The changing role of electrical systems in the offshore wind sector

TWIND Online Summer School

July 2021

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CATAPULT Offshore Renewable Energy

Agenda

- Offshore Wind – The Early Days
- Development of the Electrical System
  - Changes in Nacelle Powertrain Technologies
  - Cables & Transmission Technology
    - Array voltage
    - AC vs. DC
    - DC within a wind farm
  - Smarter Wind Turbines
    - Ancillary services provision
  - Floating wind
    - Dynamic cables
    - Subsea collectors
  - Evolution of the Energy System
    - Connecting large amounts of wind
    - Net Zero - Multi-energy sources and vectors
  - The Future?
    - Energy Islands
    - Superconducting Technology
  - Questions

Offshore Wind – The Early Days

- The UK's first offshore wind farm
  - Commissioned in December 2000
  - Consortium included E.ON, Shell Renewables and NUON (now part of Vattenfall)
  - Decommissioned in 2019

- Vestas 2MW turbines (V66)
  - Onshore turbines 'adapted' for offshore
  - Largest offshore turbines at the time
  - 1.6km offshore
  - Circa 10m water depth
  - 33kV onshore grid connection

What could go wrong…?

Blyth Offshore Wind Farm

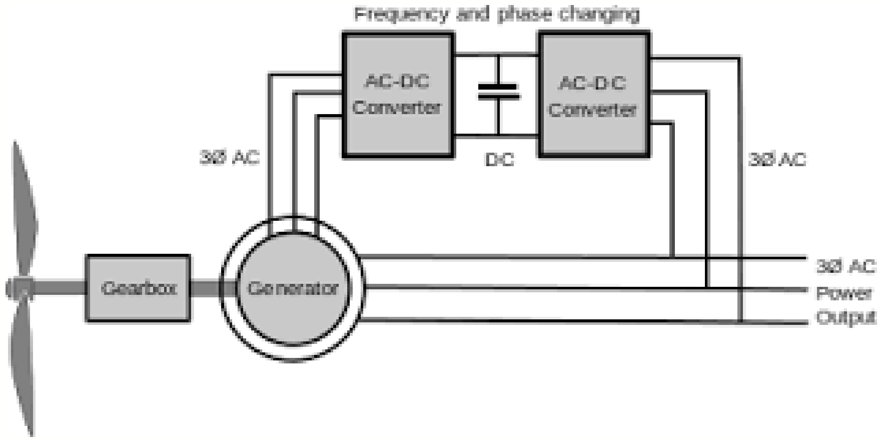
Offshore Wind – The Early Days

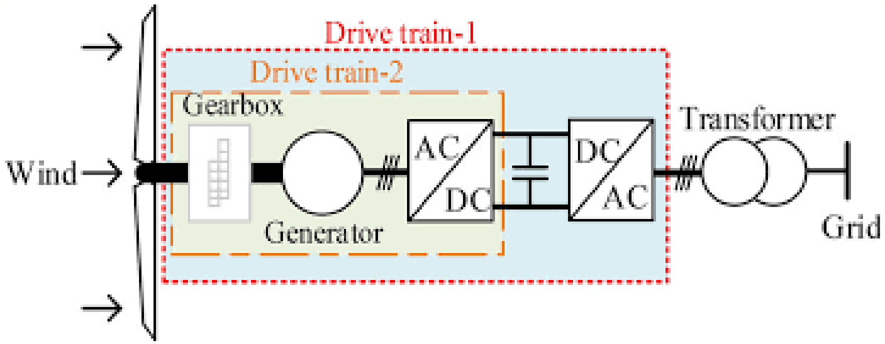
- The project was partly reliant on public funding (EU Framework funding)
- The cables were not clamped to the rocky seabed
    - Failed over time
    - Firstly one turbine and then both
- The turbines were not designed for offshore
    - Saline and contaminated environment
    - Corrosion
- How many operating hours in the 19 years?

- IEE Review Magazine – early 2000s
    - Will UK offshore wind ever be realised?
        - Is the environment too challenging?
    - Onshore vs. Offshore

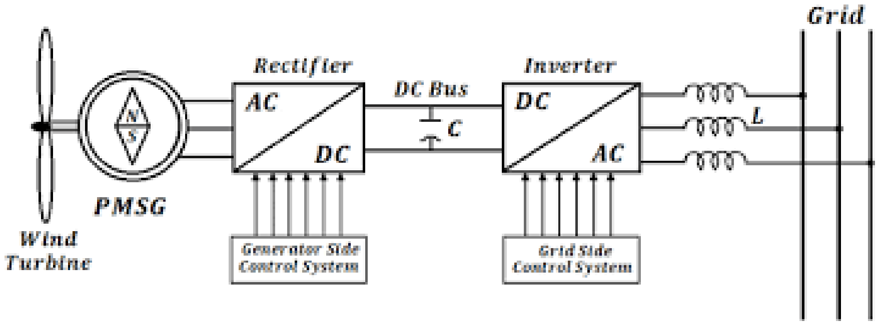


Changes in Nacelle Powertrain Technologies





Location of converter and transformer



DFIG

- Simple and low cost
- Significant control limitations

Geared

- Fully rated converter, better control
- Reliability concerns (gearbox, converters…)
  - FP7 ReliaWind – 2011

