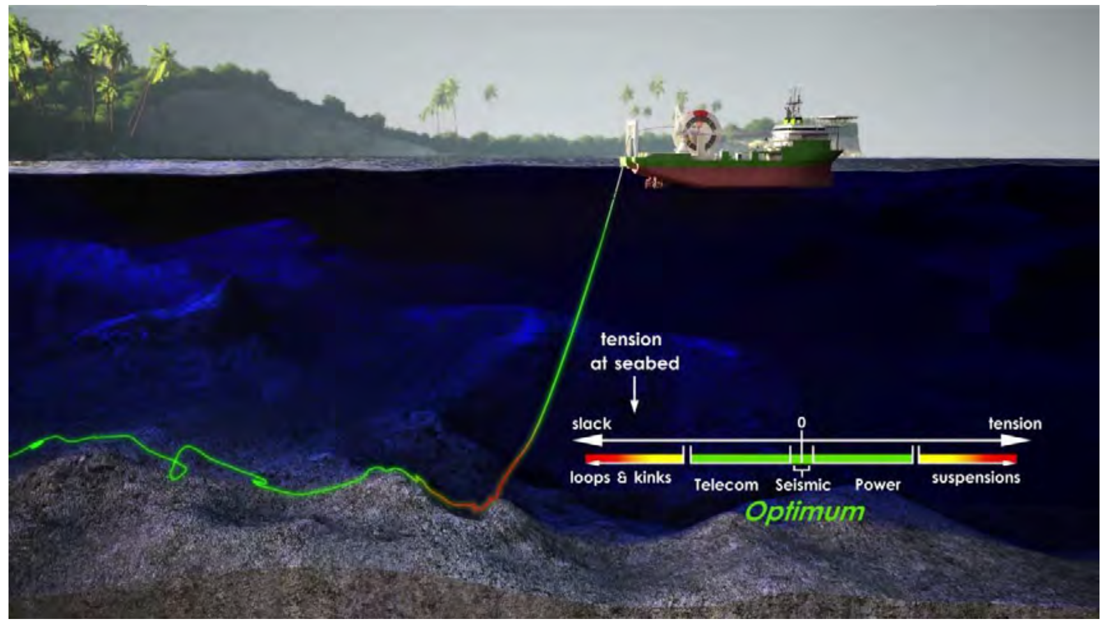
Introduction

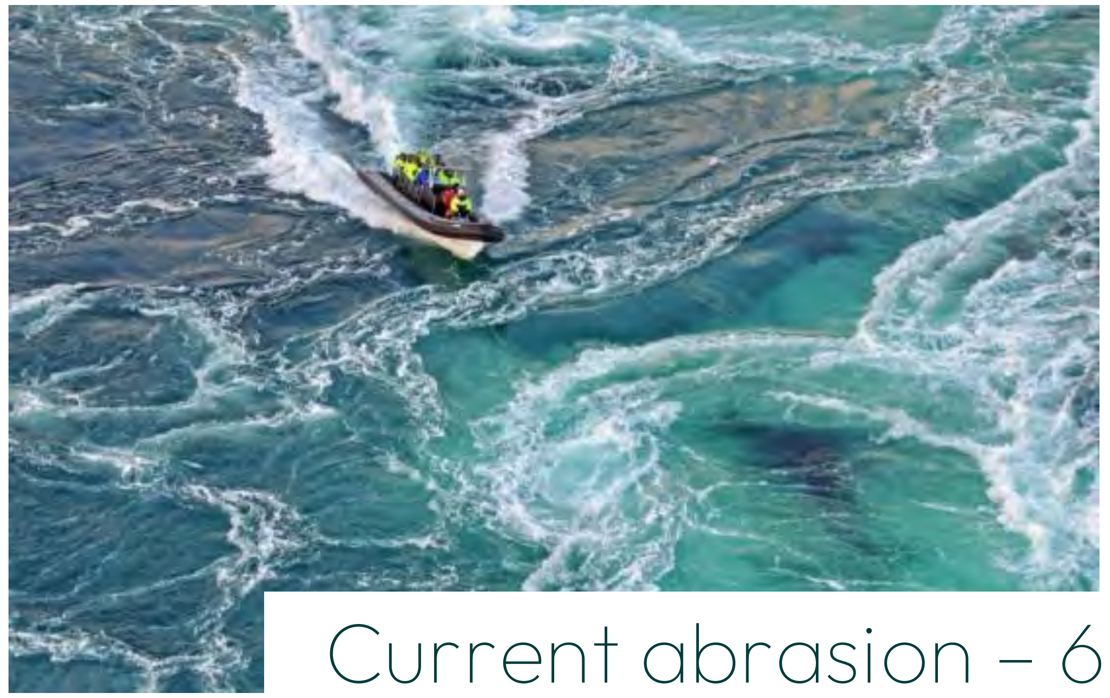
- Subsea power cables critical in the distribution of renewable energy
- Limited knowledge base of dynamic cable fatigue in renewables
- Cable failure is costly – up to £2M to repair
- Better understanding of cable failure mechanisms required



Key Failure Modes

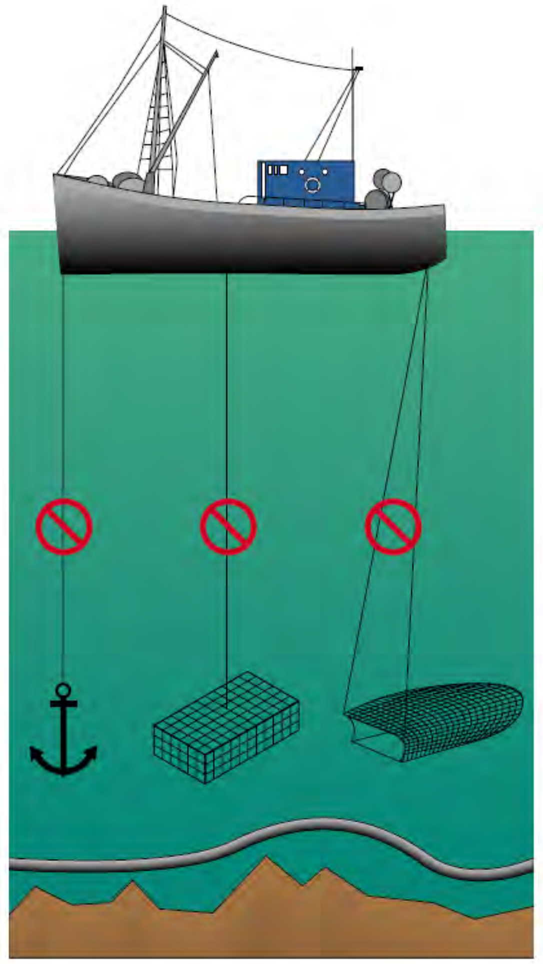
Installation – 30%



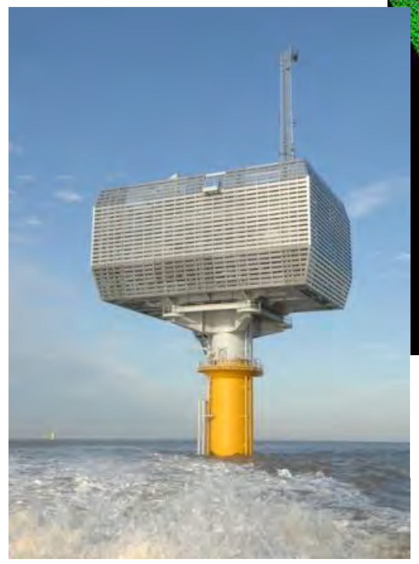


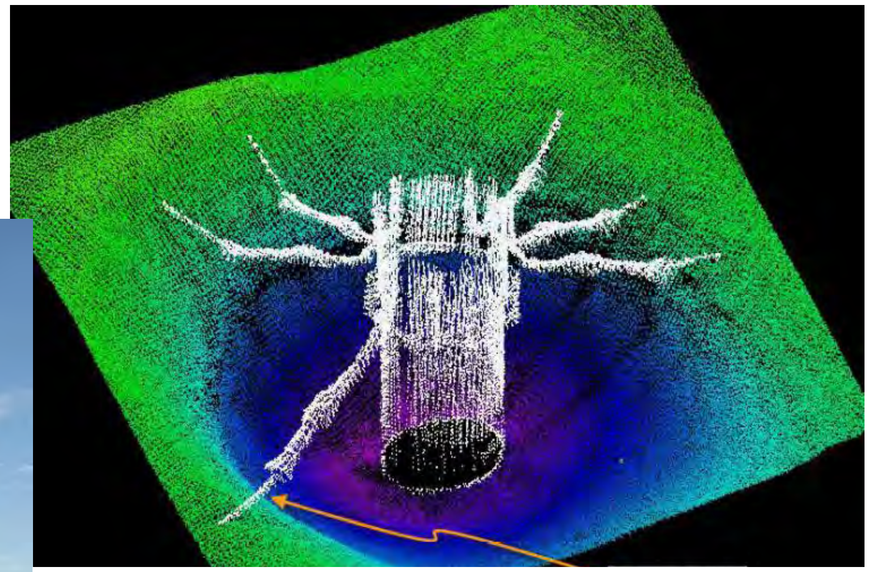
Current abrasion – 6%

Fishing & Anchoring – 55%



Marine Mammal Sabotage - <1%





Natural Disasters – 8%

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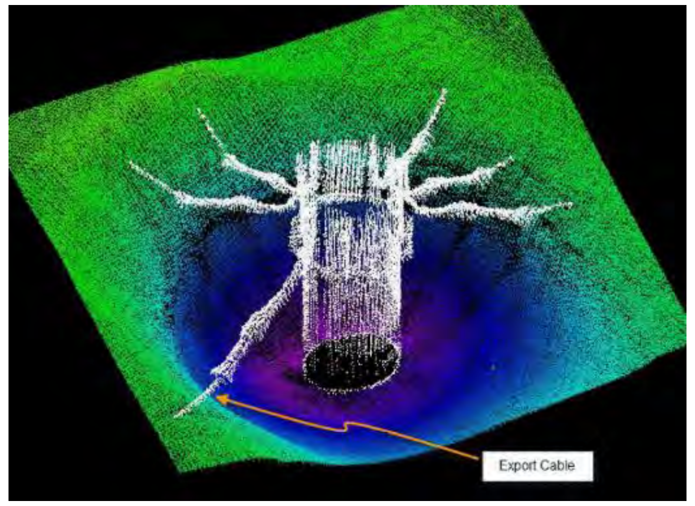
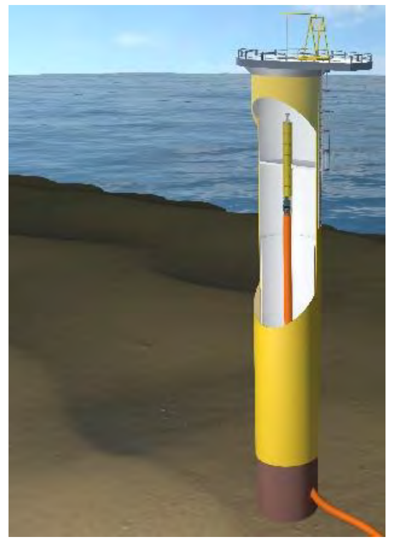
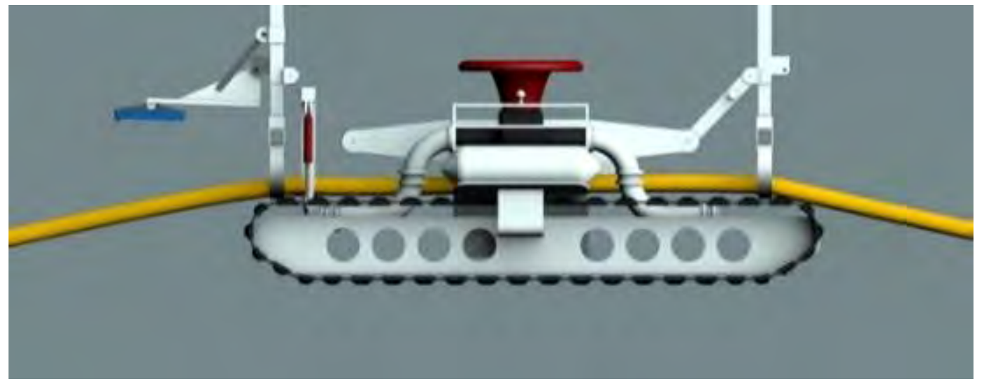
Cable Fatigue – Causes & Effects

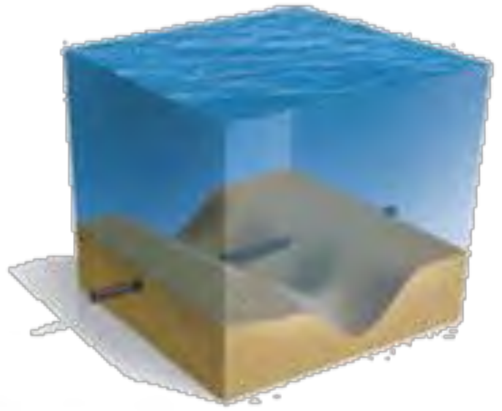
CAUSES

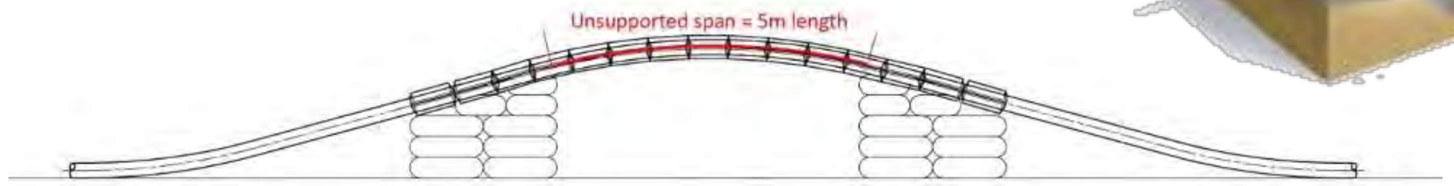
- Free hanging spans, arising from:
  - Scour
  - Crossing objects/initial lay
  - Shallow burial
  - Dynamic seabed
- Free hanging cable inside tower
- Cumulative stress from repeated handling
  - Installation
  - Repair





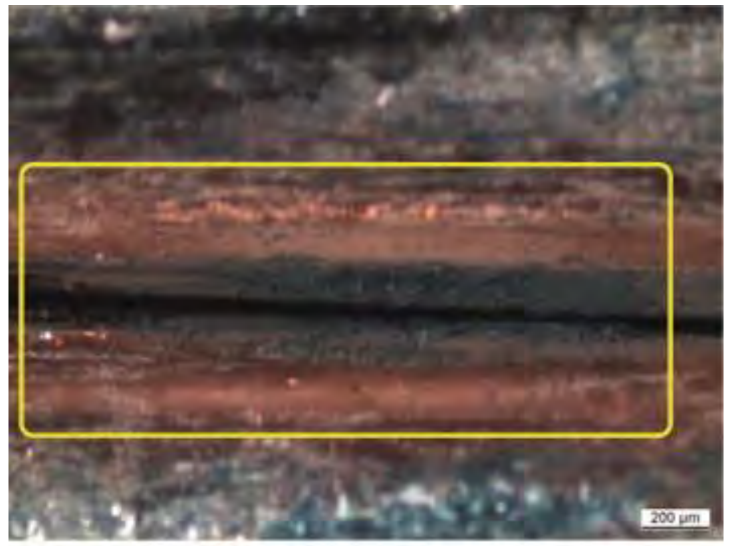




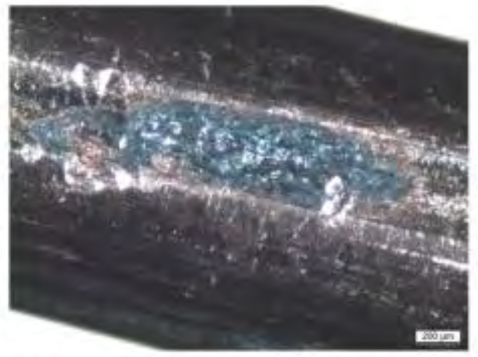


EFFECTS

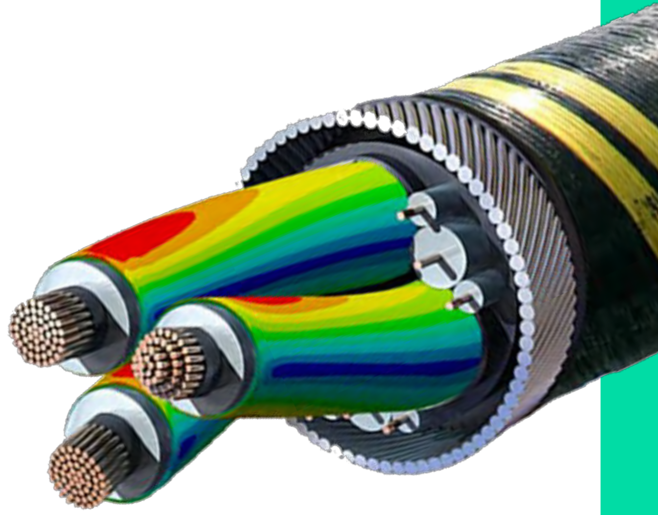
- Individual cable layers different failure mechanisms:
  - Copper = fretting, slippage, friction, creep
  - Lead = work hardening due to low cycle fatigue
  - Steel armour = brittle in very cold temperatures



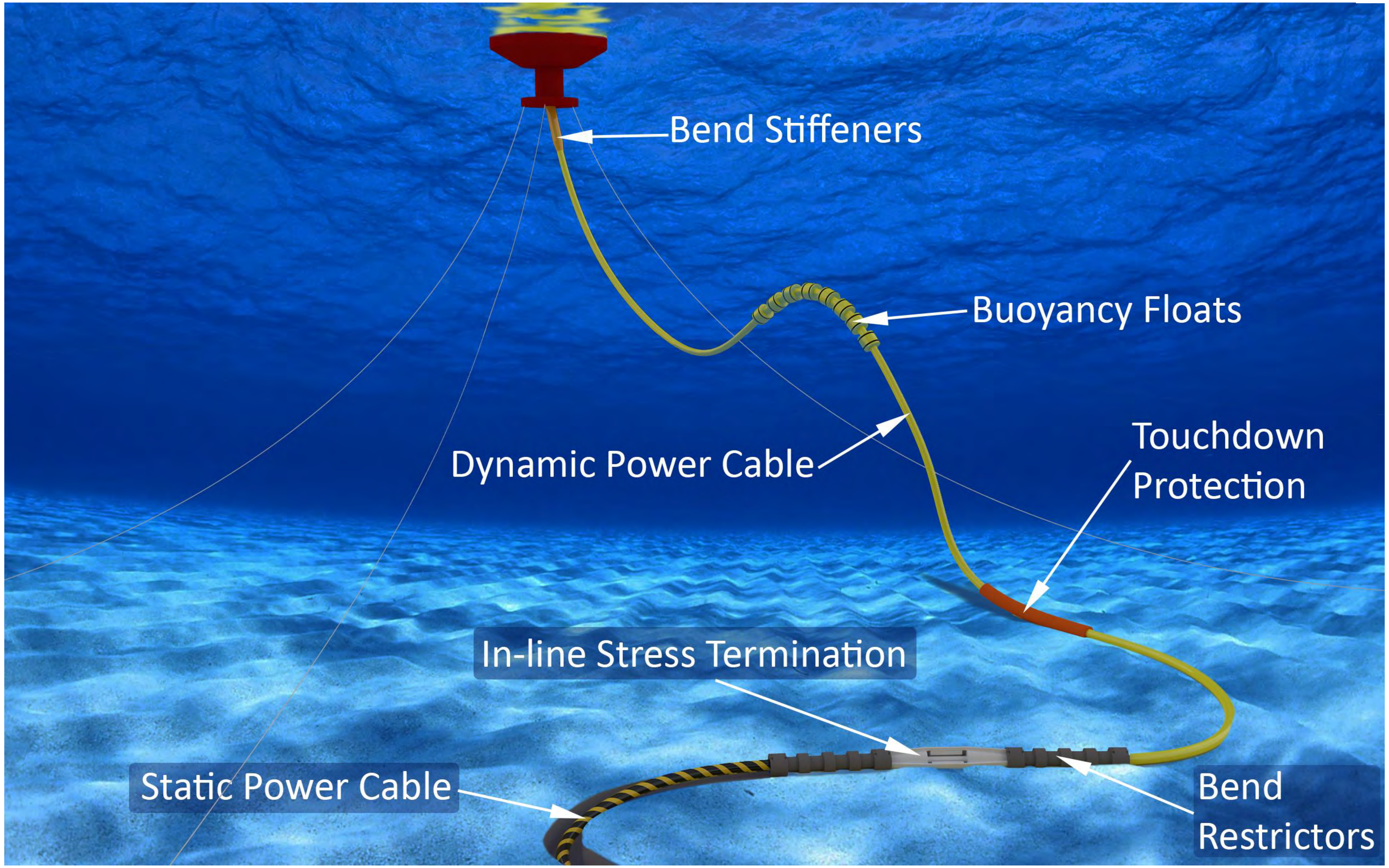
(a) Fretting between two conductor wires



(b) Fretting on conductor wire surface



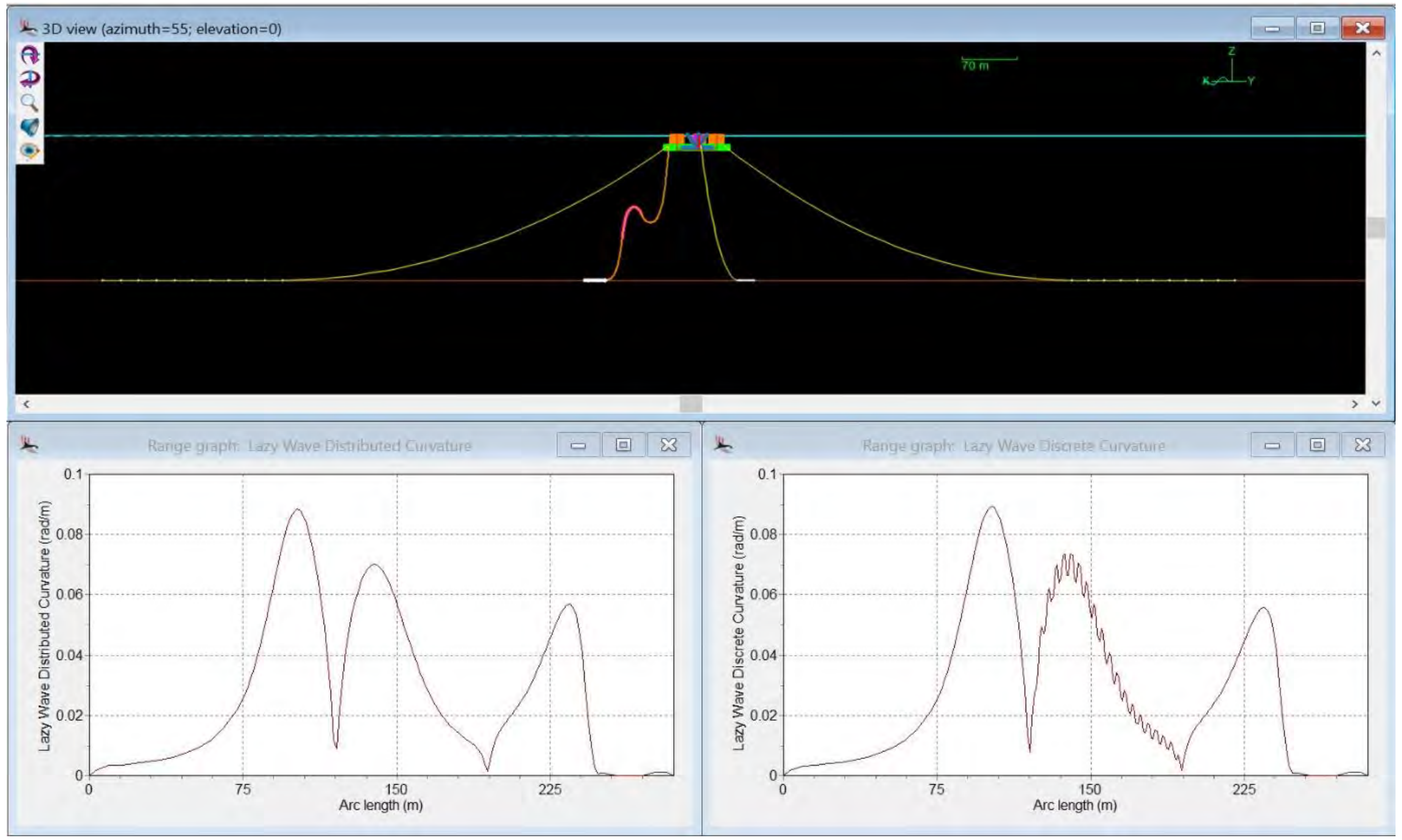
Dynamic Subsea Power Cables



Global Numerical Model

- Assess whole system:
  - Platform motions in varying sea states, including moorings and dynamic cable
  - Wind Turbine loads and response
- Requires input of cable local structural properties:
  - Bend Stiffness
  - Axial Stiffness
- Basic fatigue life estimates
  - Are S-N curves representative?





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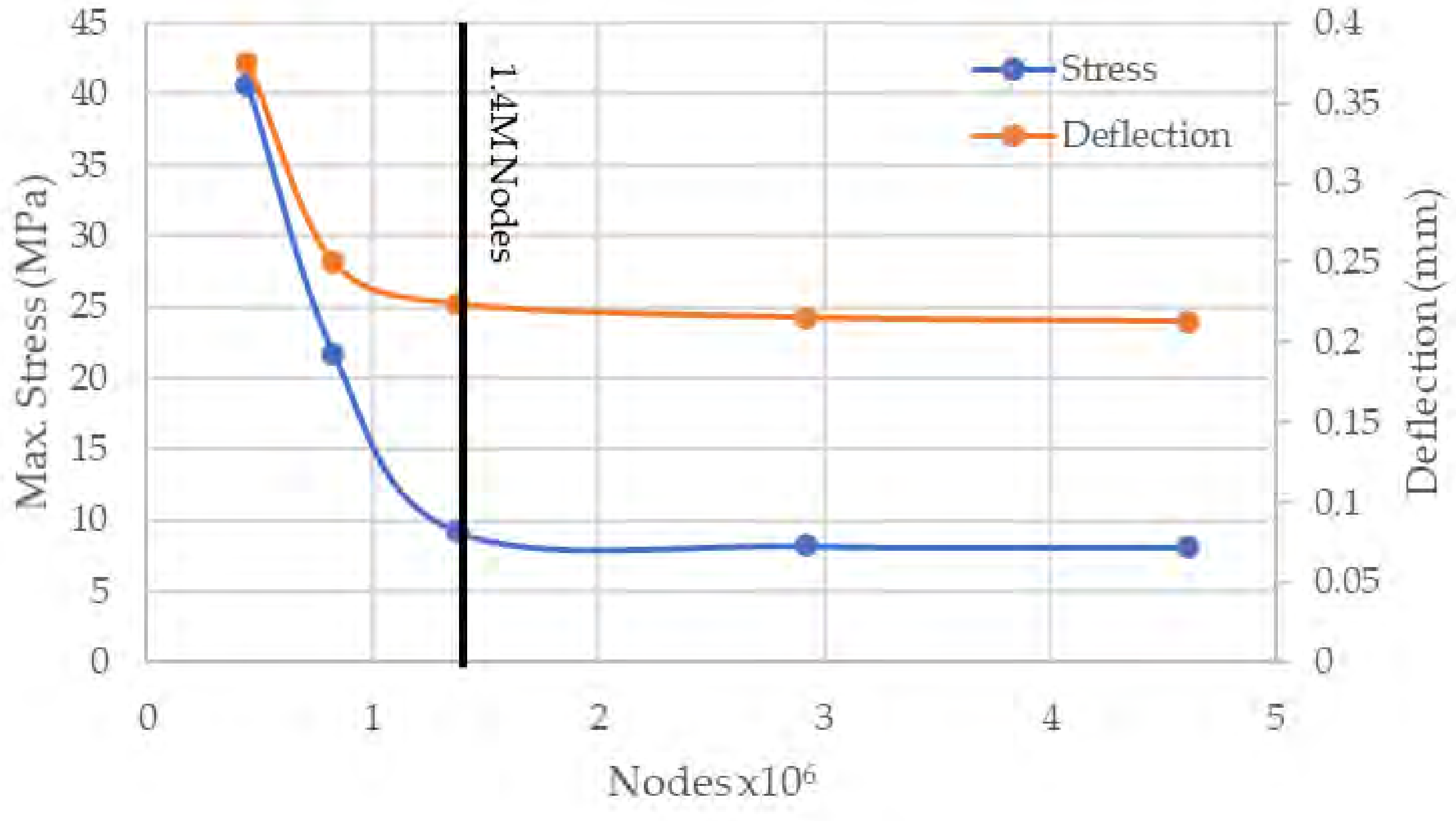
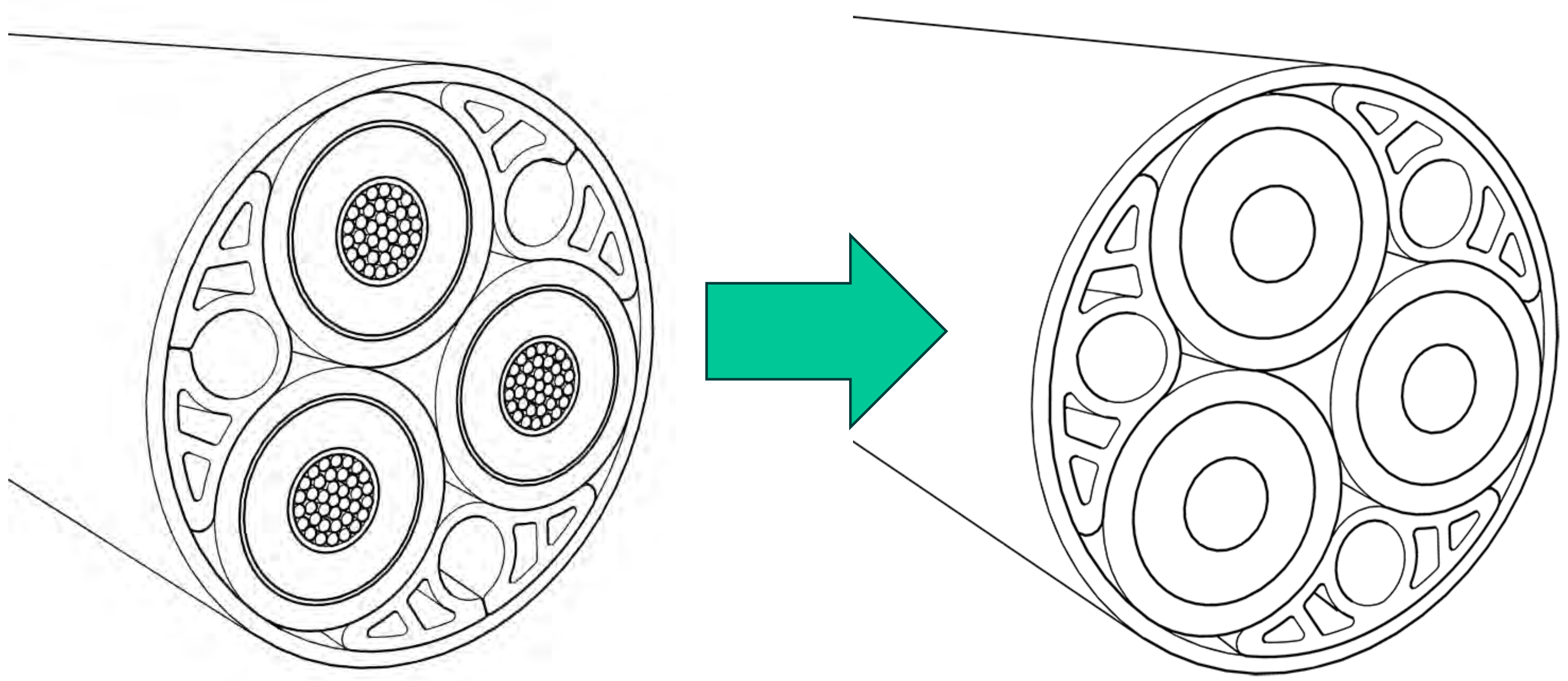
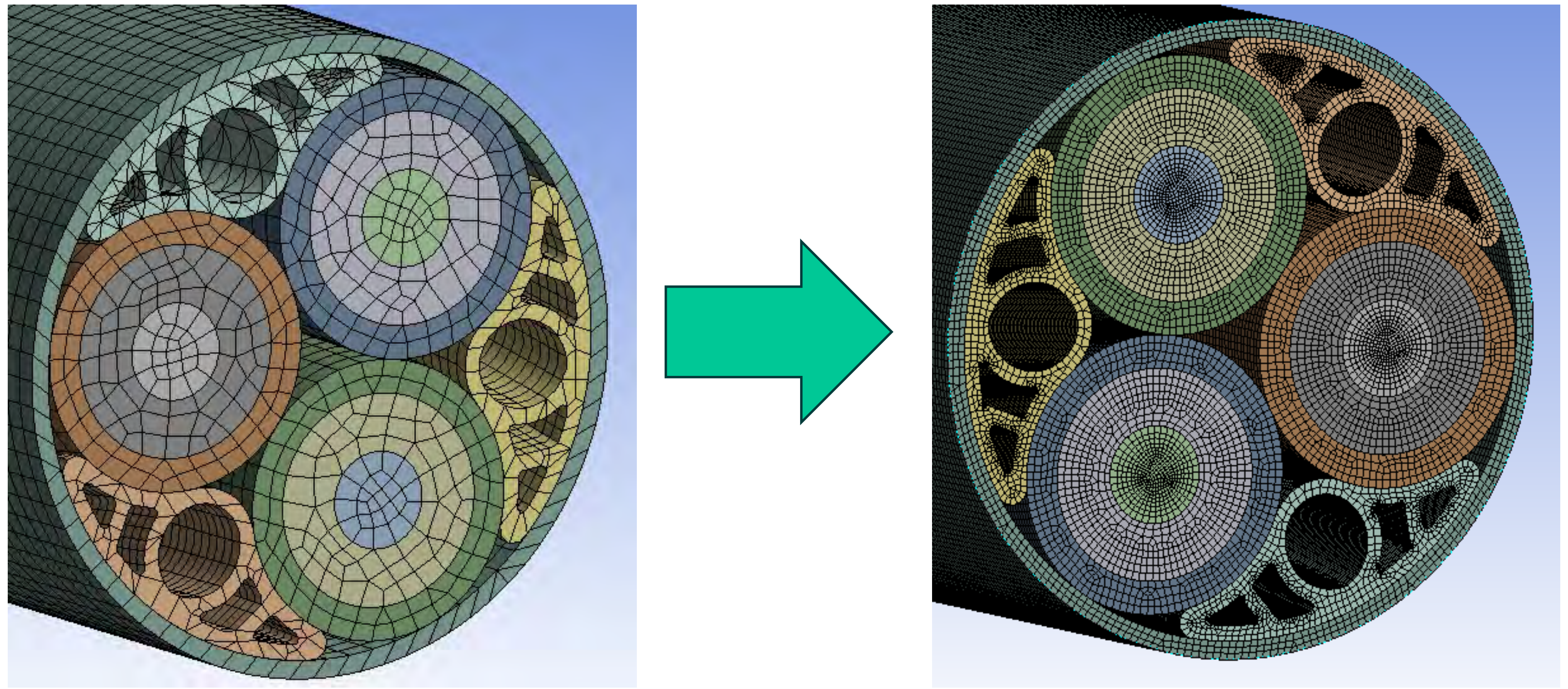
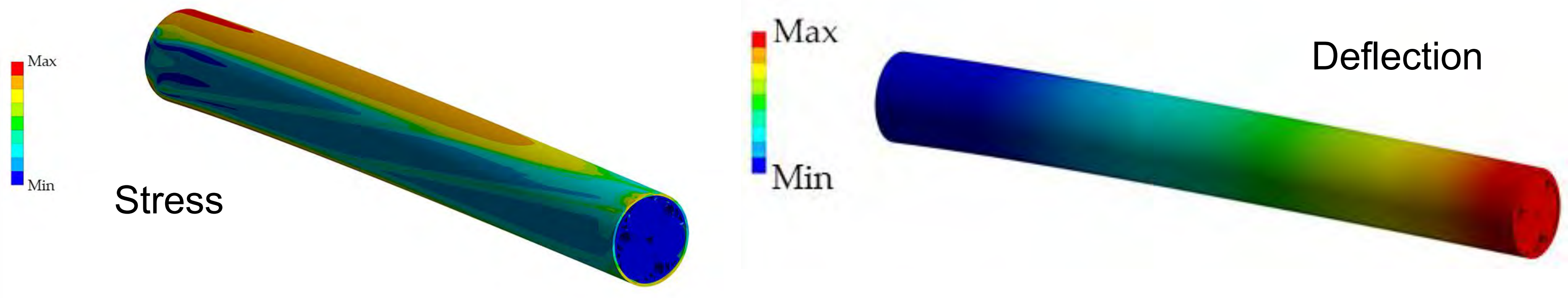
Local Numerical Model

- Model developed in ANSYS Mechanical
- Geometry simplification required:
  - 10 hours; 128GB RAM; 16 cores
- Mesh sensitivity undertaken:
  - 1.4M nodes optimal
- Cable treated as 1m cantilever beam:
  - Point load for bending stiffness
  - Axial load for axial stiffness



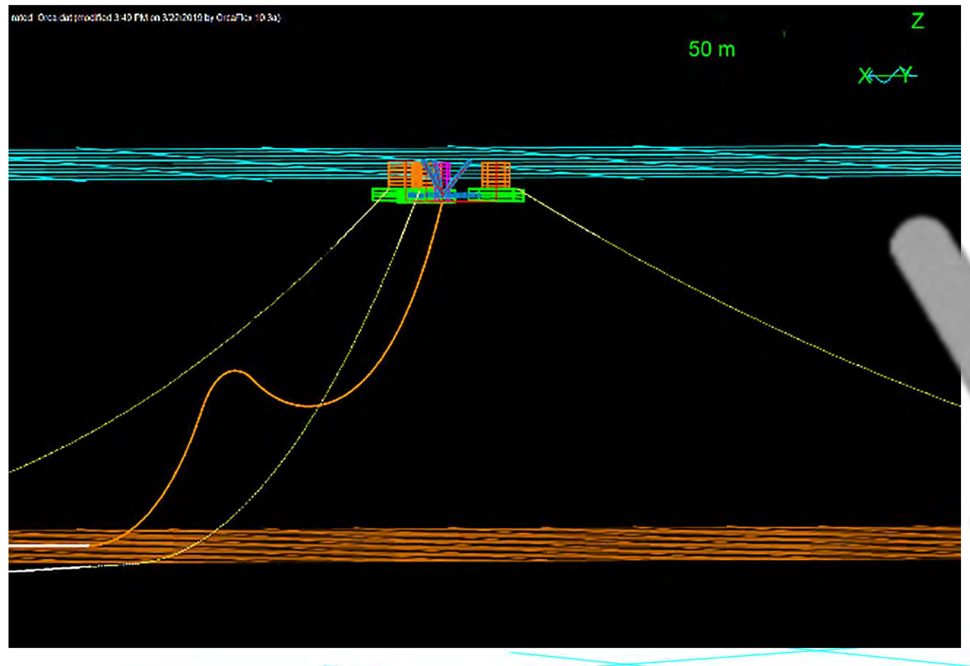


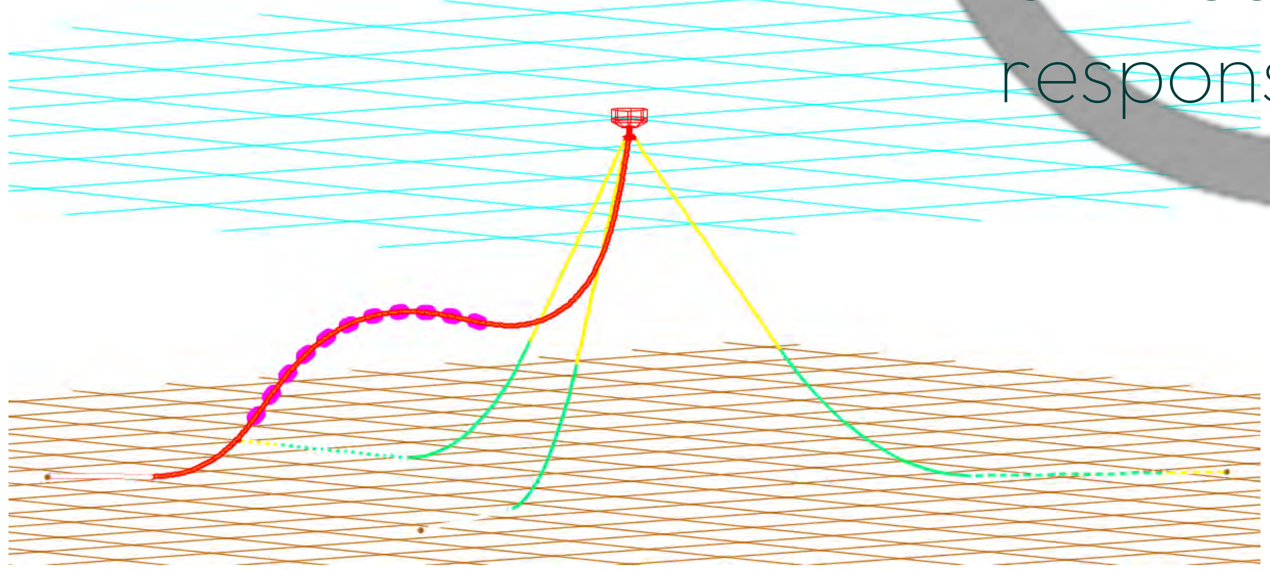




Coupled Model

- Assessment of effect governing design parameters:
  - Axial stiffness
  - Bending stiffness
- FOWT global model:
  - sensitive to change in cable axial stiffness
  - less sensitive to change in bending stiffness
- WEC global model:
  - sensitive to change in cable bending stiffness
  - less sensitive to change in axial stiffness