Direct Drive

- Maintains fully rated converter
- Large generator with slow rotational speed

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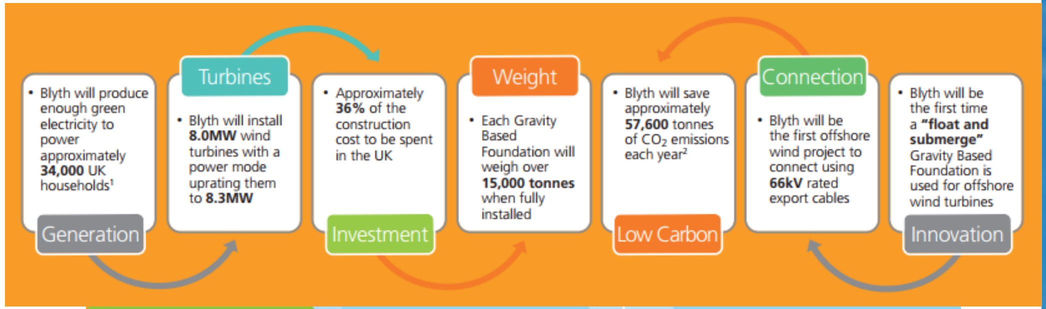
Blyth Offshore Demonstrator Wind farm

- 5x 8.3MW turbines
- 6.5km off the coast of Blyth
- 191.5m Tip Height (AOD)
- Approx. 40m Water Depth

- The industry has moved from 33kV to 66kV inter array voltages
- Increased MW rating of the wind turbine was a driving factor
- Cable size and cable losses were other considerations



Cables & Transmission Technology - AC vs. DC

- AC is more widely used in offshore wind transmission (and perceived to be more reliable)
- Can be easily stepped up and down using transformers
- Significant losses can be experienced over longer transmission distances leading to additional operating expenditure (OPEX)

- HVDC solutions generally involved higher capital expenditure (CAPEX) than AC solutions
- For longer transmission distances, there is a ‘cross-over’ point at which increased HVDC CAPEX is less significant than increased AC OPEX
    - This is where HVDC becomes a better techno-economic solution

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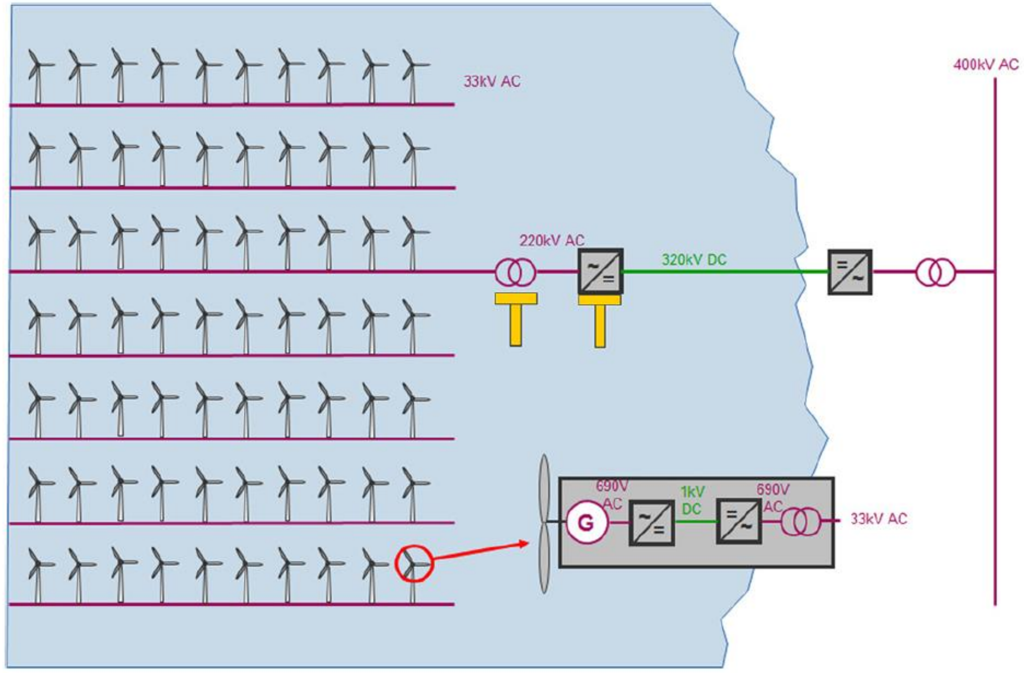
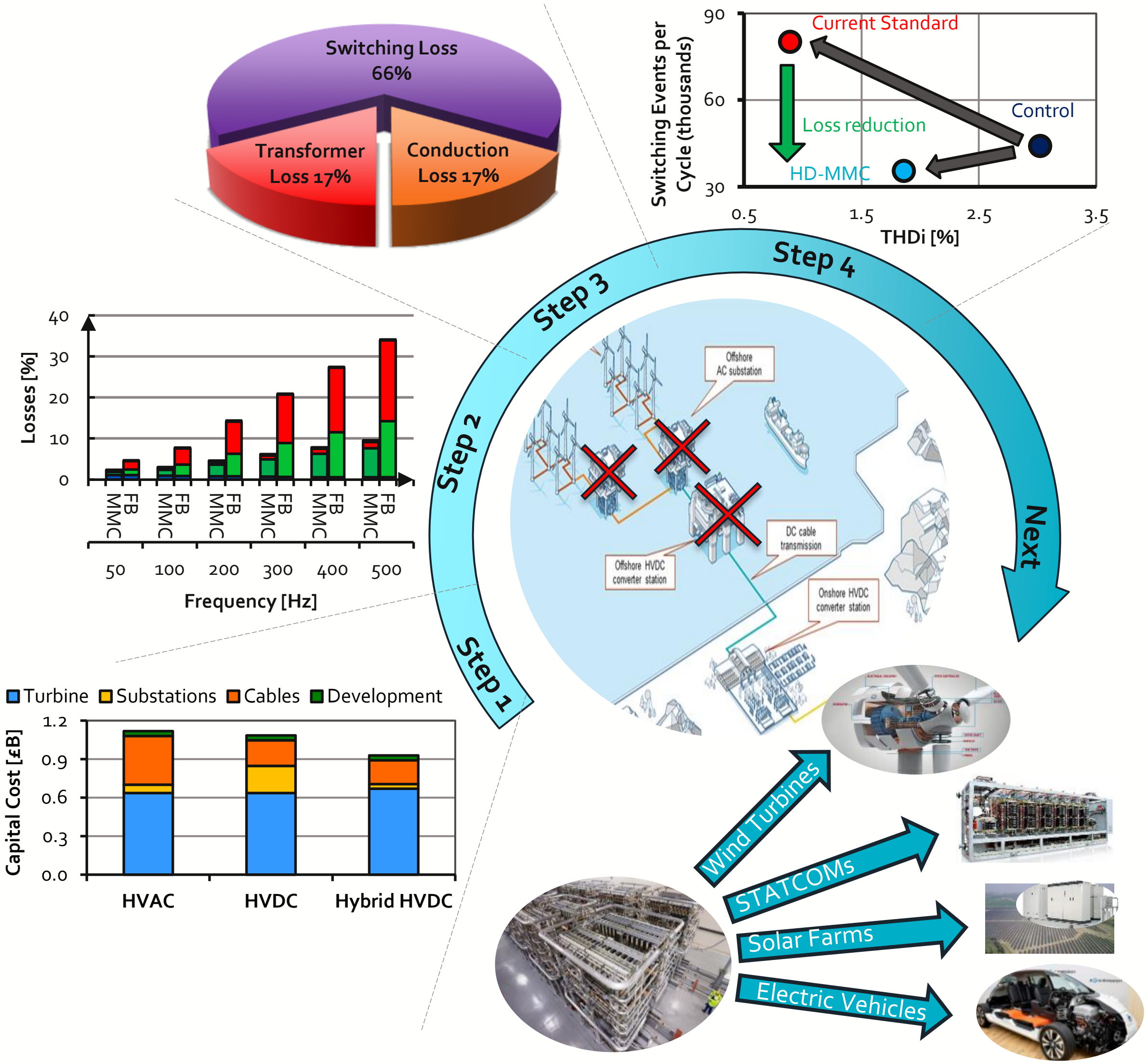
ISSN 2056-4007
www.ietdl.org

The Use of High-Voltage Direct Current Transmission for Offshore Wind Projects

Colin C Davidson MA (Cantab.), CEng, FIET Chief Technology Officer, HVDC, Alstom Grid, Stafford, UK



Cables & Transmission Technology - DC within a wind farm



Objective: reduce the cost of DC transmission by eliminating the offshore substation.

Step 1: A feasibility study found a 15% cost reduction possible by modularising offshore substations such that they fit within each turbine

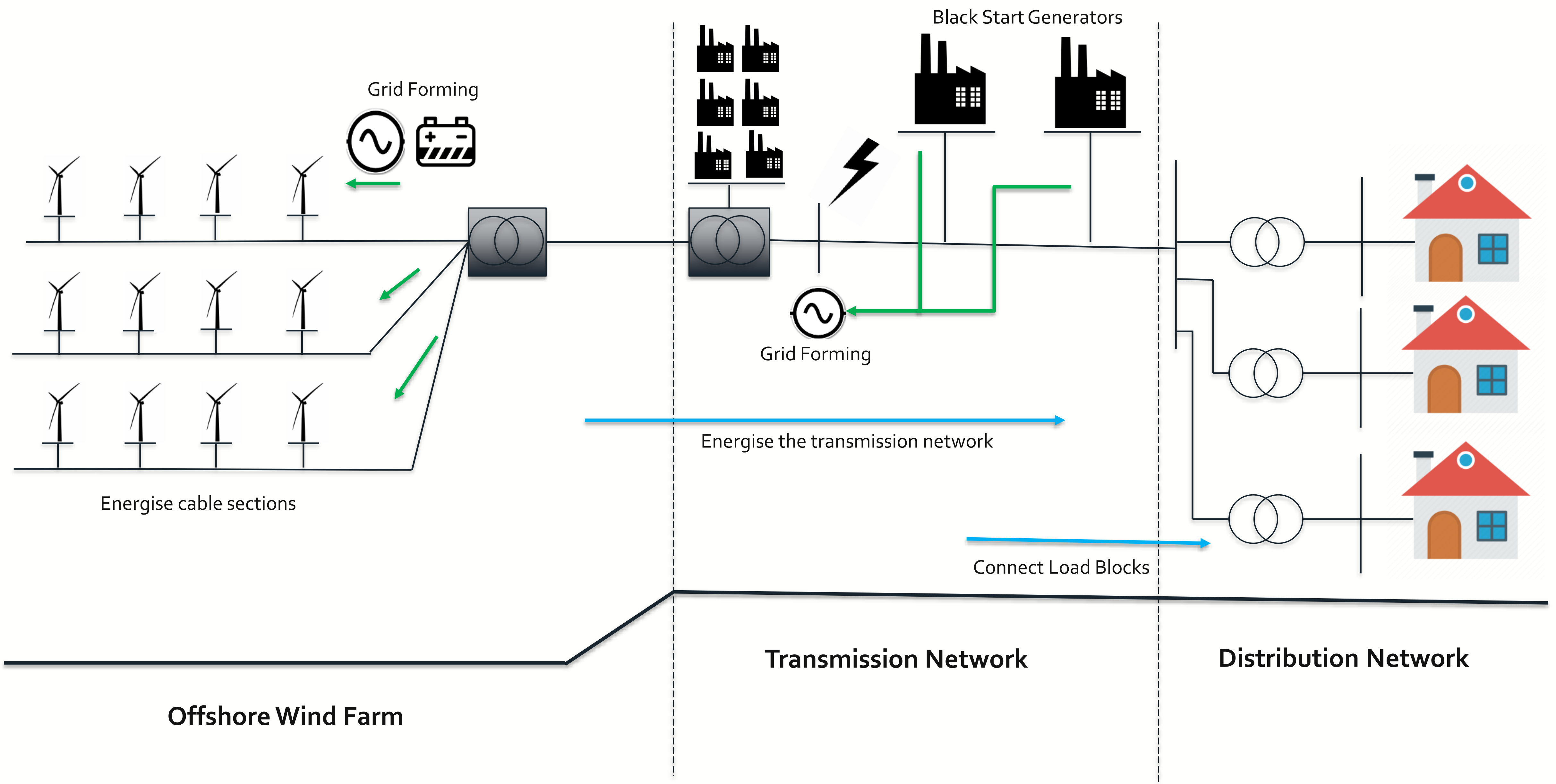
Step 2: Simulations showed optimal design of new hybrid DC transformer to use Modular Multilevel Converter (MMC) design.