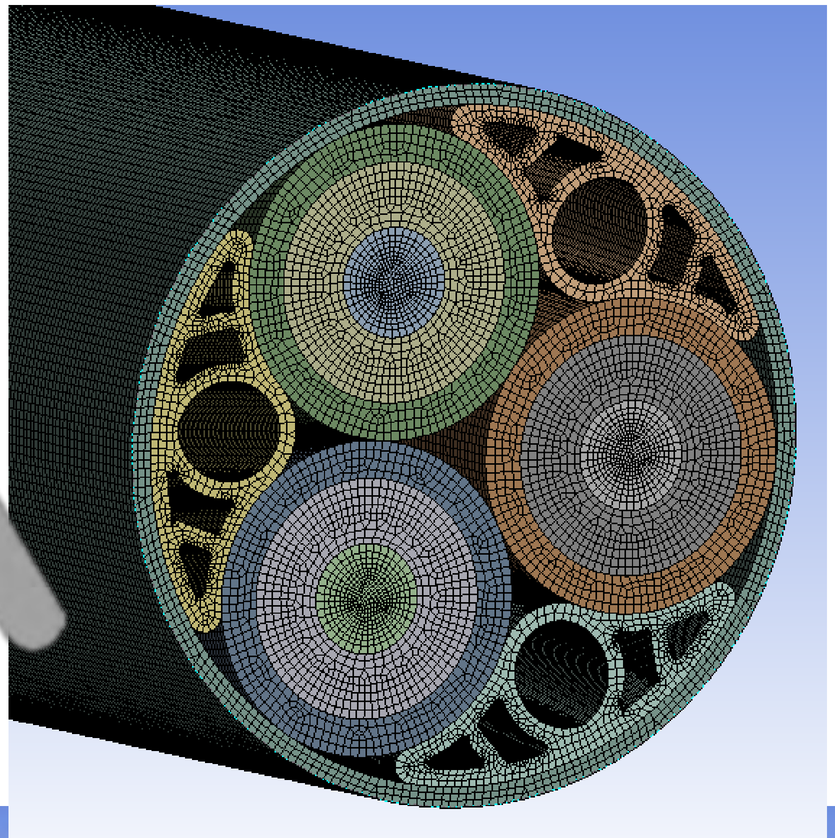


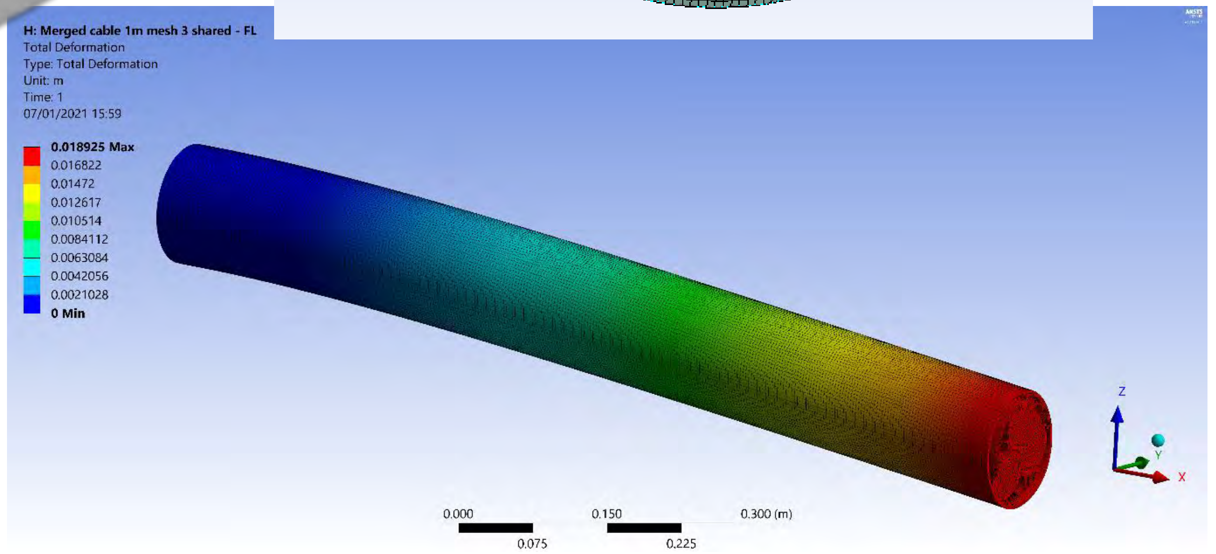
Improved accuracy

Supports cable design

Computationally expensive

Nonlinear, layerwise response of cable





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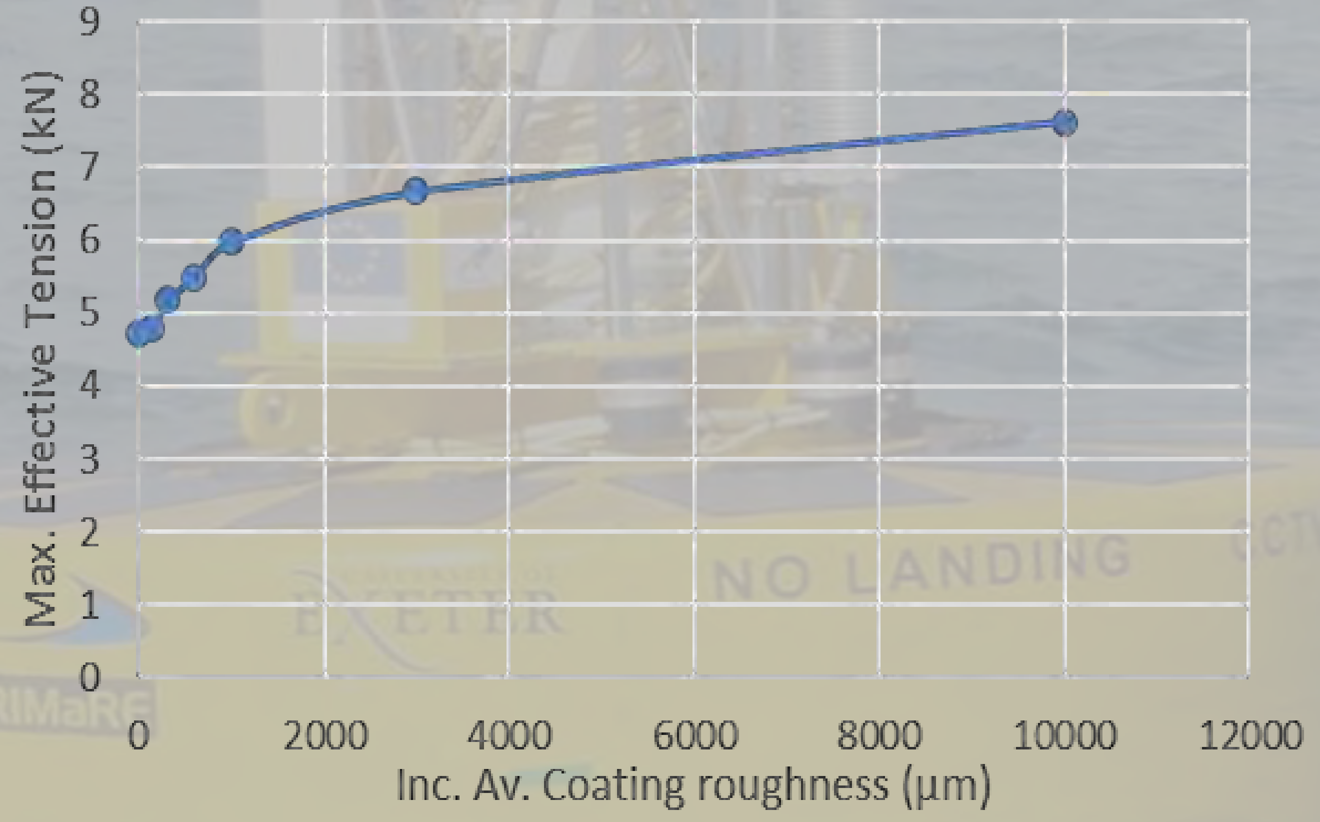
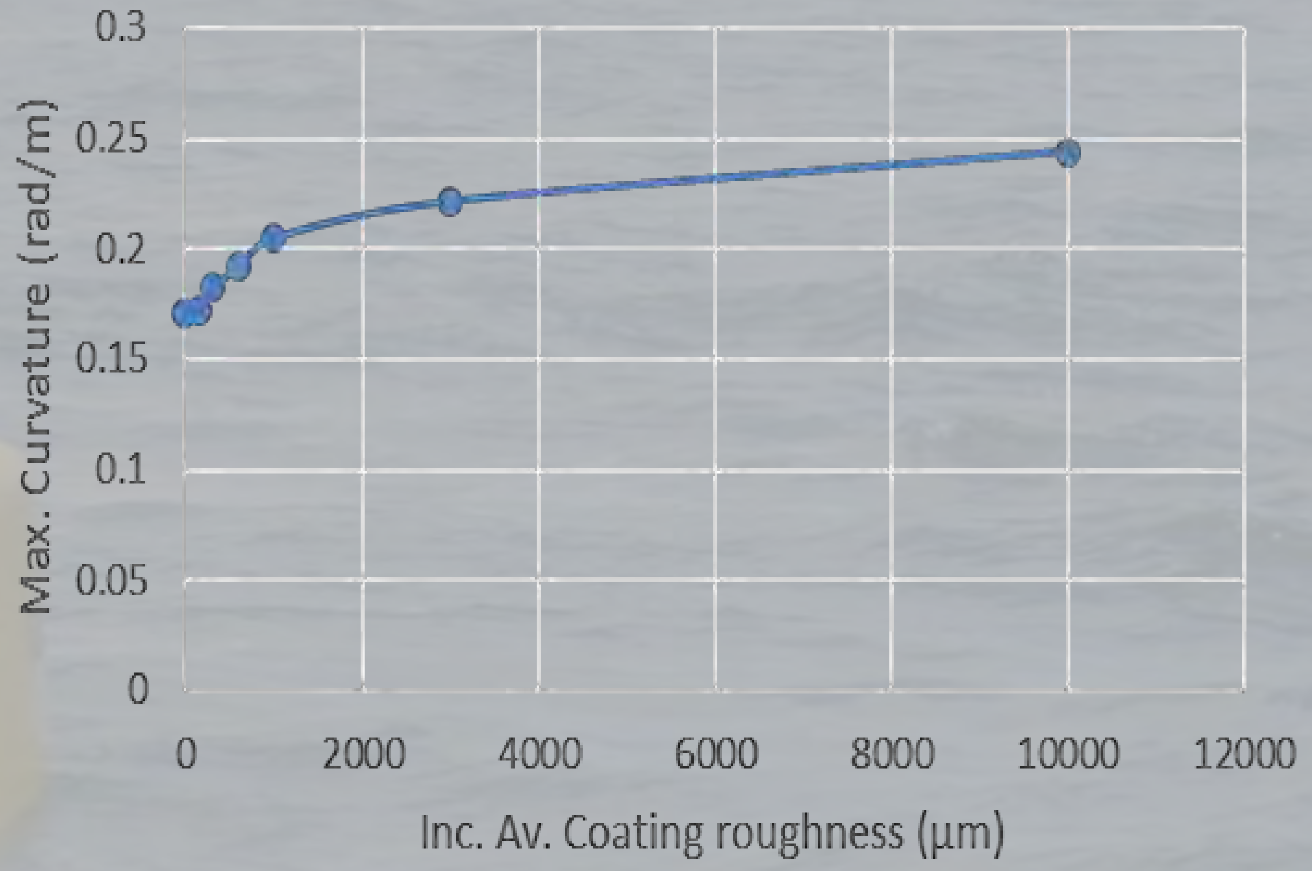
Affects of Marine Fouling

- 10 months growth on SWMFT buoy at FaBTest
- Increase in surface roughness:
  - 61% increase in max tension
  - 43% increase in max curvature
- V. lightweight cable and small platform- moves more with increase in drag
- Fouling assumed to be neutrally buoyant, applied evenly along cable, worst case scenario





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Conclusions

- Cables essential in renewable energy generation for power transfer
- Static cable failures dominated by installation/fishing/anchoring
- Concern for fatigue failure of dynamic cables
- Global numerical models assess system holistically
- Local numerical models provide detailed layerwise analysis
- Coupled models used for various assessments:
  - Governing design parameter sensitivity
  - Marine fouling studies
- Experimental testing to verify numerical models

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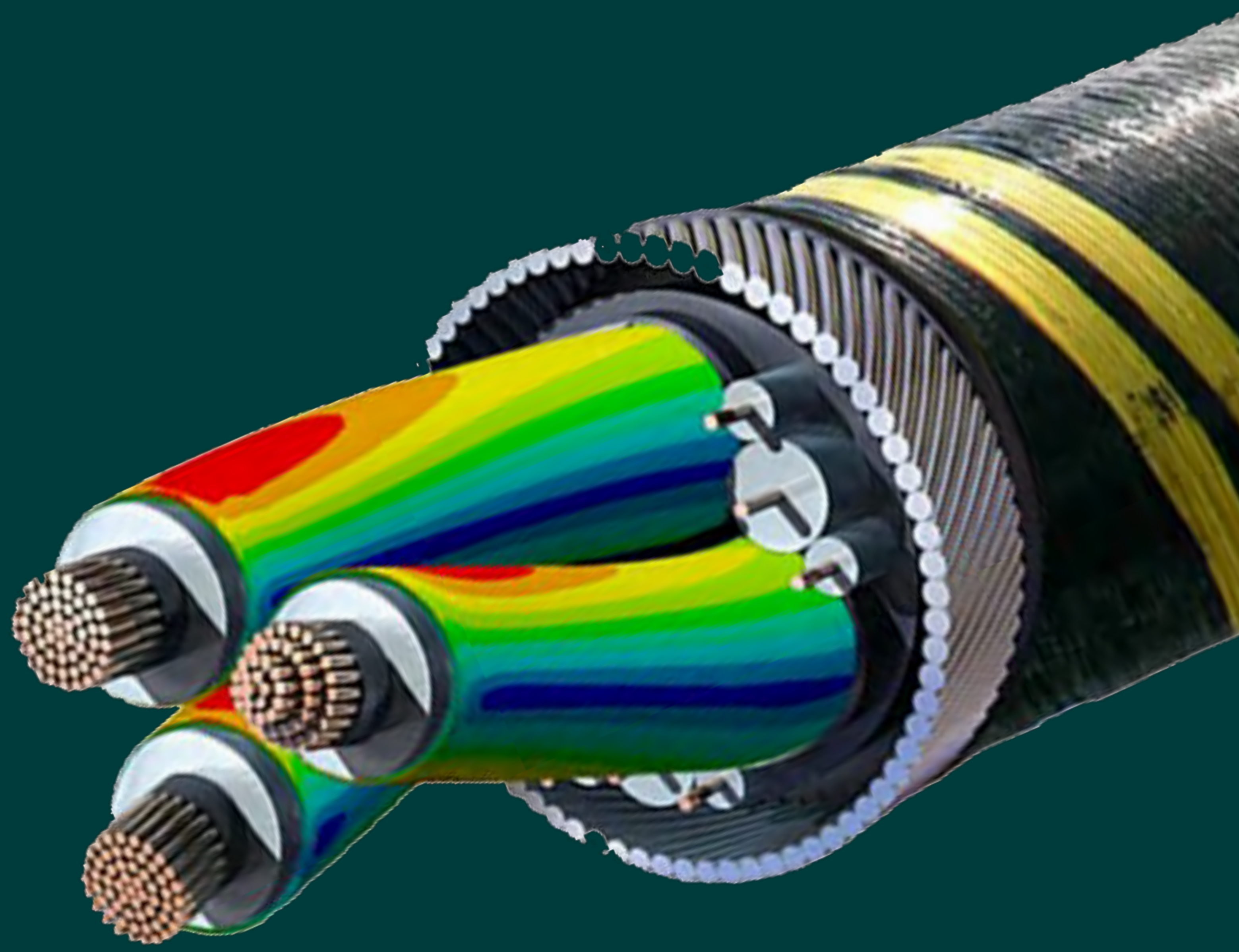


Any Questions?

Dr Rachel Nicholls-Lee

R.F.Nicholls-Lee@exeter.ac.uk

Acknowledgements: EPSRC CableDyn Project [EP/W015102/1]

CATAPULT
Offshore Renewable Energy

Title: The electrical system balance regarding floating offshore wind and the next-generation transmission

Bradley McKay – Research Engineer Electrical

28.03.2023

OUR 10 YEAR IMPACT

10 YEARS OF CATAPULT Offshore Renewable Energy

£677M

At the heart of over £677m of innovation projects by total value

148

Instrumental in bringing 148 innovative new products and services to market

1350

Over 1350 UK SMEs supported

650

Partnered in over 650 research & development projects

250

Over 250 research a analysis papers published

What we do at ORE Catapult

TECHNOLOGY DEVELOPMENT

- Testing of next generation Turbines & Balance of Plant equipment
- Design verification and component validation
- Provide technical feedback into the ORE process as an organisation independent of developer interests

OFFSHORE WIND DEVELOPMENT & OPERATIONS

- Running Joint Industry Projects through and industry led programs
- Specific Floating Wind as well as Operations & Maintenance Centre's of Excellence
- Developing best practice for Developer/owner solutions
- Higher TRL de-risking

STRATEGY & EMERGING TECHNOLOGY

- Gateway to UK academia, supporting under-pinning research
- Evaluation and support for emerging technologies
- Supporting wave & tidal in addition to offshore wind
- Assisting energy network and storage development

CATAPULT Offshore Renewable Energy

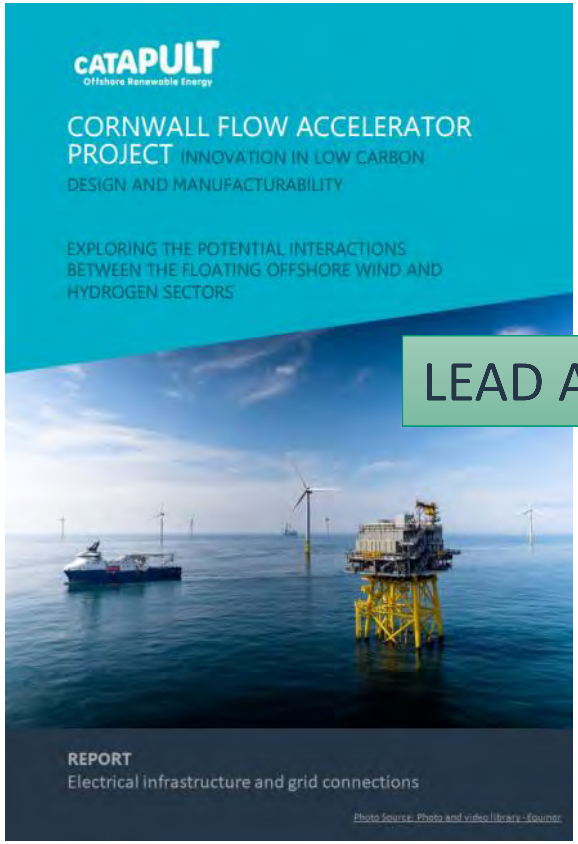
ORE Catapult Cornwall FLOW ACCELERATOR Published Reports (2022/2023)

Title: A1 Optimized cable connection options for floating offshore wind

Ref: CFAR-OC-028-03102022

Title: A2 Exploring the potential interactions between the floating offshore wind and hydrogen sectors

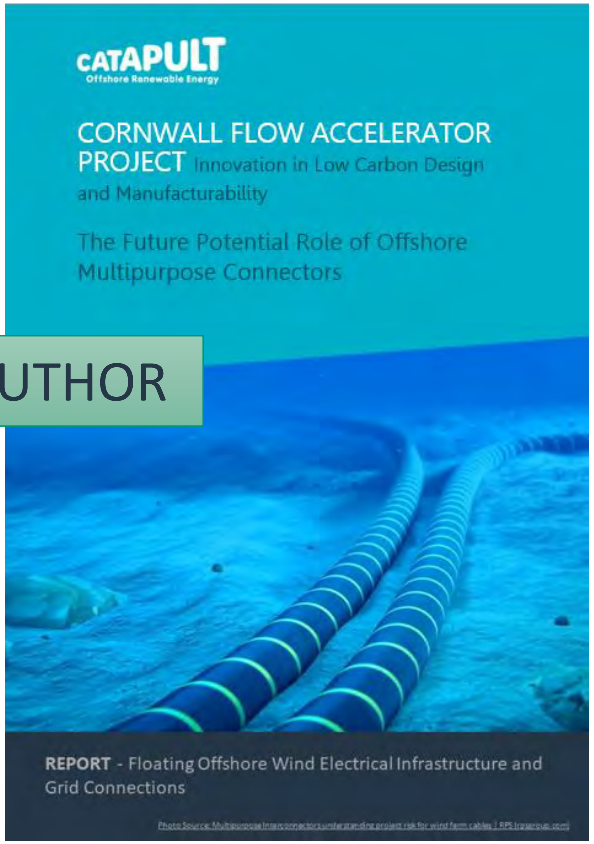
Ref: CFAR-OC-027-04102022



LEAD AUTHOR

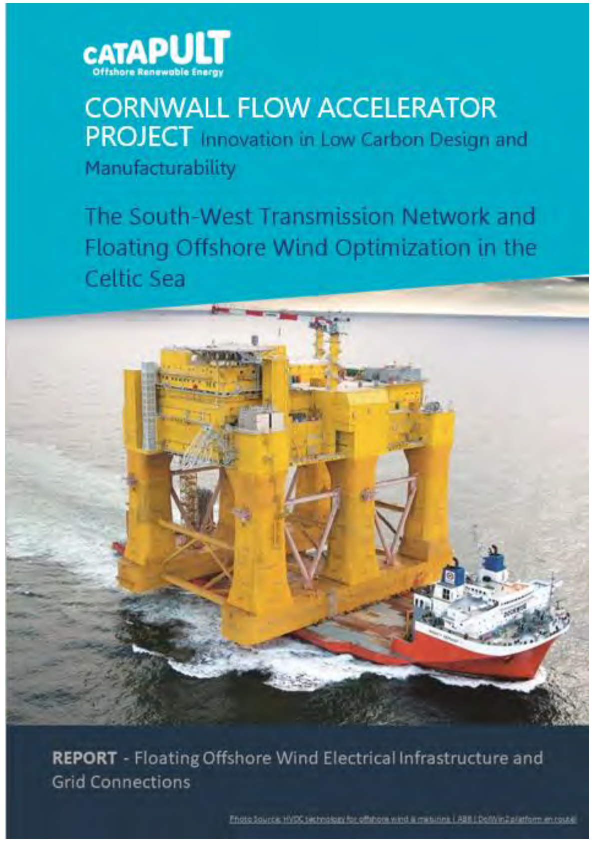
Title: A3 The future potential role of offshore multipurpose connectors

Ref: CFAR-OC-038-16032023



Title: A4 The South-West transmission network and floating offshore wind optimization in the Celtic Sea

Ref: CFAR-OC-039-17032023



DELIVERED BY Cornwall FLOW Accelerator

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HM Government

European Union European Regional Development Fund

CATAPULT Offshore Renewable Energy

Celtic Sea Cluster Publications and Case studies [Resources]

https://celticseacluster.com/resources/

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17 March 2023
New Report: Innovation in Low Carbon Design and Manufacturability The South-West Transmission Network and Floating Offshore Wind Optimization in the Celtic Sea

16 March 2023
New Report: Innovation in Low Carbon Design and Manufacturability The Future Potential Role of Offshore Multipurpose Connectors

09 March 2023
FLOW NOW! – 28th February 2023

09 March 2023
Concrete for FLOW Workshop 17th October

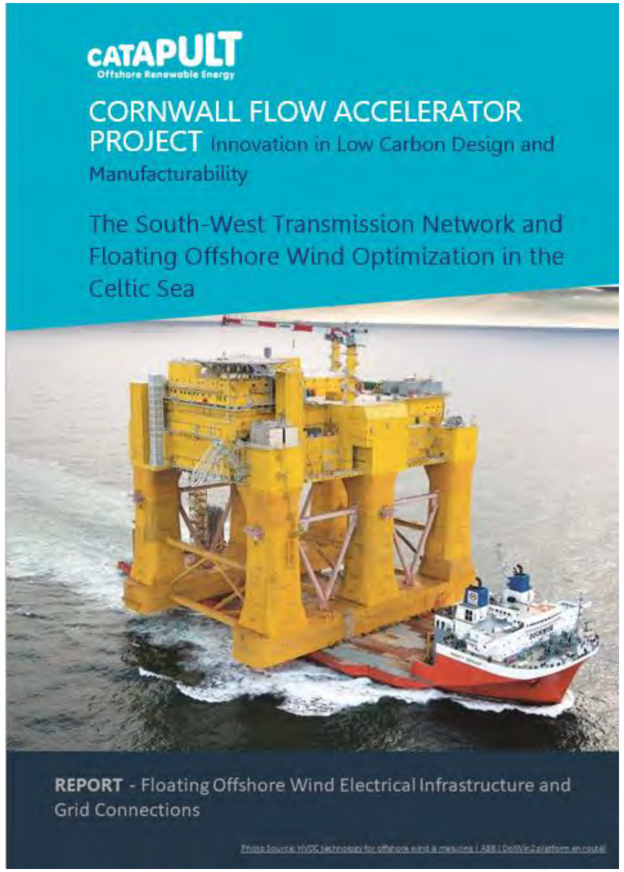
04 October 2022
Exploring the Potential Interactions Between FLOW & Hydrogen Report
Publication

03 October 2022
Optimised Cable Connection Options For FLOW Report
Publication

16 May 2022
Cornwall FLOW Accelerator Project – Low Carbon Manufacturing Reports
Publication

29 April 2022
Celtic Sea Ports, Engineering and Infrastructure
Publication

ORE Catapult Cornwall FLOW ACCELERATOR Published Reports (2022/2023)



Summary Task 6: Electrical infrastructure and grid connections

Report [A4] - The South-West transmission network and floating offshore wind optimization in the Celtic Sea Ref: CFAR-OC-039-17032023

- Integrating future floating wind developments into the South-West and South Wales energy network.
- To differentiate both technically and spatially how the distribution of energy from both short and long-term floating wind deployments can best be delivered.
- Investigate types of major electrical infrastructure, alternative solutions and investment may be required, linking the importance of inter-array cable arrangements, dynamic and export cable routes and definitions.

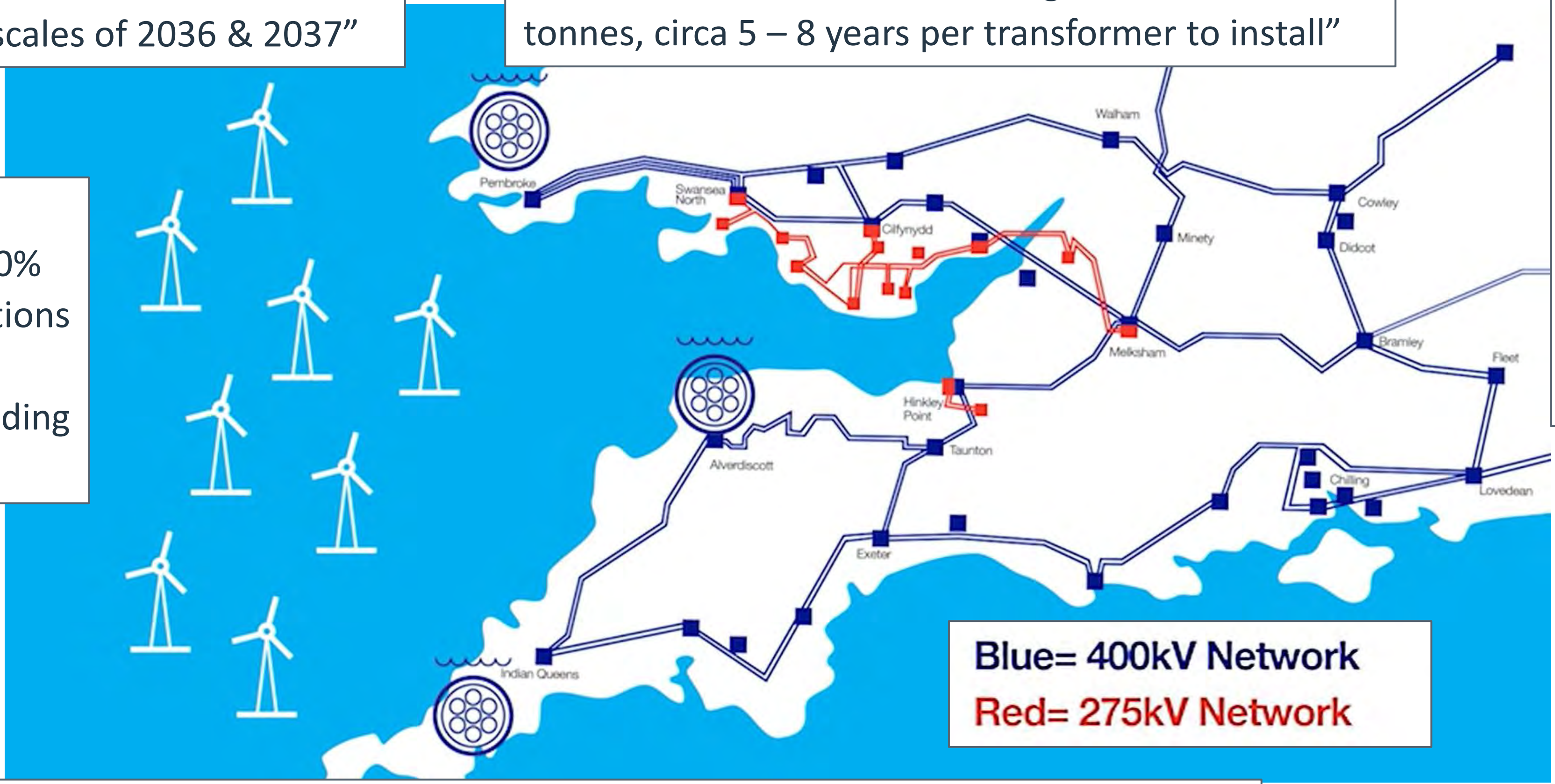
National Grid Electricity System Operator & IET(E&T)

According to:

IET(E&T) “Transmission connection dates extended to timescales of 2036 & 2037”

IET(E&T) “Supergrid 400 kV transformers are huge electrical infrastructure that weight several hundred tonnes, circa 5 – 8 years per transformer to install”

IET(E&T)
“Approximately 80% of the 300 substations across England & Wales need upgrading *~ £31 bn*”



October 2022 Uncertainty (NGESO – South Wales & South-West Regions)

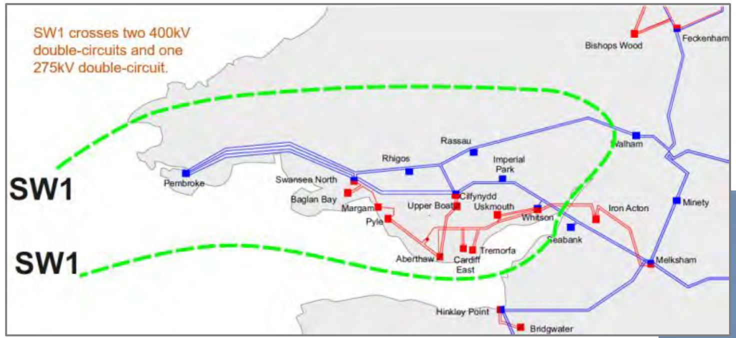
- 27.4 GW signed generation contracts
- 10.9 GW out for signature
- 5 GW in application process

IET(E&T) “Slowing investment, physical reduction of rate of RE installed capacity to the Grid – put the UK behind the curve to meet 2035 Energy Security Targets”

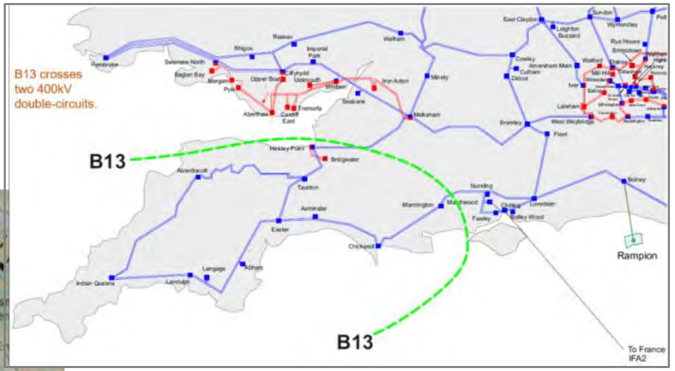
IET(E&T) “To reach our net-zero targets for more quicker RE connections – **3 things are needed** – **1.** continued focus on innovation & flexibility **2.** investment & overhaul to enable network capacity in anticipation of future need **3.** a coordinated & accelerated planning system”

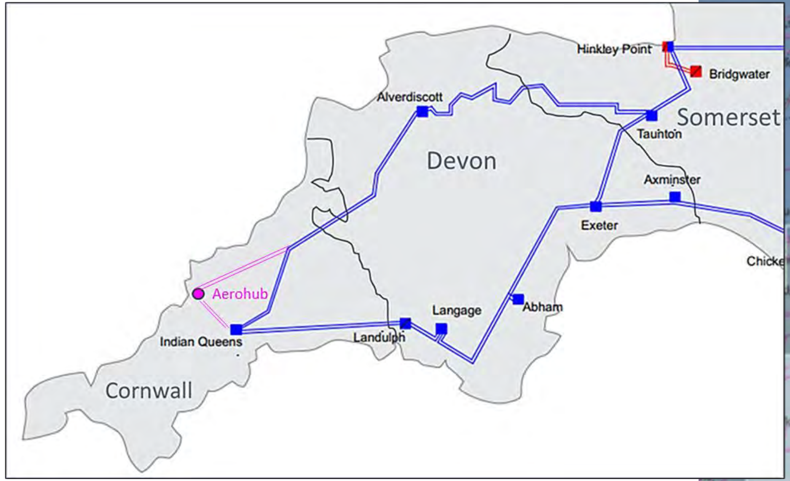
Source1: The Institution of Engineering and Technology (Engineering & Technology) March 2023
Source2: Regional updates | National Grid ET

ORE Catapult CFA & HND Alternative Scenarios & PDZ (research 2022/2023)

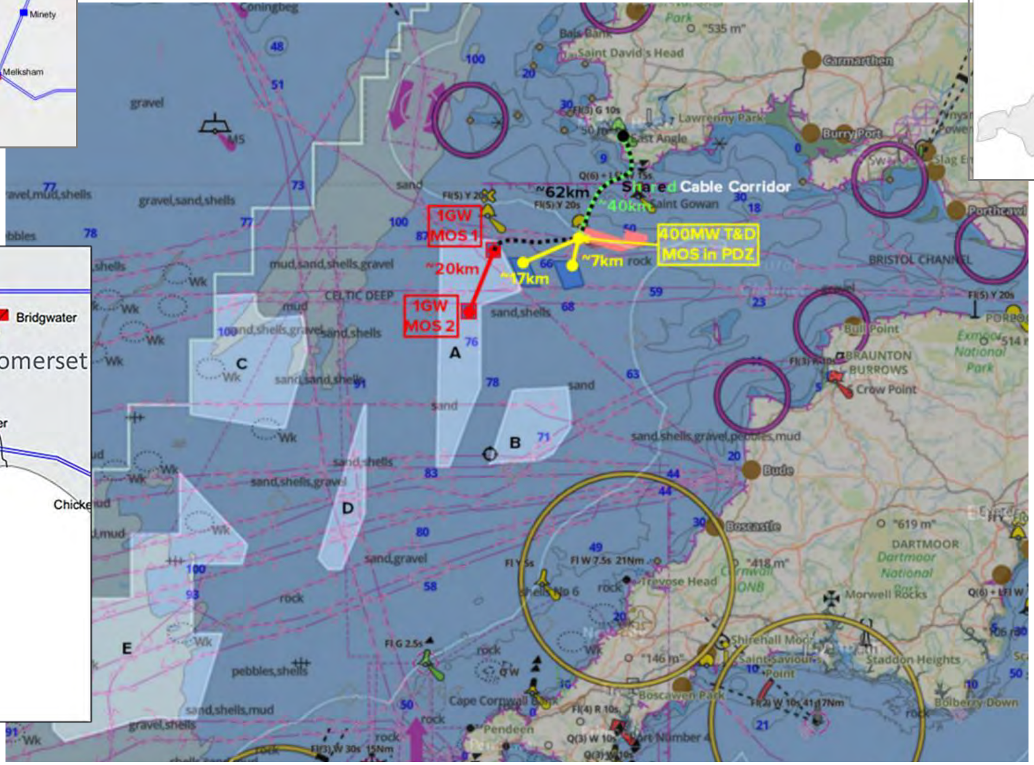


South Wales (SW1) - 400 kV ring (Walham to Pembroke)
South-West (B13) crosses two 400 kV double-circuits

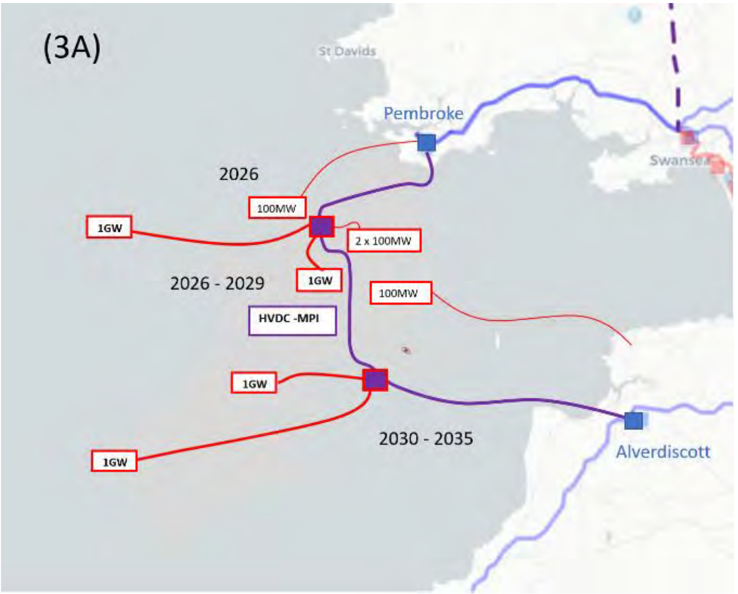




Potential “Aerohub Substation”
Cornwall Airport Newquay



The Crown Estate – Refined Areas of Search using the Pembrokeshire Demonstrator Zone (PDZ) or also known as Multipurpose Offshore Substation (MOS)



HVDC Interconnector Scenario

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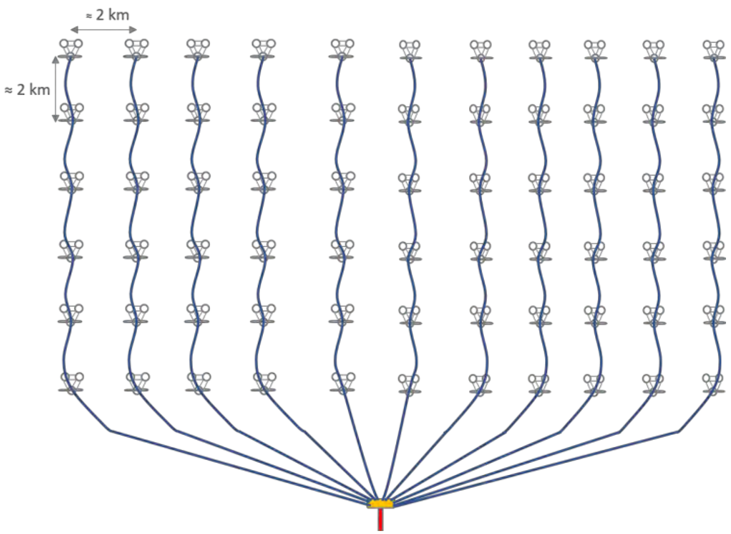
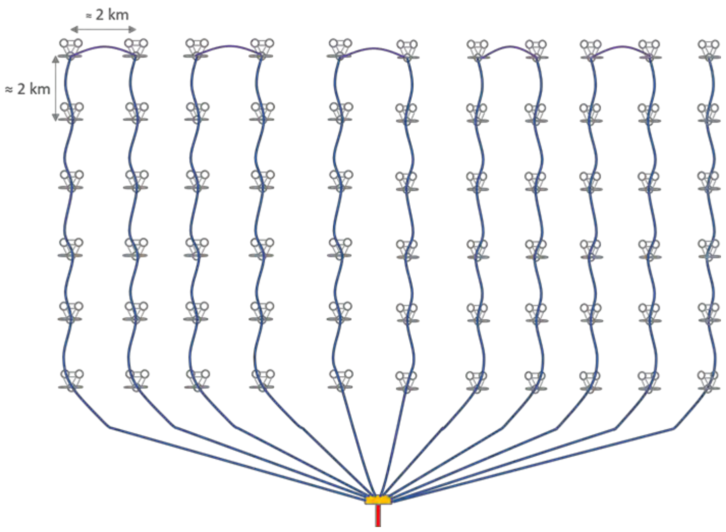
ORE Catapult CFA Offshore Wind Array Configurations (research 2022/2023)

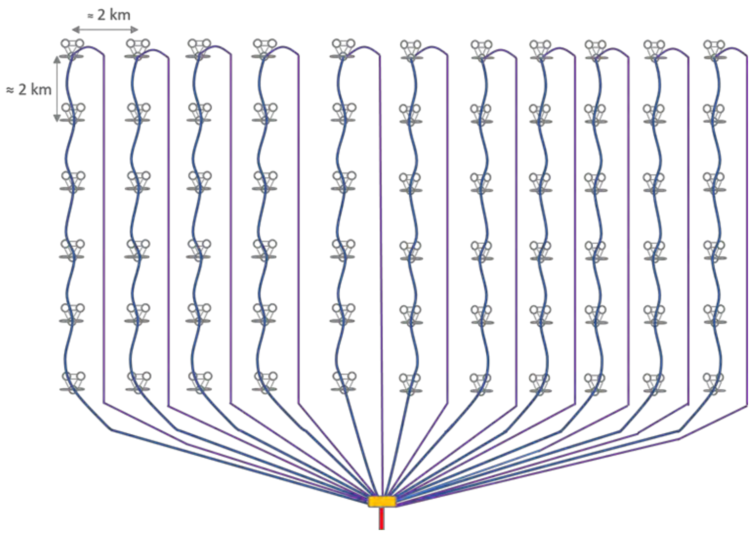
1: Non-Redundant Daisy Chain Layout



2: Daisy Chain Ring Layout



3: Daisy Chain Return Layout

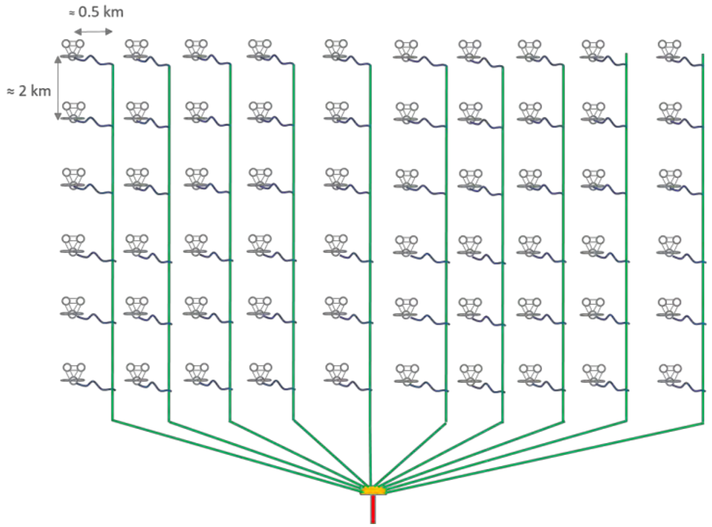


Daisy chain (most used)

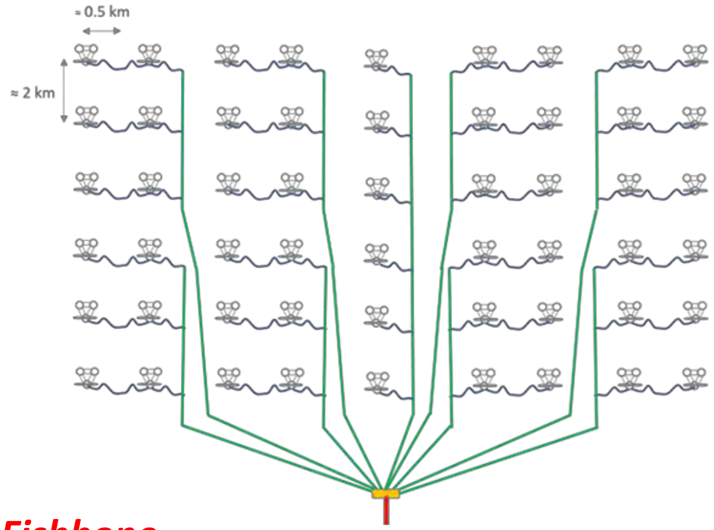
- configuration includes "strings" of several FOWT's each connected to the previous turbine via dynamic cables
- this design means each dynamic cable carries the total current of the number of turbines previously in the string
- the cable rating and size may increase towards the end of the string to the offshore substation
- configuration raises issues that each turbine in a string is connected in series - in the event of failure or short-circuit of a single turbine, or cable, then the whole string must be shut-off until maintenance is complete

ORE Catapult CFA Offshore Wind Array Configurations (research 2022/2023)

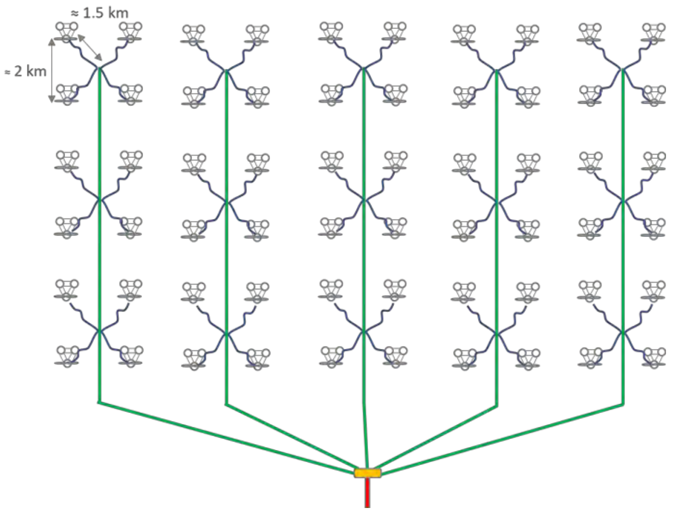
4: Fishbone Layout



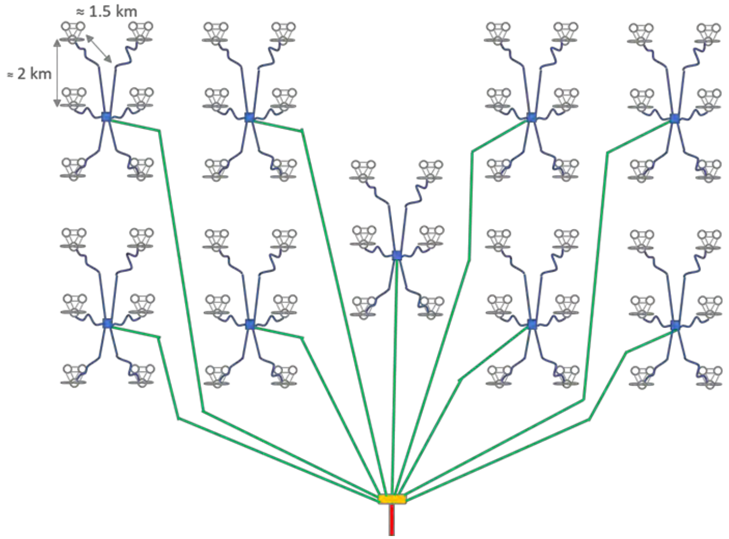
5: Fishbone-Daisy Chain Hybrid



6: Star layout (four-connection groups)



7: Star layout (six-connection groups)



Fishbone

- configuration, each FOWT uses one dynamic cable which connects to a central string static cable which exports to the subsea substation

Star (least preferred)

- configuration also requires one same size dynamic cable for each turbine connection to a static cable via a junction box along with several turbines on the seabed (dependent on turbine ratings)
- configuration requires the most area to avoid clashing as well as the wake effect from turbine spacing, large cable connectors and increased cable lengths

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ORE Catapult CFA Electrical Power Output (research 2022/2023)

Power output from a wind turbine

- Based on **15.0 MW** turbines; with a **236 m** rotor diameter (i.e., **115.5 m** blades), it is expected that turbines are spaced 8x the rotor diameter due to the wake effect of the prevailing wind direction (therefore expressed by calculation, 8 x 236 = 1,89 circa **2 kms**)

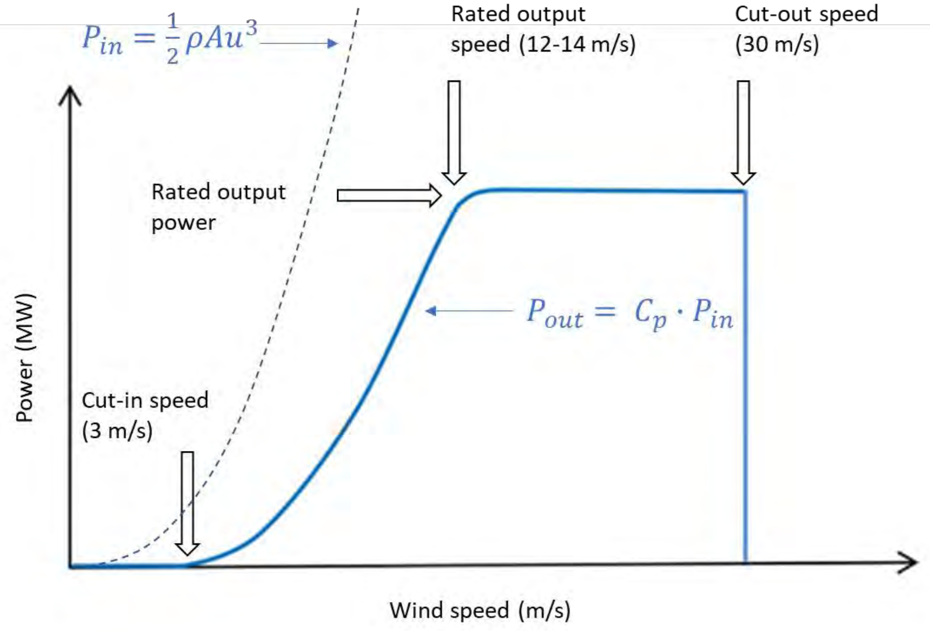
  For a **66 kV** cable rated string, the maximum number of 15 MW FOWT's allowable in a string is 5 (based on the industry standard equates to less than **80 MW**).