Step 3: Due to high frequency, switching losses too high

Step 4: A new control algorithm was developed and tested that improves the waveform quality and reduces losses

Next: Larger scale model required to increase industry confidence. Many potential markets available!

Smarter Wind Turbines - Ancillary Services Provision



Control and Protocols for black start from Offshore Wind (CAPOW)

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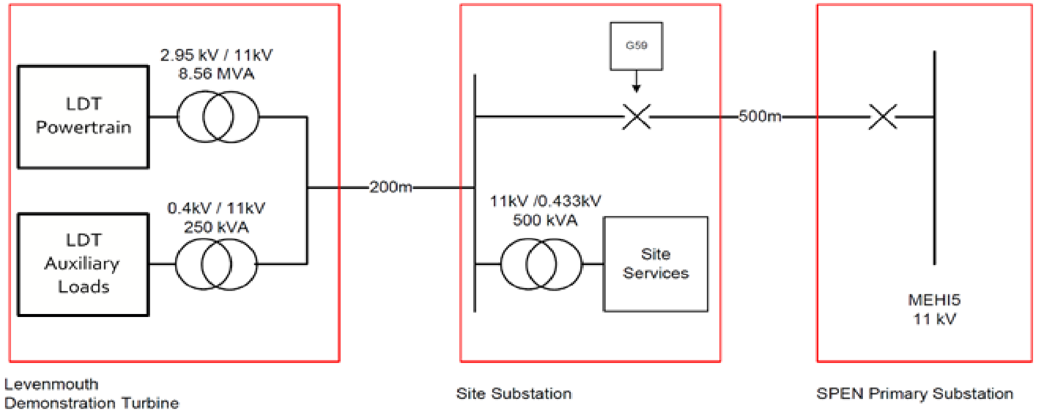
Objectives

1. Develop new warmup protocols, energisation protocols and associated control functions to enable black start of OWTs and subsequent energisation of internal array MVAC cable networks
2. **Demonstrate the performance of these protocols and control functions for the black start of OWTs and local MVAC networks using the LDT and associated electrical infrastructure**
3. Simulate and establish the technical and cost feasibility of continuing all subsequent black start stages (e.g. array cables, offshore power transformers, export cables, local transmission system, etc.)

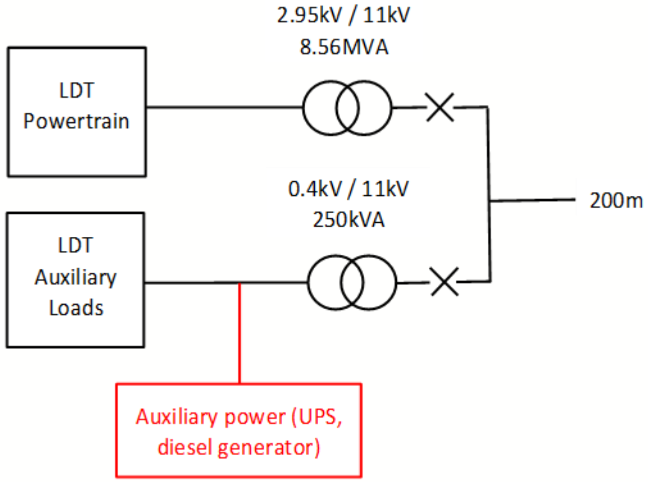
Work Completed

1. Specification of powertrain, control and protection requirements
2. Offshore wind turbine black start simulation studies



DNV·GL

ABB



Floating Wind - Dynamic cables modelling

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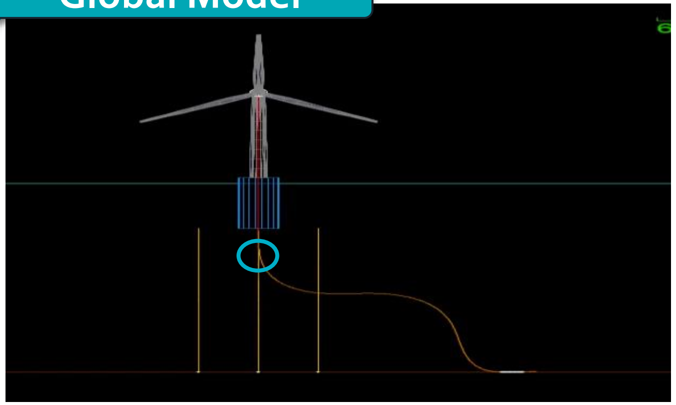
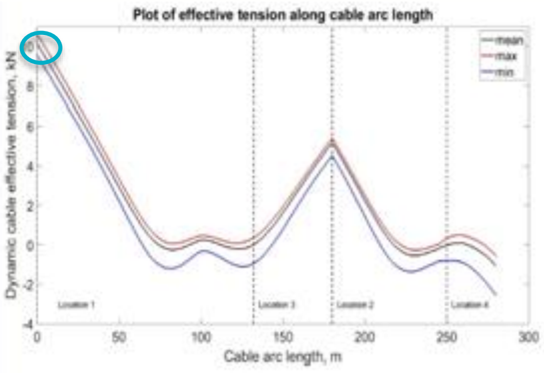
Global Model

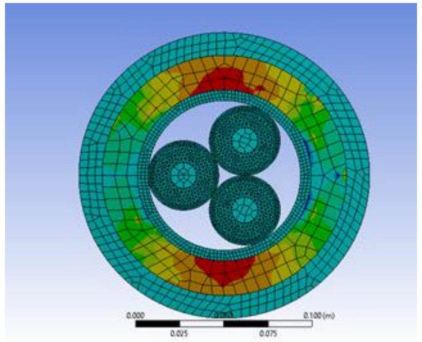


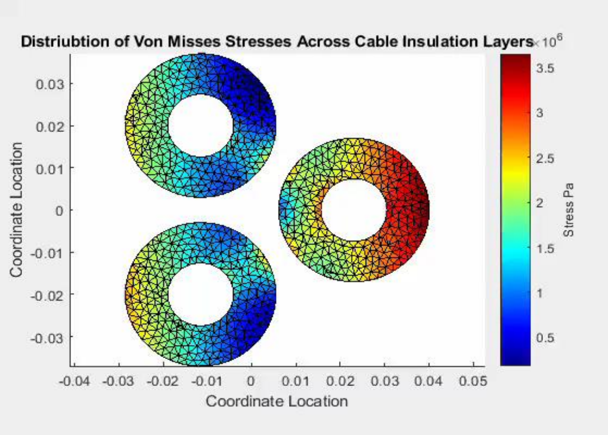


(e) F_z

A global dynamic model can be built to show where along the cables length, the environmental forces will be of greatest concern.

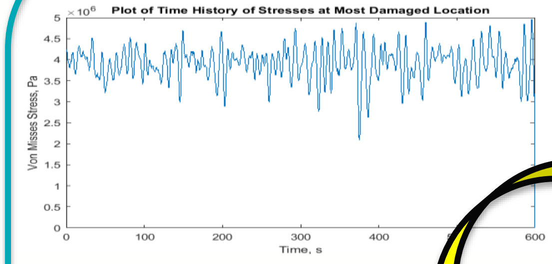
Local Model

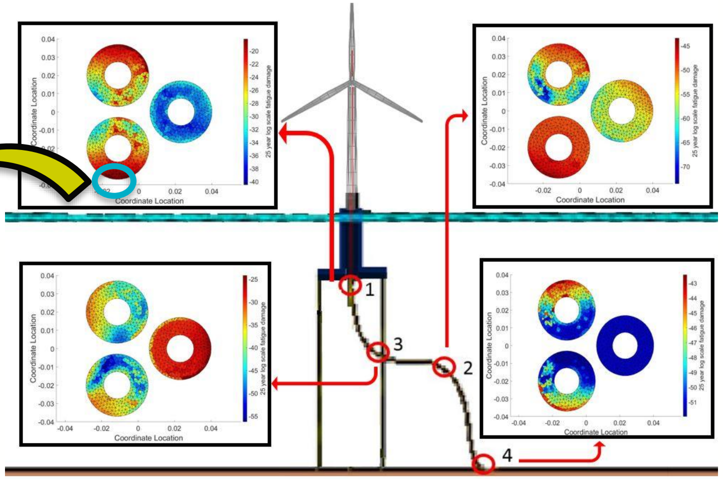




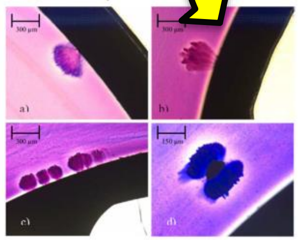
Combining the FEA and the dynamic model can produce a time history of stresses of any cable component., in any environment.

Damage Calculation

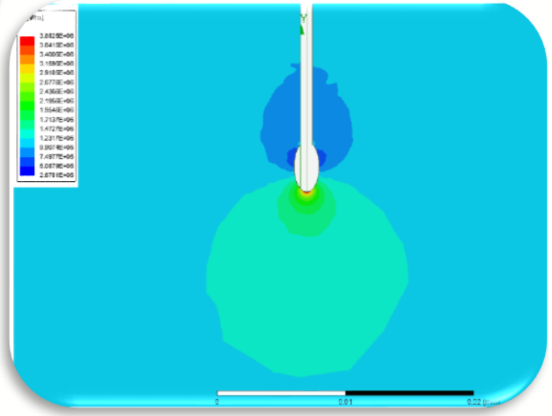




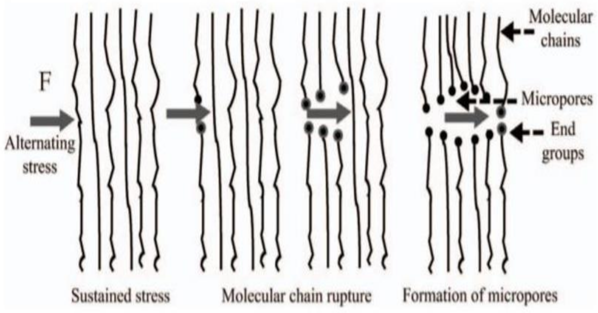
$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$



Electric field model



Polymer chain rupture



Electrical field is greatly distorted and concentrated at the tip of the water tree. Generates alternating stress acting on polymer chains