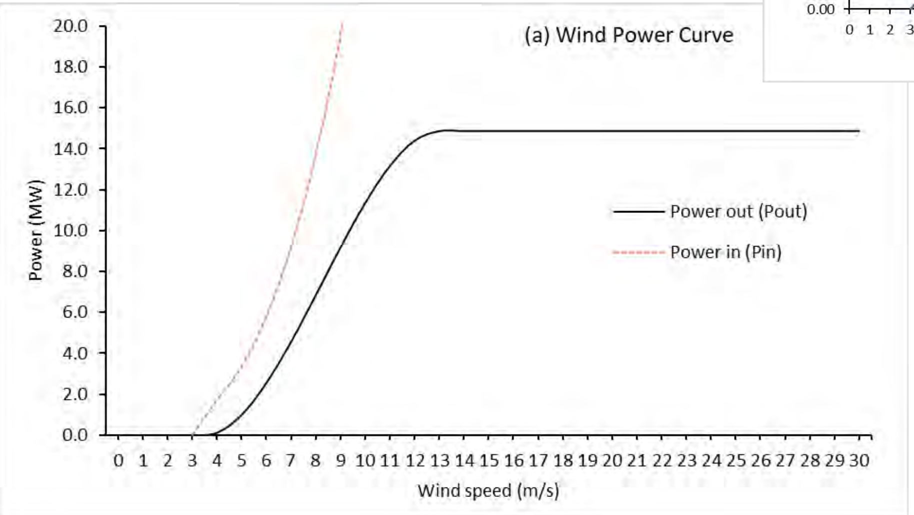
  For a **132 kV** cable rated string, the maximum number of 15 MW FOWT's allowable is 10 (based on the industry standard equates to less than **160 MW**)

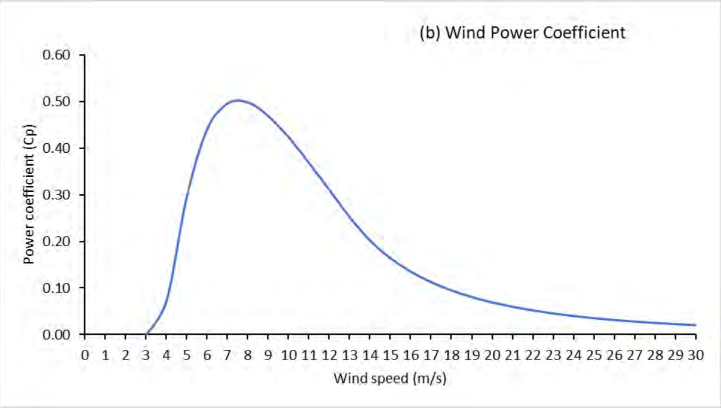
- Wind turbines have performance characteristics such as power output versus wind speed, or versus rotor angular velocity that must be optimized to complete the wind resource availability

ORE Catapult CFA Electrical Power Output (research 2022/2023)

Power Curve 15 MW wind turbine representing power and wind speed







Betz Limit

- Theoretically, the maximum power coefficient of a horizontal axis wind turbine is 59.3%, which is called the Betz limit (law)
- The factor is described as a factor of 0.593, or alternatively we can write the maximum power coefficient as $C_p = \frac{16}{27} = 0.593$

Wind Turbine Power Coefficient (C_P)

$$C_p = \frac{P_{out}}{P_{in}} = \frac{(actual\ electrical\ power\ produced)}{(wind\ power\ into\ turbine)}$$

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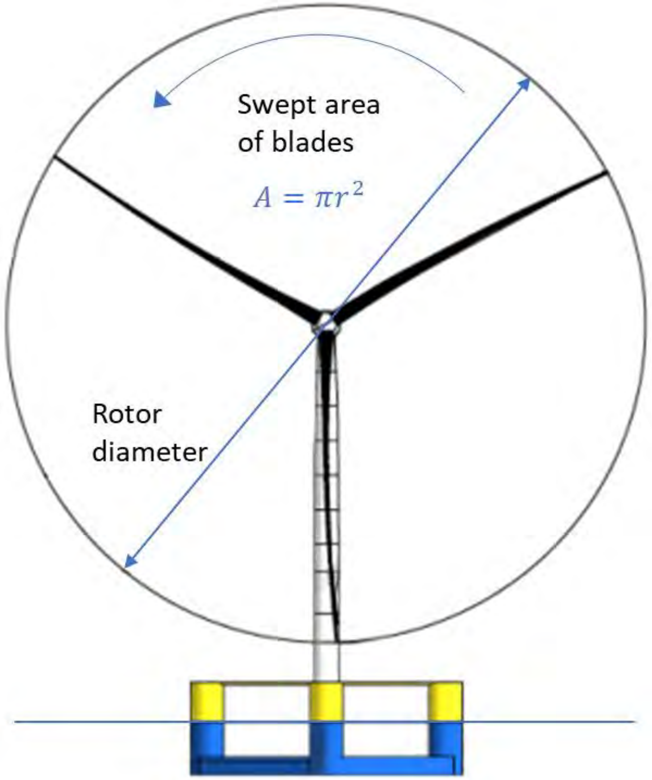
ORE Catapult CFA Electrical Power Output (research 2022/2023)

Available or 'theoretical' electrical power output

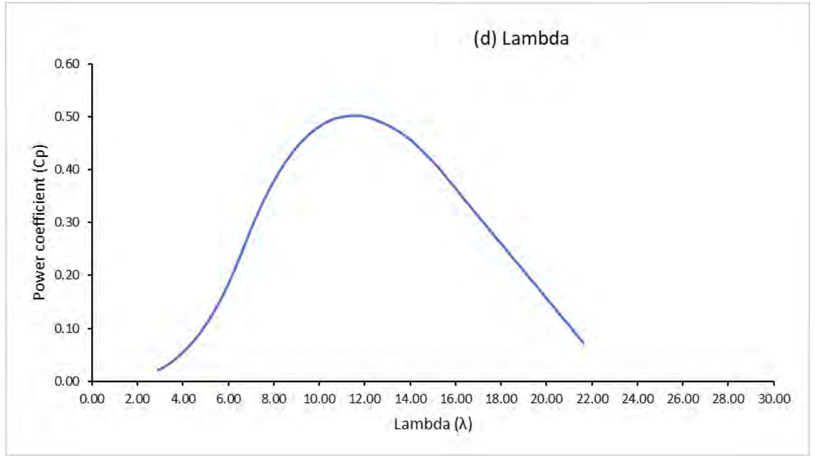
$$P_{in} = \frac{1}{2}\rho A u^3 = \frac{1}{2}(1.225)(43{,}743.536)(9^3) = 19.53\ MW$$

P_{in} is so effective, is that the power of wind varies with velocity cubed



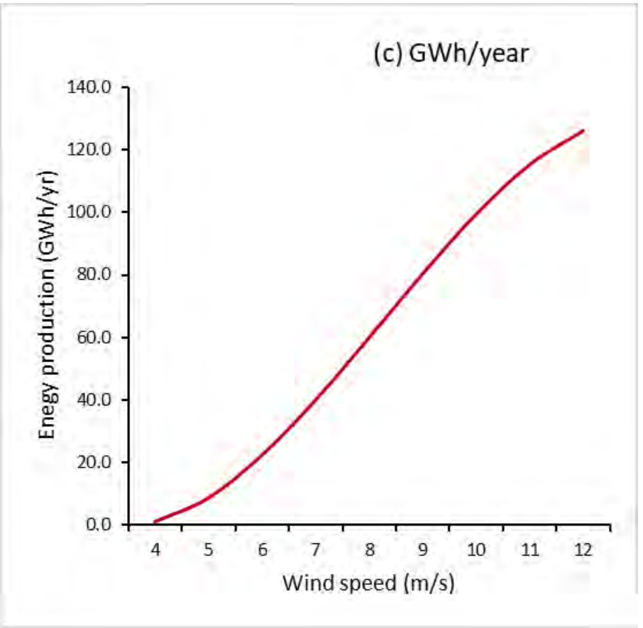
Tip speed ratio lambda

$$\lambda = \frac{blade\ tip\ speed}{wind\ speed}$$



Actual electrical power output

$$P_{out} = C_p\ (0.47)\ x\ P_{in}\ (19.5) = 9.16\ MW$$



Rate of electricity production

$$Energy = P_{out}\ (9.16)\ x\ time\ (8{,}760)$$
$$= 80.2\ GWh/yr$$

ORE Catapult CFA Electrical Conductor Power Losses (research 2022/2023)

The Capacity Factor

- CF measures a power plant's actual generation compared to the maximum amount it could generate in a given period without any interruption
- CF decreases rapidly with increasing values of rated wind speed in relation to the power coefficient

For example: If based on the 495 MW OWF scenario, from 33 by 15 MW turbines this produces 2,647.7 GWh in a year (at a yearly mean wind speed of 9 m/s), the maximum possible output is 4,293.5 GWh in a year

$$CF = \frac{P_{out}\,(actual\ energy\ output)}{P_{out}\,(maximum\ possible\ output)}$$

$$= \frac{2{,}647.5\ (GWh/yr)}{4{,}647.7\ (GWh/yr)} = 0.616$$

$$= 61.6\%$$

Electrical Conductor Power Losses

- Power cables have resistance, therefore power lost in the conductors can be calculated as:
- $P = I^2R$ with R as the resistance of the cables and I as the current that passes through them
- Power at the load is $P = UI$, so if the voltage U increases by $2x$, only half the current I will be needed to deliver the same power.
- Therefore, in $P = I^2R$, if half the current passes through the same conductors, the system will lose only a quarter of the power

$$I_n = \frac{P_n}{\sqrt{3}\cdot U_{correct}\cdot pf} = \frac{15MW}{(1.732\ \cdot\ 125.4kV\ \cdot\ 0.95)}$$

$$= 72.69\ x10 = 726.96\ A$$

ORE Catapult CFA Electrical Conductor Power Losses (research 2022/2023)

Conductor Losses: $P_{core} = nRI^2$

$$R = \frac{\rho L}{A} = \frac{1.77x10^{-8} \cdot 1}{800x10^{-6}} = 2.212x10^{-5}\ \Omega/m \qquad P_{core} = 3(2.212x10^{-5})(726.96)^2 \qquad P_{core} = circa\ 35\ W/m$$

- *Conductor losses result from Joule heating of electrical currents in the conductors, measured in Watts per metre.*

Screen Losses: $P_{screen} = n\lambda_1 RI^2$ $\quad$ *Circulating losses & eddy current losses for foil averaged* λ_1

$$P_{screen} = 3(0.2)(2.212x10^{-5})(726.96)^2 \qquad P_{screen} = circa\ 6\ W/m$$

- *Screen losses are caused by circulating currents, only occurring in single core cables, measured in Watts per metre. Screen losses are only applicable to alternating current cables.*

Armour Losses: $P_{armour} = n\lambda_2 RI^2$ $\quad$ *Loss factor of the armour averaged* λ_2

$$P_{armour} = 3(0.4)(2.212x10^{-5})(726.96)^2 \qquad P_{armour} = circa\ 15\ W/m$$

- *Armour losses are only applicable to alternating current cables, measured in Watts per metre.*

Dielectric Losses: $W_{d_t} = 3W_d$ $\quad$ *Dielectric loss per unit length in each phase averaged* W_d

$$W_{d_t} = 3(0.1) \qquad W_{d_t} = circa\ 0.4\ W/m$$

- *Dielectric losses is the electrical power that is wasted by heating the dielectric in the electric field, measured in Watts per metre; energy losses occur at the constant and variant current in the dielectric.*

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ORE Catapult CFA Electrical Conductor Power Losses (research 2022/2023)

Power generated $\boldsymbol{P_{in}}$ by the wind turbine is **15 MW**, and the total length equals to **23 kms**, therefore the following $P_{total-losses}$ is:

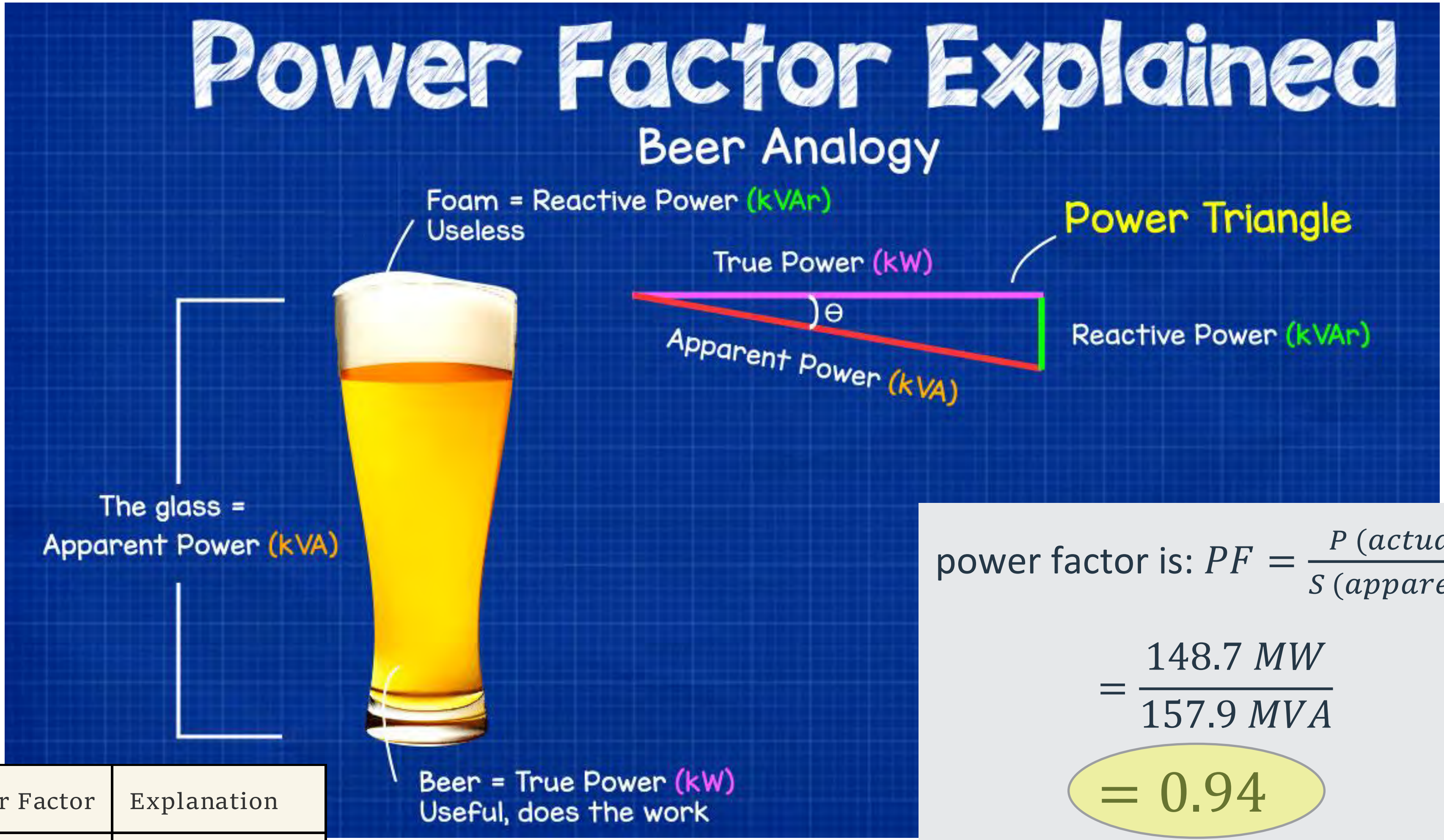
$$P_{total-losses} = P_{core} + P_{screen} + P_{armour} + W_{d_t}$$

$$= circa\ 1.3\ kW$$

From the total power losses calculated across the system, the final power $\boldsymbol{P_{out}}$ can be worked out as follows, in $\boldsymbol{MW}$

$$P_{out} = P_{in} - P_{total-losses}$$

$$= 148.7\ MW$$



Power Factor	Explanation
Good	- 0.95
Poor	0.95 - 0.85
Bad	0.85 and below

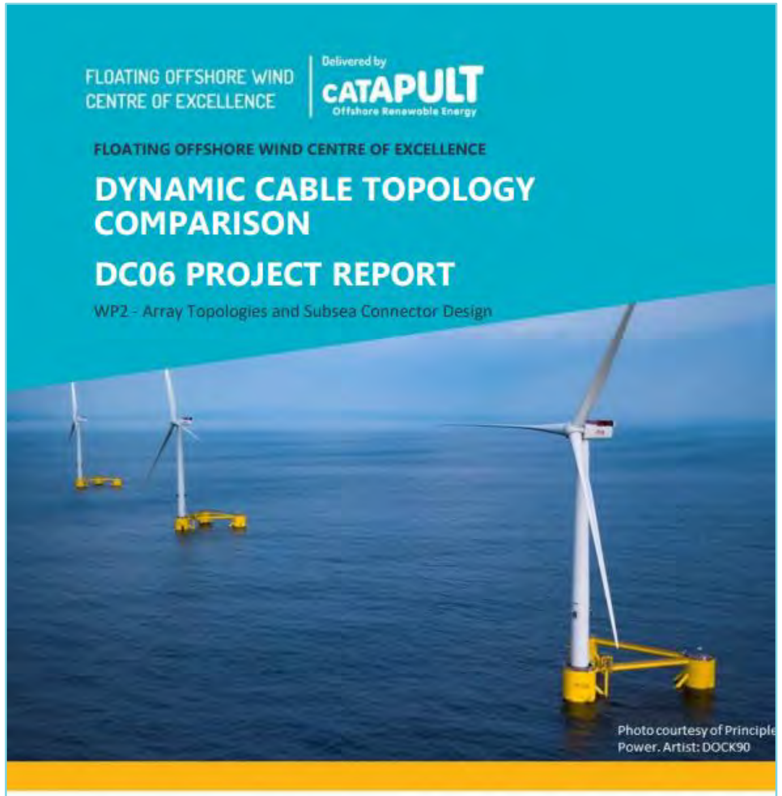
power factor is: $PF = \dfrac{P\,(actual)}{S\,(apparent)}$

$$= \frac{148.7\ MW}{157.9\ MVA}$$

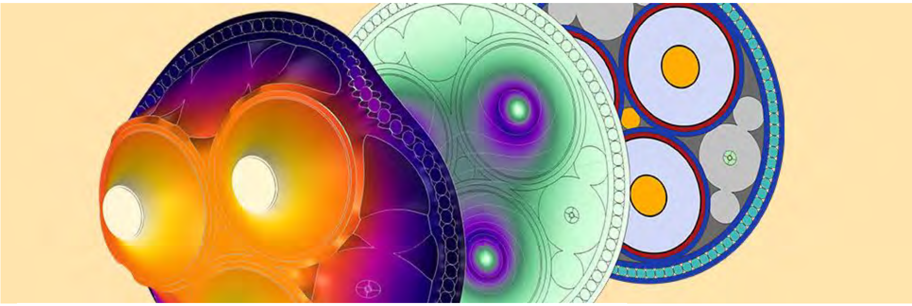
$$= 0.94$$

ORE Catapult FOW Centre of Excellence & Collaboration 2023

Cable Topology Comparison - Array topologies and subsea connector considerations



MANCHESTER 1824
The University of Manchester



COMSOL

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ORE Catapult CFA Published Reports (March 2023)

Title: The South-West transmission network and floating offshore wind in the Celtic Sea

Key Findings and Industry Challenges: Ref: CFAR-OC-039-14022023

- Currently, in the Celtic Sea there are no offshore cable routes to connect offshore wind farms, nor to connect South Wales to South-West England directly without having to transmit through the National Grid onshore infrastructure.
- Further alternative scenarios have also been explored by ORE Catapult and Celtic Sea Power feeding evidence back to the National Grid which assumes a greater, more realistic capacity in the Celtic Sea by 2030.

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MY CONTACT DETAILS

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GLASGOW

BLYTH

LEVENMOUTH

GRIMSBY

ABERDEEN

CHINA

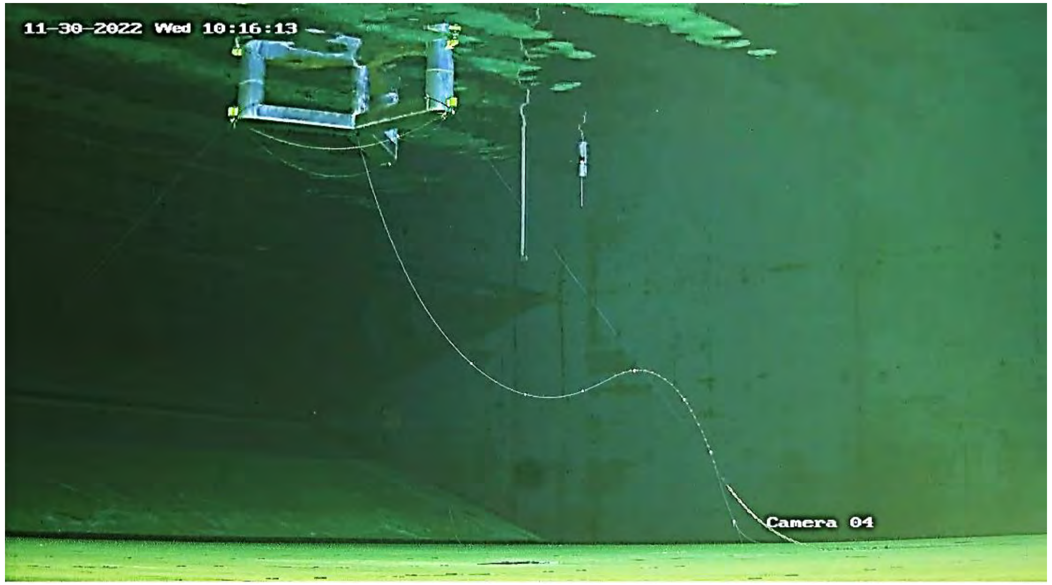
LOWESTOFT

PEMBROKESHIRE

CORNWALL

Offshore Renewable Energy

Physical scale-modelling of dynamic power cables for floating offshore wind



Anna Holcombe
COAST Engineering Research Group
University of Plymouth

UNIVERSITY OF PLYMOUTH

Introduction

My background: BEng Mechanical Engineering , MSc Renewable Energy Engineering

Currently: PhD (2nd year of 3.5 years)

PhD supervision: Martyn Hann, Shanshan Cheng, Robert Rawlinson-Smith, Scott Brown, Rachel Nicholls-Lee

Modelling dynamic cables

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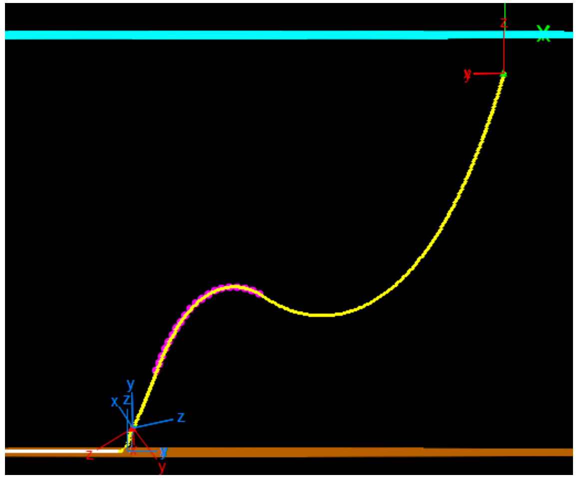
Global modelling

- Motions and loads of entire cable
- In context of full floating wind turbine system
- e.g. Orcaflex, scale physical models

Local modelling

- Internal loads (FEA analysis)
- More complex cross-section
- e.g. ANSYS



(Nicholls-Lee, 2021)

Modelling dynamic cables

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Global modelling

- Motions and loads of entire cable
- In context of full floating wind turbine system
- e.g. Orcaflex, scale physical models

Local modelling

- Internal loads (FEA analysis)
- More complex cross-section
- SYS

Simplifications

Uncertainty

Limitations

Modelling dynamic cables

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Simplifications	• Cross section simplified • Experiment scaling effects • Seabed interaction
Uncertainty	• Accurate cable data used in model
Limitations	• Specific cases not valid?

Higher design safety factors

Expensive/ overengineered cables

Possible cable failure

Experiment: 1:70 scale model

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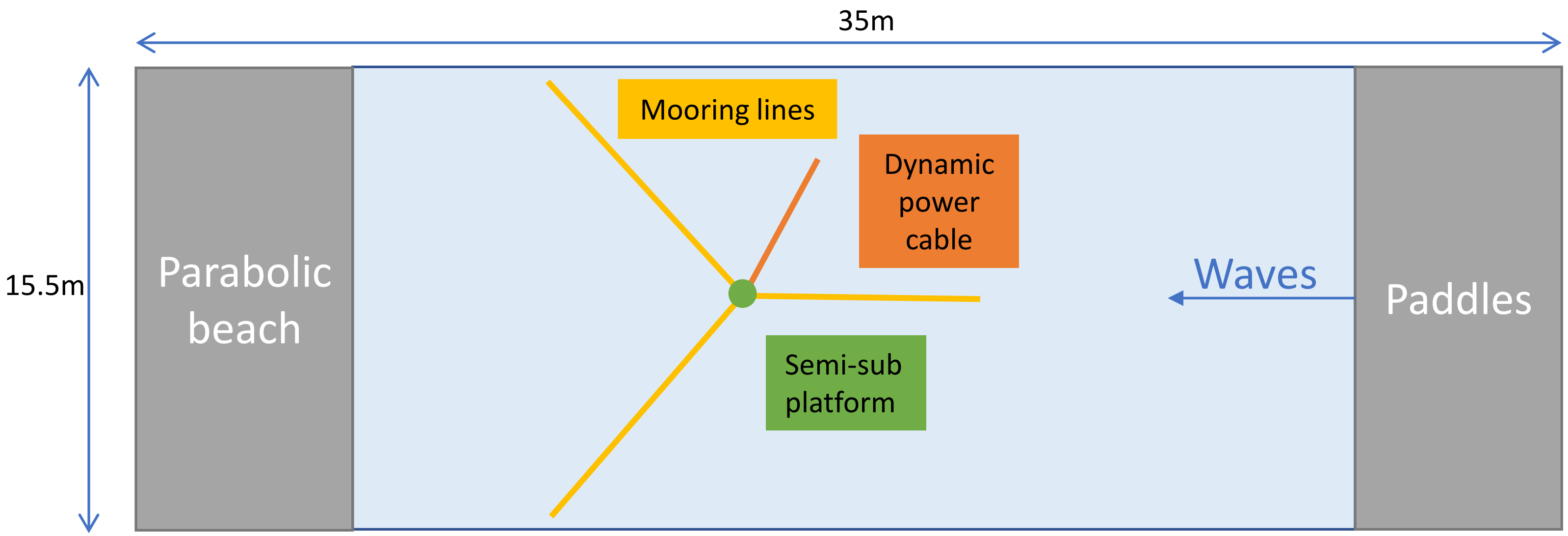
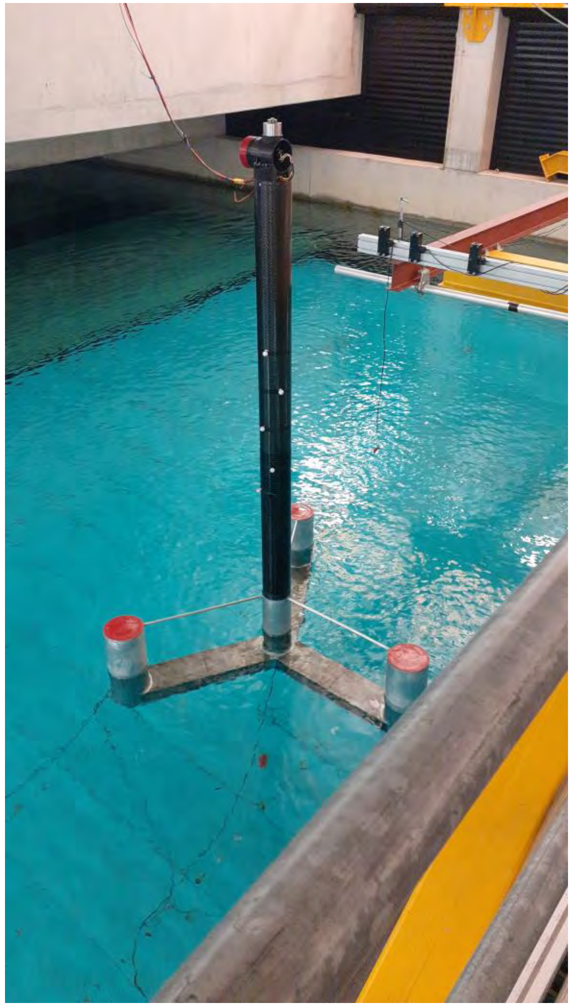
- COAST laboratory Ocean Basin
- 1:70 scale, modelling 200m water depth
- Semi-submersible 15MW floating offshore wind reference platform, UMaine VolturnUS-S



Floorplan of experimental set-up



Experiment: Cable model

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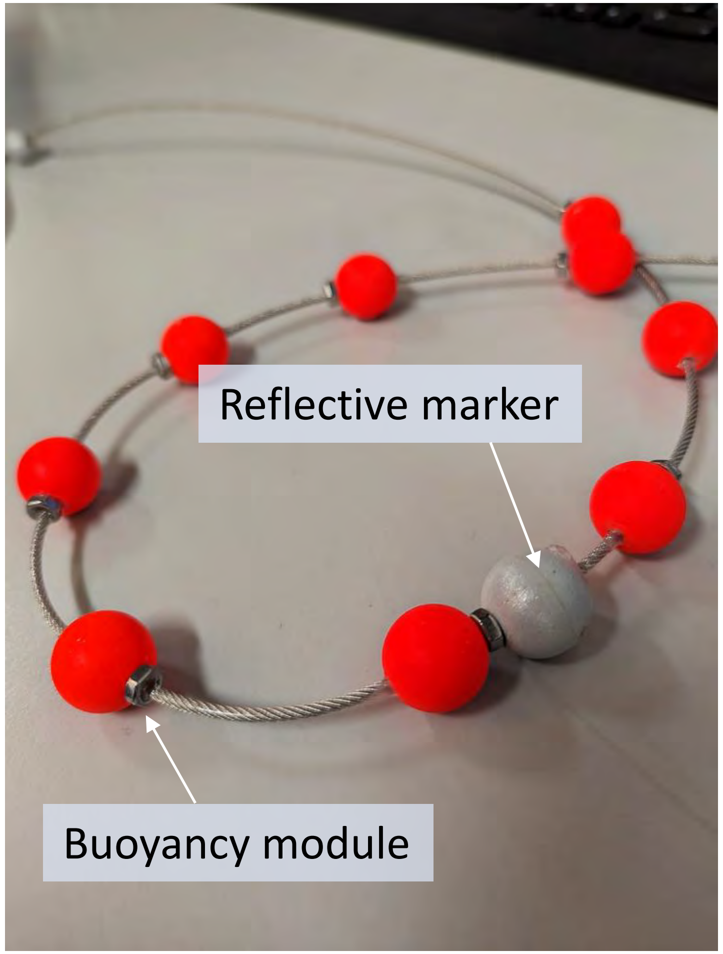
Froude scaled the properties of cable and buoyancy modules

Cable property	**Full-scale**	**Target 1:70 scale**	**Achieved 1:70 scale**
Weight in water per unit length (N/m)	400	0.082	0.084
Outer diameter (mm)	190	2.7	2.3
Axial stiffness (kN)	400000	1.17	To be tested
Bending stiffness ($N.m^2$)	20000	1.2×10^{-5}	To be tested



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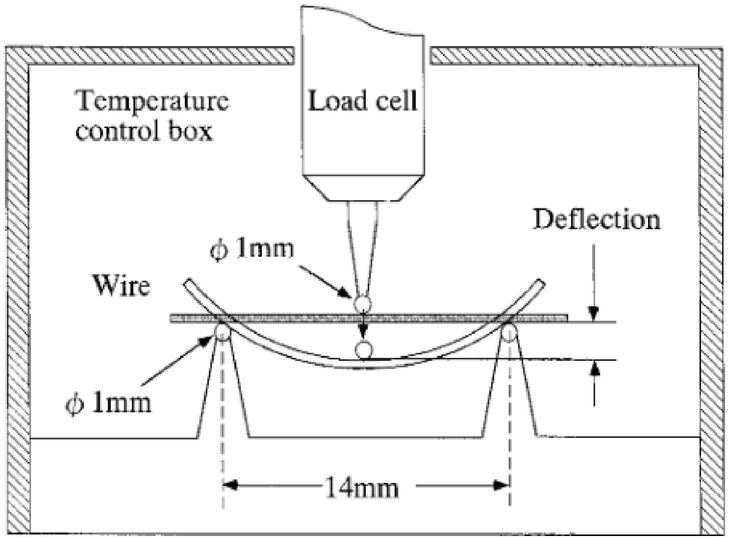
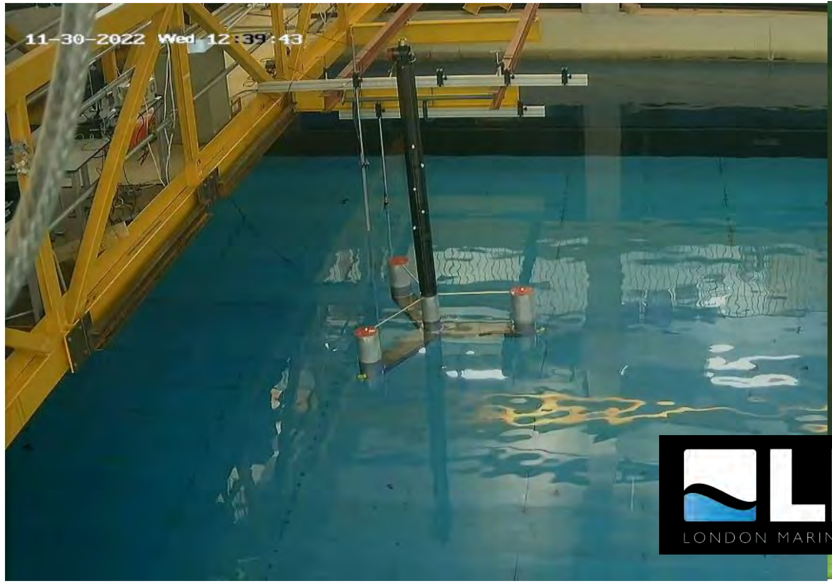
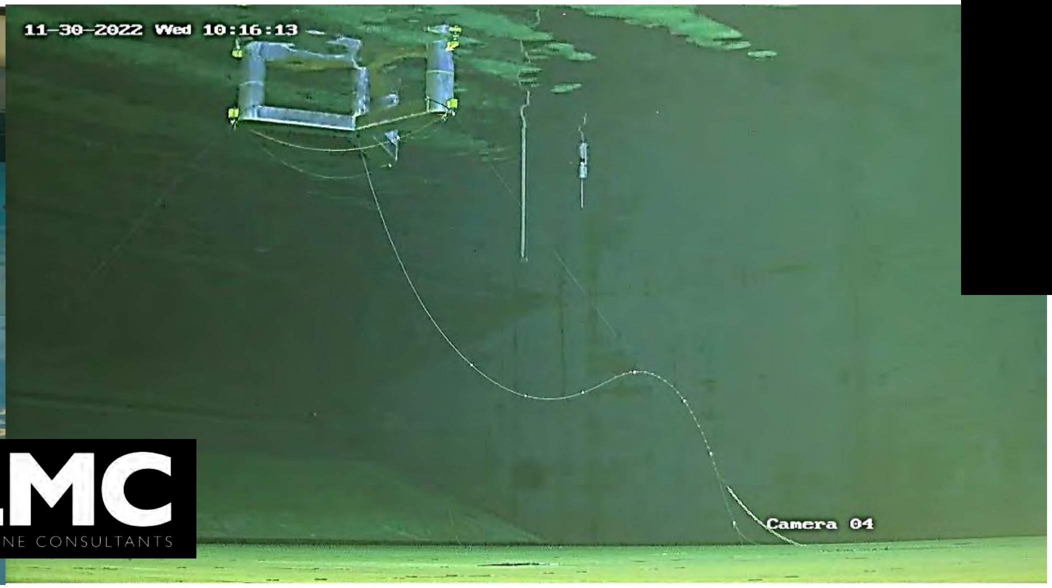


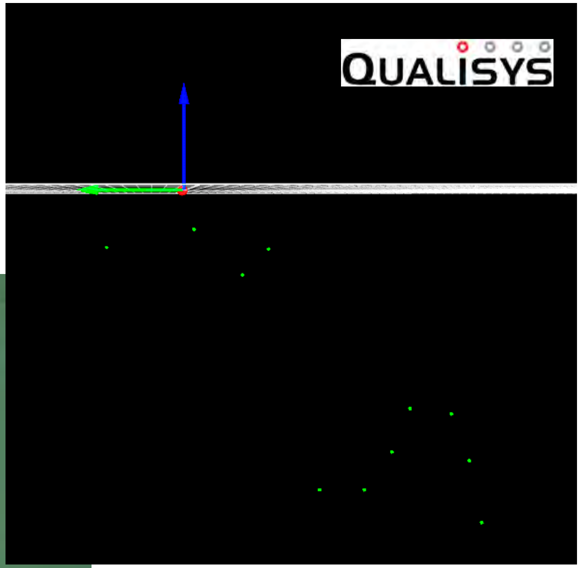
3-point bending test
(Nakano, 1999)

Experiment: Measurements

- Qualisys system used to track motion of markers located along cable
- Three cable configurations tested
  - Catenary, lazy wave, tethered wave








Camera 03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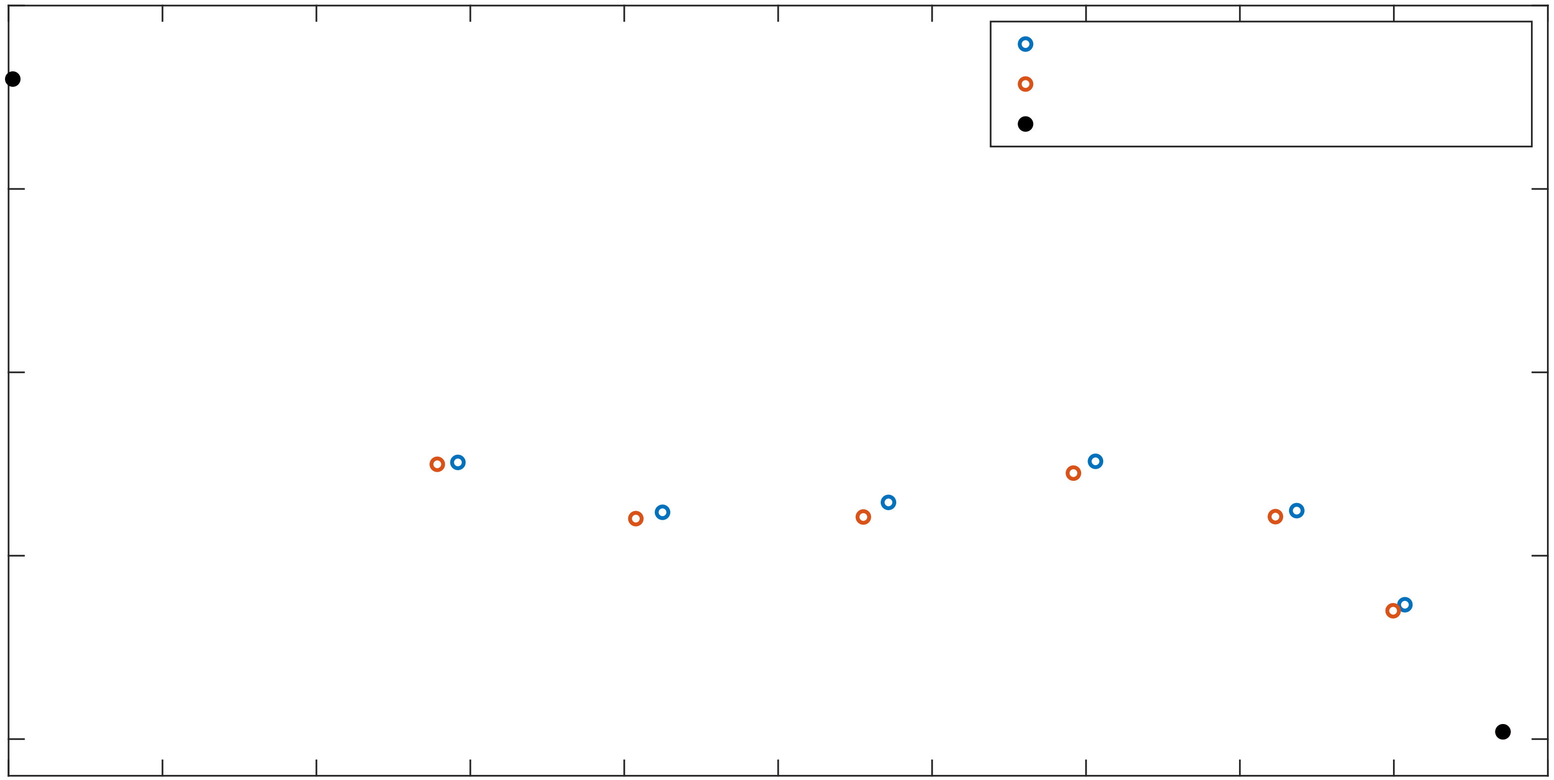
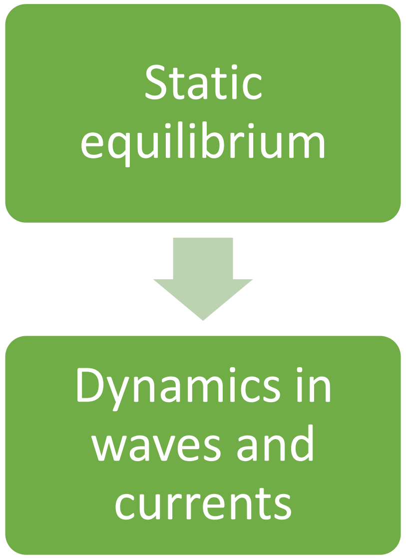
Camera 04

Preliminary comparison with Orcaflex





E.g. vertical seabed clearance, or horizontal distance between sag and hog bends

Use of scale-physical modelling

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Simplifications
- Cross section simplified
- Experiment scaling effects
- Seabed interaction
- Cable data i.e. constant stiffness

Limitations
- Specific cases not valid?

Uncertainty
- Means higher safety factors
- More expensive/ overengineered
- Possible cable failure

Use of this work →

- Identifying possible differences between experimental/numerical global models
- What are the limitations of simplified global models?
- Quantifying uncertainty
- Increasing confidence in global models

Thank you

Any questions or thoughts?

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www.linkedin.com/in/anna-holcombe/

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Hirokazu Nakano, et al., “Mechanical properties of several nickel-titanium alloy wires in three-point bending tests”, (1999).

Nicholls-Lee, Rachel, Philipp R. Thies, and Lars Johanning. "Coupled modelling for dynamic submarine power cables: interface sensitivity analysis of global response and local structural engineering models." (2021).

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Floating Offshore Wind CoE: Dynamic Cable Technology Qualification and Topology Comparison

Charlotte Strang-Moran

28.03.2023

Floating Offshore Wind Centre of Excellence (FOW CoE)

- **Accelerating the commercialisation of Floating Offshore Wind** – to deliver net zero and drive economic growth;
- **Collaborative programme** with industry, stakeholder, academic and supply chain partnerships;
- Developing and delivering a portfolio of collaborative project activity across four workstreams…
  - **Technology Development;**
  - **Supply Chain, Infrastructure, Construction and Operations;**
  - **Development and Consent;**
  - **Delivering Net Zero (Policy);**

https://ore.catapult.org.uk/FOWCoE/

bp
CIP Copenhagen Infrastructure Partners
Corio
EDF Energy
equinor
ESB
Mainstream Renewable Power
Northland Power
OW Ocean Winds
Ørsted
RWE
ScottishPower Renewables
Shell
sse Renewables
TotalEnergies
Vattenfall
Supergen Offshore Renewable Energy
Department for Business, Energy & Industrial Strategy

Catapult Offshore Renewable Energy

FOW CoE Strategic Programme

Dynamic Cabling Systems Technology Development and Qualification Prog.