Dynamic Cable Test Rig

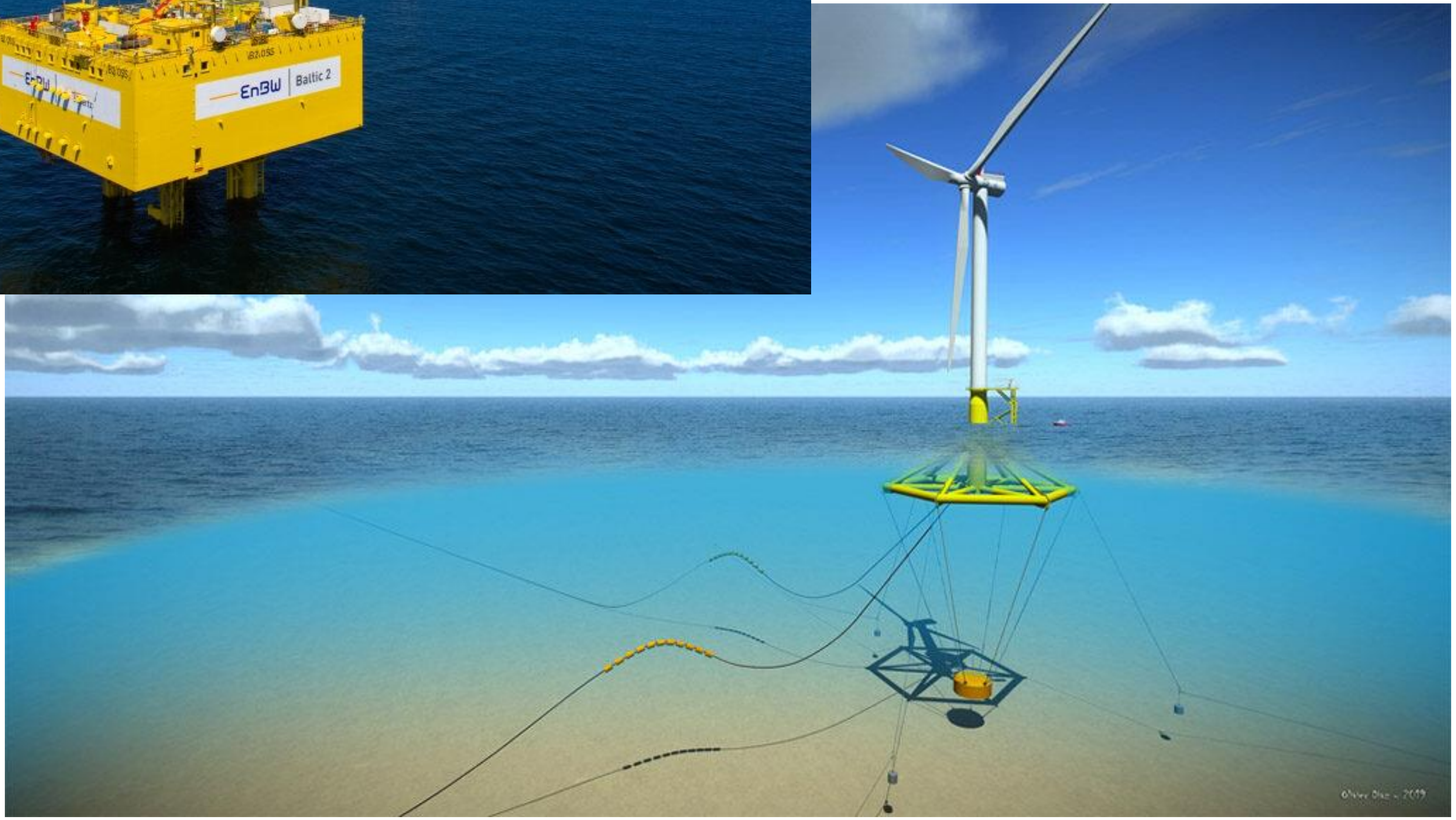
A bespoke, state-of-the-art cable bend fatigue test rig supporting the development – and improving the performance and reliability of – subsea cables. The rig is capable of testing floating wind and tidal cables, carrying out operational research, and acting as a representative test bed for all aspects of subsea cable development.

Unique features include:

- Testing while fully submerged in seawater.
- Performing electrical and mechanical testing simultaneously.
- Testing within a UKAS-accredited laboratory.

Over the coming years, the rig will be used to prove our cable models and validate new dynamic cable designs for offshore wind. For more information, click here: https://ore.catapult.org.uk/press-releases/dynamic-cable-test-rig/

Floating Wind - Subsea Collectors



- Floating offshore wind requires dynamic cables
- Floating offshore wind requires floating substations
  - … or does it?
  - Subsea collector technology is looking to put some of the electrical equipment on the seabed
  - Still requires dynamic cables from the wind turbine
  - More costly and 'operation critical' transmission cable is static on the seabed
    - Like current offshore wind

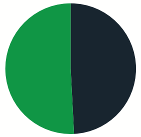
Evolution of the Energy System

Current Energy System

11 GW of offshore wind

Majority of properties heated by natural gas

Fuel engine vehicles are the most popular



50% of electricity generation comes from fossil fuels

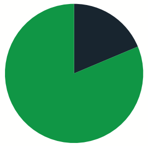
Meter reading send once every half a year

Future Energy System

40 GW offshore wind by 2030

Properties use electric heating or gas network converted to hydrogen

All new vehicles are electric, hybrid or hydrogen-powered

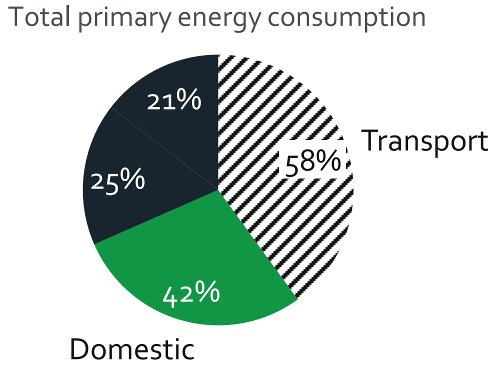


Only 20% of electricity generation comes from fossil fuels in 2030

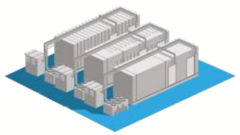
Smart meter reading send every half an hour

Outcomes

① Offshore wind deployment will be much bigger than we have now (80GW by 2050)