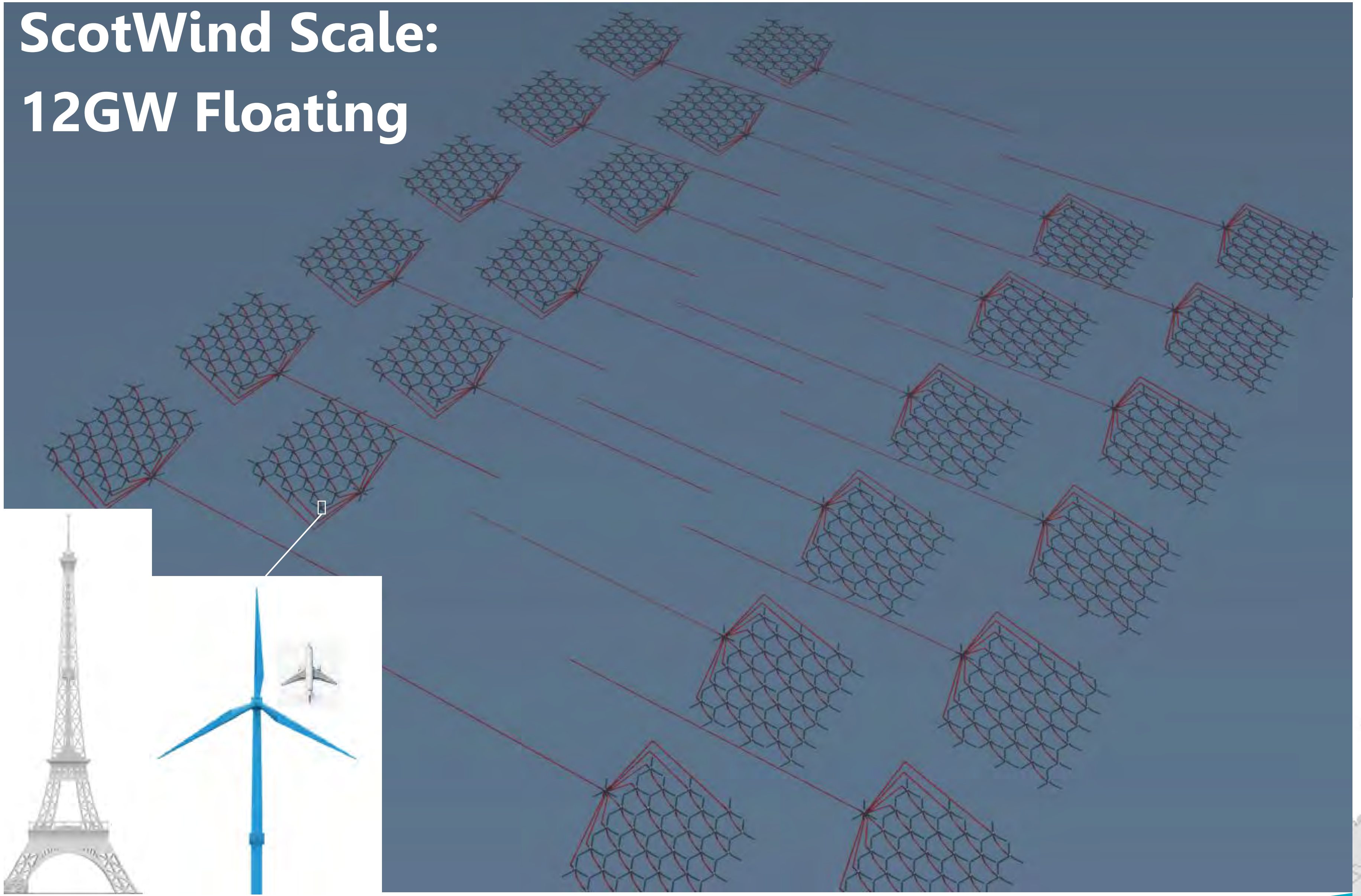
Mooring Systems Technology Development and Qualification Prog.

Environmental Interaction Data and Research Programme

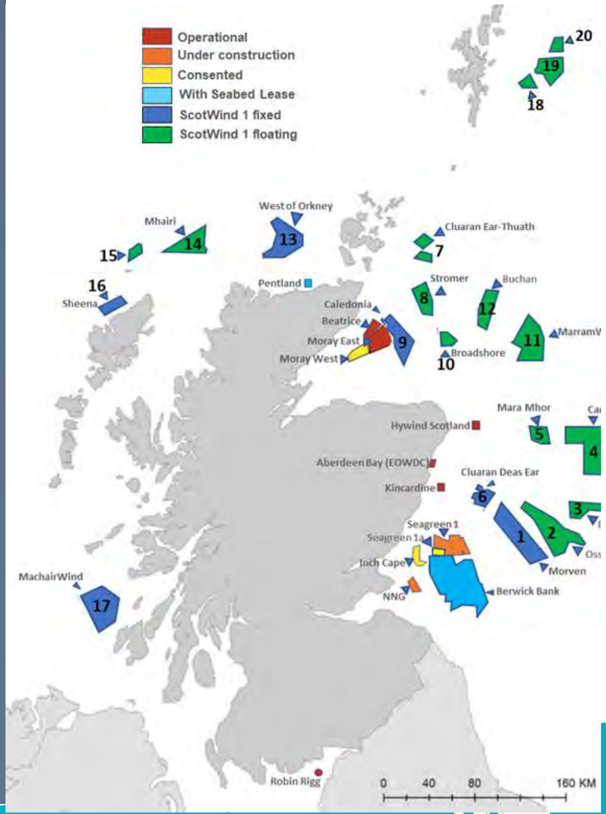
Supply Chain Data and Development Programme

Construction, Operations and Maintenance Programme

ScotWind Scale: 12GW Floating



ScotWind Floating Sites in Green
(Offshore Wind Scotland)



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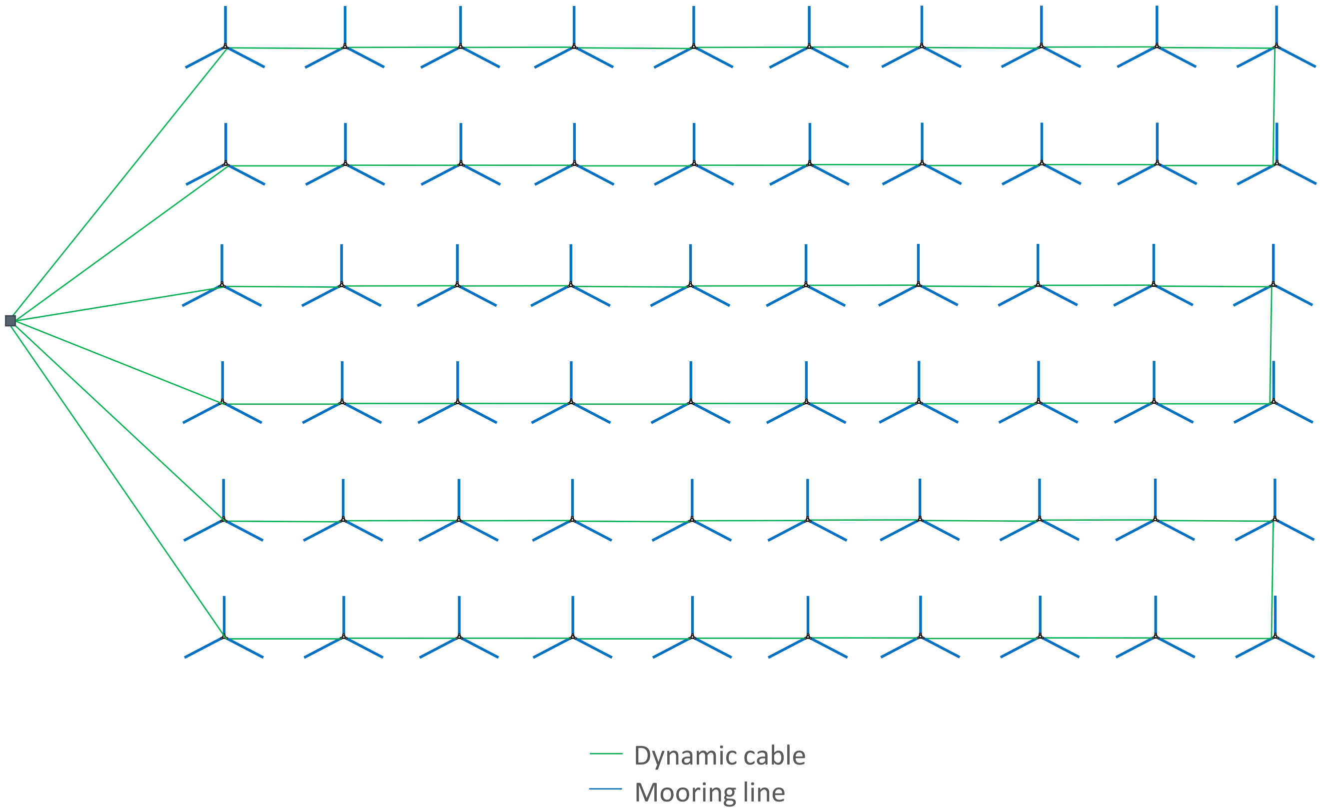
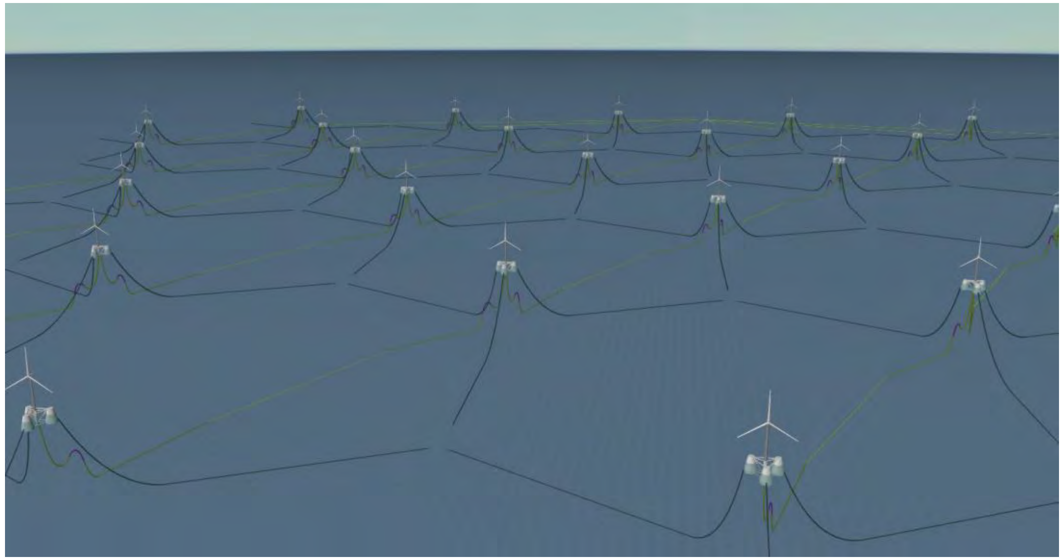
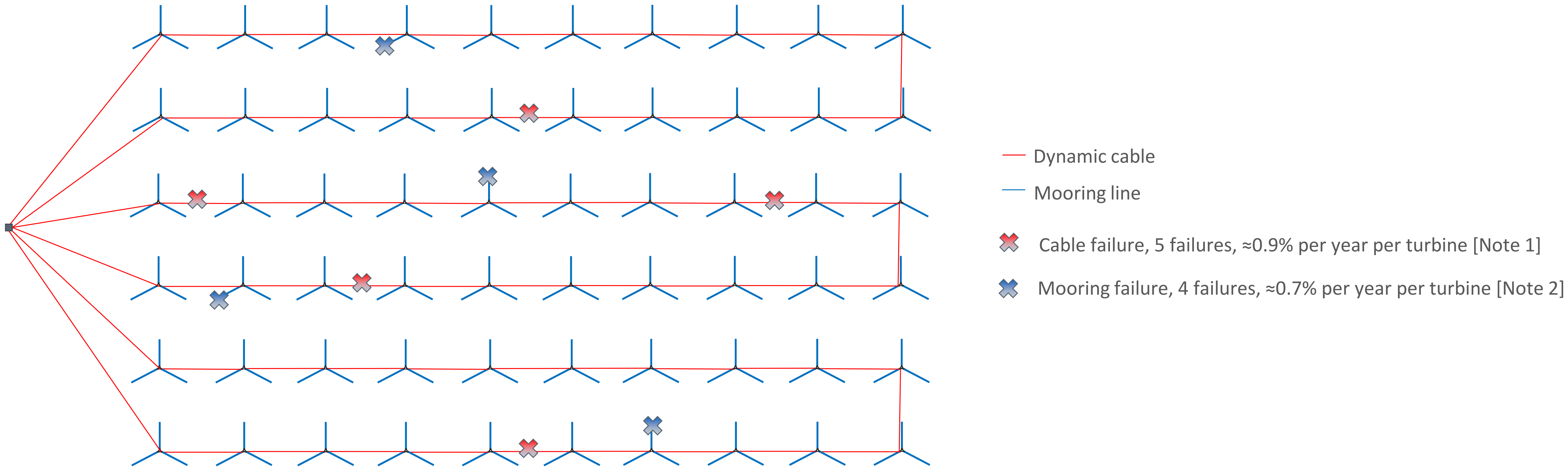
Typical 1GW Array (60 x 15MW)



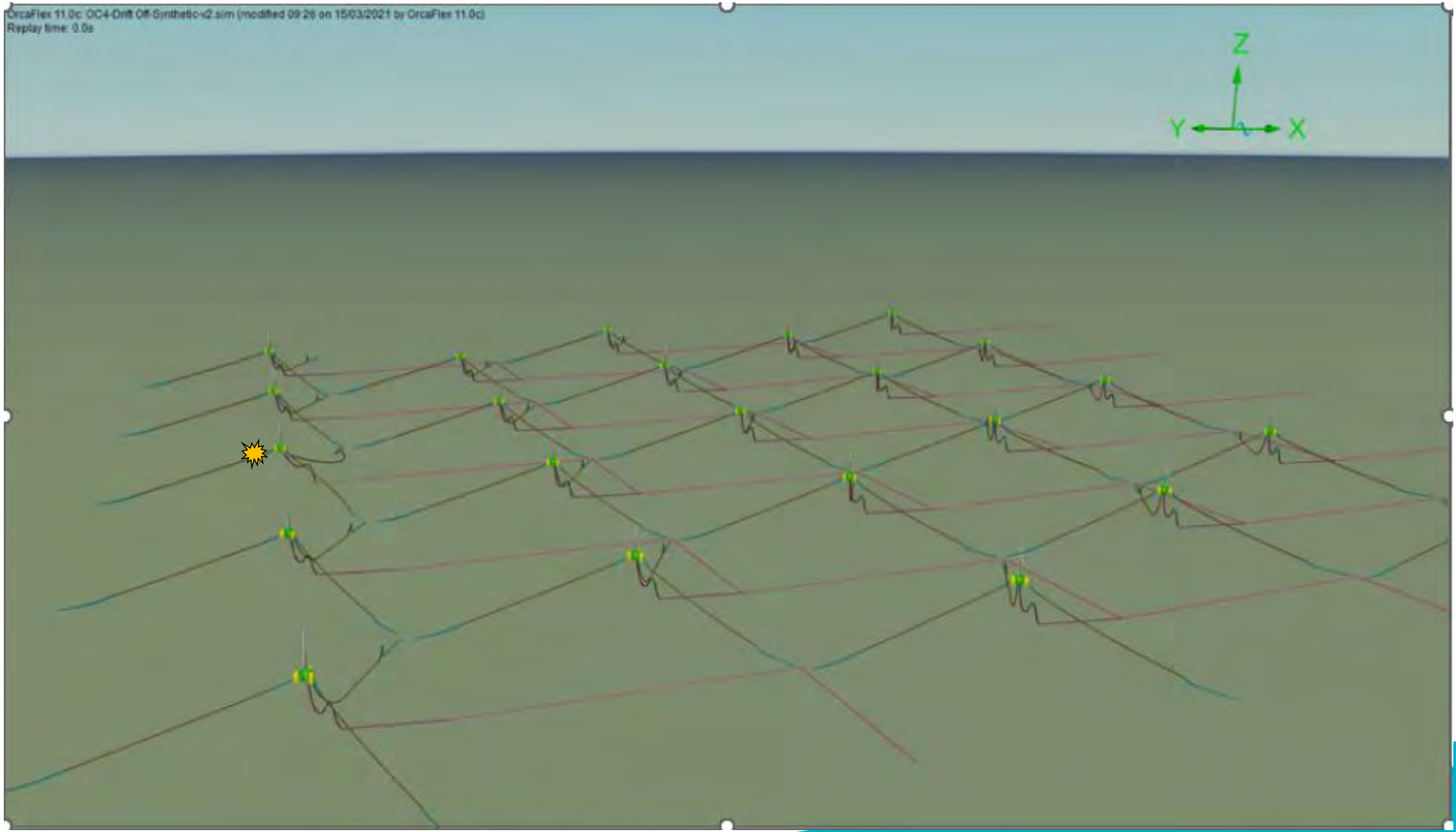


1GW Array: picture of mooring and cable failures over 10-years

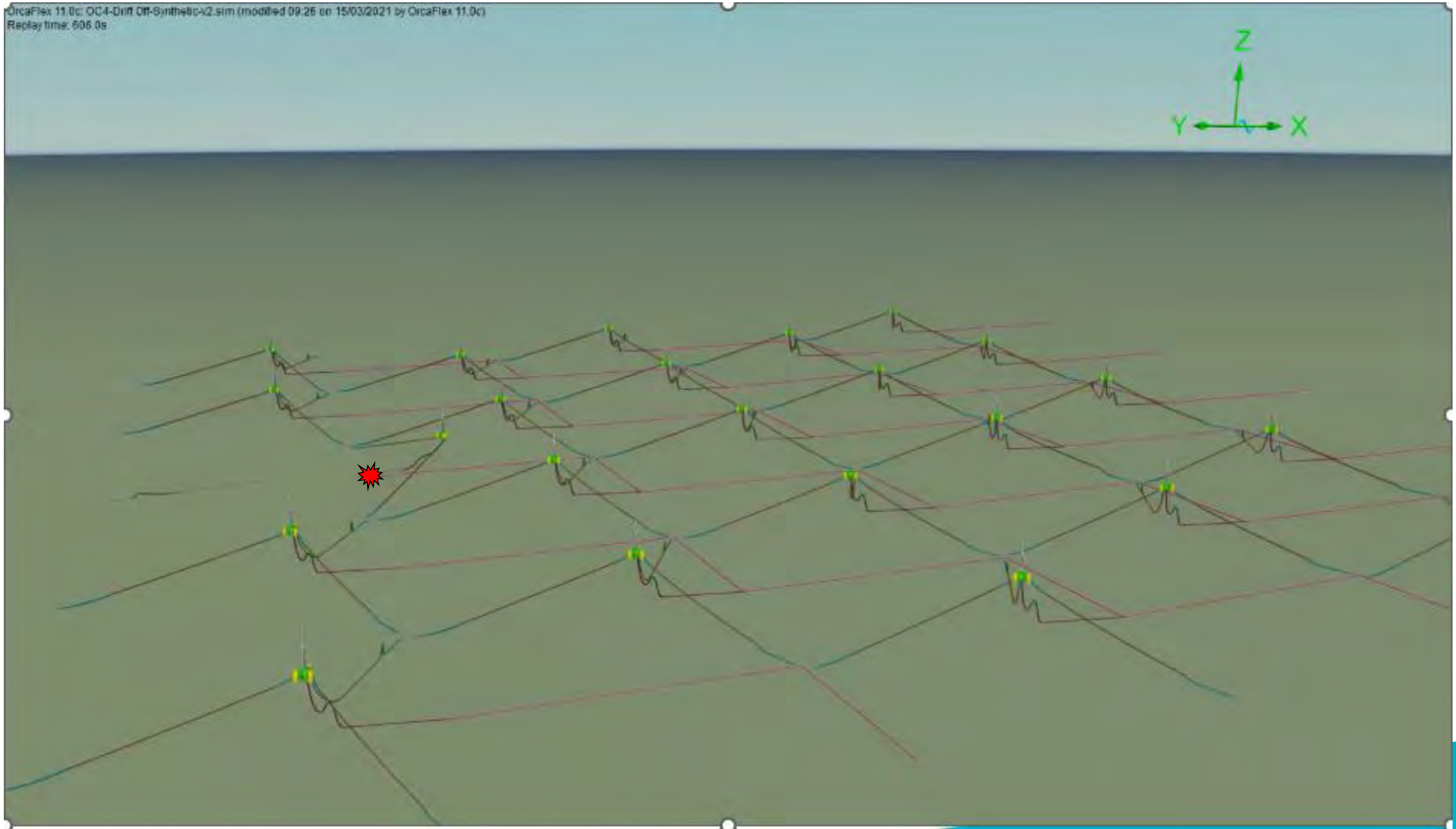


Note [1]: Failure rates of offshore wind transmission systems 2019 paper, 0.003 failures/km/year x 2.2km = 17% for static cables.
Note [2]: 2.4E-3 failures per mooring line per year x 3 lines = 18%. From Deepstar mooring integrity study of permanent O&G units.

What are we trying to avoid?



What are we trying to avoid?



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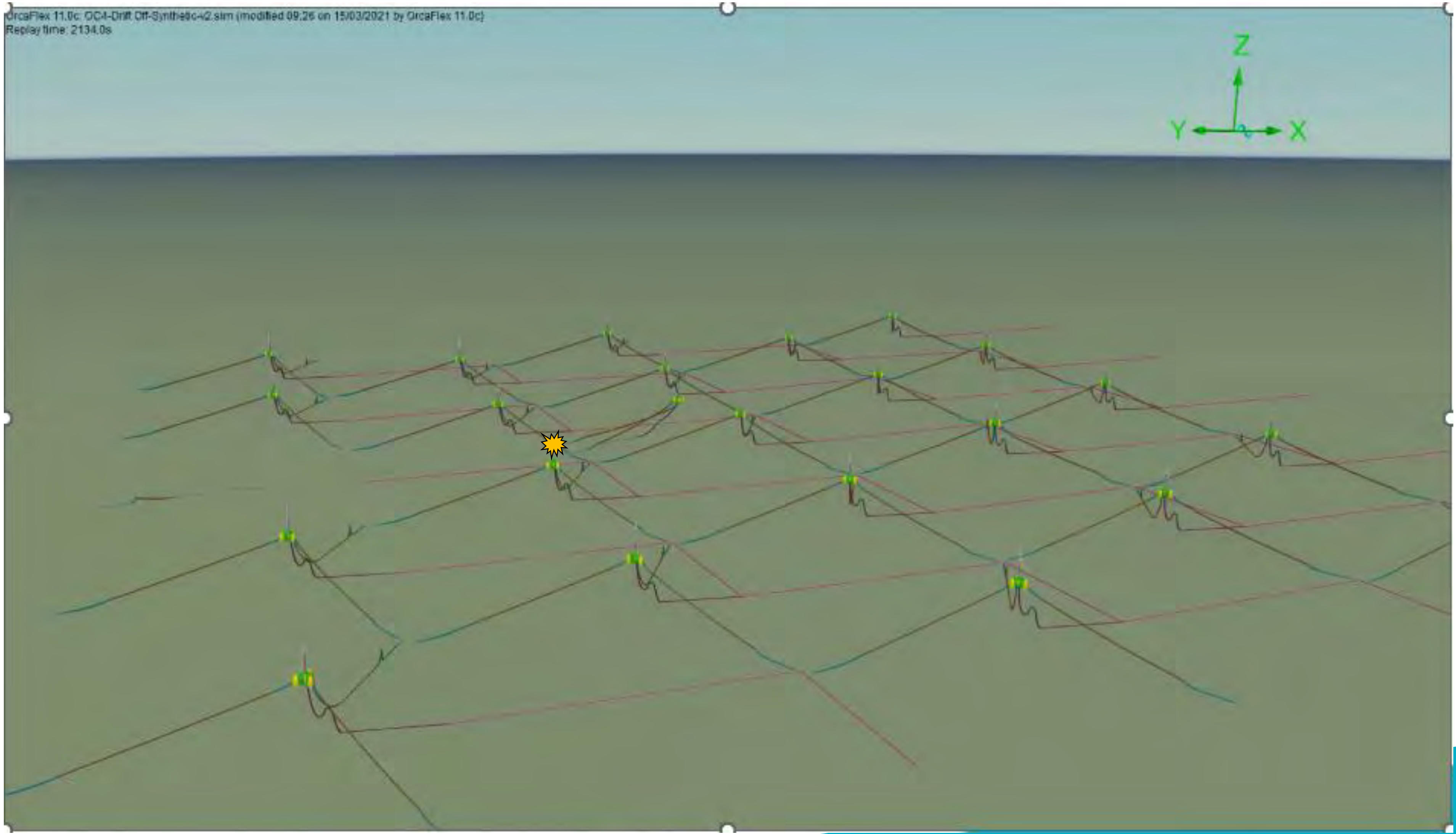
What are we trying to avoid?



Dynamic Cables & Moorings Technology Qualification

Filter Technology:
1 or 2 items per year

Based on FOW CoE partner interest
- AC power cores
- Monitoring
- Quick-connect
- …
- …
- …

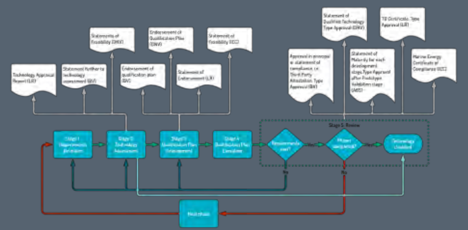
Sept 2022

Filter Suppliers:
1 or 2 per year

Competitive structured application process
- Technical capability
- Commercial impact
- Qualification Needs

Oct 2022 – Jan 2023

TQ Part 1
Desk based TQ plan



With Classification Society partner
- Define target TRL, project definition
- Review existing documentation
- Develop TQ plan
- Scope and budget

Feb – July 2023

TQ Part 2
Practical activity

Identify partners and secure funding
- Detailed testing plan
- Test and demo activity
- Model validation
- Plan/TRL review

Aug 2023 + ~2yrs

Will be rerun periodically with new technology focus areas (6-12 monthly)
Parallel moorings programme

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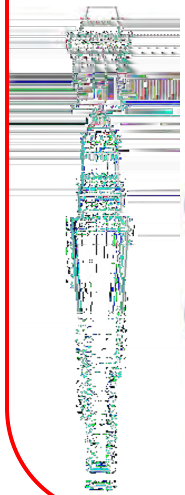
Cable Connection Technology Focus Areas

Subject	Technology Topic	Justification	Types of Test Activity
Dynamic Cables	**1) Bend Stiffener Connector Reliability**	• Known O&G problems; uncertainty in terms of long-term reliability. • Gaps in qualification test standards.	• Develop consistent qualification requirements • Laboratory fatigue and extreme load testing • In-water connect/disconnect & load tests • Stiffness characterization tests
Moorings	**2) Compliant ropes**	• Highly compliant rope (e.g., nylon) offers huge potential cost and reliability savings • Gaps in reliability and qualification knowledge	

Examples of Bend Stiffener Connectors
(not an exhaustive list)

First Subsea



Oil States

FES

Examples of Synthetic Ropes Under Test

Image Credit: Bridon Bekaert

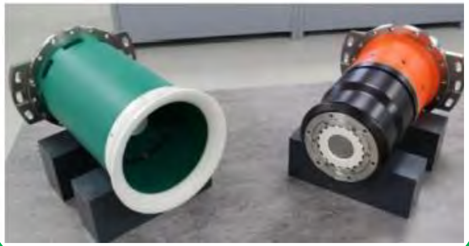
Image Credit: Instituto de Pesquisas Tecnológicas

Dynamic Cables Next Technology Focus Areas

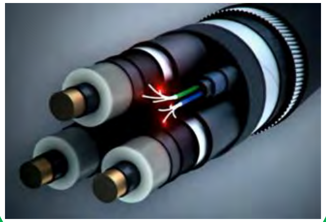
- High-interest technology areas for qualification are outlined below.
- Next technology area qualification applications planned to open June ‘23 to deliver Oct ’23

Bend Stiffener Connectors
Source: First Subsea

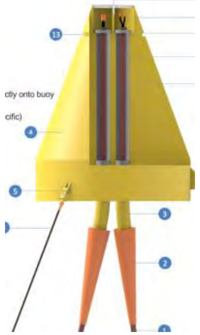
Wet Mate Connectors
(Source: Siemens)



Smart Condition Monitoring



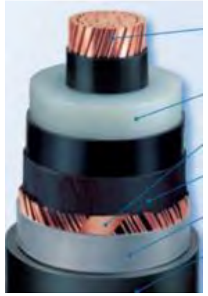
Disconnectable FOWT Quick-Connect
(Source: SBT)



Deep Water Cable Solutions
(Source: Hellenic)

External Inspection
(source: Innospection)

Cable Power Cores



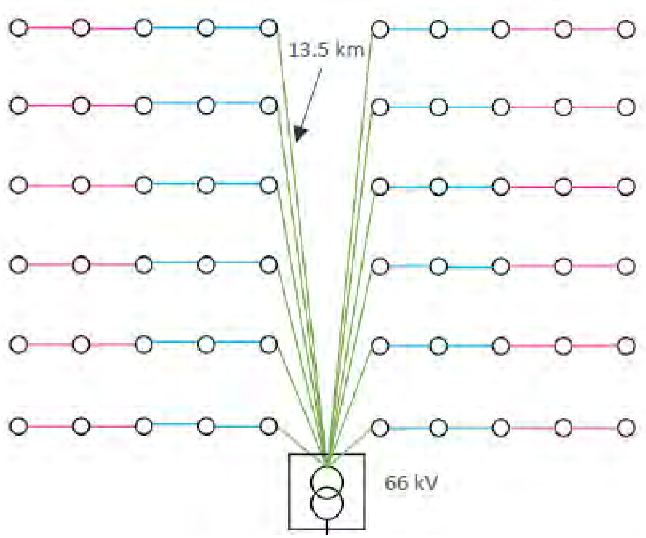
Topology Design Comparison

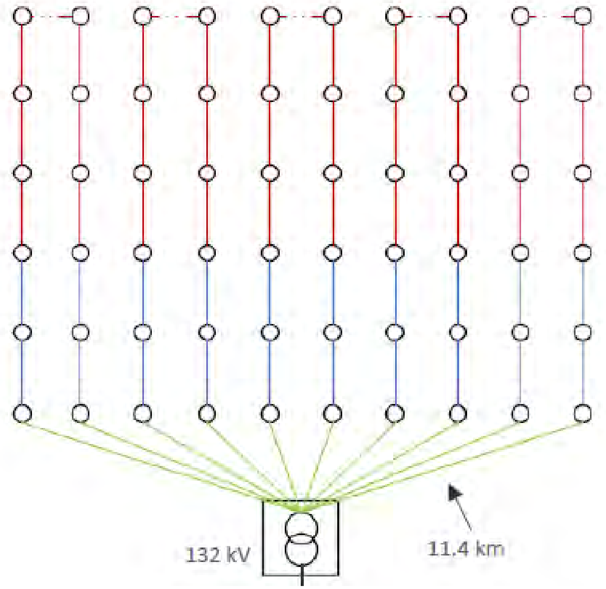
- Each topology design is compared in terms of CSA, costs (CfD, supply), losses and redundancy.
- 21 different combinations of connectors and topologies that will be assessed in the detailed.
- Further work: installation of mooring systems and dynamic cables, deep water FOW, Subsea and Floating Substations

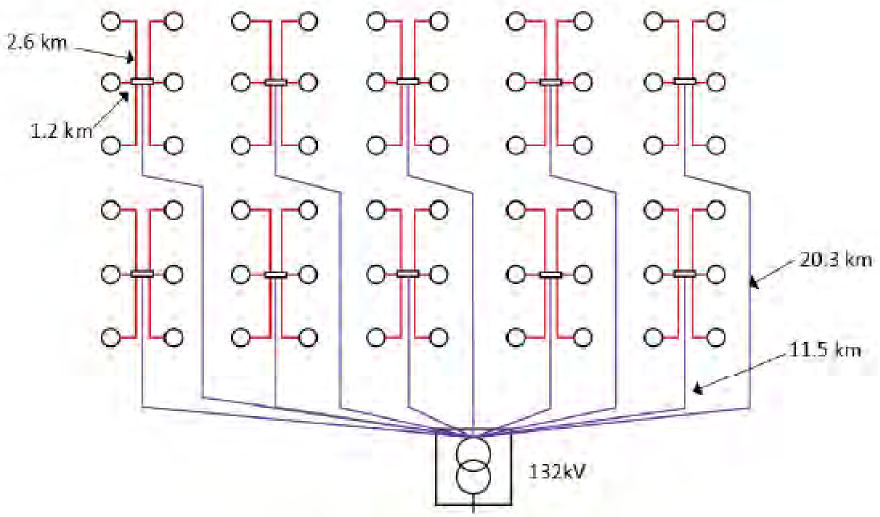
$$I_{nom} = \frac{P_{nom}}{\sqrt{3}U_{nom}}$$

$$I_{equivalent} = \frac{I_{nom}}{U_{op} \times P_f \times F_{depth} \times F_{temp} \times F_{resistivty}}$$

$$P_{loss} = 3 * 1000 * I^2 * \rho * \frac{L * 1000}{CSA}$$



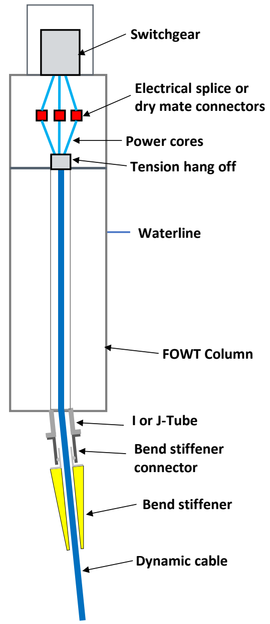




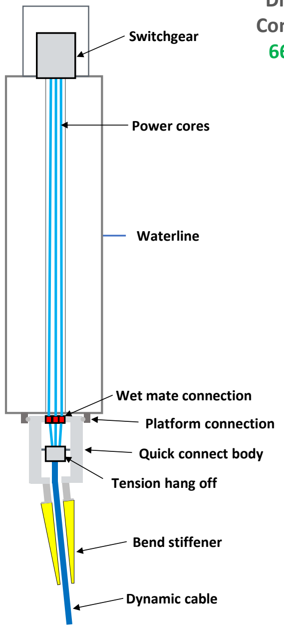
Cables Focus: Topside and Subsea Connection

- Each configuration has been combined with appropriate enabling connection technologies:

Dry Platform Connection

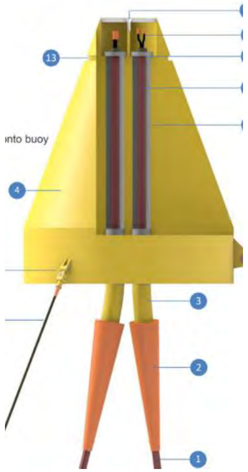


Wet Mate Connection

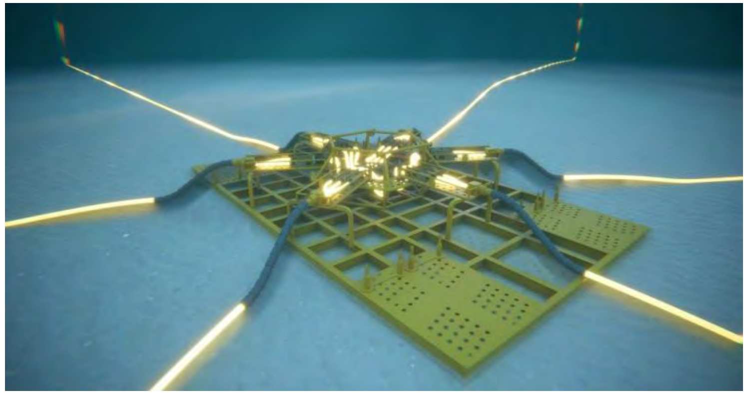


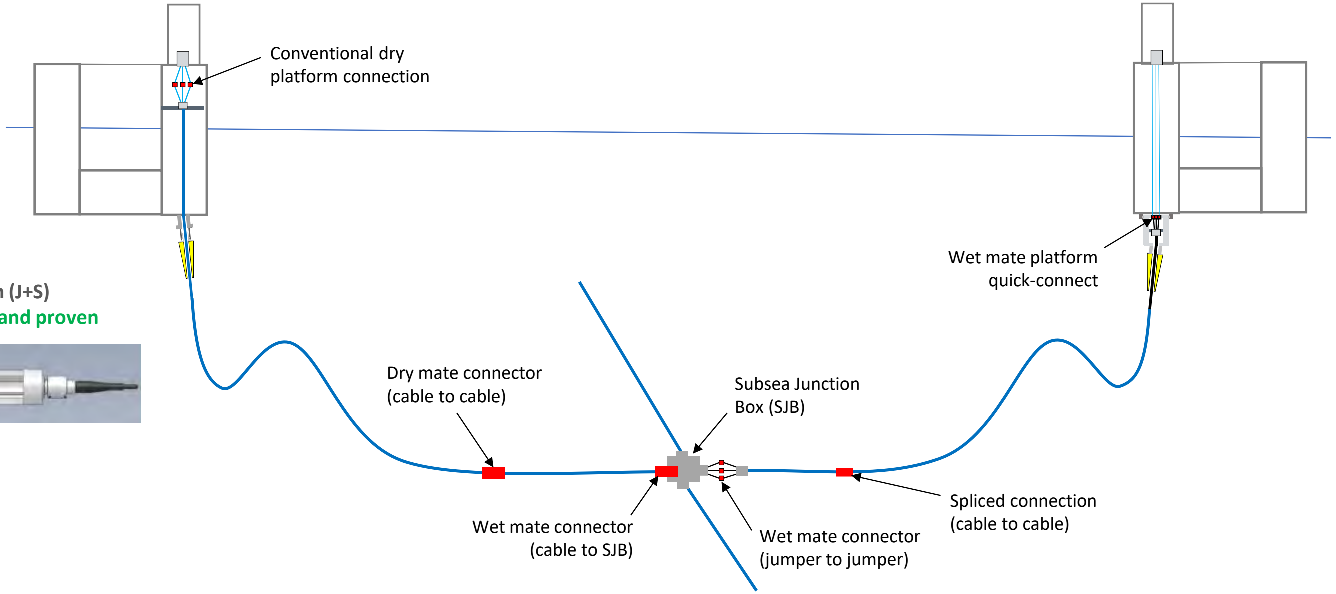
Disconnectable Dry Spliced Connection (Principal Power)
66kV qualified and proven

Wet Mate Buoy (SBT)
Early concept design



Subsea Junction Box with wet mates (Siemens / Subsea 7)





Single Phase Wet Mate Connector (Siemens)
36kV qualified, 66kV in qualification, 132kV Early concept

Dry Mate Connector (ETA)
66kV & 132kV qualified & proven

Spliced Connection (J+S)
66kV & 132kV qualified and proven

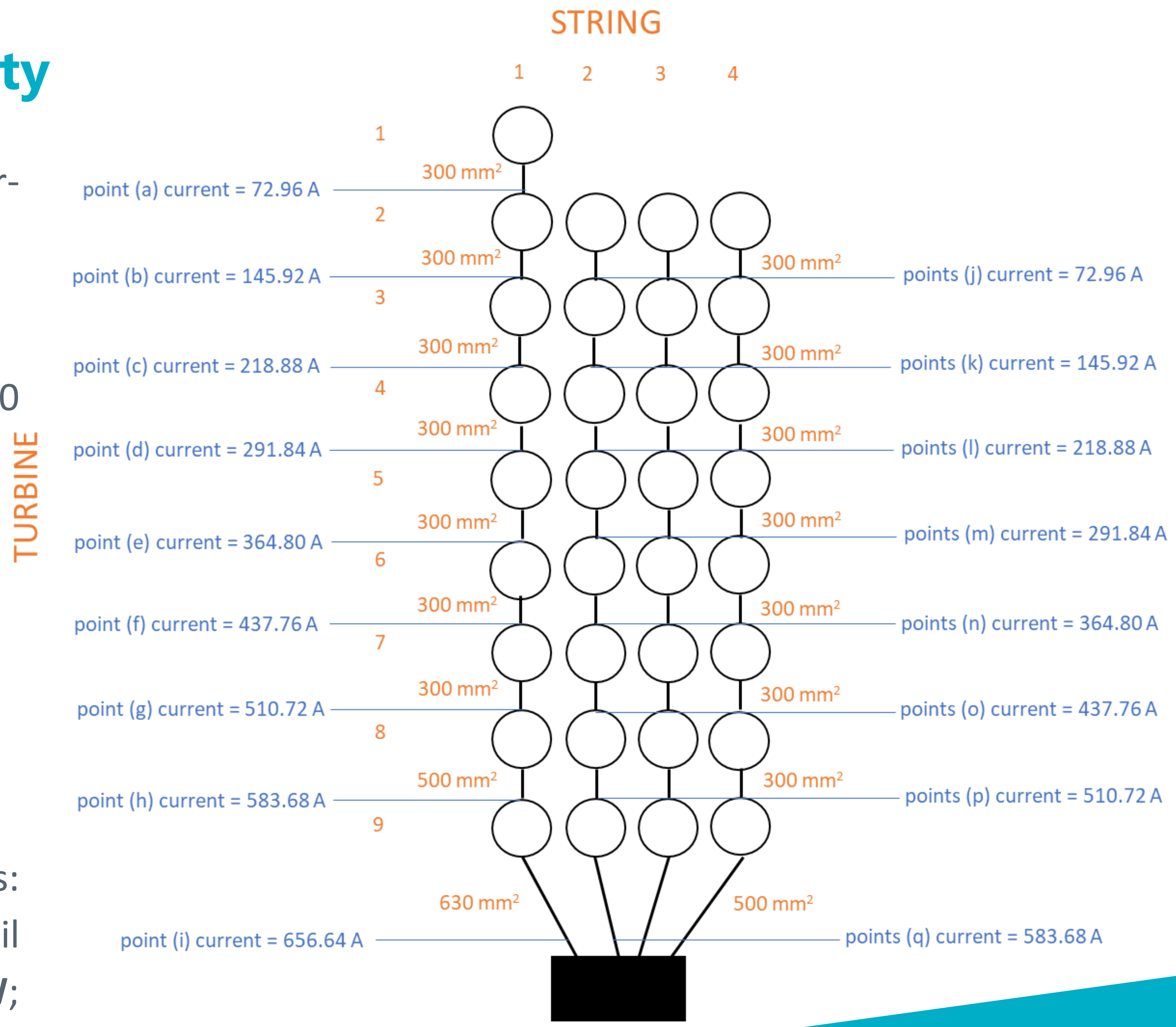
Thermal Considerations and Ampacity

- **132 kV**, three core CSA at **800 mm²** submarine inter-array cable.
- The resistivity of copper is used at **1.77x10⁻⁸ Ω.m,**
- **15 MW** with **72.69 A** per turbine, and **726.96 A** for 10 turbines in a string that will be used in this example.

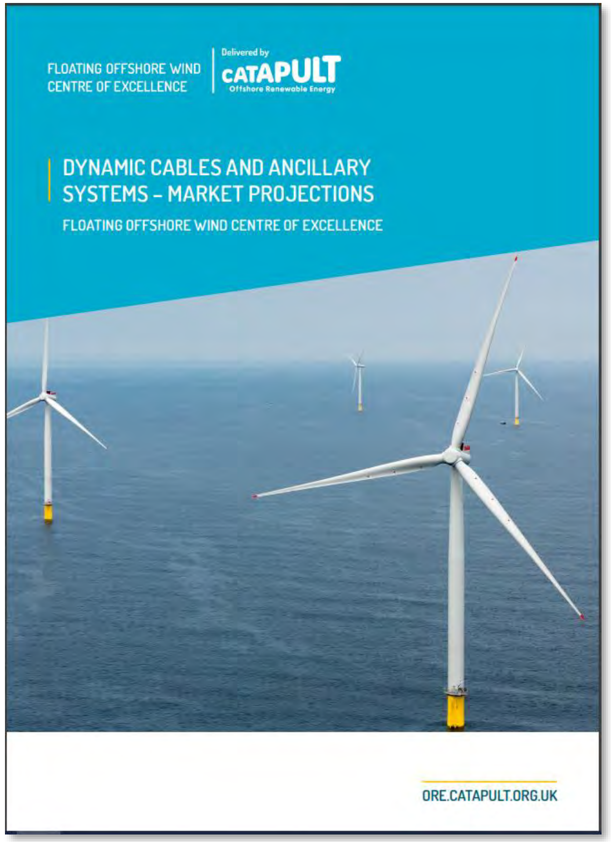
$$I_n = \frac{P_n}{\sqrt{3} \cdot U_{correct} \cdot pf}$$

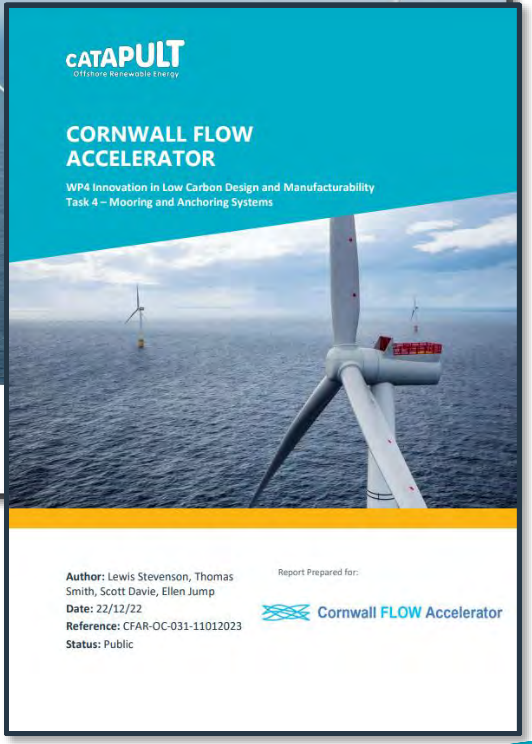
$$= \frac{15MW}{(1.732 \cdot 125.4kV \cdot 0.95)} = 72.69\ A$$

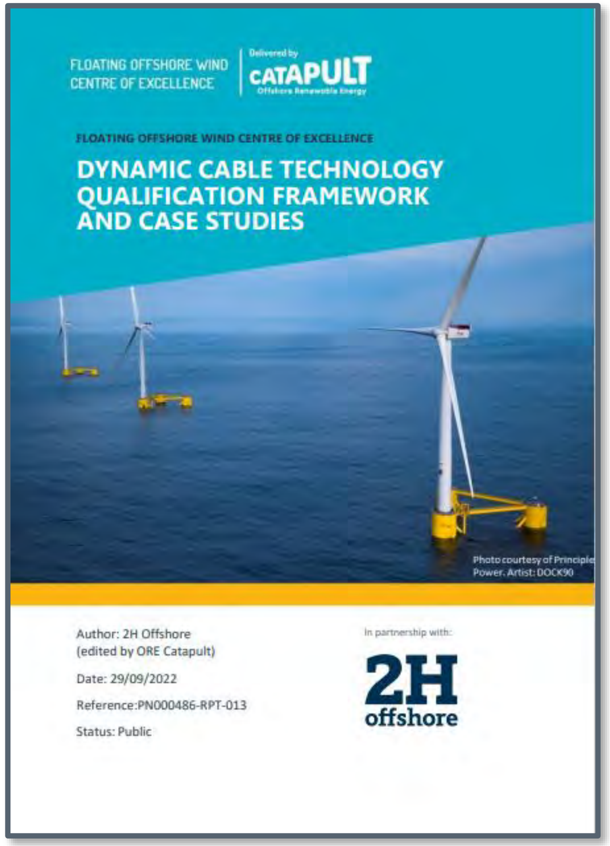
- De-rating factors: The lay configuration is as follows: cable buried in seafloor at a **1 m** depth; seabed soil temperature **15° C**; soil thermal resistivity **0.7 K.m/W**; solidly bonded sheaths; one circuit thermally independent.

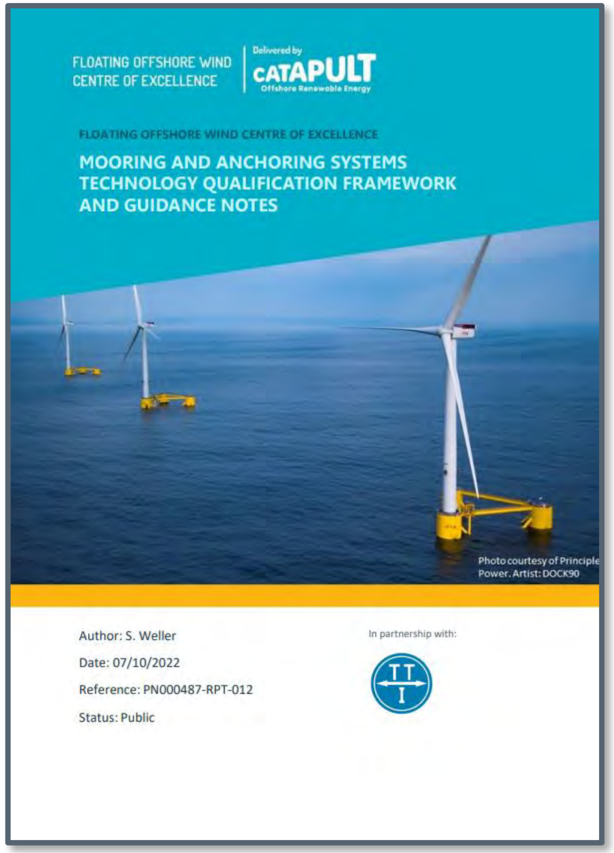


Further Reading: Moorings and Cables Public Reports









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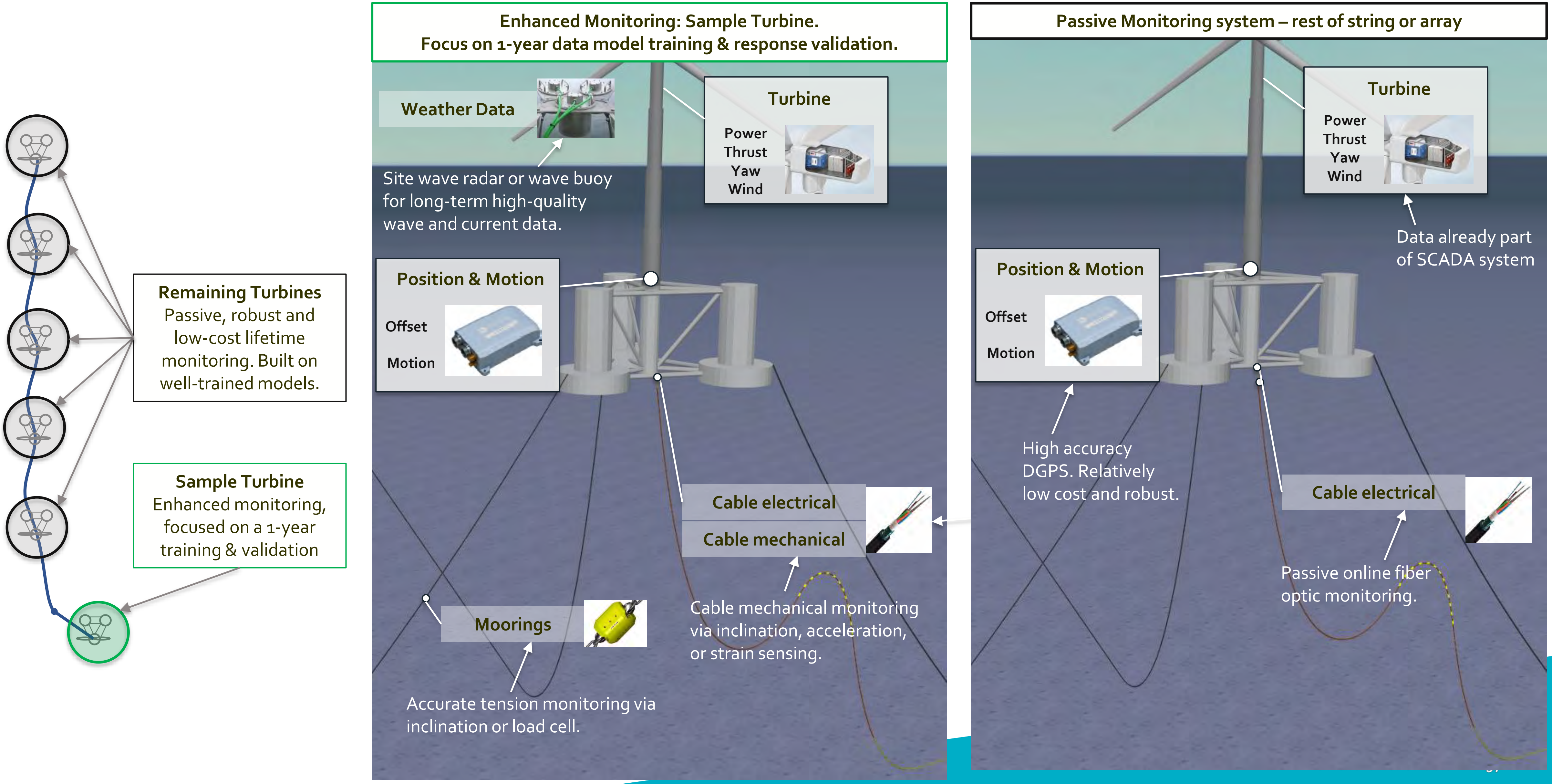
Floating Wind Health Monitoring (digital twin)



ORE Catapult Testing Capability

- Failure investigations, lifetime prediction and independent witnessing
- Power systems analysis (including fast transient analysis)
- Specialist testing services based on market need
- HV and materials test facilities
- Research ability and partnerships in place to support innovative projects
- Quality assured and independent

HV Laboratories

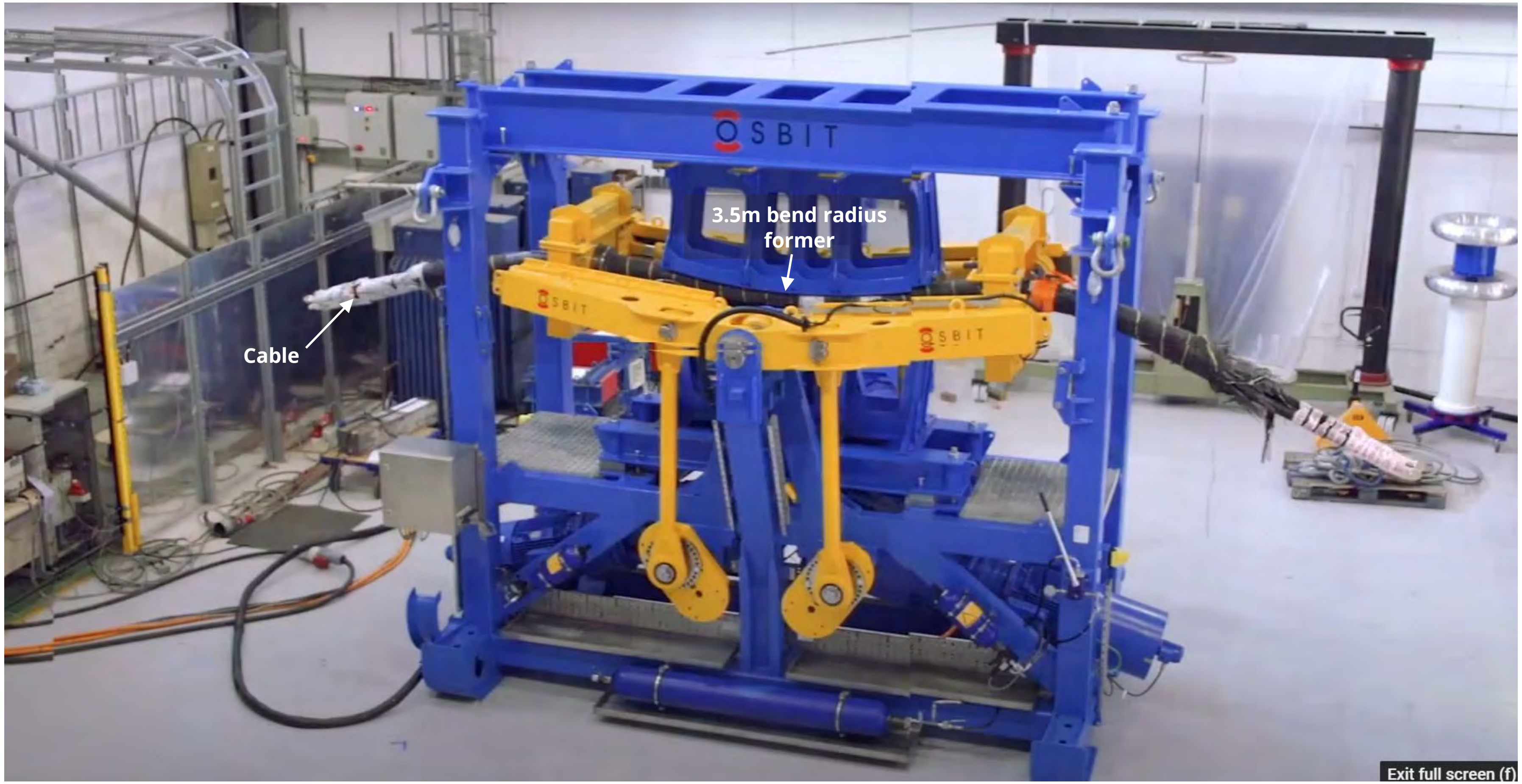
- AC Power Frequency: up to 600 kV AC (rms)
- Lightning impulse: up to 1,2 MV
- DC Voltage: up to 1 MV
- Screened faraday cage
- Artificial rain capability
- High Current (up to 8 kA)
- Oil processing and lab (mobile)
- Materials laboratories (solid insulation and oils)
- Indoor and outdoor HV test laboratories
- *Dielectric Testing*
- *Load cycling*
- *Accelerated ageing* (500Hz and 50 Hz)

Materials Laboratories

- Range of equipment to analyse and image materials
- Oil and solid insulation moisture analysis
- Microscopic Analysis of System Components (Possible for wear / fracture)
- Insulation (including wate tree) characterisation
- Other materials analysis (FTIR, DSC…)
- Applications beyond lab supporting analysis – field aged infrastructure

CATAPULT
Offshore Renewable Energy

Cable Testing Focus: Dynamic Cable Flex Tests



CATAPULT Offshore Renewable Energy

Thank you.

Any Questions?

Charlotte.strang-moran@ore.catapult.org.uk

GLASGOW

BLYTH

LEVENMOUTH

GRIMSBY

ABERDEEN

CHINA

LOWESTOFT

PEMBROKESHIRE

CORNWALL

CATAPULT
Offshore Renewable Energy

HELLENIC CABLES
Member of CENERGY HOLDINGS

Dynamic Cables

A Link to the Floating Offshore Industry through Innovation

Kostas Grivas
Offshore Engineering Dept.

Contents

Floating Offshore Wind Market Overview

www.hellenic-cables.com

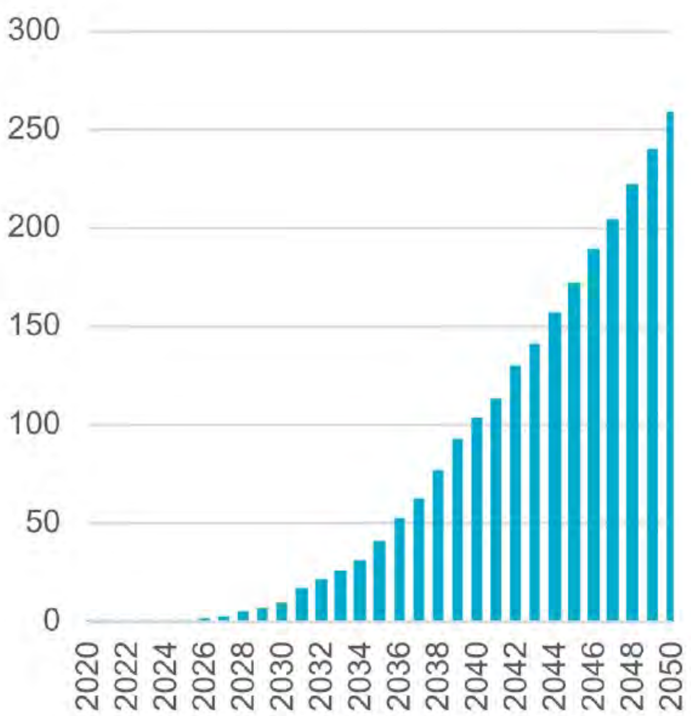


***Figure:** Long-Term Floating Offshore Wind Global Forecast (GW)*
***Source:** ORE Catapult, Floating Offshore Wind Centre of Excellence, International Market Opportunities*

*“The Global Pipeline of Floating Offshore Wind, bolstered by increasing policy support, indicated that **well over 10 GW is on track to be commissioned by the end of 2030**”*

2022 - 2030

- United Kingdom
- South Korea
- Japan
- Norway
- France
- Ireland
- Taiwan
- China
- Poland
- Spain
- Portugal
- United States

2030 - 2035

- Italy
- Greece
- Canada
- Sweden
- Vietnam
- Philippines
- Brazil
- Australia
- Romania
- India

2035 - 2050

- Colombia
- Bulgaria
- Morocco
- Tunisia
- Turkey
- Finland
- Lithuania
- South Africa
- New Zealand
- Chile
- Costa Rica
- Kenya

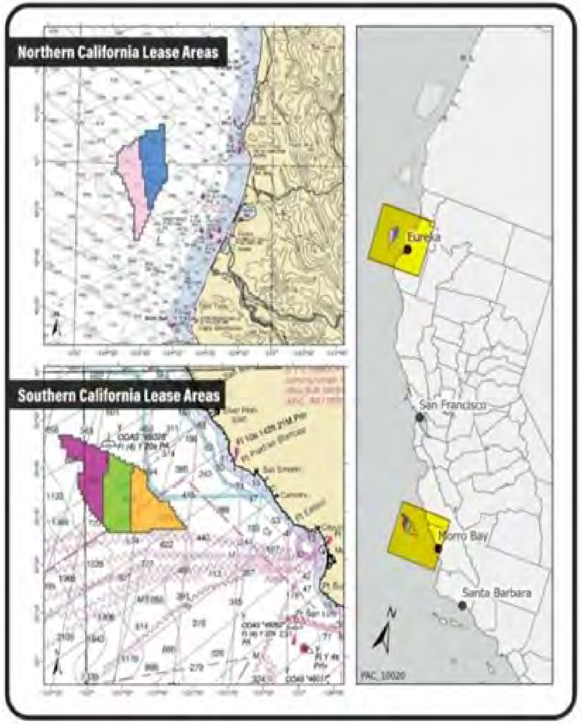
Estimated installed capacity of 10GW by 2030, rising to 270 GW by 2050

Auctions and Key Players

ScotWind (UK)

ScotWind auction tender (completed)
- **16 GW** Floating projects

California (US)



USA - California leasing round (completed)
- **4,5 - 6,6 GW** Floating projects

Celtic Sea (UK)

UK – Celtic Sea (auction in 2023)
- **4 GW** Floating projects

INTOG (UK)

UK – INTOG (auction in 2022/23)
- **4 GW** Floating projects

Norway (4,5 GW), MED (Greece – Italy): 3-5 GW
France (2GW), South Korea and Japan (5-12 GW)

All known market players have moved into Floating Offshore Wind

Corporate Overview

€5.375mi Revenue 2021
€514mi a-EBITDA 2021
12.000 employees

VIOHALCO

VIO LISTED EURONEXT BELGIUM

- Headquartered & Listed in Brussels
- One of Europe's largest metals processing groups
- **80% export-oriented,** globally

Aluminum	Copper	Steel	Steel Pipes	Cables	Real Estate	Recycling	R&D

€1.054mi Revenue 2021
€104mi a-EBITDA 2021
2.600 employees

CENERGY HOLDINGS

CENER LISTED EURONEXT BELGIUM

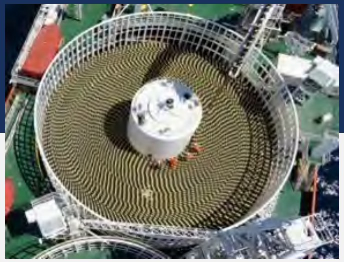
CORINTH PIPEWORKS

HELLENIC CABLES
Member of CENERGY HOLDINGS

- Headquartered & Listed in Brussels
- Global player in **Energy Transition**
- Leveraging experience and know-how in energy transmission

Activities & Products

Energy Transmission, Distribution and Renewables



- Power Cables: LV, MV, HV & EHV
- Submarine & Land
- XLPE, EPR insulated
- Composite power & FO

Telecom & data transmission

- Telecom network cables
- Optical fiber cables
- Submarine Optical Fiber cables for Repeaterless applications

Construction & Industrial

- Signalling & Control
- High temp, low sag, Flame retardant, Mining
- Wind and Solar

Established strong Relationships and Solid Track Record with Blue Chip Customers:

Developers

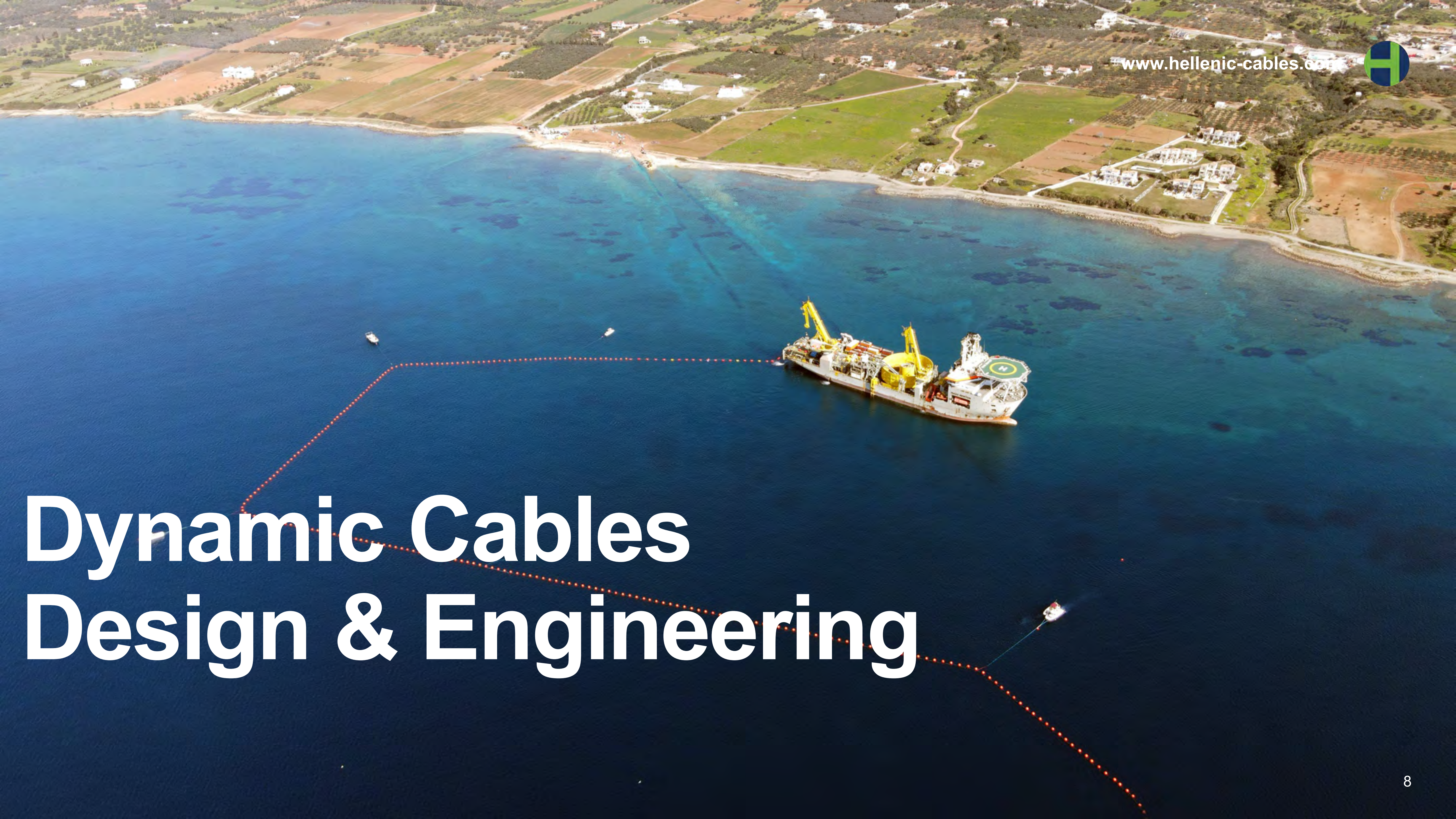
Ørsted, Vattenfall, SSE, RWE, OW Ocean Winds, Equinor

Grid Operators

TenneT, Elia, Dominion Energy, ΑΔΜΗΕ, Energinet

Installers

Van Oord, DEME, Jan De Nul, Subsea 7, Asso.subsea



www.hellenic-cables.com

Dynamic Cables Design & Engineering

66 kV Inter-array cable system

CU/XLPE/CWS/PE/DWA/PE

For the inter-array dynamic cables up to 66 kV the main design features are:

- The utilized XLPE insulation system has successfully undergone the *wet ageing test* according to CIGRE TB 722 at 500Hz adopted at 66 kV.
- The utilized XLPE insulation system was successfully subjected to the *2 year long wet ageing test* according to CIGRE TB 722 regime A.
- The offered cables up to 66 kV are of *wet type* (CWS).
- The offered cables are *torsionally balanced* in order to be able to withstand the load conditions for at least 25 years of lifetime.

Up to 275 kV Export cable system

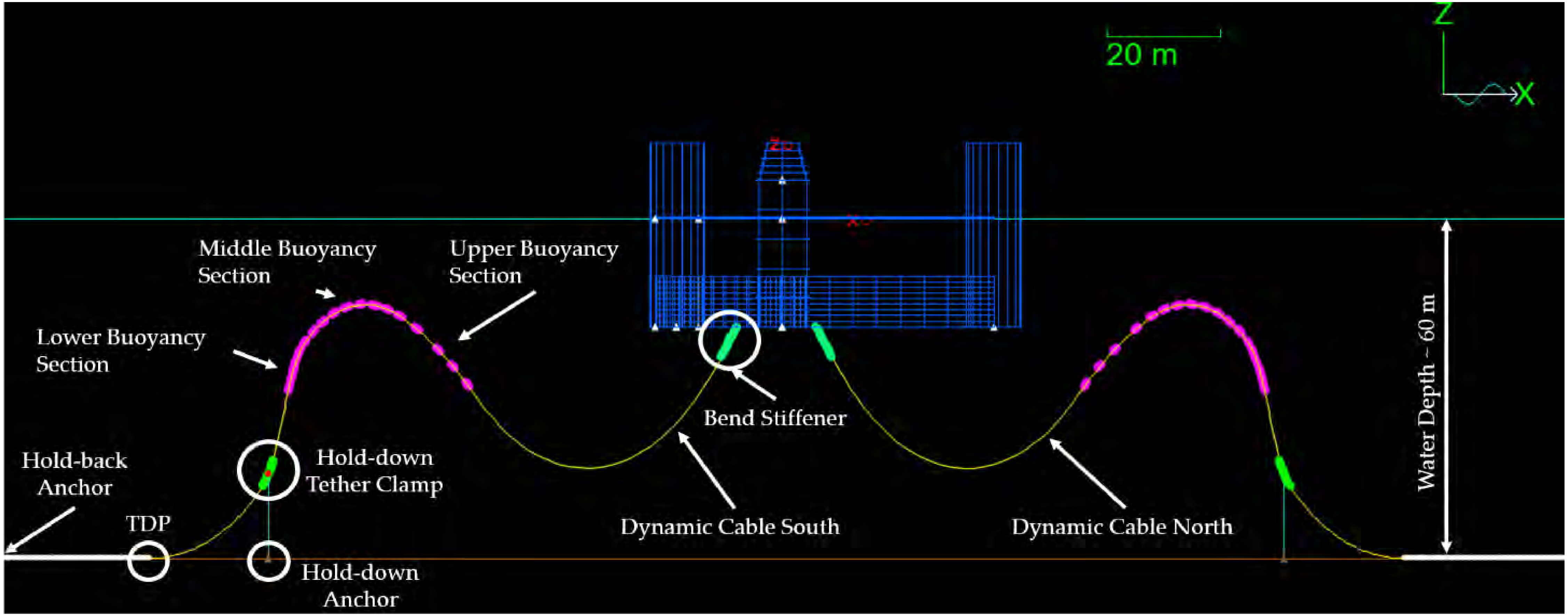
CU/XLPE/CWCS/PE/DWA/PE

For the export dynamic cables up to 275 kV the main design features are:

- The utilized *XLPE insulation system is of ultra clean level* according to IEC 62067.
- The cables are of *dry design*. Moreover, for the dynamic section of the route the metallic screen of the cable shall consist of welded corrugated copper. In addition, for the static section of the route the metallic screen of the cable shall consist of extruded lead. Finally, at the transition from the static to the dynamic section a *factory joint* on each core shall be implemented.
- The cables are *torsionally balanced* in order to be able to withstand the load conditions for at least 25 years of lifetime.

Design Engineering

IAC & Export Dynamic Cables



Dynamic Ancillaries

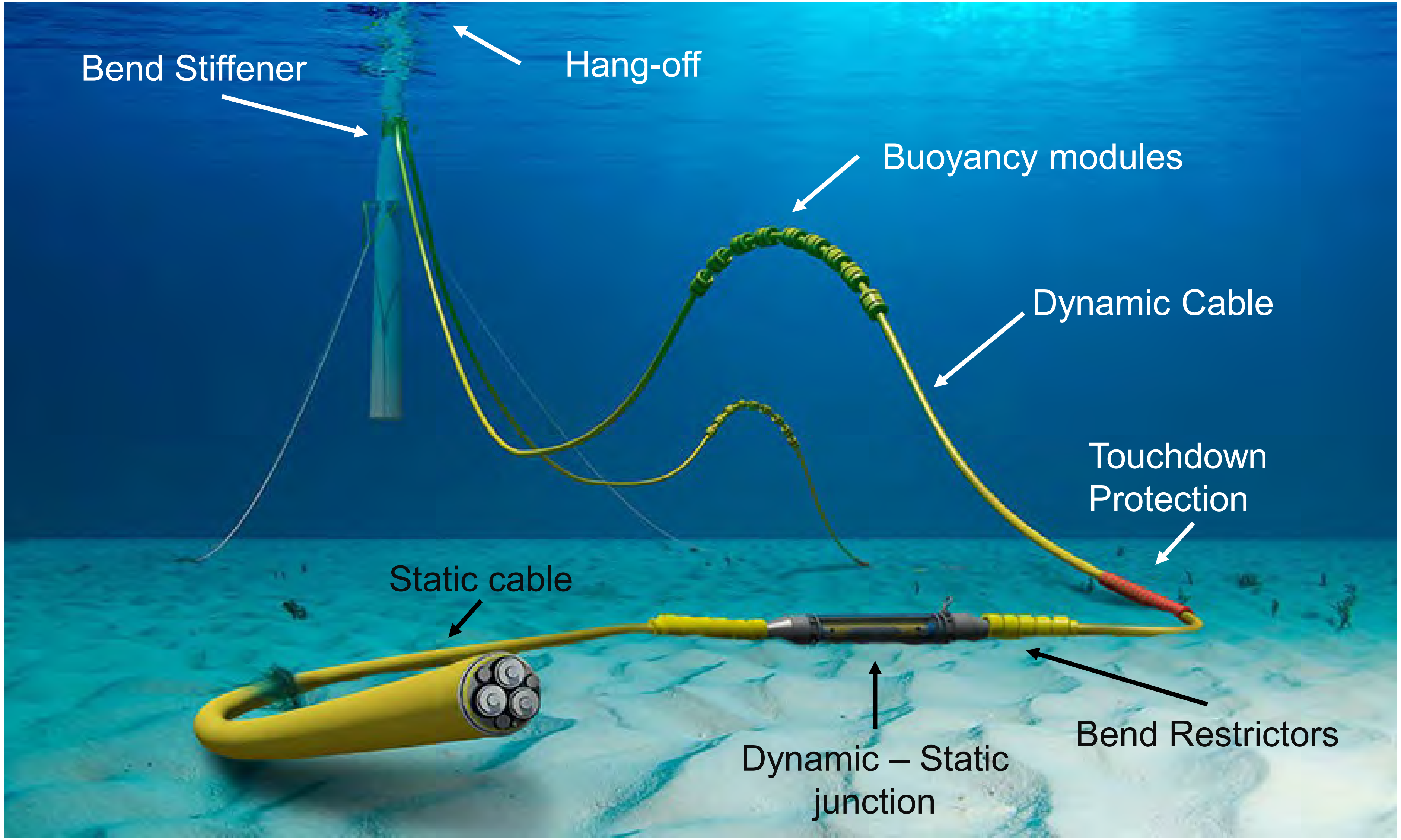


*Illustration by Joshua Bauer (NREL)

Dynamic Ancillaries

Dynamic Cable System Components:

- **Accessories:**
  - ✓ **Commercially available – mature solutions:**
    - o Buoyancy modules
    - o Bend stiffeners
    - o Bend restrictors
    - o Tethers
    - o Anchors
    - o Diverless Bend Stiffener Connector (DBSC)
    - o Hang-off
  - ✓ **Project specific – Under development**
    - o Weak link – Breakaway system
    - o Planned Disconnection – Heavy Maintenance

Dynamic Cables Development

Accelerate Time to Market is key

Market moving fast from Pilot to Commercial scale development

Understand market needs & gaps → **Develop critical components** → **Position with key developers**

FLOATANT

Array (66 kV) cable
Innovative conductor & armour

University of Exeter

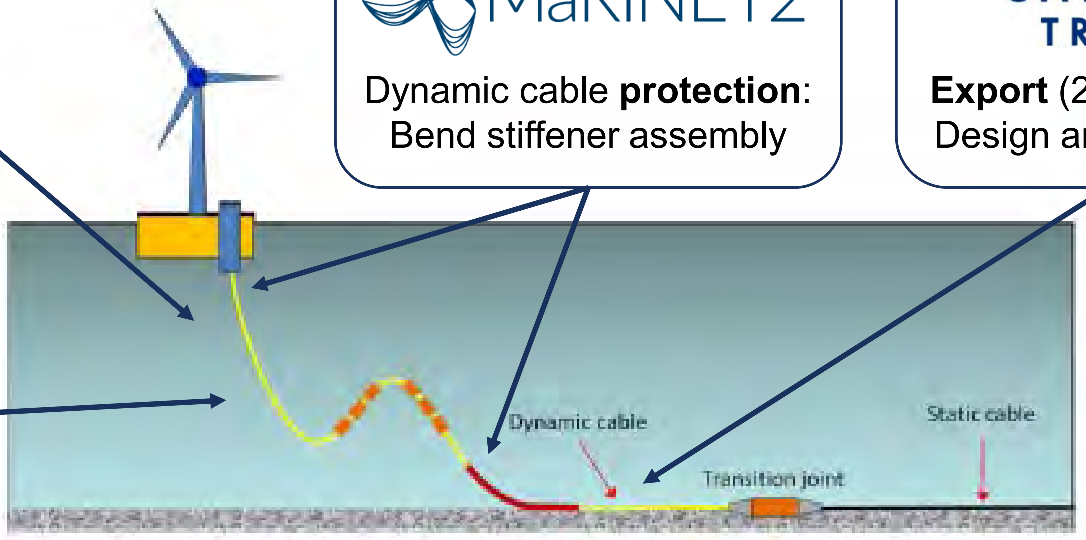
Array (66 kV) cable
mechanical tests

MaRINET2

Dynamic cable **protection**:
Bend stiffener assembly

CARBON TRUST

Export (220 kV) cable
Design and test cores



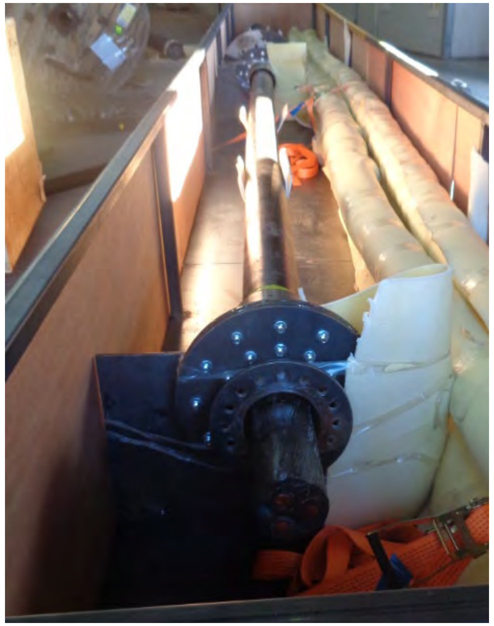
NextFloat
Next Generation
Integrated Floating Wind
Optimized for Deep Waters

INFINITE

Dynamic Cables

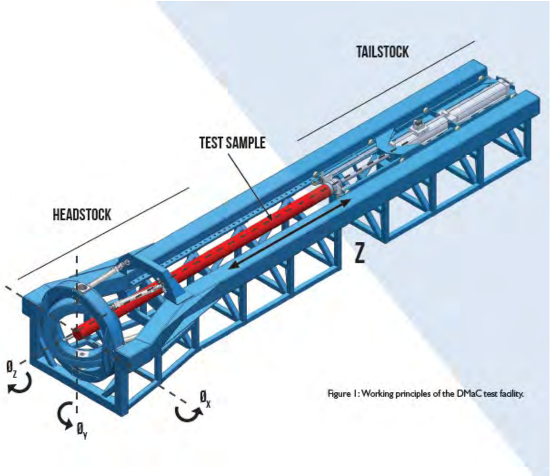
Research projects – IAC (up to 72.5kV)

The project involves the designing, manufacturing and fatigue testing of a 66kV Dynamic 3-core power cable in collaboration with the University of Exeter.



Certification of a 66kV Dynamic Cable

University of Exeter



MaRINET2

* Press Release MaRINET2: Testing confirms CRP Subsea's Bend Stiffener prolongs the fatigue life of a power cable -CRP Subsea

Dynamic Cables

Research projects – IAC (up to 72.5kV)

Grant agreement
No. 815289

FLOTANT project proposes to develop an innovative unit optimized to sustain a typical 10+MW wind turbine generator (WTG) in deep waters (100-600m), integrated by an anchoring system, a mooring system, a floater with its mast and a power export system, including a design for a deep-water substation, and O&M strategies, sensoring and monitoring.

- ✓ Aluminium conductor
- ✗ Copper conductor
- ✓ Synthetic - hybrid armouring
- ✗ Steel armour

Dynamic Cables

FLOTANT Project – IAC (up to 72.5kV)

DYNAMIC CABLE & EXPORT SYSTEM OPTIMISATION

This WP developed innovative dynamic power cable solutions and corresponding connectors providing an optimized power transmission system for deep water (range 100-600m) Floating Offshore Wind farms.

The specific objectives of this WP were:

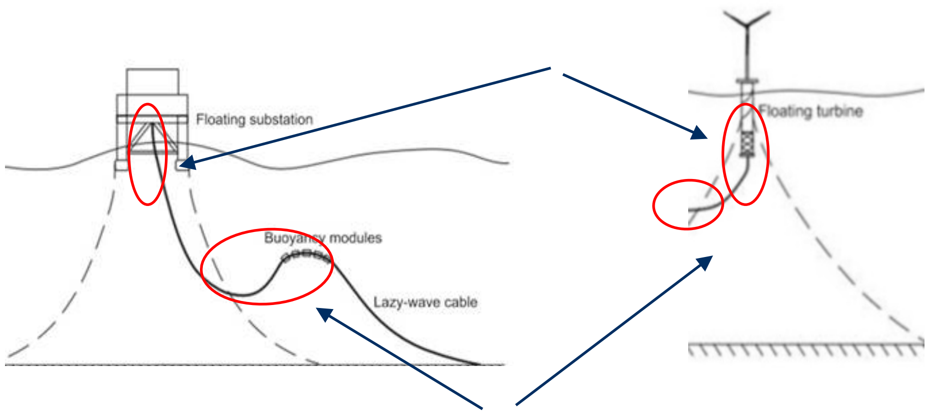
- ✓ Develop novel connector components (mechanical hang-off and breakaway system) to enable reliable and fast Plug & Play connection and disconnection operations.
- ✓ Investigate new application of materials for highly dynamic cable operational performance (mechanical, electrical, anti-fouling and anti-bite → conductor, armour, jacket).
- ✓ Develop innovative cable core conductor, armour and jacket for 72.5 kV dynamic cable.
- ✓ Provide suitable prototype components for tests (cable core conductor, cable armouring, connectors, cable jacket and final 72.5 kV dynamic cable).
- ✓ Model and simulate dynamic local components behaviour required to validate expected cable performance during service life.

Dynamic Cables

FLOTANT Project – IAC (up to 72.5kV)

DYNAMIC CABLE & EXPORT SYSTEM OPTIMISATION

Connector: connects inter array or export cable with turbine or substation respectively



Dynamic power cable transmits electric power

✓ Collects from each successive turbine to substation (inter array)

✓ Transmits power from substation to onshore termination (export- could be part dynamic - part static)

Task 3.1: Development of mechanical hang off and breakaway system

Objectives:

- Plug and play quick connection and disconnection
- Emergency breakaway
- Prototype components for testing

Task 3.2: Cable core conductor innovations

Objectives:

- Innovative cable core
- Prototype components for testing

Task 3.3: Development of complete cable with novel outer armouring

Objectives:

- Novel cable armour
- New materials for jacket
- Prototype components for testing

Task 3.4: Dynamic Cable local component analysis and fatigue modelling

Objectives:

- Numerical models for local mechanical stress analysis, for calculation of bend radii, estimation of remaining fatigue life

Dynamic Cables

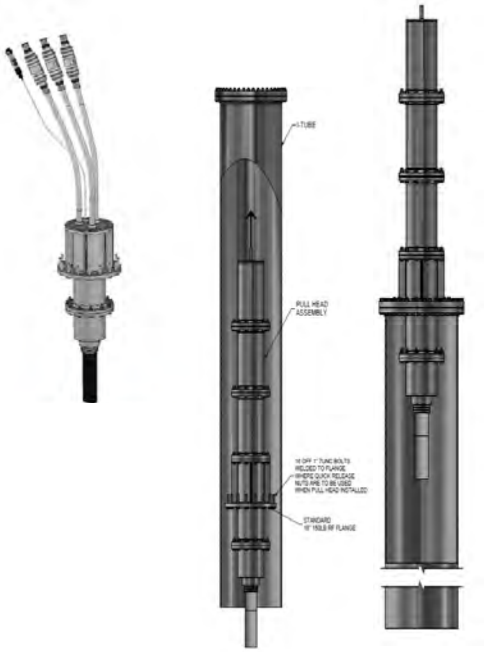
FLOTANT Project – IAC (up to 72.5kV)

Development of mechanical hang off and breakaway system HydroBond (HB)

- ✓ **Development and testing of new subsea electrical connector incorporating quick "plug and play" connection-disconnection capability of the pre-terminated power cable to floater electrical interface.**

In order to maintain low costs, the physical electrical connector design utilizes previously existing and offshore qualified product. The fibre optic connections also use existing proven technology.

The Hang off system provides a physical interface between the dynamic export cable and the floating wind turbine. The assembly incorporates the electrical and fibre optic connections and the mechanical interface. The hang off assembly consists of a pull head, a breakout chamber, strain termination and I tube fitting and release mechanism.



I-tube pull in and locking operation

- ✓ **Development of "diverless" installation and operational procedures**

PLUG & PLAY

HB procedures foresee an installation time of **41 minutes** leading to reduced installation and maintenance costs

Dynamic Cables

FLOTANT Project – IAC (up to 72.5kV)

Power cable design and manufacturing

Task 3.2: Cable core conductor innovations (participants **Hellenic Cables**, University of Exeter, Cobra)

The Task 3.2 overall objective is the development and manufacture of an innovative aluminium conductor core, XLPE insulated for a 72.5 kV dynamic submarine cable to be aged in water tank.

Task 3.3: Development of complete cable with novel outer armouring (participants **AIMPLAS**, Hellenic Cables, ITA-RWTH, HydroBond, MARIN, University of Exeter, Cobra

The Task 3.3 overall objective is to develop and manufacture an innovative flexible light weight dynamic 72.5 kV submarine power cable

- XLPE insulated cores with aluminium conductor.
- Enhanced outer jacket (development by Aimplas, application of jacket by Hellenic Cables).
- Flexible lightweight armour of impregnated carbon fiber / synthetic materials (development and application by ITA-RWTH / Hellenic Cables).
- Complete cable for fatigue testing at DMaC and mechanical and electrical testing at Hellenic Cables submarine cable plant test facilities.

Dynamic Cables

FLOTANT Project – IAC (up to 72.5kV)

www.hellenic-cables.com

Water ageing test performed by Hellenic cables / FULGOR Plant
2 years long term ageing test at 50 Hz according to CIGRE TB 722 regime A

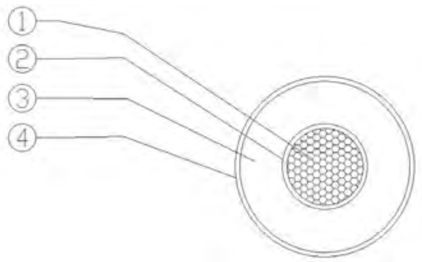
Cable samples of 3x240sq.mm Aluminum conductors rated at 38/66 (72.5) kV

1 – Aluminum stranded compacted of nominal cross-section equal to 240 sq.mm.

2 – Conductor non-metallic extruded screen.

3 – XLPE Insulation.

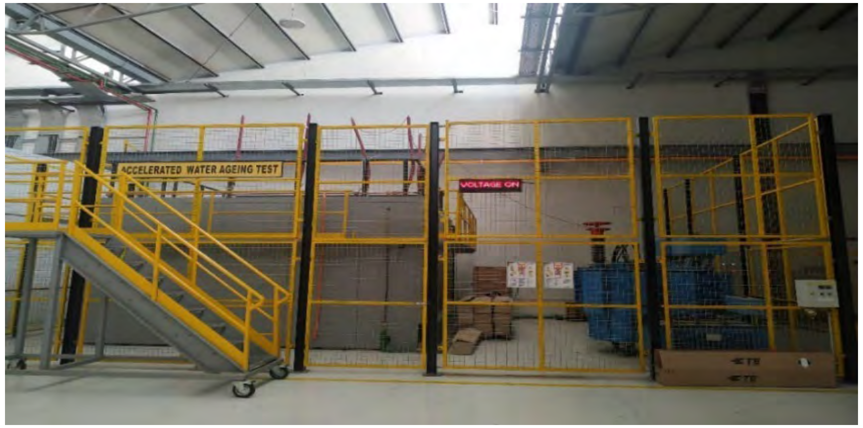
4 – Core non-metallic extruded screen.



Test conditions	Unit	Applied value	Required value
Voltage test	kV	54 ± 3%	54 ± 3%
Frequency	Hz	~ 50	49 - 61
Temperature of water	°C	40 ± 5	40 ± 5
Salinity of water	%	~ 4.0	3 - 6
Duration of 1st year	hrs	> 8.750	≥ 8.750
Duration of 2nd year	hrs	> 17.500	≥ 17.500

Twelve (12) samples were tested, and the results exceeded the requirements within CIGRE TB 722 regime A.

Testing facilities



Dynamic Cables

FLOTANT Project – IAC (up to 72.5kV)

Mechanical and electrical testing performed by Hellenic cables / FULGOR Plant

Mechanical tests

- Tensile bending test
- Impact test
- Crush test
- Crush test for long term stacking

Non-electrical tests

Electrical tests

- Partial discharge
- Tanδ measurement
- Heating cycle voltage test
- Lightning impulse voltage test

Water penetration tests

- Conductor longitudinal water penetration test
- Metal sheath longitudinal water penetration test
- Longitudinal water penetration test of optical fibre unit

Type	3x240 mm² AL
Rated voltage U_0/U	38/66 (72.5) kV
Standard specification	IEC 63026, IEC 60840 ed 5 (where applicable), CIGRE Recommendations No. 490 and CIGRE Recommendations No. 623
Manufacturer	FULGOR S.A.