② Variability of renewables will need to be largely overcome



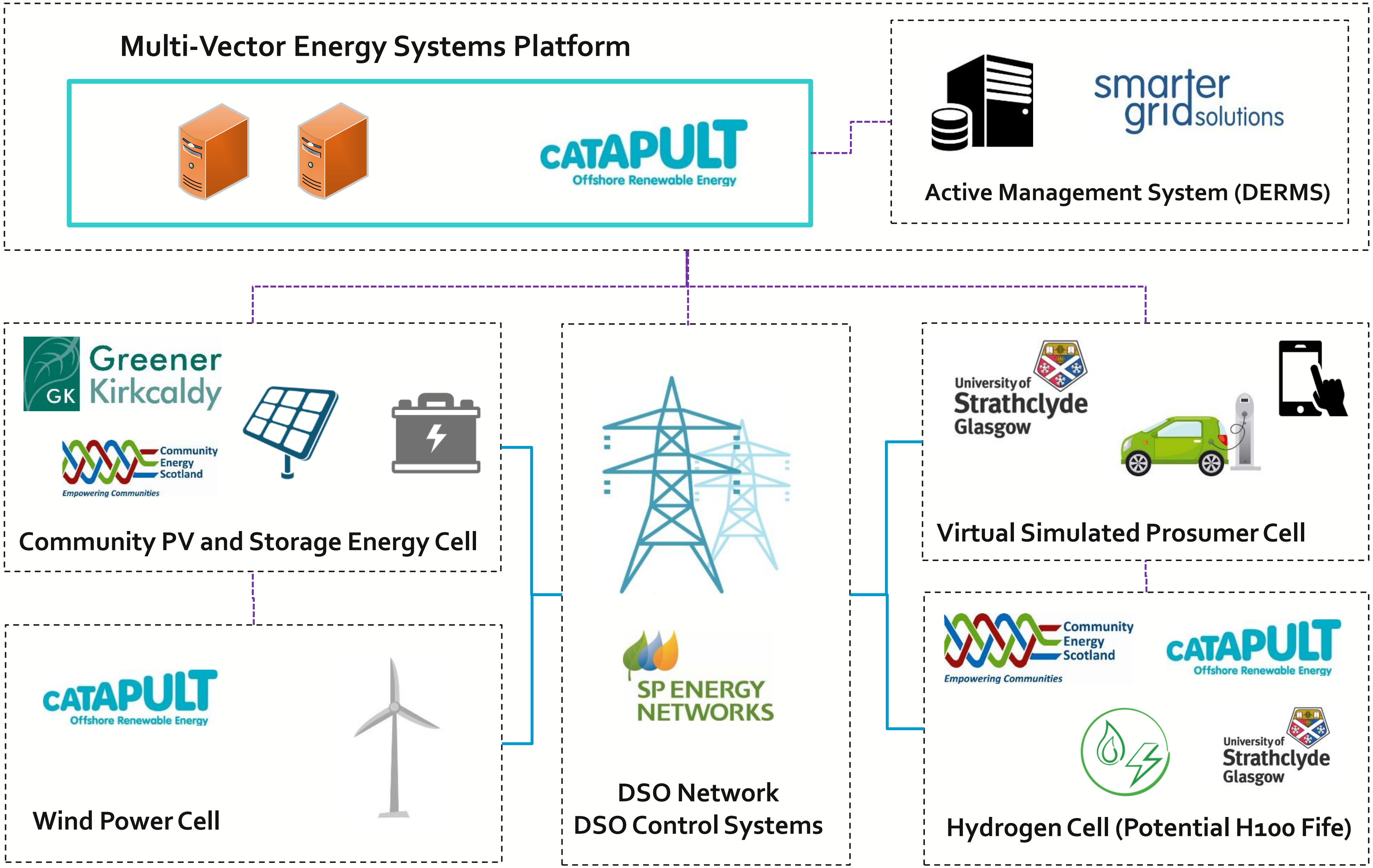
Connecting large amounts of wind

The first 100% H_2 to homes, zero carbon network in the world (located at Levenmouth)

Levenmouth Demonstration Turbine (LDT);

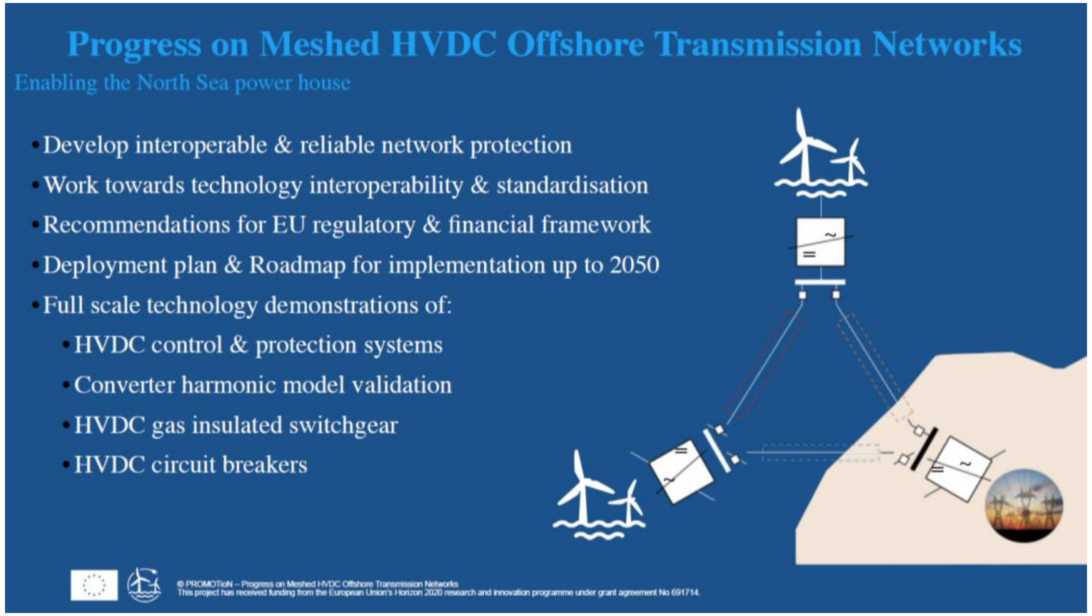
- Heating for around 300 local homes, in Phase 1, 2022 to 2025; using 100% hydrogen gas produced by an electrolysis plant, powered by our LDT
- Supply of hydrogen from renewables puts Levenmouth at the forefront of the clean energy revolution
- Pricing terms agreed last year with SGN
  - PPA contract expected in 2021
- LDT has capacity to supply up to 1,000 homes (see Phase 2)
- Operational links with the project CLUE are being developed (Hydrogen Cell in CLUE LEC demonstrator)