1 – Tensile bending

2 – Impact test

3 – Crush test for long term stacking

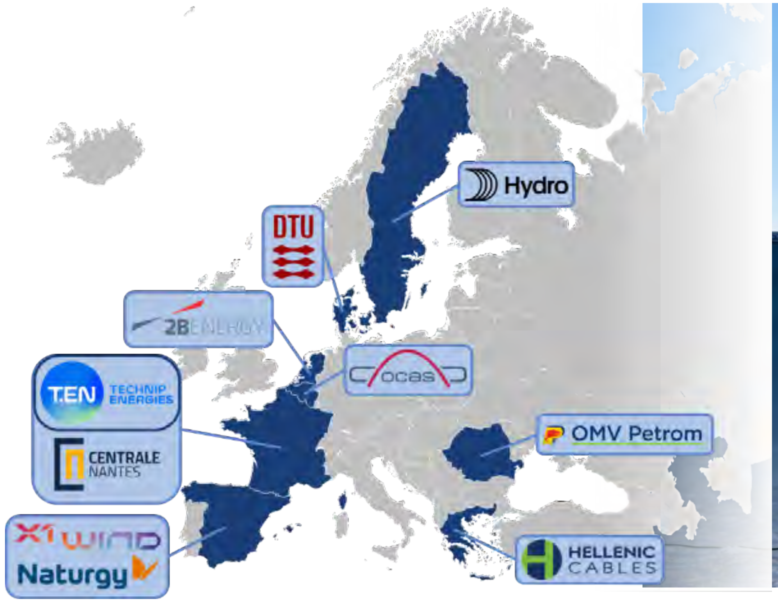
Next Float

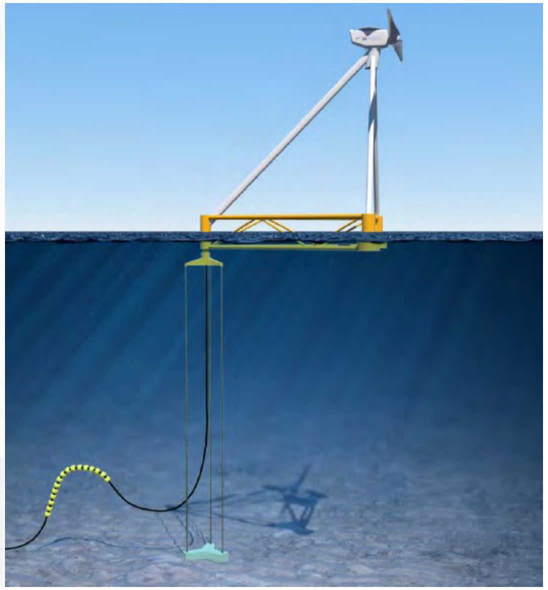
Next Generation Integrated Floating Wind Optimized for Deep Waters

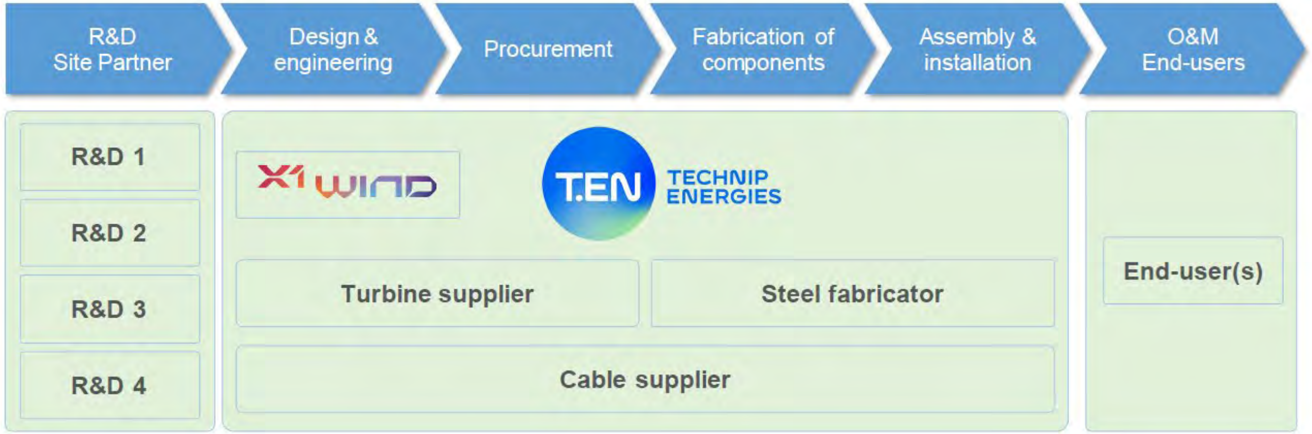
Horizon Europe – THE NEXT EU RESEARCH & INNOVATION PROGRAMME (2021 – 2027)

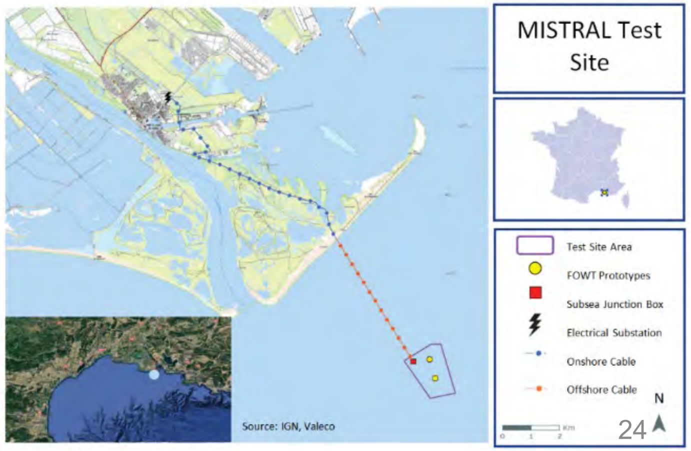
- Project ambitions:
  - **Deploy** and test a 6 MW floating wind pilot system (**reference**)
  - Design for 20+ years lifetime
  - Prepare scalability and industrialization plan
  - Concept design of a 14MW unit

- **Hellenic Cables' contribution:**
  - Dynamic Cable supply and certification of 20 kV (300m)
  - Innovation: Light-weight design through:
    - Using Al instead of Cu conductor









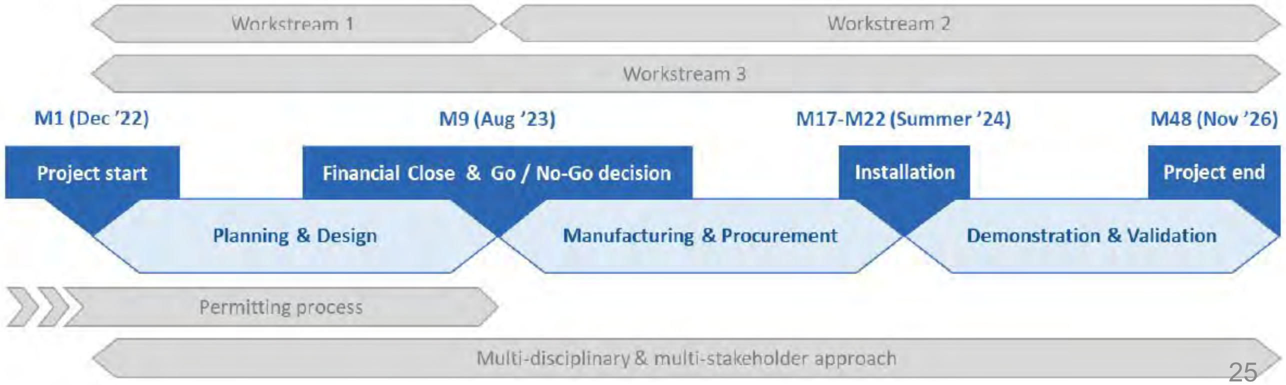
INFINITE

Horizon Europe
THE NEXT EU RESEARCH & INNOVATION PROGRAMME (2021 – 2027)
European Commission

acciona energía

- Project ambitions:
  - **Deploy** and test a 11 MW floating wind pilot system at 100m water depth (**reference**)
  - Disruptive and environment-friendly concrete tension leg platform anchored with an innovative tendon-based mooring system
  - Design for 20+ years lifetime
  - Prepare scalability and industrialization plan
  - The innovations result in an LCOE of 85.3 EUR/MWh at project end and set the path to achieve 43.3 EUR/MWh by 2030.

- **Hellenic Cables' contribution**:
  - Dynamic Cable supply and certification of 66 kV (1.5km)
  - Innovation: Light-weight design through:
    - Using Al instead of Cu conductor
    - Integrate fibre optic element for strain monitoring.
    - Optimise the cable towards global loading regime and mechanical stress.

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Thank you

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The Challenges and Opportunities of the Celtic Sea

INYANGA marine projects

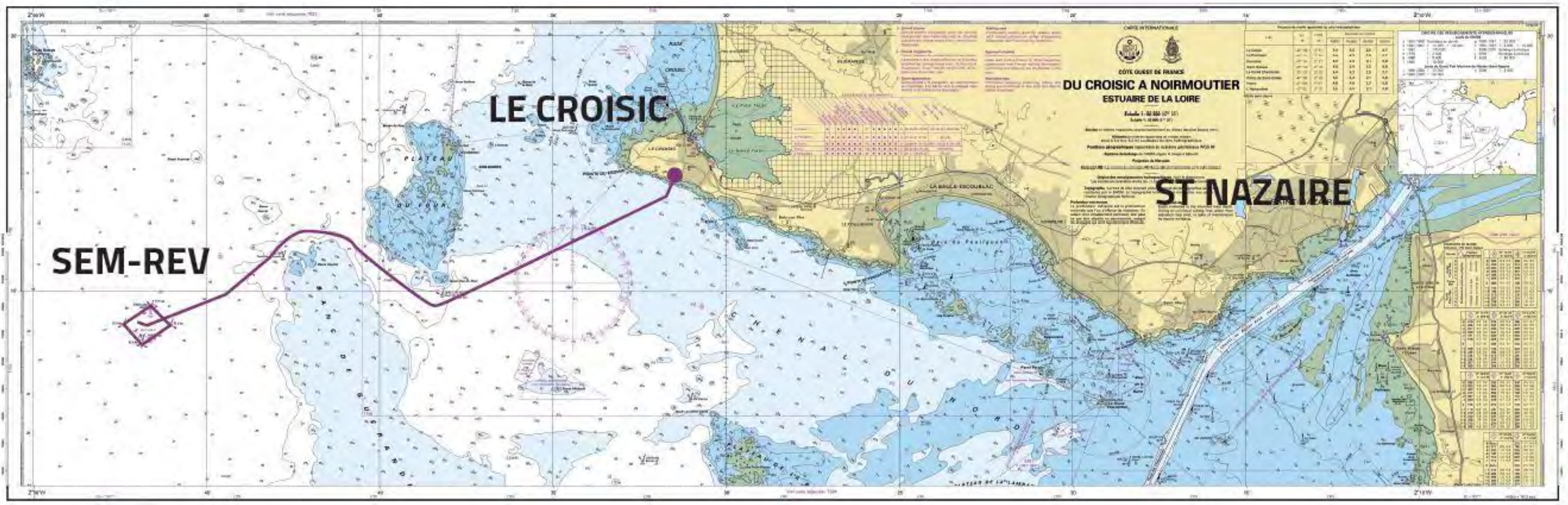
Sem-Rev Floating Wind Test Site

CENTRALE NANTES SEM-REV - LHEEA

cnrs

EOLINK
Cost-effective Floating Wind Farms

- Support design and ops planning:
  - Power cables
  - Moorings and anchoring



University of Exeter – Marine-i Research

MARINEi
accelerating growth through innovation

European Union
European Regional
Development Fund

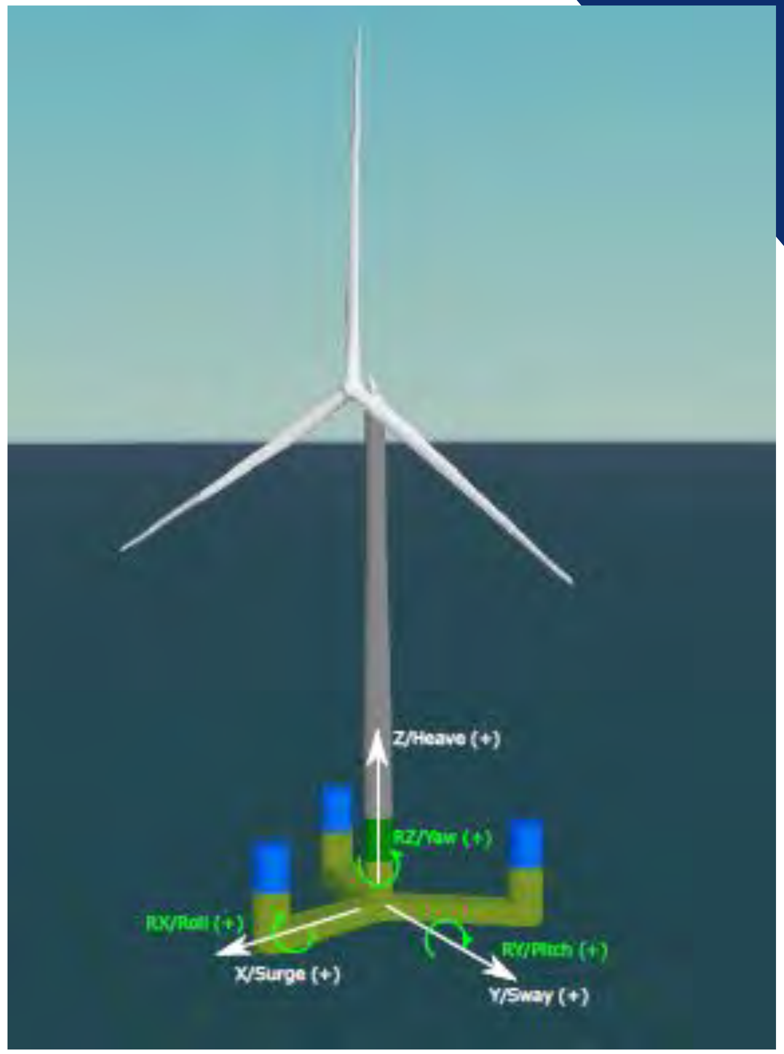
UNIVERSITY OF EXETER

Model/Simulation setup

- 15MW Turbine
- 70 m water depth
- 3 mooring line makeups (Chain, Chain+ 50m Synthetic, Chain+novel damper)
- 3 mooring line lengths
- Combined wind and waves with directionality offsets
- Load cases inline with the IEC 61400-3-2
- Included ULS and ALS (broken mooring leg) scenarios
- Shared pile case modelled with large mooring spread inline with downstream wake recovery
- 96 different simulations

		Mooring footprint (single turbine model)			Mooring footprint (three turbine model)		
		Small	Medium	Large	Small	Medium	Large
Mooring construction	Chain	✓	✓	✓	x	x	✓
	Synthetic	✓	✓	✓	x	x	x
	Novel	✓	✓	✓	x	x	x

Line length [m]		
Small	Med	Large
265.0	300.7	808.3



Conclusion Single mooring pile

- Moving from small to large footprint (270→800m moorings) reduces loads **56% (11.12→4.85 MN)**

Conclusion shared pile

- Reduces ALS loads 70%
- Shared piles further reduces load by **67% (4.85→1.61 MN)**
- Total reduction in load 86% (**11.12→1.61 MN)**

Opportunity for significantly reduced cost of piling

Paper Reference - A.C. Pillai, 2019 - Anchor Loads for Shallow Water Mooring of a 15MW Floating Wind Turbine - Part I: Chain Catenary Moorings for Single and Shared Anchor Scenarios

INYANGA marine projects

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FLOW- Offshore Operations

- Dynamic Cable installation;
- Dynamic cable design and modelling, specification of cable-jewellery;
- Installation of Subsea Hubs
- Hook-Up of Dynamic Cables
- Cable procurement, storage, and Spooling

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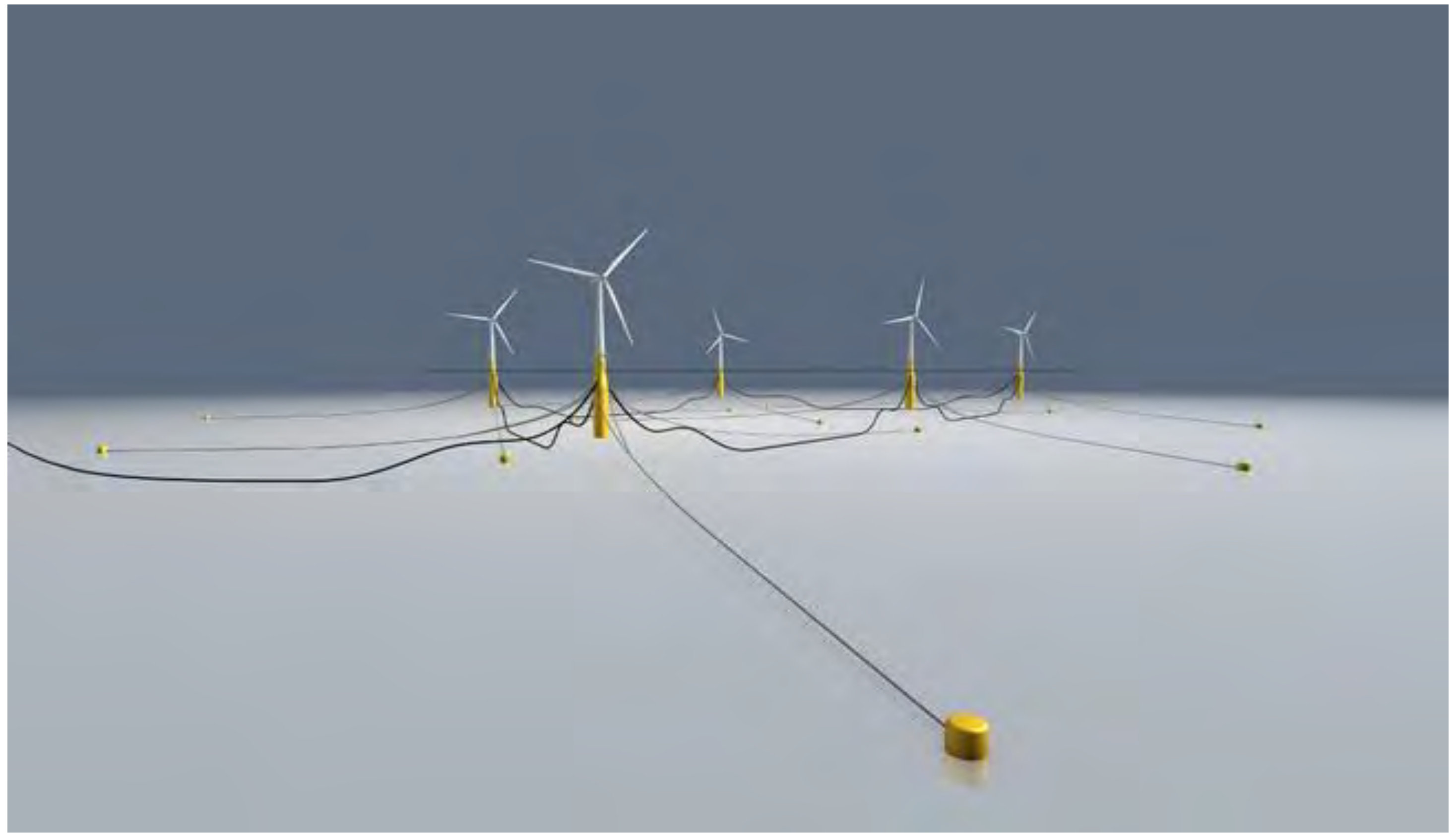
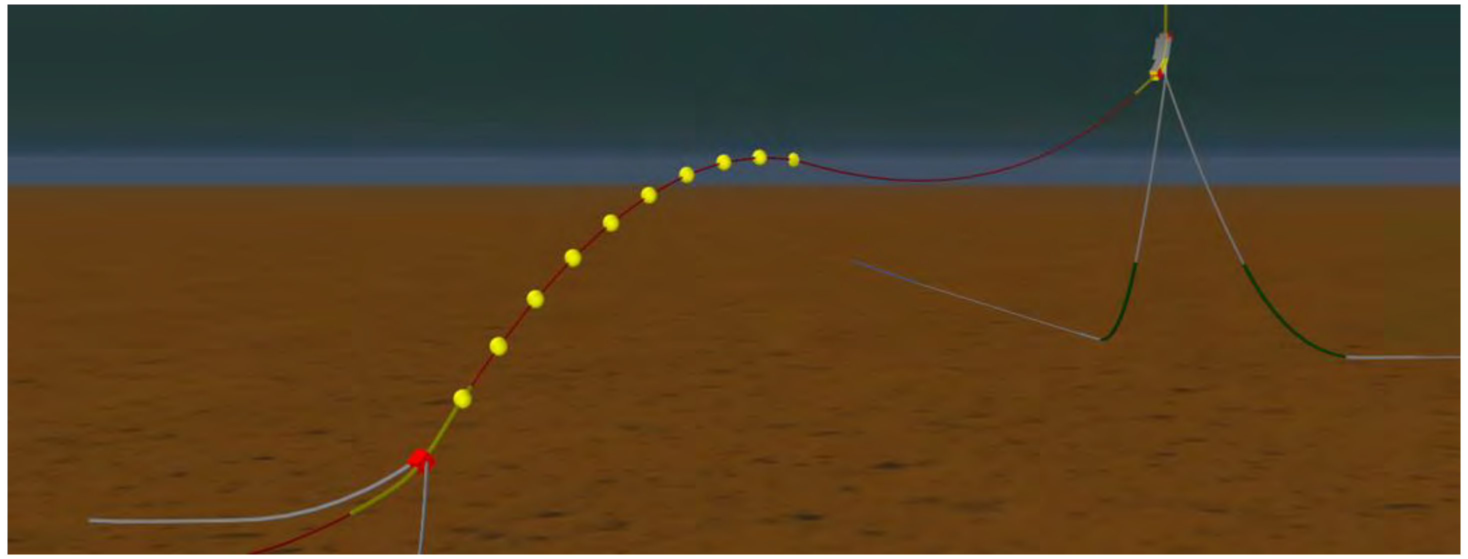
FLOW- Riser Umbilical Hook-Up

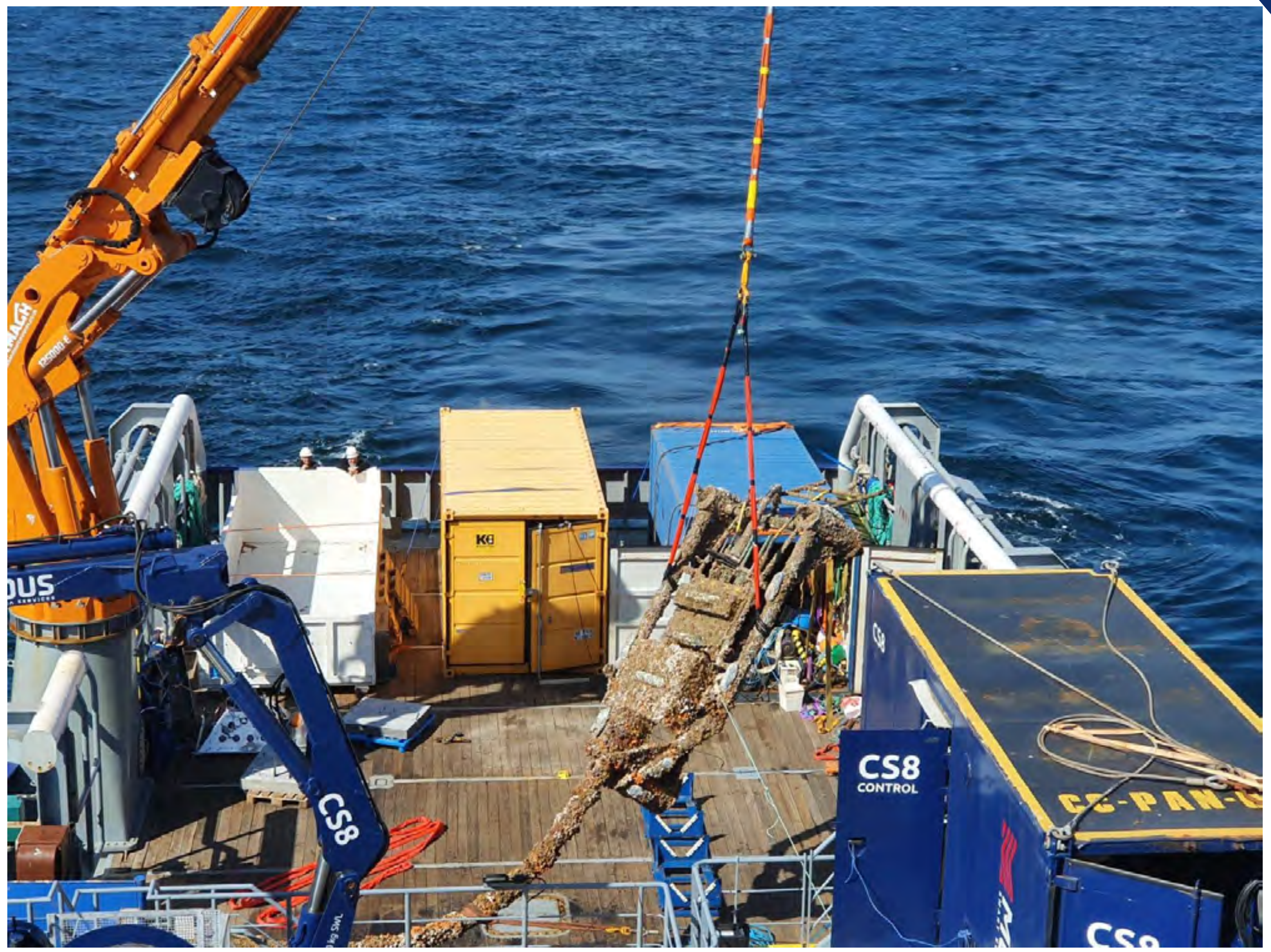


Challenges:
- Survivability
- O&M- Disconnection and Reconnection
- Excursion Limits
- Umbilical Fatigue
- Connectors



Opportunities:
- High Voltage Connectors
- Jewellery and components
- Umbilical design
- Offshore operations

FLOW- Cable Lay

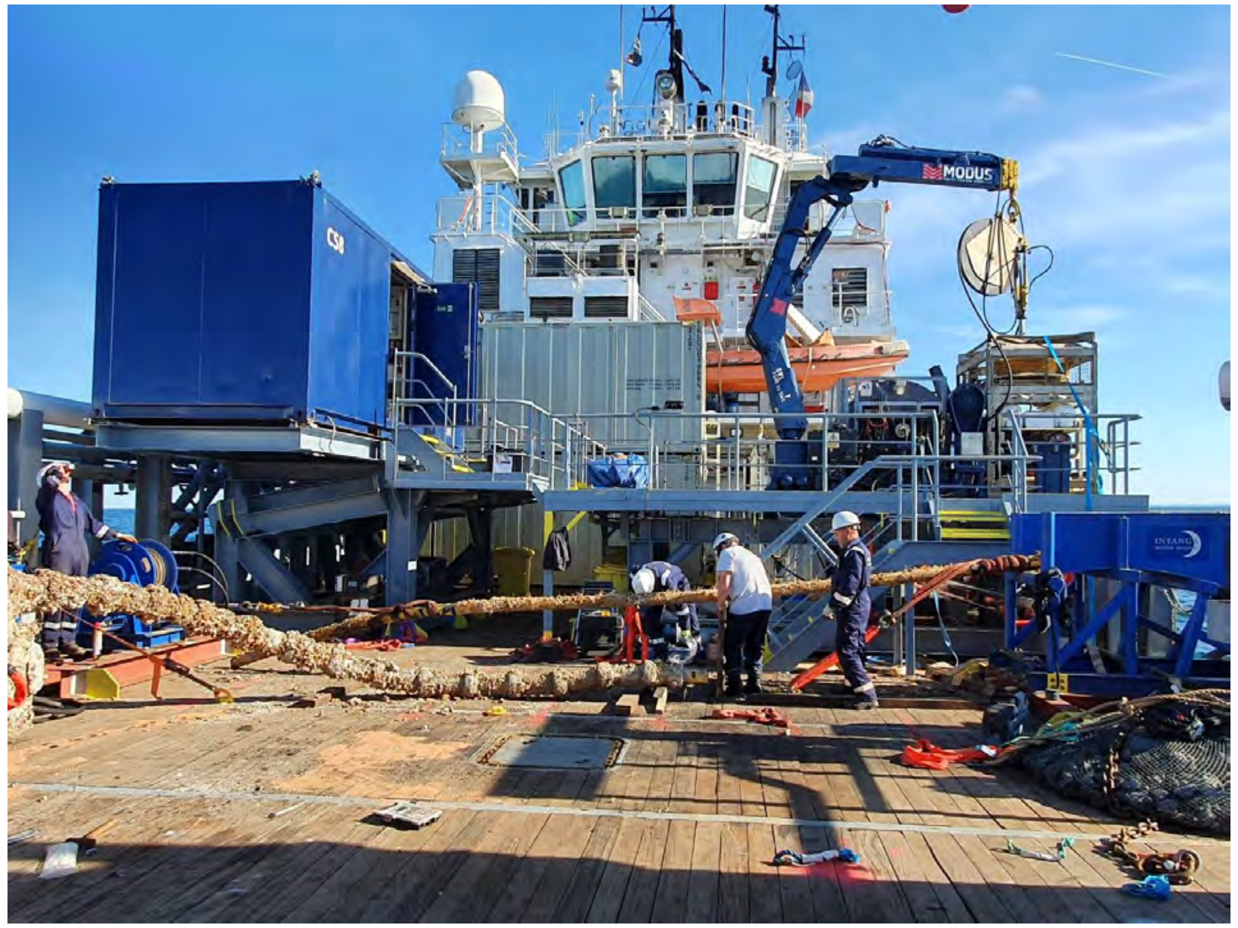


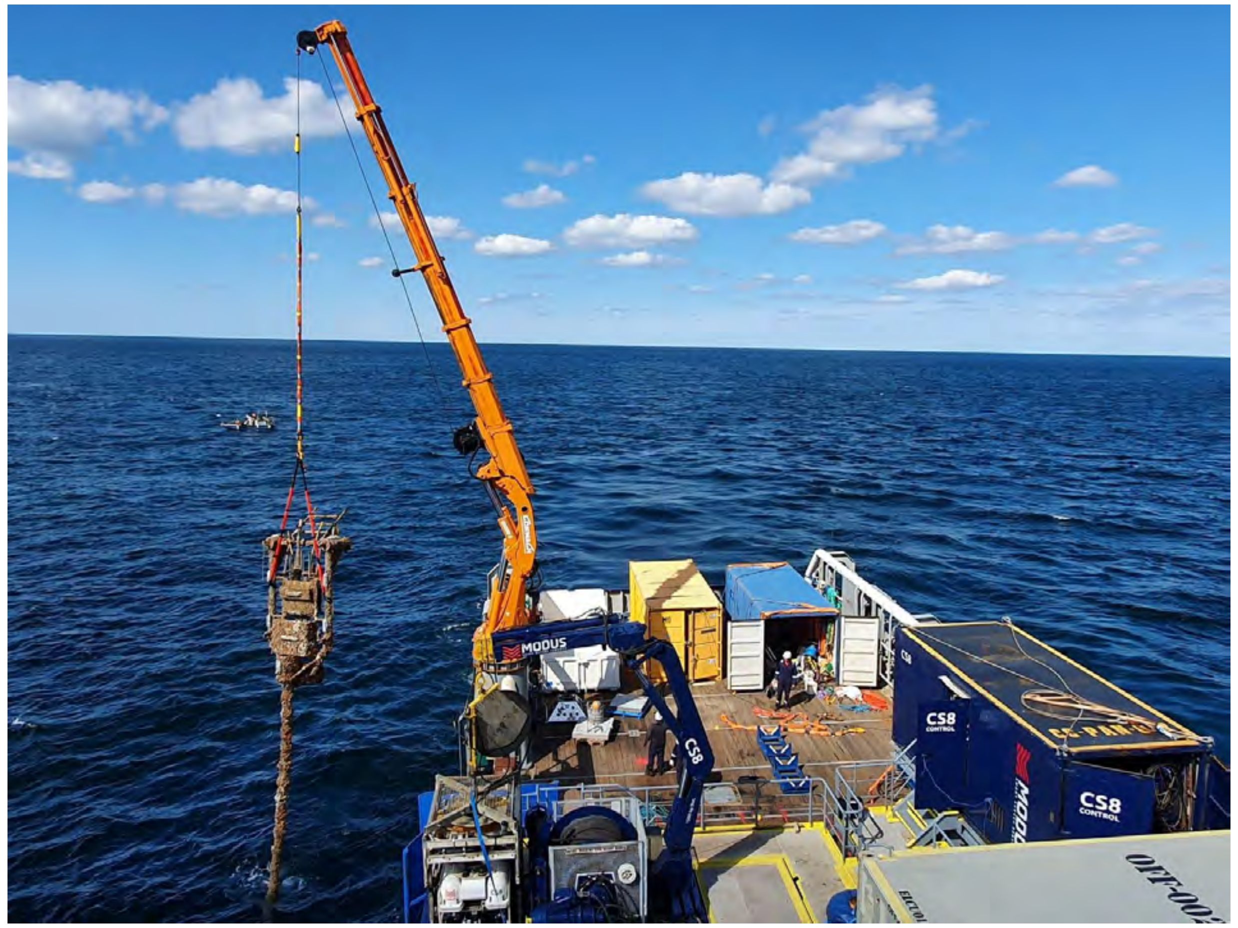
Challenges:

- Long distances to shore- cable cost;
- Transition to dynamic Cables;
- Fatigue and failure on dynamic cables;
- HV- 66KV – corona effect on connectors;
- Cable failures- Insurance;
- Cable stability;
- Grid Capacity;

Opportunities:

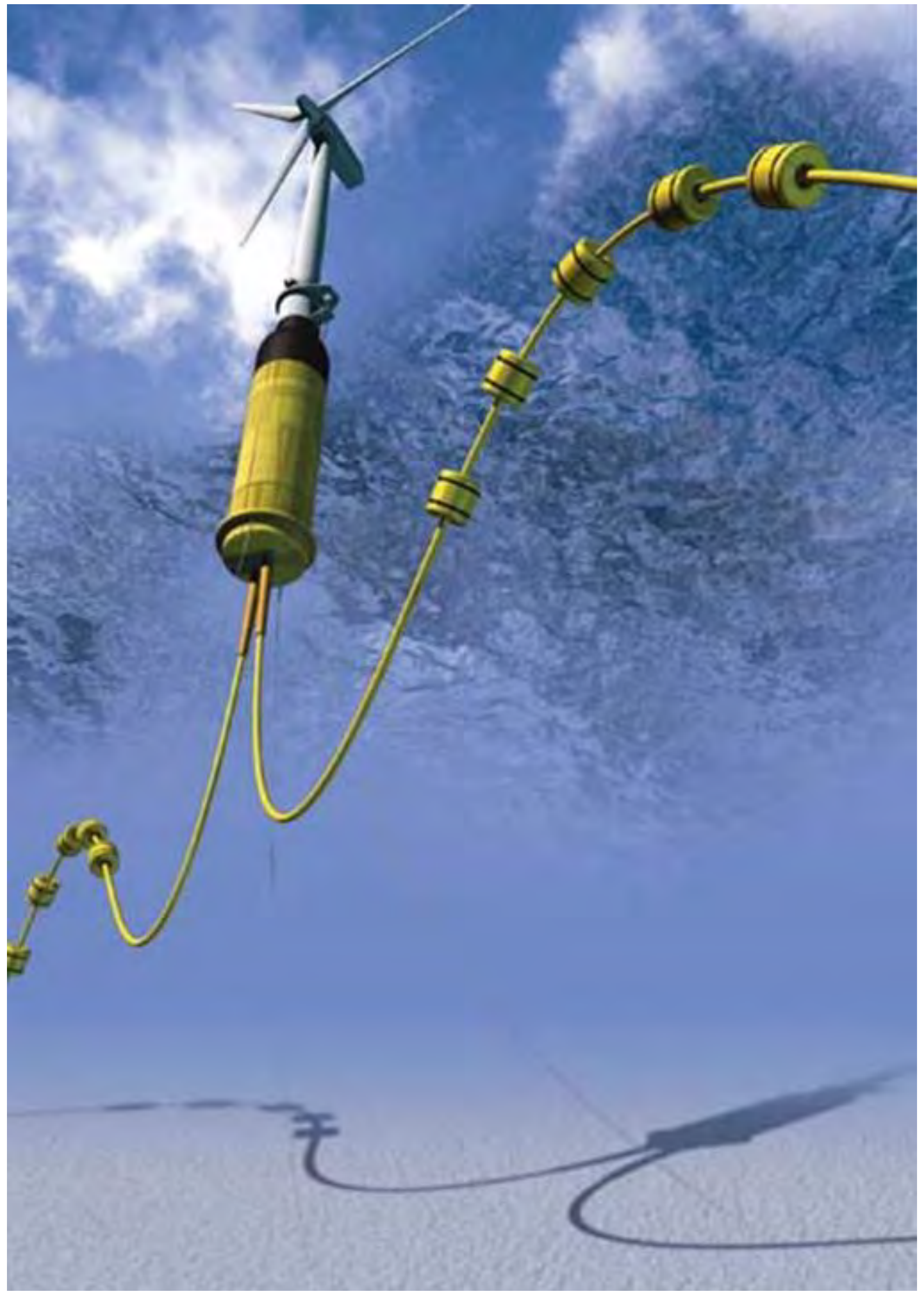
- Cable Repair;
- Cable Routing- surveys;
- Cable stabilisation;
- Hydrogen production.





FLOW- Local Supply Chain Challenges and Opportunities

Challenges:
- Commitment for 65% UK Content?
- Floating units built in Portugal?
- HyWind Scotland- minimal local content;
- Need to use local Supply Chain;
- Local Supply Chain Capabilities;
- Established big players in Installation- Bourbon, Maersk, Boskalis etc.
- Developers willingness to accept new ideas and collaboration???
- Packing Density;
- Anchor dragging, Mooring Failure
- Need to Reduce Costs- Still to Expensive!!



Opportunities:
- Local Supply Chain has good track record in Marine energy;
- Innovation in Local Supply chain;
- Collaboration between suppliers;
- Collaboration with Universities;
- Innovative ideas to reduce costs;
- Innovative solutions to solve challenges;
- Emergency response;
- Collaboration and support to Tier 1 suppliers.

THANK YOU FOR YOUR TIME

INYANGA
marine projects

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Dynamic Array Cables - Component verification testing

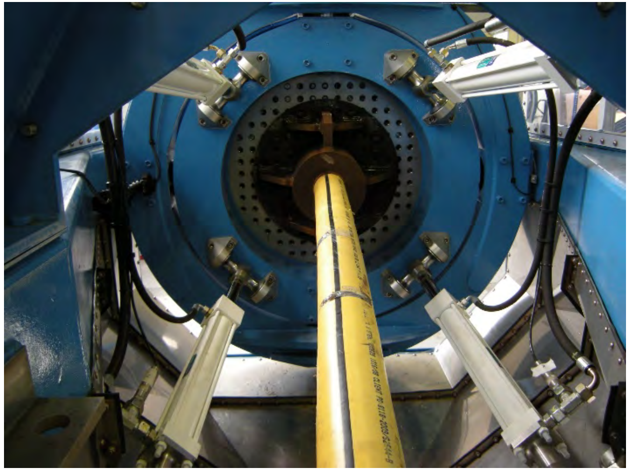
Professor Philipp Thies
P.R.Thies@exeter.ac.uk

Marine –I Cable Event, Falmouth, 28nd March 2023

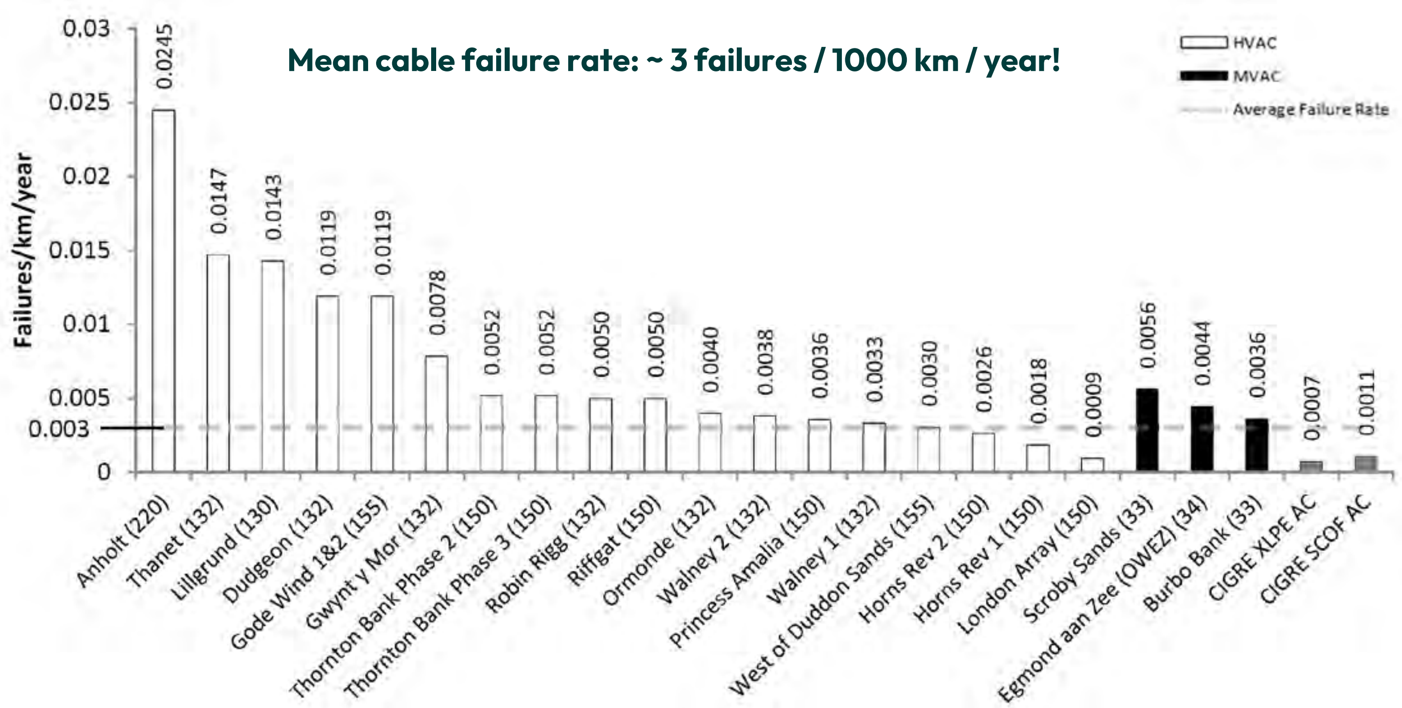
University of Exeter

Outline

- Challenge
- Component Verification
  - Cable
  - Cable + Bend restrictor
  - Cable + Bend stiffener
- Discussion & Summary



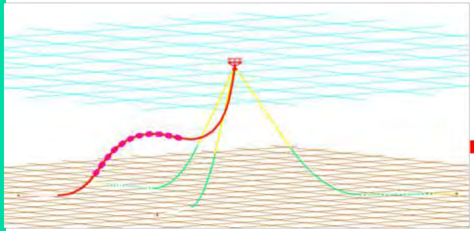
Cable failure rates

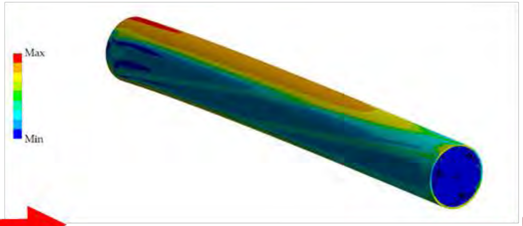


Warnock et al, 2019, EU wind farms AC cable failure rates

Cable modelling

Global Model	Local model 2D	3D Stress analysis	Physical testing





Dynamic simulation

Interaction between environment and entire cable

Cross-sectional analysis

Cable properties

Advanced computational analysis

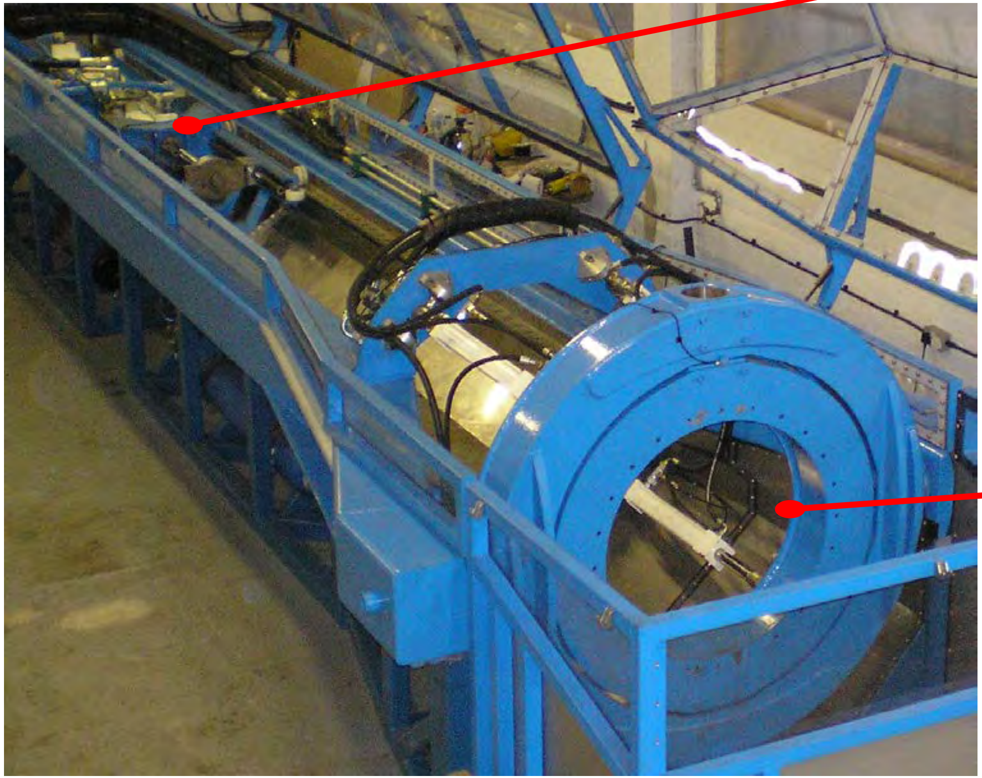
Cable properties

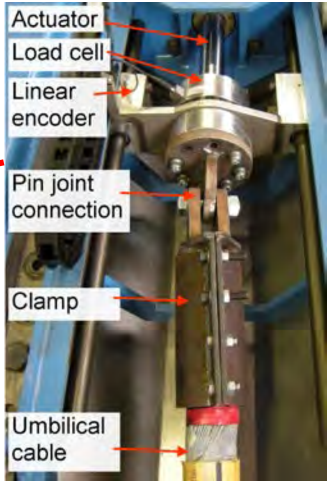
Cable testing

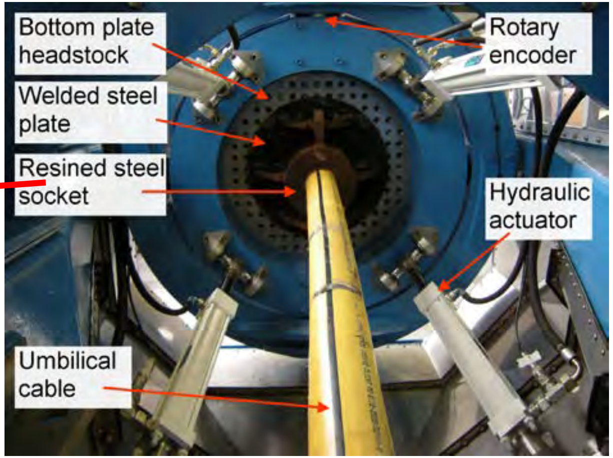
Electrical testing

Mechanical testing

Cable Testing







Cable Testing

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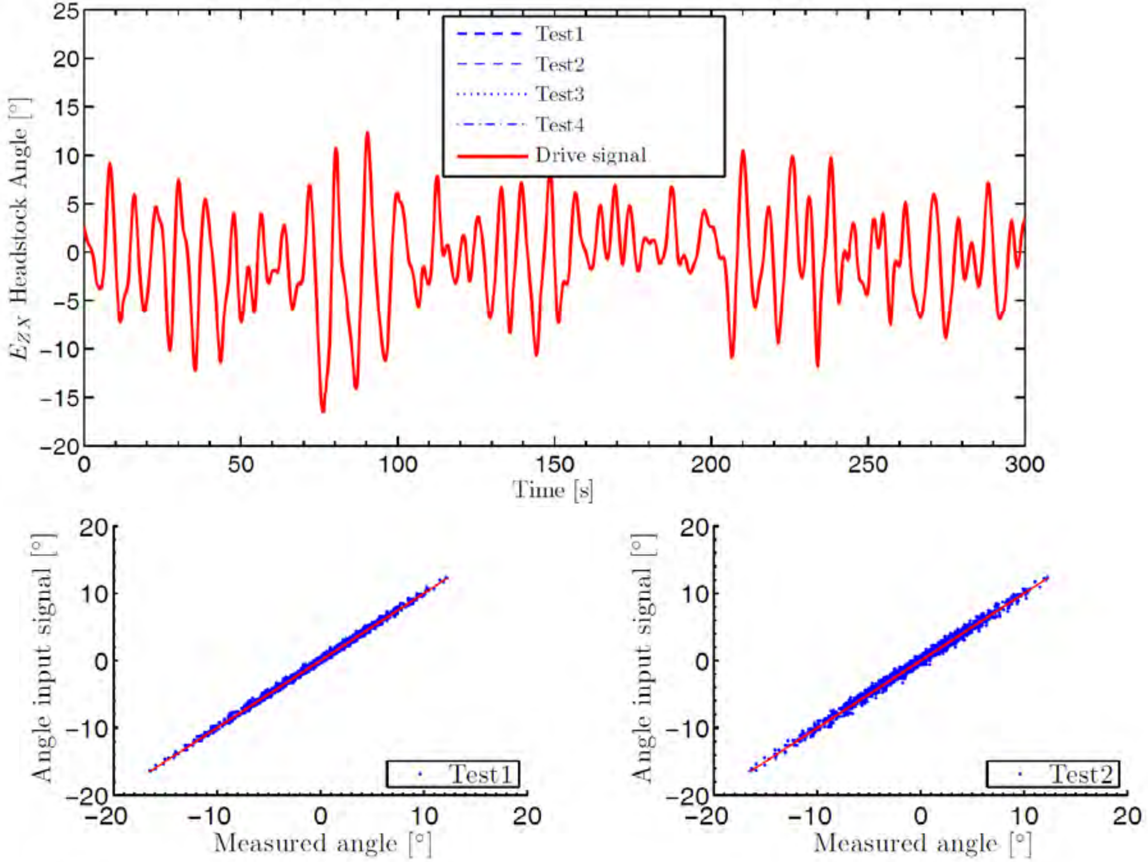
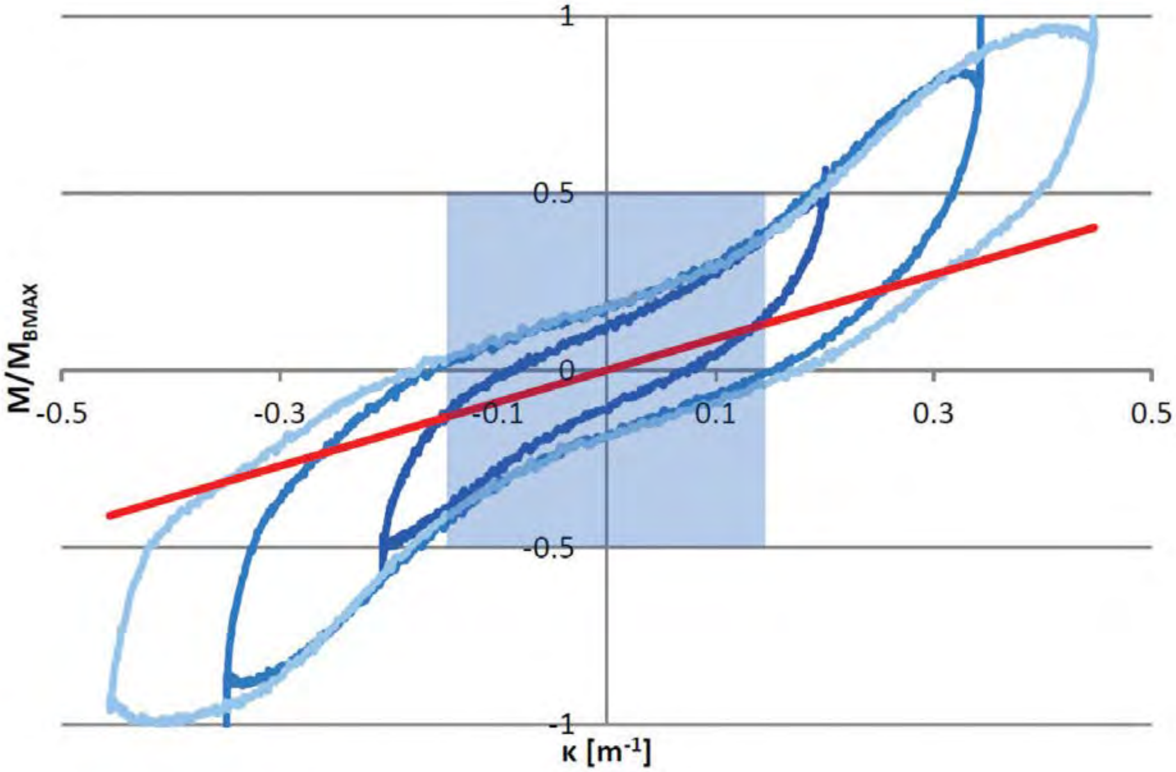
Cable Testing



Cable Testing



Mueller-Schuetze et al., 2015.