Net Zero - Multi-energy sources and vectors



The Future – Energy Islands

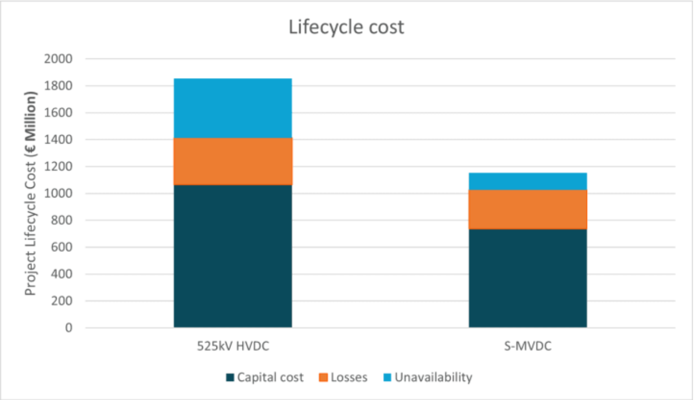
- A potential solution for a future North Sea offshore network (Supergrid)
- Denmark (Energinet) has already started work on developing energy islands in the North Sea and Baltic Sea
- Provides a natural home for offshore network substations and O&M facilities for ‘far from shore’ wind farms
- May also facilitate the realisation of a meshed HVDC offshore network

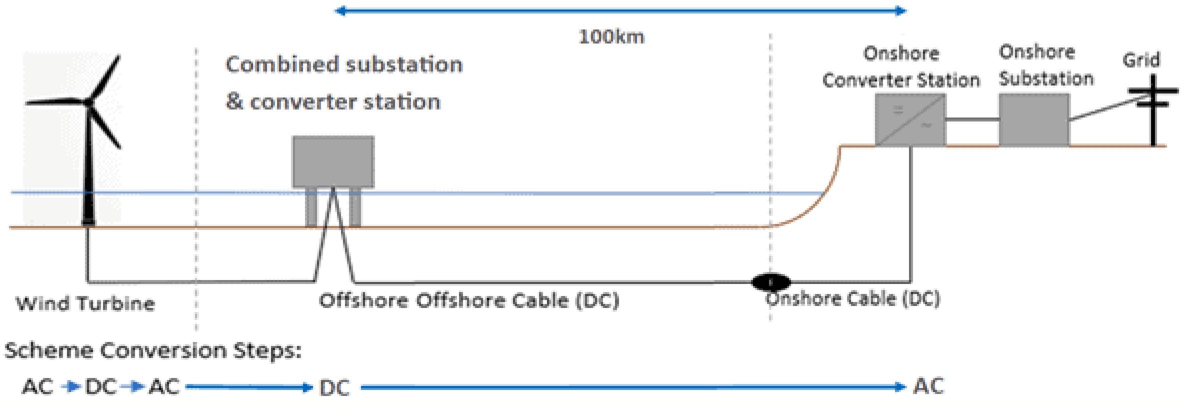


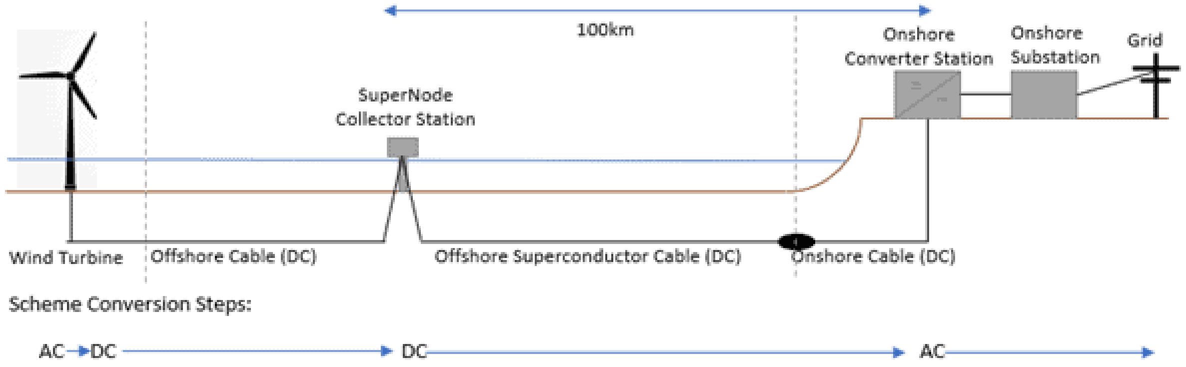
The Future – Superconducting Technology

- Superconducting cables provide a technology that significantly reduces cable losses whilst significantly increasing cable transmission capacity
- Provides a potential alternative to current HVDC solutions
- Early studies show that this technology can be competitive when considering lifecycle costs
- It could provide an effective solution for connecting the large amounts of planned offshore wind in the North Sea by 2050

https://supernode.energy/supernode-superconductor-cable-shown-by-university-of-strathclyde-ore-catapult-to-be-competitive-with-hvdc/







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