Cable & bend restrictor testing

University of Exeter

FAST-Orcaflex Model

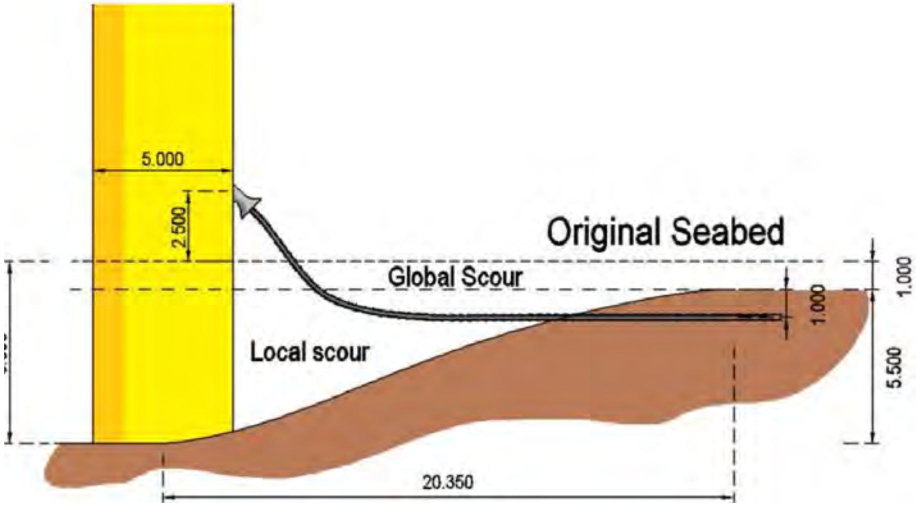


Table 3: Maximum load results between monopile/J-tube and CPS

CPS	Shear F_{max} [kN]	Axial F_{max} [kN]	Bending M_{max} [kN.m]
CP137-333	15.61	11.58	12.35

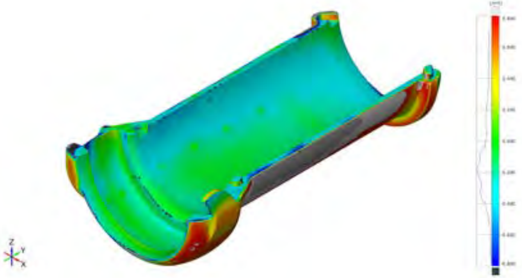
NSW a General Cable company · cp/nl engineering · MARINET

Thies et al. 2016

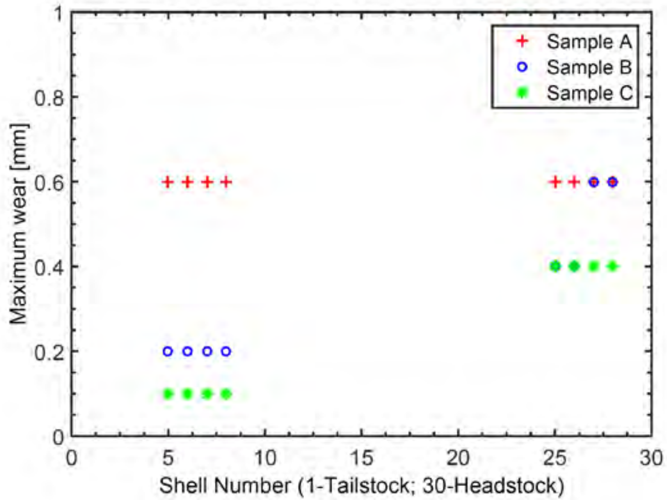
Cable & bend restrictor testing

University of Exeter

Supergen Offshore Renewable Energy



Thies et al. 2016



NSW a General Cable company

cp/nl engineering

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Cable & bend restrictor testing

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MARINET

Cable & Bend stiffener testing

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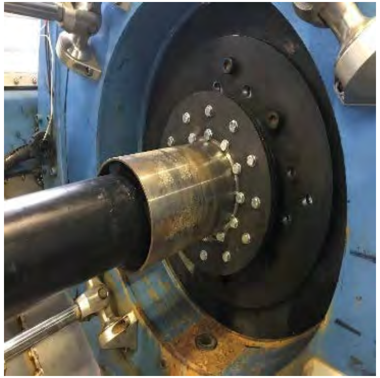

HELLENIC CABLES
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Halswell et al, 2021

Cable & Bend stiffener testing

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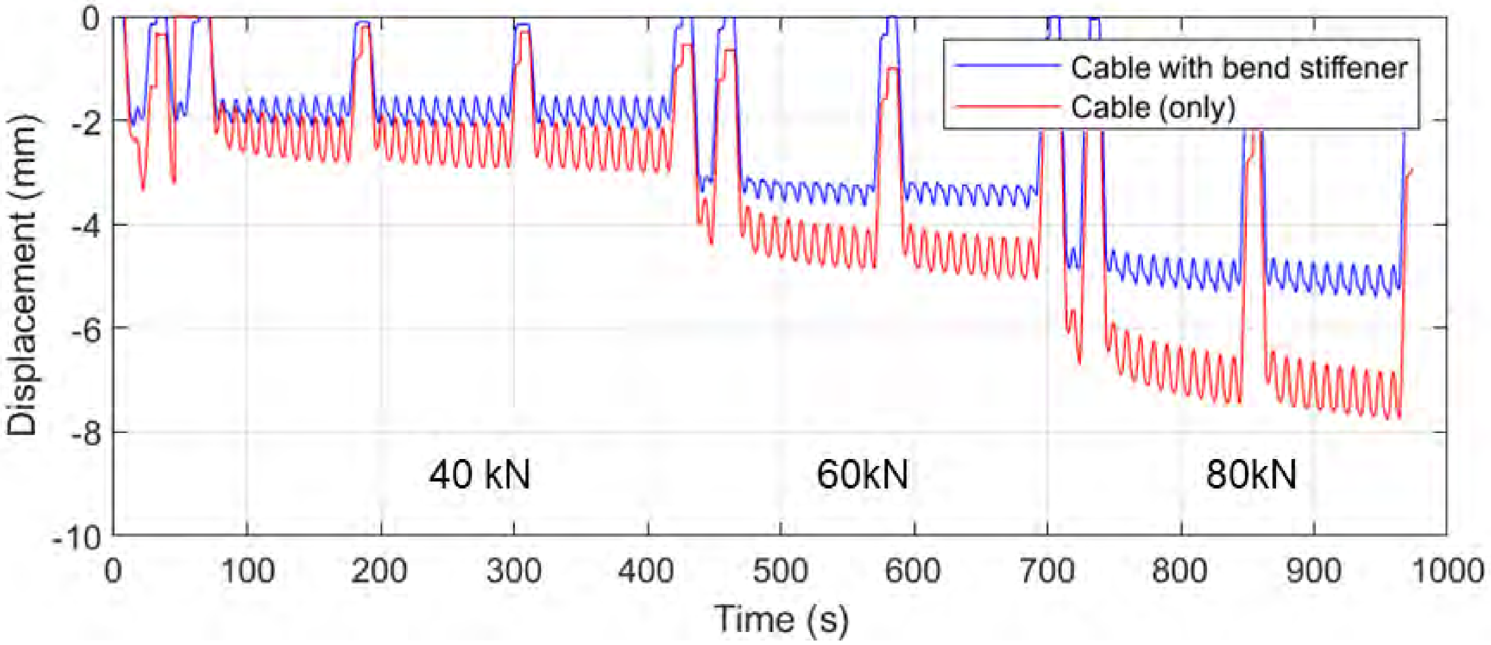

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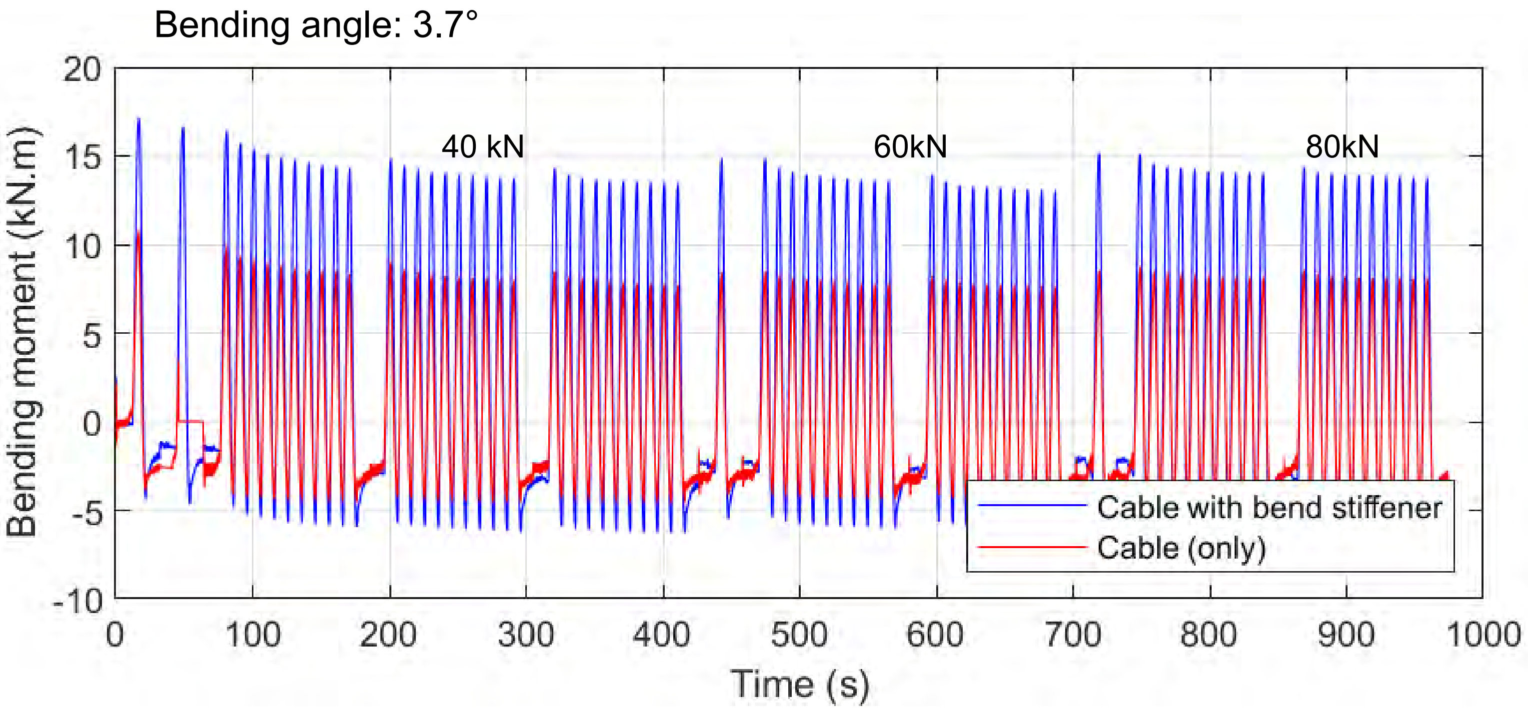
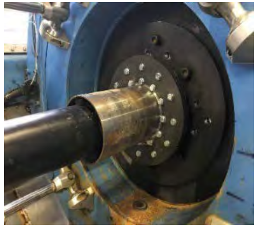
Cable & Bend stiffener testing



Halswell et al, 2021

Cable & Bend stiffener testing

Force (kN)	Maximum bending moment (kN.m)			
	Cable (only)		Cable with bend stiffener	
	1st cycle	Last cycle	1st cycle	Last cycle
40	10.7	7.68	16.9	13.4
60	8.40	7.57	14.9	13.0
80	8.53	8.03	15.2	13.8



Halswell et al, 2021

Cable & Bend stiffener testing

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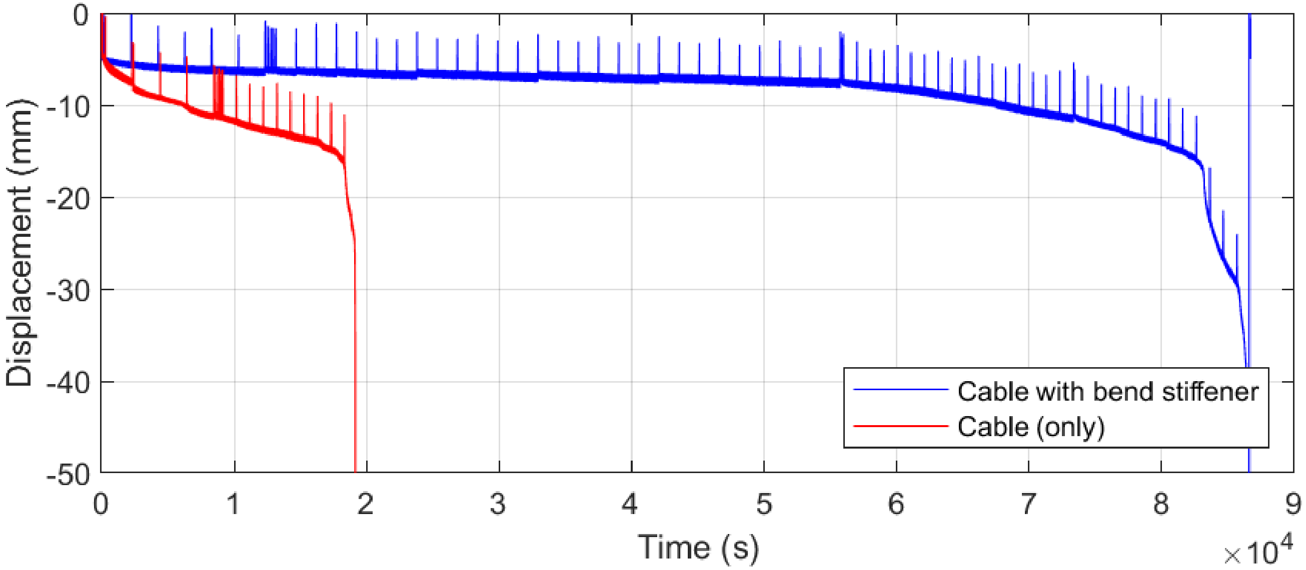
Fatigue Testing – Tension = 80kN; Angle = 4°



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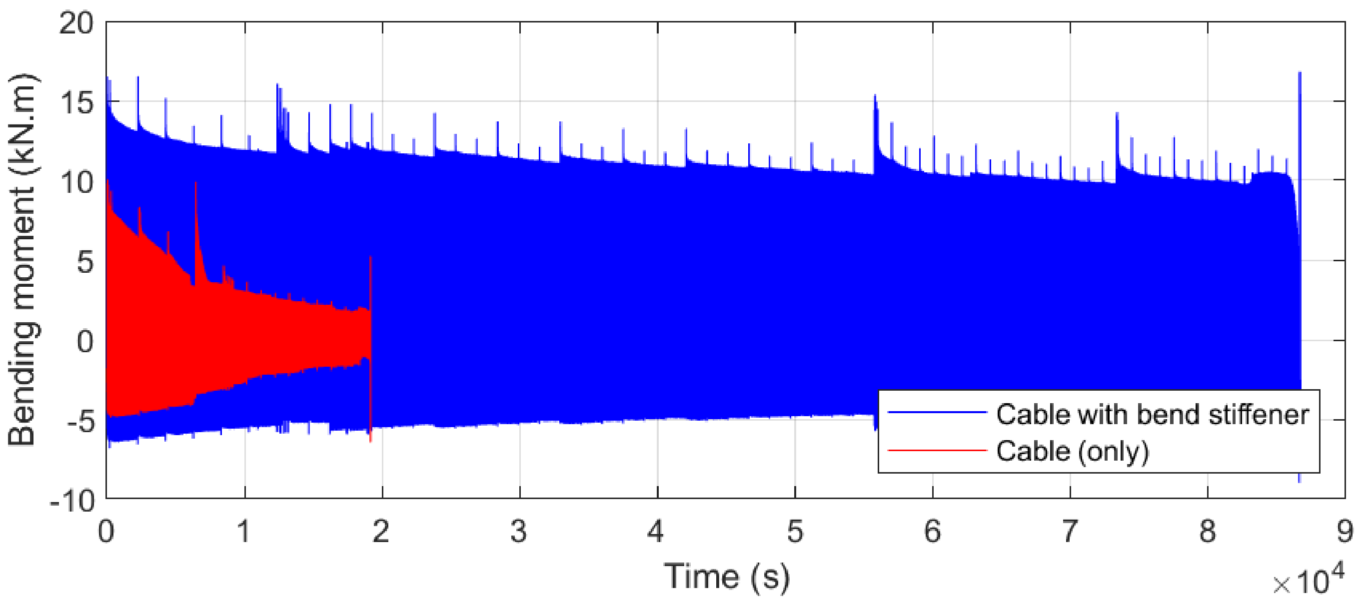

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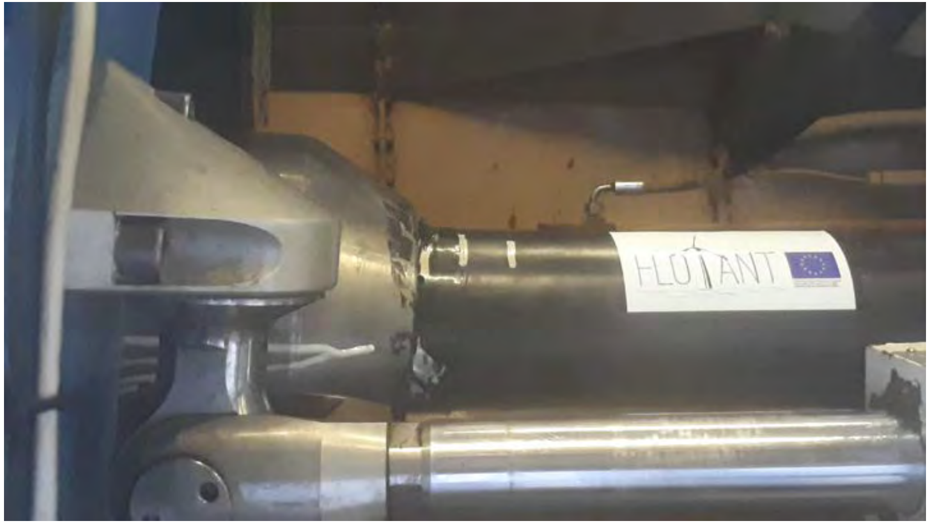
Halswell et al, 2021

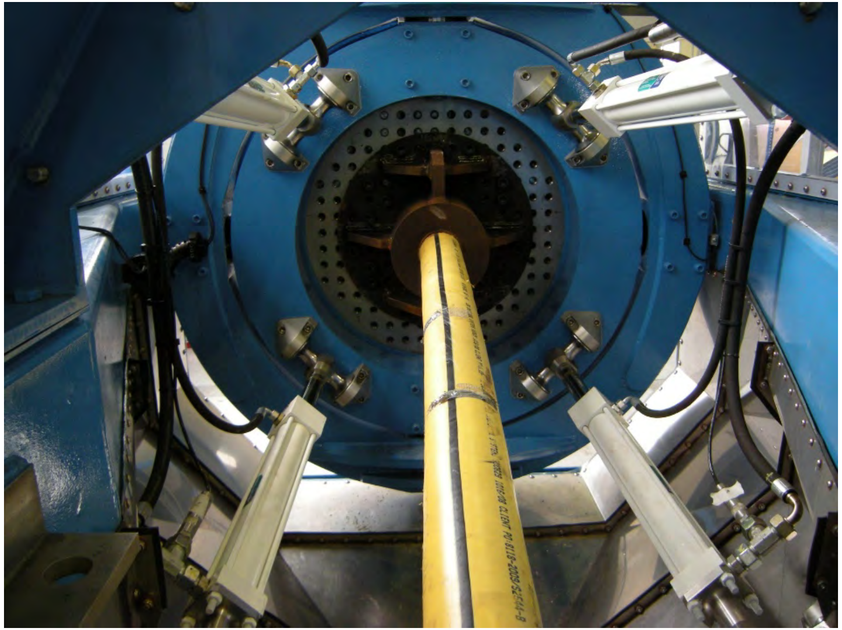
Discussion & summary

- Component Verification testing serves multiple purposes
  - Cable properties
  - Cable failure modes
  - Cable interaction with ancillaries
  - Fatigue testing
- Testing for new applications
- Allows to quantify cable endurance



Thank you for your attention

P.R.Thies@exeter.ac.uk



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Advanced systems engineering to meet tomorrow's energy needs

Floating Offshore Wind Cables Coalesced thinking…

Arran Armstrong

28th March 2023

Power Cable Design for Shallow Water (<100m)
Design Requirements and Parameters

Power cable must accommodate harsh conditions:

- ~30m lateral motions
- ~8-12degree dynamic rotations
- ~25m wave heights
- ~0.8-1m/s currents

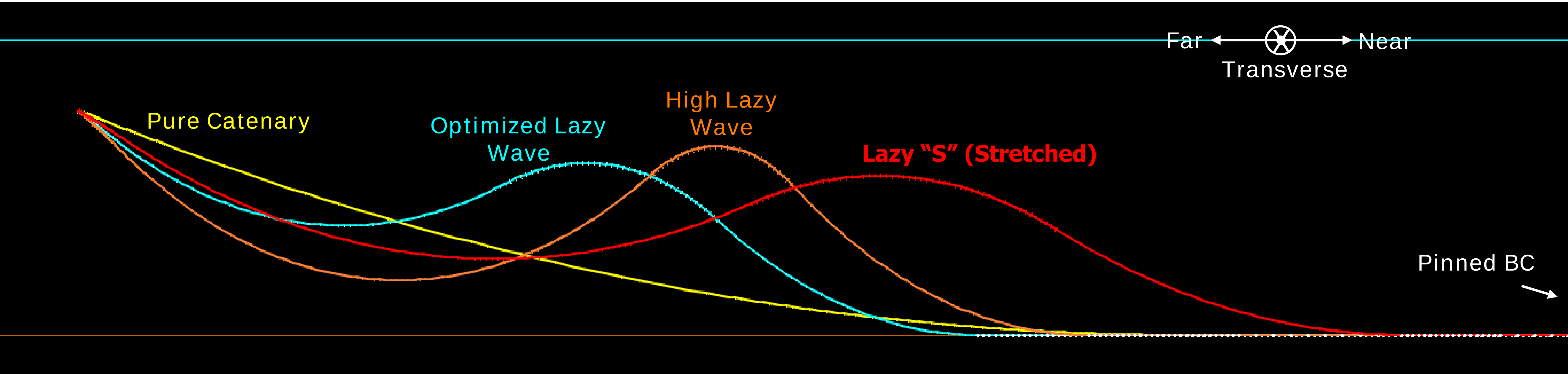
Must still meet design requirements:

- Structural limits respected e.g. min bend radius (MBR), max tension, compression
- Sag bend not to impact seabed
- Hog bend to maintain sufficient clearance for vessel access
- Minimizing seabed movement at touch down point

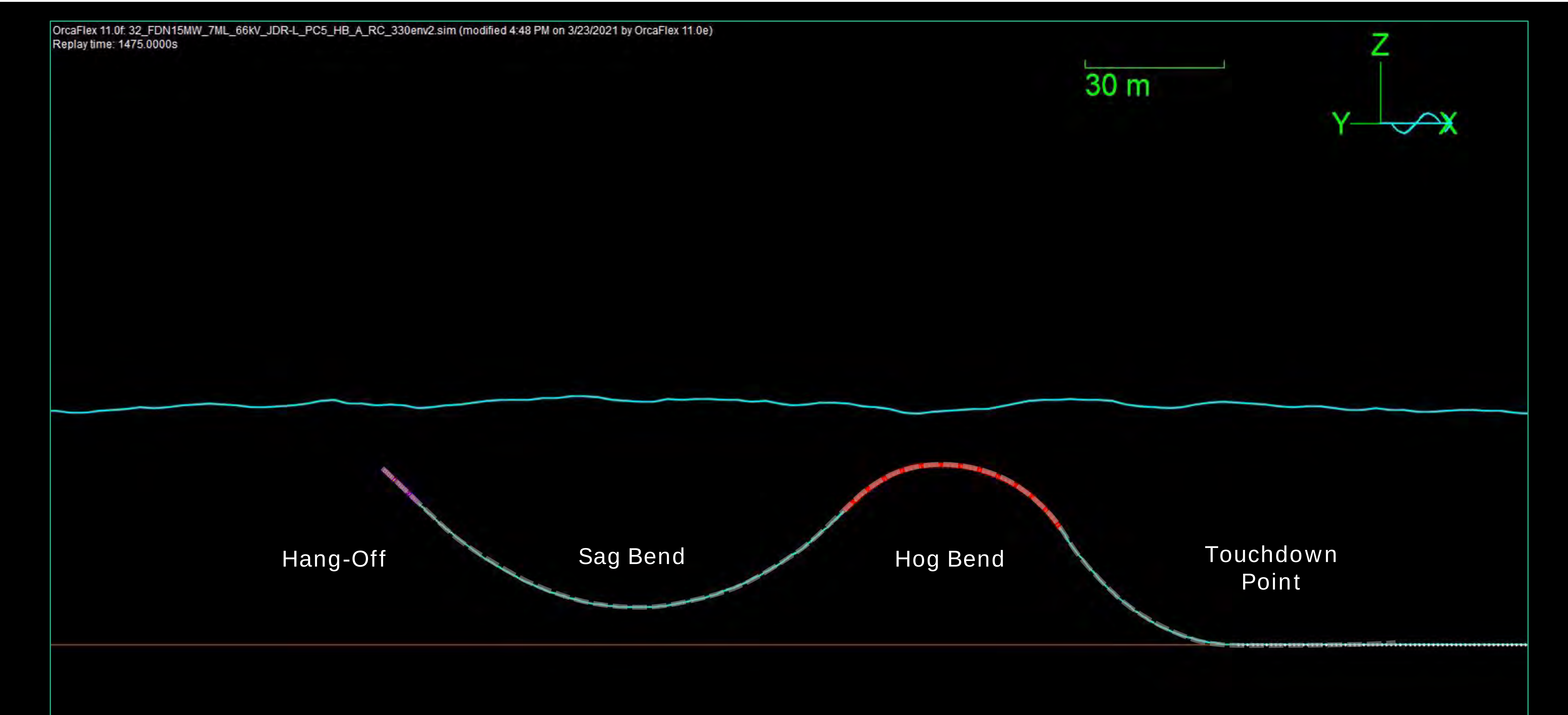
Power Cable Design for Shallow Water (<100m) Configuration Development

Findings of a particular case study

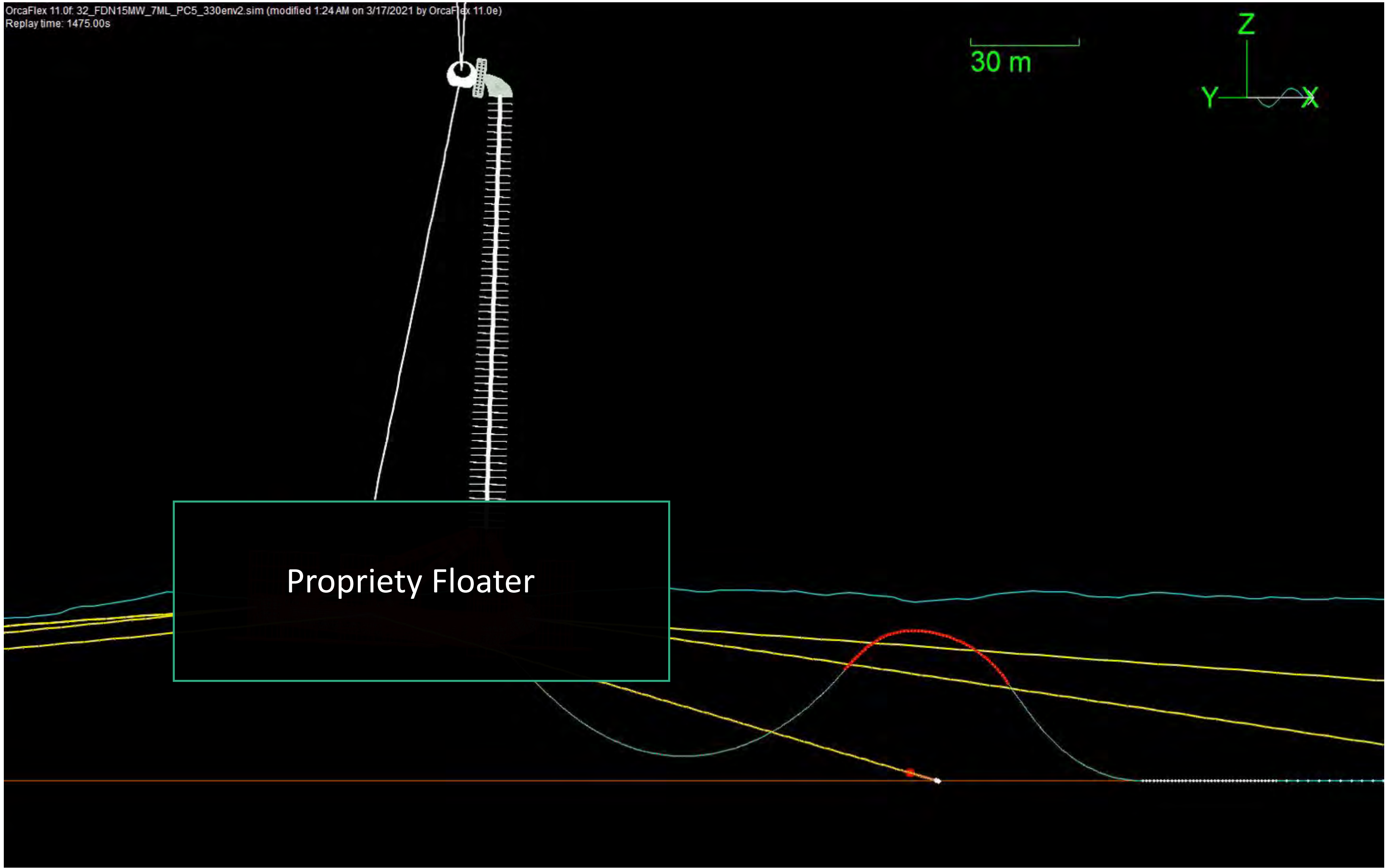
- Several configurations were considered (some shown above).
- Pure catenary configuration found to exceed MBR at touchdown, have high compression, and can exceed tension.
- High lazy wave (high arch, low sag) gives good compliance and smaller footprint but can compromise MBR (particularly in near conditions)
- Lazy “S” (stretched) gives good response with near conditions, but can compromise tension and has larger footprint
- Selected configuration is based on response with truncated sea states and later evaluated with full extreme storm matrix and coupled with foundation



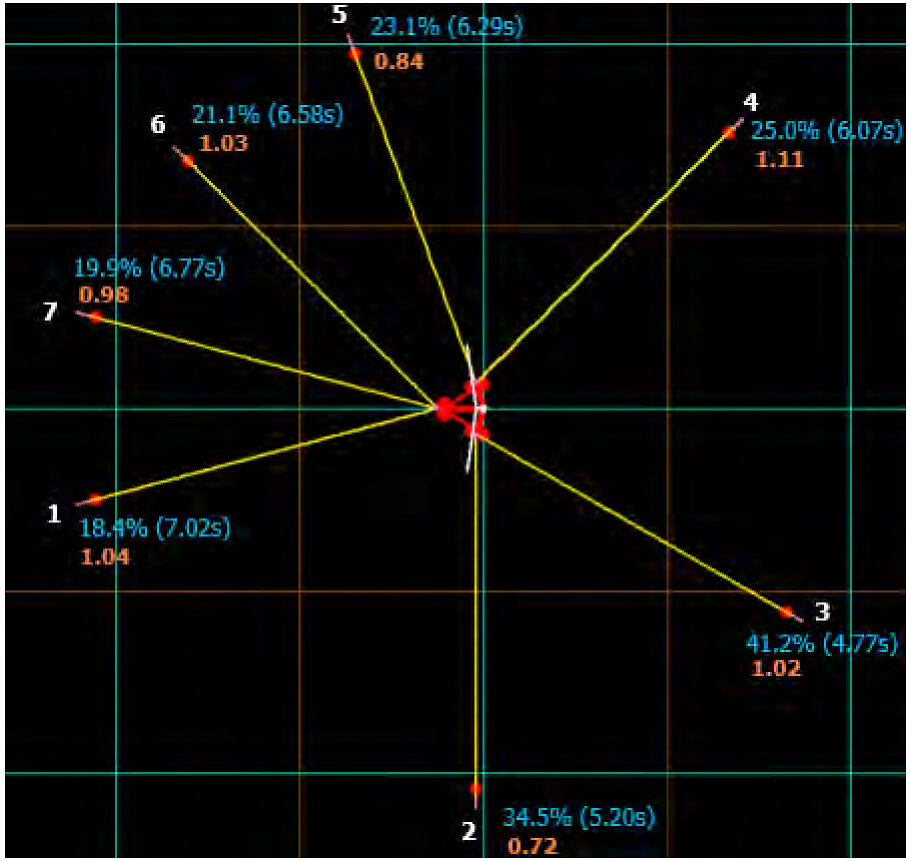
Power Cable Design for Shallow Water
Selected Configuration

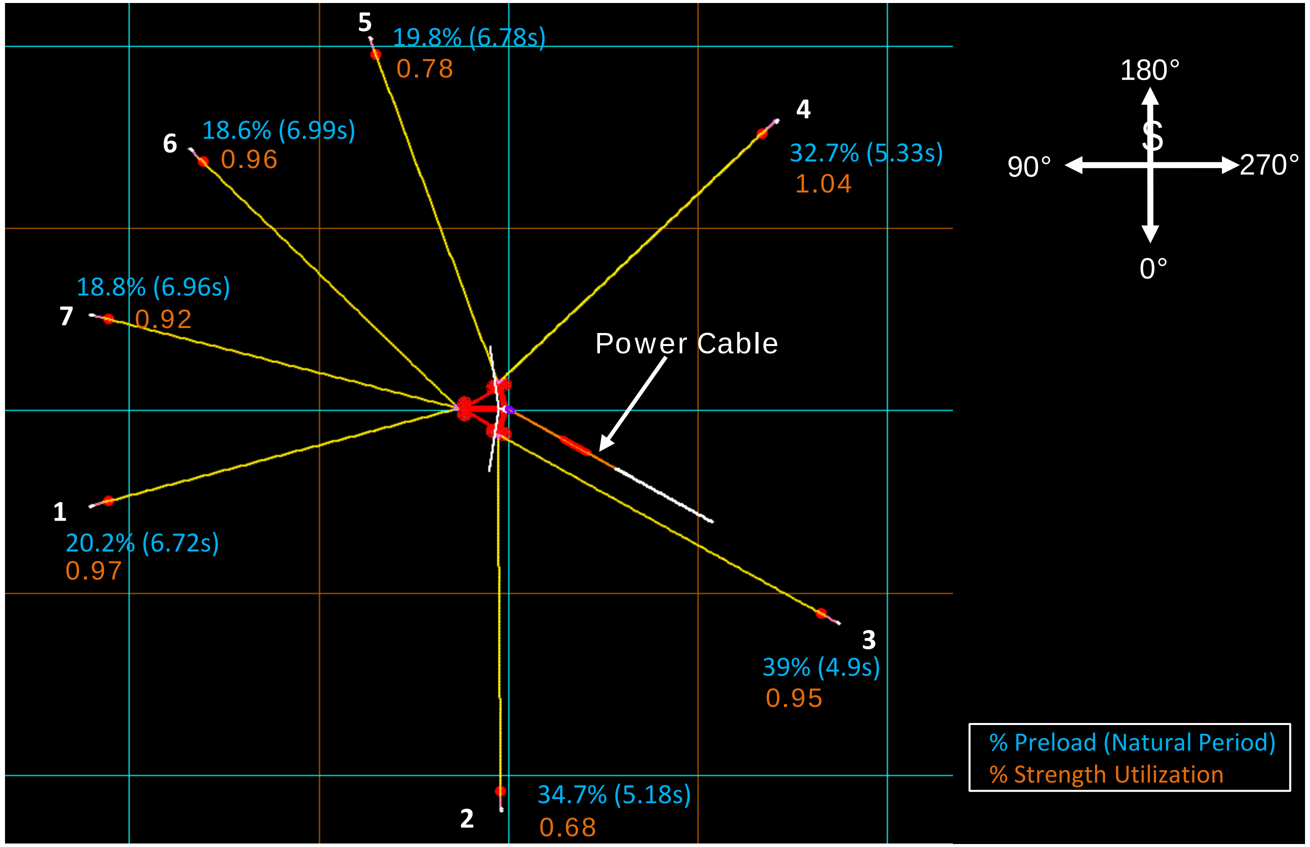


Power Cable Design for Shallow Water (<100m)
Fully Coupled Analysis



Power Cable Design for Shallow Water (<100m)
Effect of Power Cable - Fully Coupled Analysis





Mooring line response improved when power cable is included

Cable Touch Down Zone

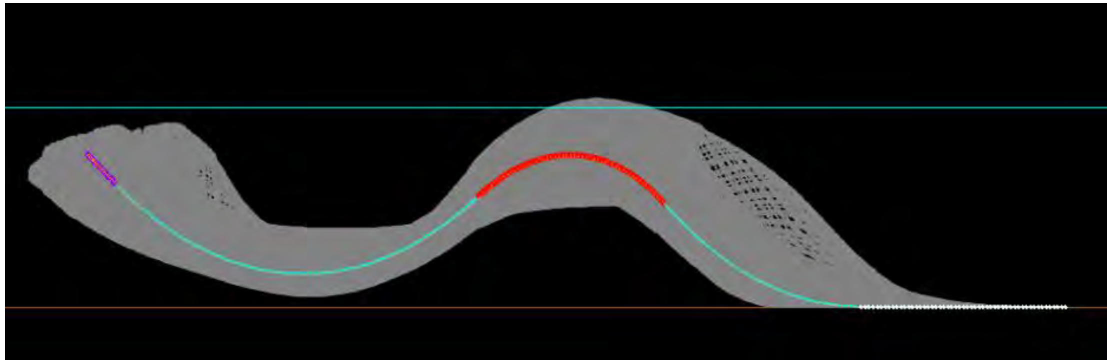
Examples of trenches at riser touch down point of dynamic catenary. This is a common challenge in O&G, potentially a similar scenario for FOWF power cables?

In this example trench depths of >9m were observed.

Trenching may affect the structural integrity of the cable. Trench collapse onto cable could cause excessive tension loads. Trench collapse under cable could cause excessive compression loads. The trench it-self may restrict cable movement, in essence buckling the cable.

There are methods to minimise the length of the touch down zone, i.e. clump weights on the power cable, tethering the near seabed power cable.

Understanding when the power cable is “stable” on the seabed is critical.



Cable Burial Risk Assessment (CBRA)
Inter-array Cables; Fixed vs. Floating

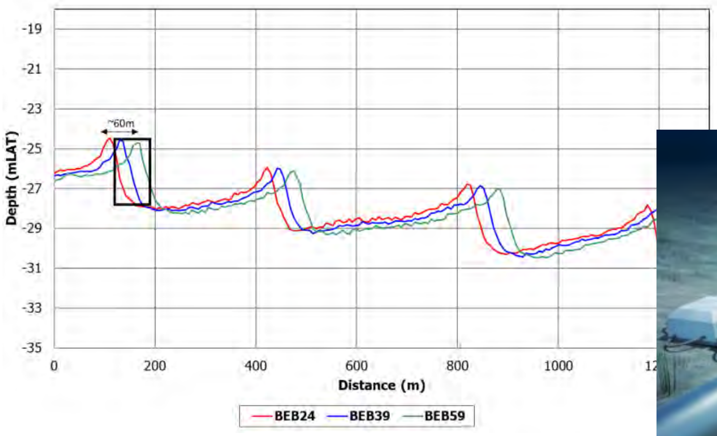
Typically, for fixed wind, a CBRA would assess:

Risk from natural hazards – Evaluation of shallow geo-hazards, slopes and sediment mobility

Anthropogenic hazards – Evaluation of:

- Fishing activity
- Commercial shipping –risks to cable from anchoring

Achievable burial depth – Evaluation of geophysical & geotechnical data



TDN Fleximat

However, in floating offshore wind inter-array cables the scenario is different.

Risk from natural hazards – Much of the risk will be associated with cable stability and over burial due to mobile sediments, i.e. potential for thermal damage

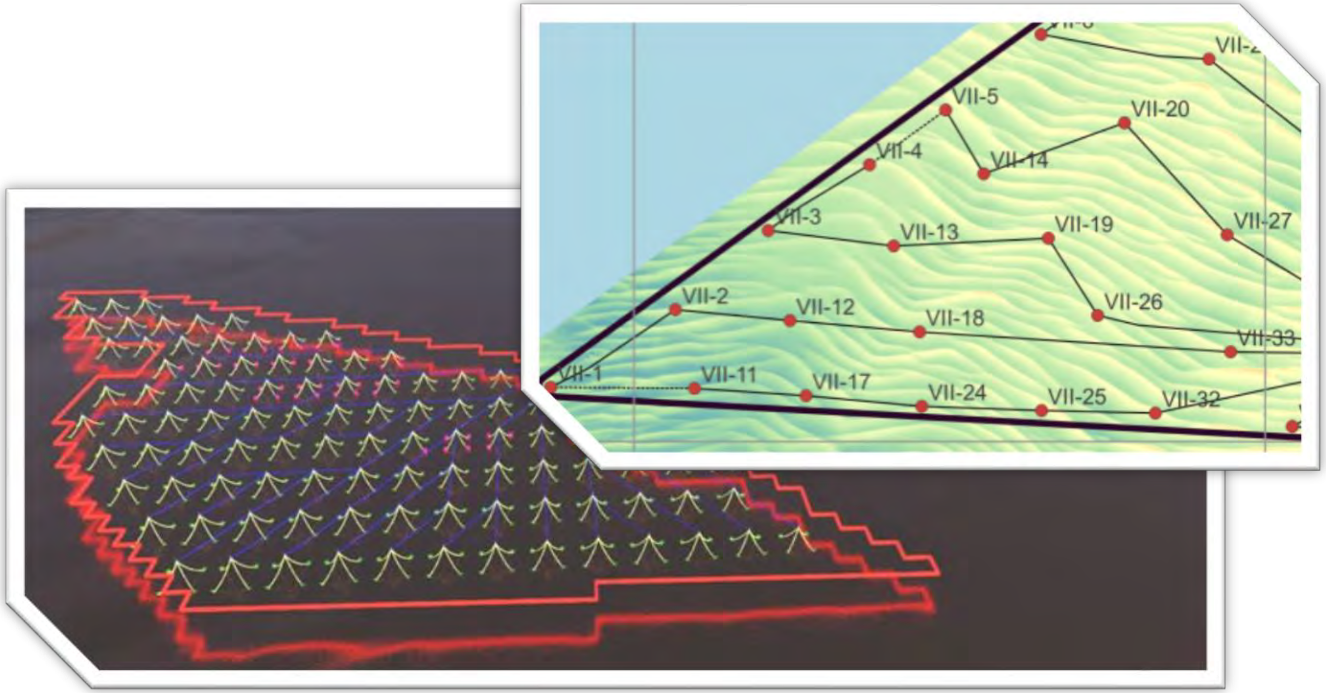
Anthropogenic hazards – Will fishing and shipping be a real risk to FOWF power cables? Do the mooring lines provide protection to the power cables? Maybe not for tension leg designs?

Achievable burial depth – Is the cable protected by the mooring lines? If so, can burial be avoided, thus improving thermal performance? Can some other form of seabed stability be used, i.e. rock dump, mattresses, etc. Could this be cheaper and quicker? Are the cables pre-laid prior to installation of the floaters and mooring lines?

Electrical Optimization

Electrical optimisation of cables for Fixed Wind generally, at a high-level, comprise of:

- Overall topology of electrical system
- Copper or Aluminium core
- Core cross-sectional area, in regard to maximum Amperage. Which does vary depending where on the string the cable is located.
- Level of armour is generally consistent across the site



Considerations for FOWF:

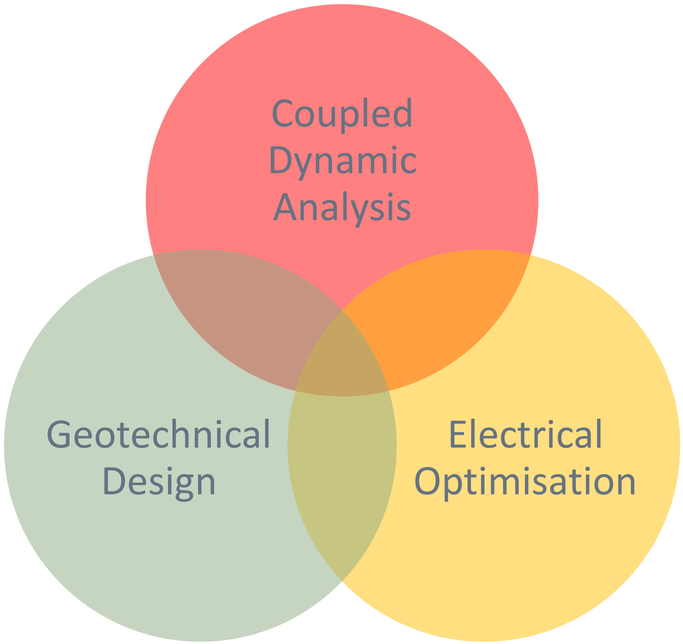
- Level of armour, i.e. is it commercially efficient to transition between dynamic and static power cable (similar to fixed wind cables). Level of armour controls the strength and fatigue resistance.
- Cable weight optimisation, i.e. steel versus composite
- Cables currently strong (tension) enough for shallow water, cables need step change for deep water sites.

Summary

The design of the power cable is unique to the floater design, water depth, metocean conditions, geotechnical conditions and the mooring design.

The coupled dynamic analysis, electrical optimisation and geotechnical design are intertwined, for example:

- The power cable itself can have a dynamic damping effect, that can improve utilisation of mooring loads. Thus, improving the geotechnical design of the anchors.
- The cable touch down zone performance is influenced by the dynamic performance of the cable and the geotechnical conditions.
- Electrical optimisation can be improved using the cable dynamic behaviour to determine where the cable is either dynamic (heavily armoured) or static (less armour requirement).
- The inter-array cable system for floating wind should be designed and optimised considering the interplay of these three domains – structural dynamics; geotechnical; electrical – in order to minimise the capital outlay and maximise reliability during operation.



Questions?

There's lots to do!!!

THANK YOU

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How Wet Mate Connectors Can Help Solve the Challenges of FOW?

SIEMENS energy

Presentatio n Overview

Introduction to Siemens Energy

2 Key challenges facing floating offshore wind and experiences so far

3 Experiences and Lessons Learned So Far

4 Key Enabling Technology – Wet Mate Connectors

5 How can wet mate connectors help solve some of the challenges of FOW?

Introduction to Siemens Energy

Siemens Energy – Connector Portfolio

Located in Ulverston, Cumbria in the North West of England.

We have been the Market leaders in O&G for Subsea Wet Mate Electrical Connectors since 1975.

We have supplied more than 150 projects globally with over 300,000 wet mate connectors ranging from 1kV to 45kV in water depths of up to 2200m.

Key Challenges Facing FOW

Key challenges facing Floating Offshore Wind

Reduce Levelized Cost Of Energy

Maximise Turbine Uptime

Improve First Power Date

Supply Chain Capacity

Smaller Weather Windows

Incorporate a tow to port requirement

Experiences and Lessons Learned So Far

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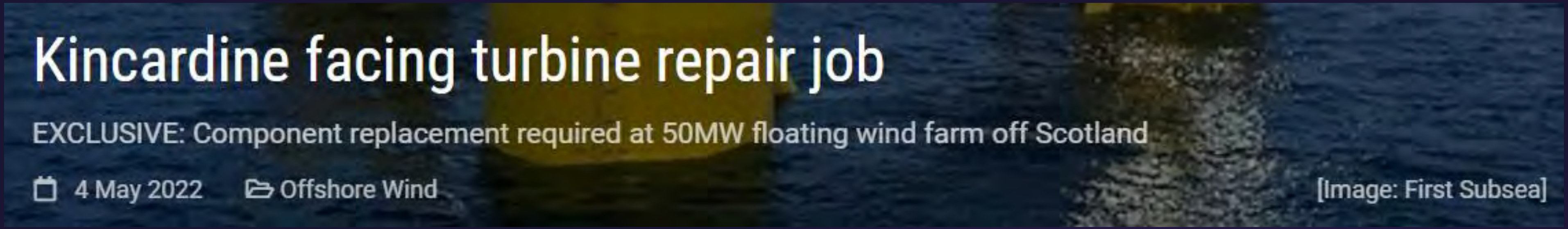

Kincardine facing turbine repair job

EXCLUSIVE: Component replacement required at 50MW floating wind farm off Scotland

4 May 2022 Offshore Wind [Image: First Subsea]

So, what do we know already? We know a lot about costs and consequences of subsea cable failures. The most commonly quoted estimate (although estimates vary) is that 75-80% of the industry's insurance claims are related to cable failure. We know of individual cases

Source: ORE Catapult

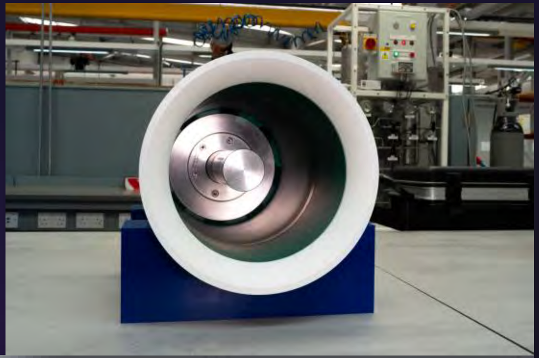
FOW must not copy fixed wind but find its own path.

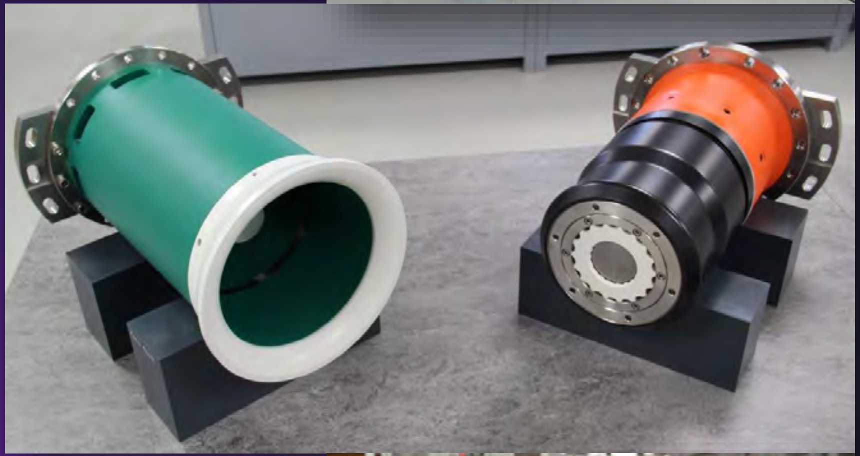
Key Enabling Technology – Wet Mate Connectors

Subsea Wet & Dry Mate Connectors

SIEMENS energy

- Subsea connectors can be **mated underwater** via an **ROV** or as part of a **stab plate system**. They can also be mated **topside** either by **technician** or as part of a stab plate system.
- All of the assembly work including the termination to the cable is **completed onshore**.
- These connectors can be **wet stored.**
- **SpecTRON66** will be the **worlds first 66kV wet mate connector** when our testing program is completed this summer.





Subsea Wet Mate Connectors for Floating Offshore Wind

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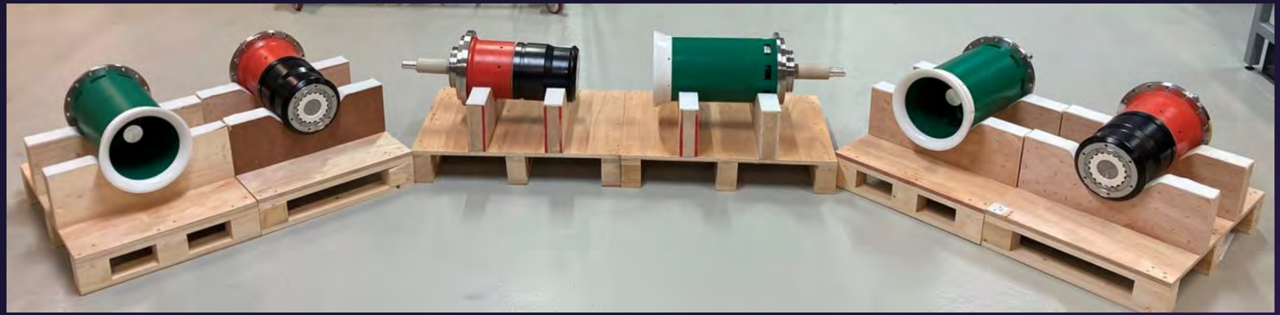

	SpecTRON45	SpecTRON66
Voltage Class	26/45(52) kV	36/60(72,5)
Rated Current	1250 A	1250 A
Water Depth	3000m	3000m
Mating Type	Dry & Wet Mate	Dry & Wet Mate
Number of mates	100	100
TRL	4	3

	DigiTRONf
Number of optical Lines	12
Insertion Loss	<0.2dB
Water Depth	4000m
Mating Type	Wet mate
Number of mates	1000
TRL	7

How can wet mate connectors help solve the challenges of FOW

Options of how to use wet mate connectors & linked technologies

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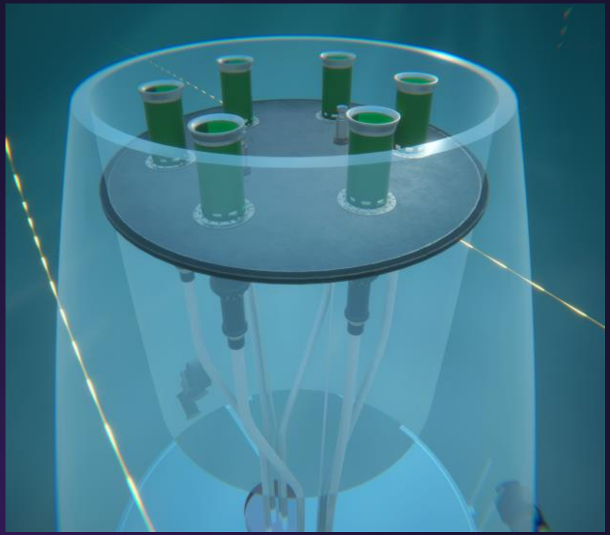
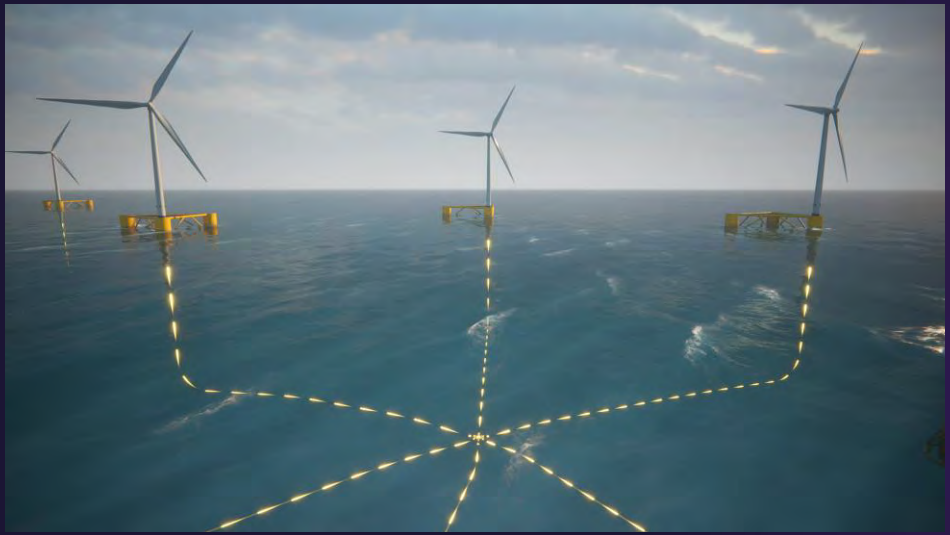
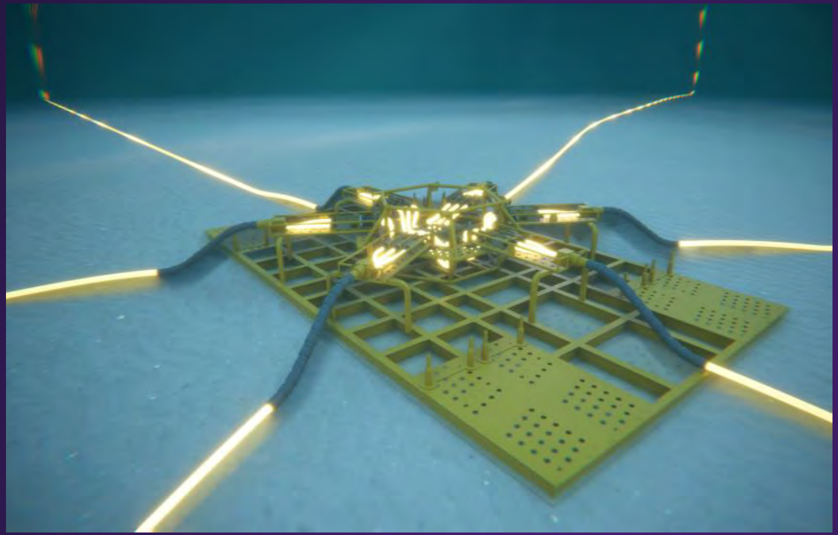





How can wet mate connectors help solve the challenges?

SIEMENS energy

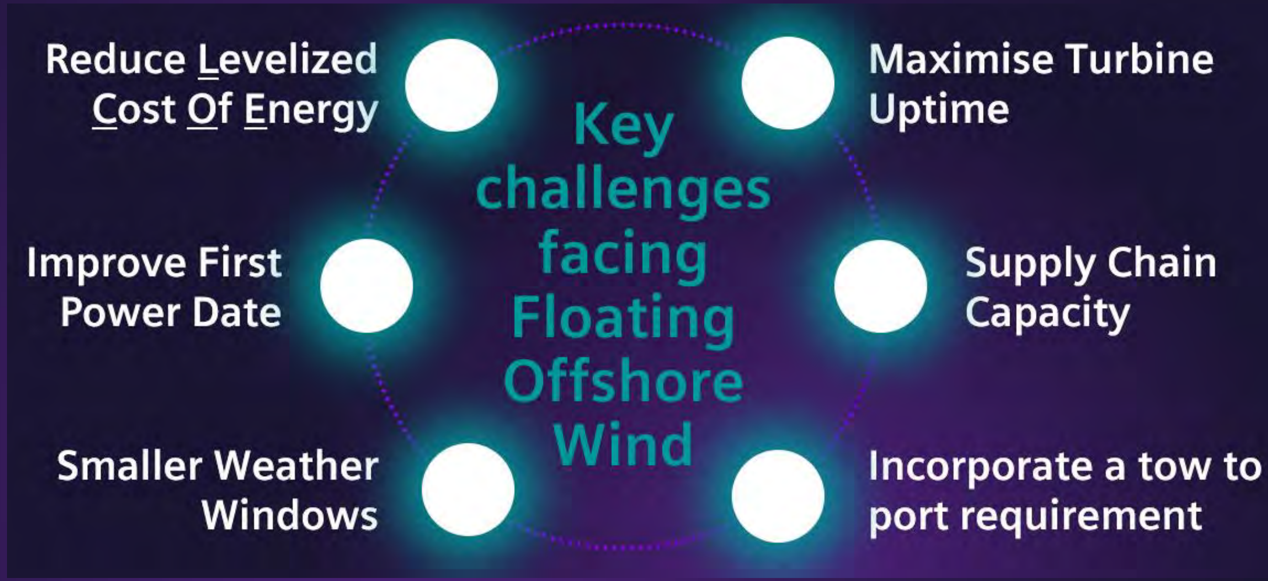
Wet mate connectors and the **subsea hubs** they enable unlock the much-needed **plug and play** system that ultimately helps in **reducing the LCOE.** With the areas most affected being **installation** and **Operations & Maintenance** phase.

Installation

- Can be **phased** over multiple campaigns.
- Less affected by **smaller weather window.**

O&M

- Enables and reduces the impact of the **Tow to port requirement**.
- Increase turbine uptime by making **every turbine independent** from the others.



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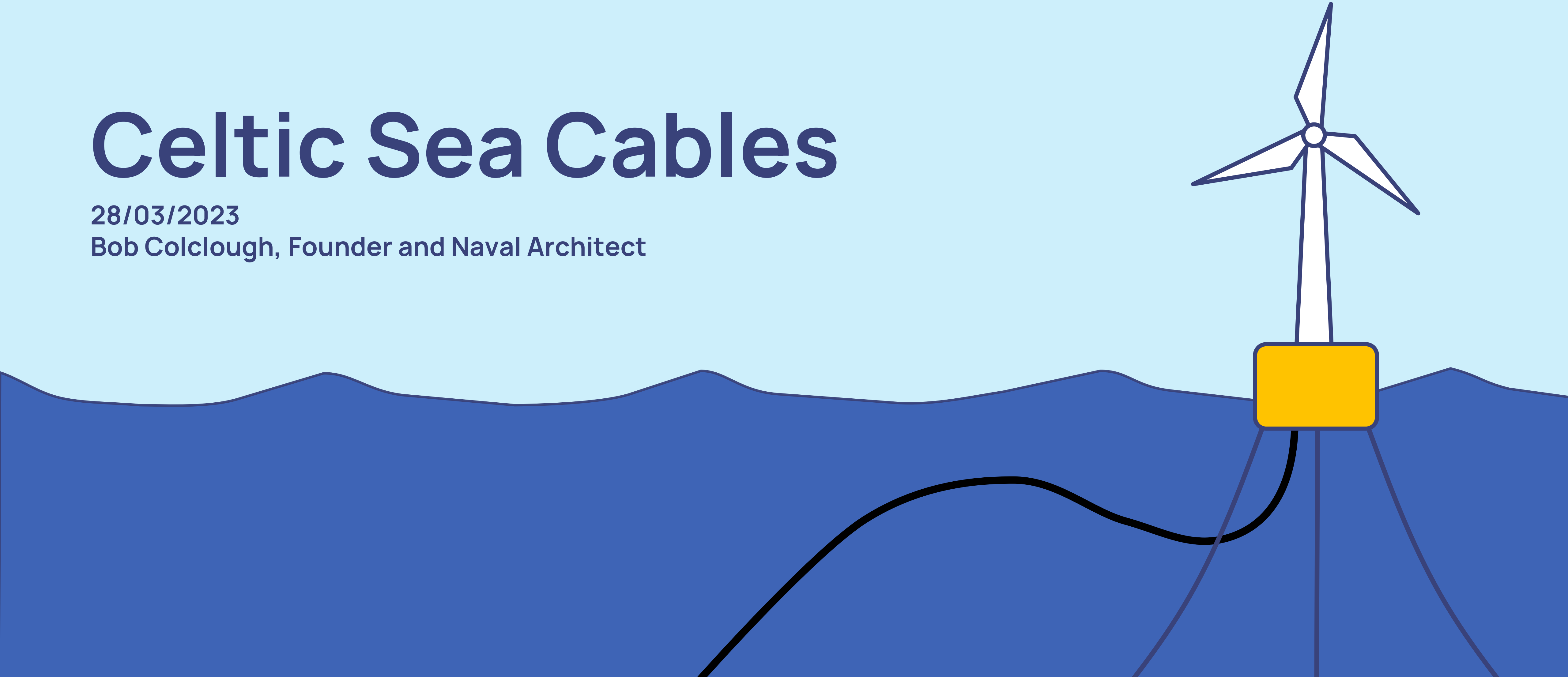
MOREK

NAVAL ARCHITECTS
& MARINE ENGINEERS

Celtic Sea Cables

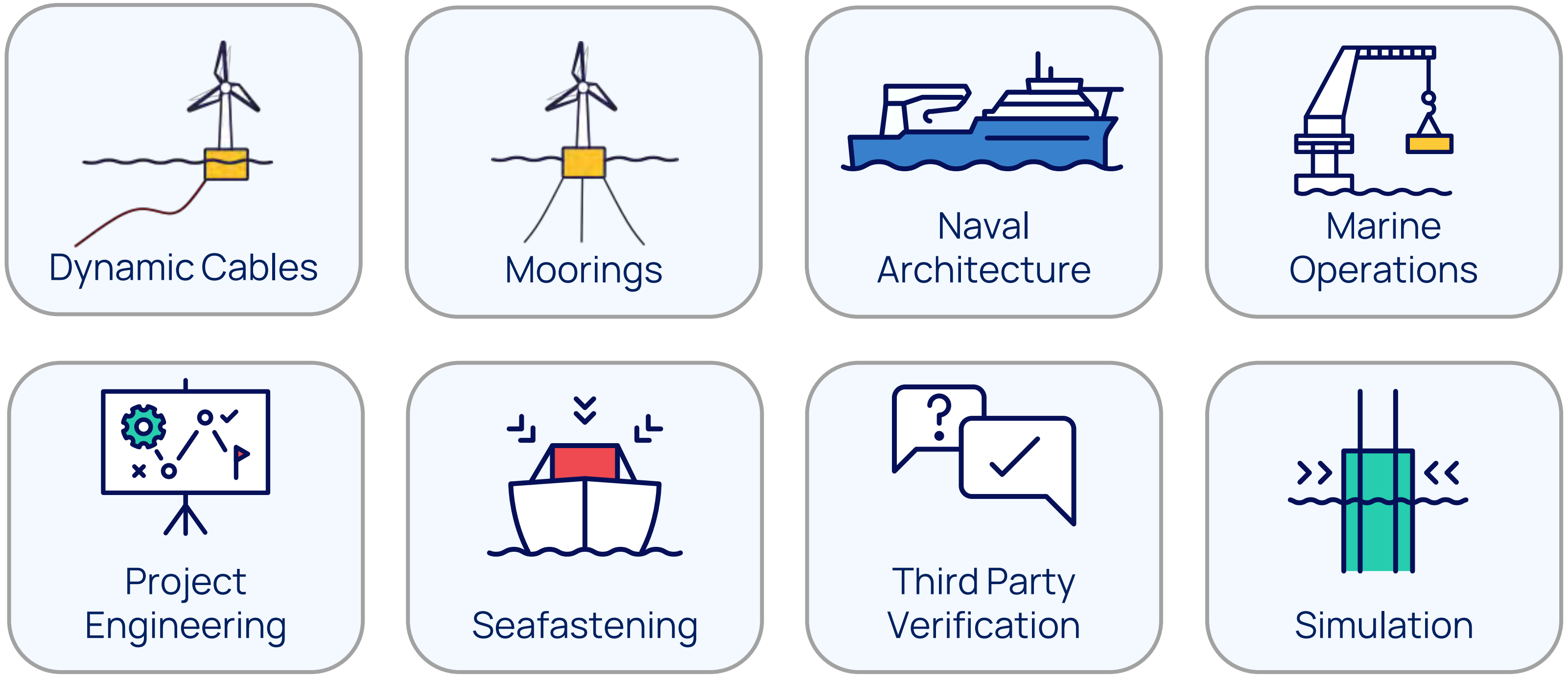
28/03/2023

Bob Colclough, Founder and Naval Architect



Our services

- Formed in 2019 to provide technical skills to the offshore renewables sector
- Based in Falmouth UK, working globally
- Support project developers, contractors and technology developers in FLOW
- Regularly design dynamic umbilical systems
- Frequently involved in the design and planning of offshore cable works



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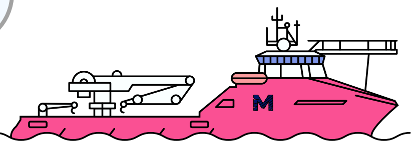


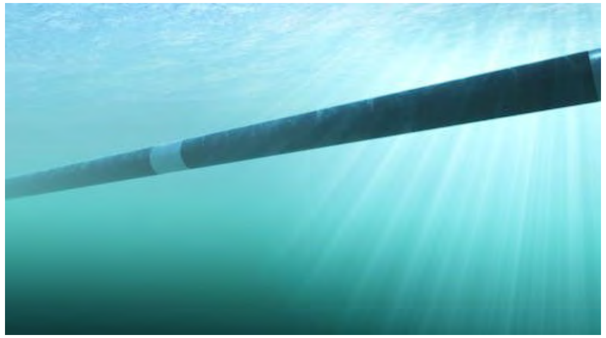
FLOW cabling - Challenge

The volume and scale of opportunity for FLOW is unprecedented and with it brings challenges across all areas when compared to a Fixed Offshore Wind installation.

We <u>aren't</u> putting the first man on the moon, but we will be….

- Using existing products in new environments (loading, configuration/arrangement etc)
- Challenging the cost point of previously 'gold plated' oil and gas technologies
- Innovating solutions to install high volumes of standardised products
- Generating a wide demand of skill and services which currently only exist in niche pockets

FLOW will need to provide industrialised solutions, (reliability, cost and production volume) a huge challenge for un-proven technology



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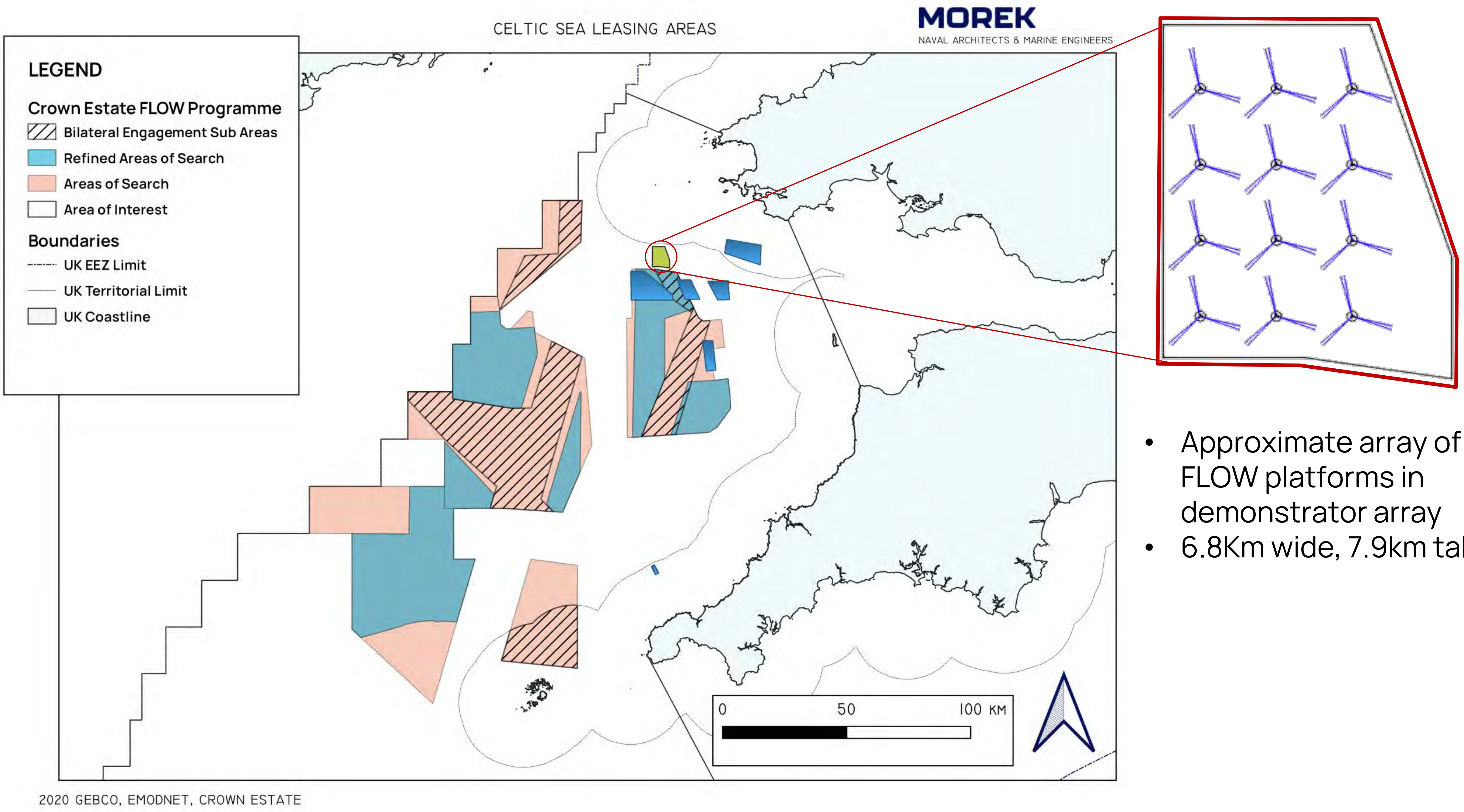
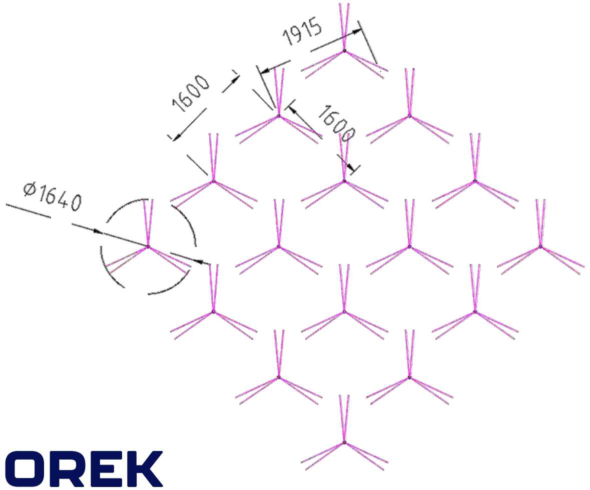


- Approximate array of FLOW platforms in demonstrator array
- 6.8Km wide, 7.9km tall

Design - Array Scale

- Skilled integrators stand to be most successful in FLOW project design and development.
- Combining knowledge and expertise at FEED and detailed design stage to consider through life stages
- Balance demands of each subsystem to provide the most reliable overall solution
- Fit and forget in unlikely to be achieved in the short-term
- Across an array there will be varying levels of intervention throughout the project lifecycle
- Planning and routing must consider all phases of project lifetime
- Cable and Mooring crossings need careful consideration



Design - Device Scale

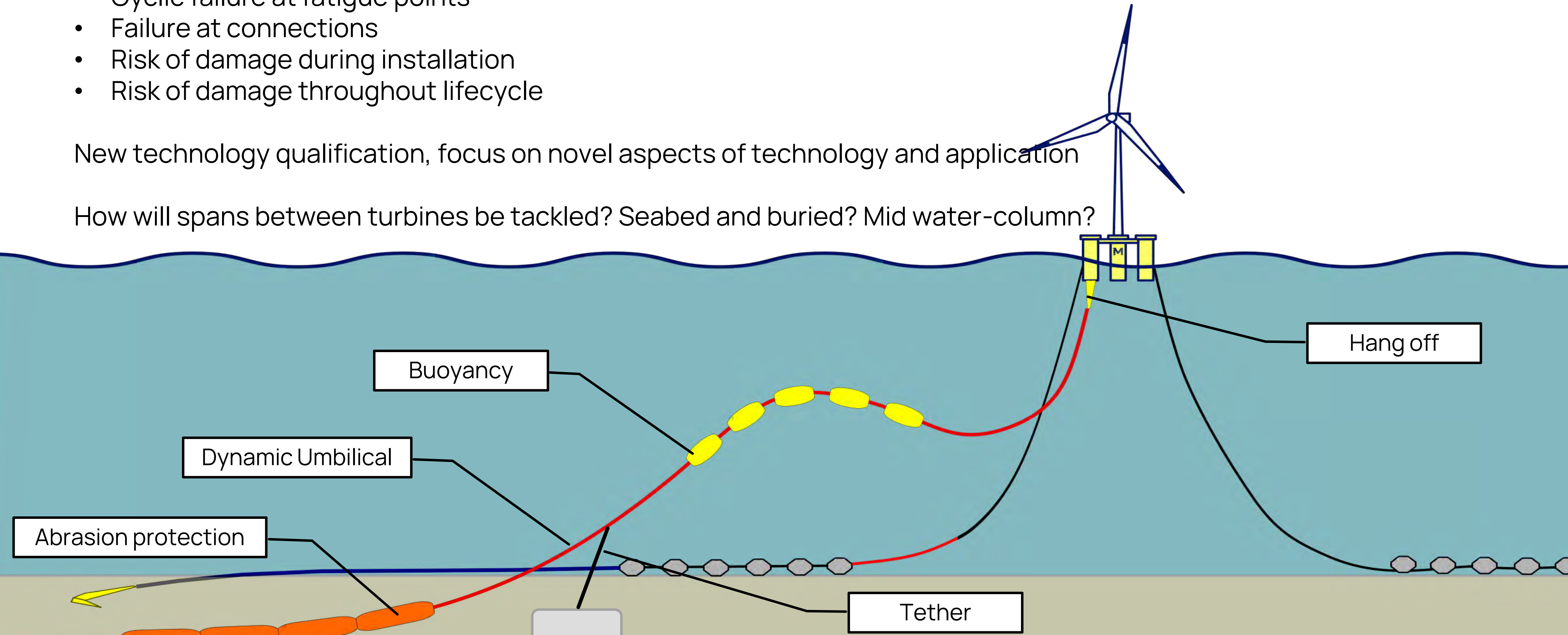
Most components already exist, a basic layout is shown below

Identify known failure modes, target in design and accommodate in spec

- Cyclic failure at fatigue points
- Failure at connections
- Risk of damage during installation
- Risk of damage throughout lifecycle

New technology qualification, focus on novel aspects of technology and application

How will spans between turbines be tackled? Seabed and buried? Mid water-column?



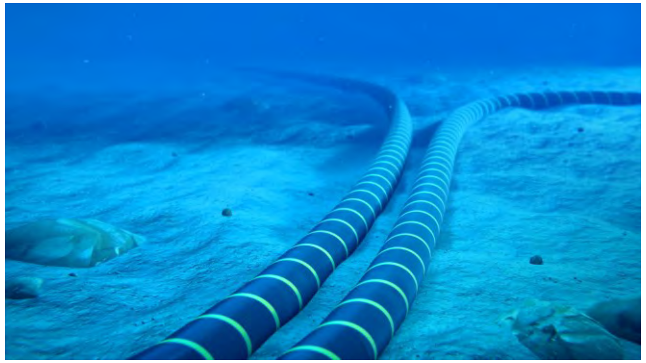
Installation 1

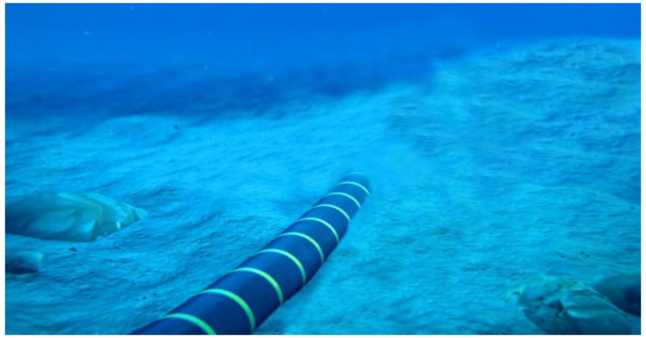
Very important to consider offshore operations during all stages of design

Link owner engineer with knowledge and expertise of cable installation contractors

Mix the existing challenges and solutions of fixed wind such as
- Crossing existing cables/interconnectors
- On bottom stability, free spans and turning points
- Impact of seabed type, some areas rocky, some sediment
- Protect against bottom trawling/anchoring

With the fresh challenges of FLOW
- Constant motion of cable and ends
- Cables in the water column
- Moving touch down points
- Hand-over and terminating on floating structures



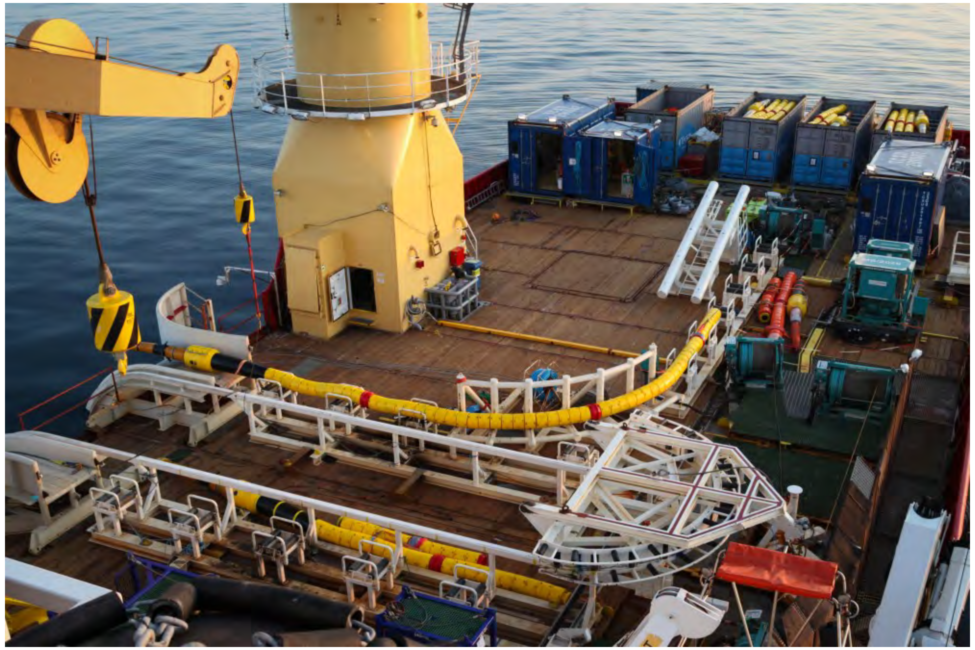


Installation 2

Key decisions for the installation contractor

- Vessel selection
- Cable spread design and layout
- Resupply strategy
- Connection approach

Sequence of installation –
Moorings, prelay and hookup
Export cable installation
Interarray cable lay, pull-in and terminations



Operation & Maintenance

Failures will occur during the lifecycle of the project, potentially resulting in full replacement of some DAC, also planned maintenance must be undertaken to maximise the reliability of the asset

Major part of the BOP service contract to include repair operations

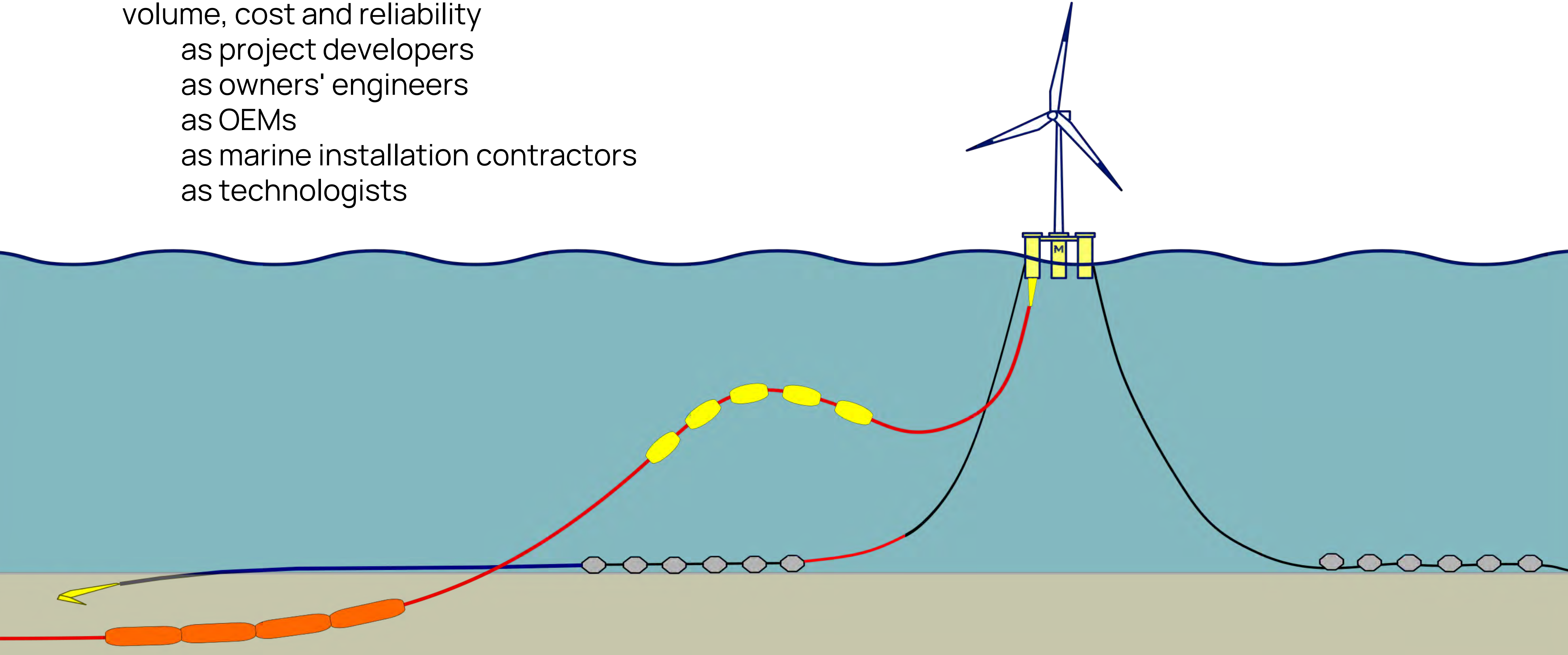
Setting up a specialised onshore facility to supervise one or more FLOW arrays is imperative.

Response times to rectify failures
- Marshalling and storage of spares
- Ease of mobilisation
- Pre-planning of repair activity scenarios

Summary

To meet the challenges of FLOW cabling needs we need to work together to tackle the challenges of scale, volume, cost and reliability

- as project developers
- as owners' engineers
- as OEMs
- as marine installation contractors
- as technologists



Discussion / Questions ?

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