Making Headway on DC System Interoperability- and What’s Next in the Development towards Further & Larger DC Networks

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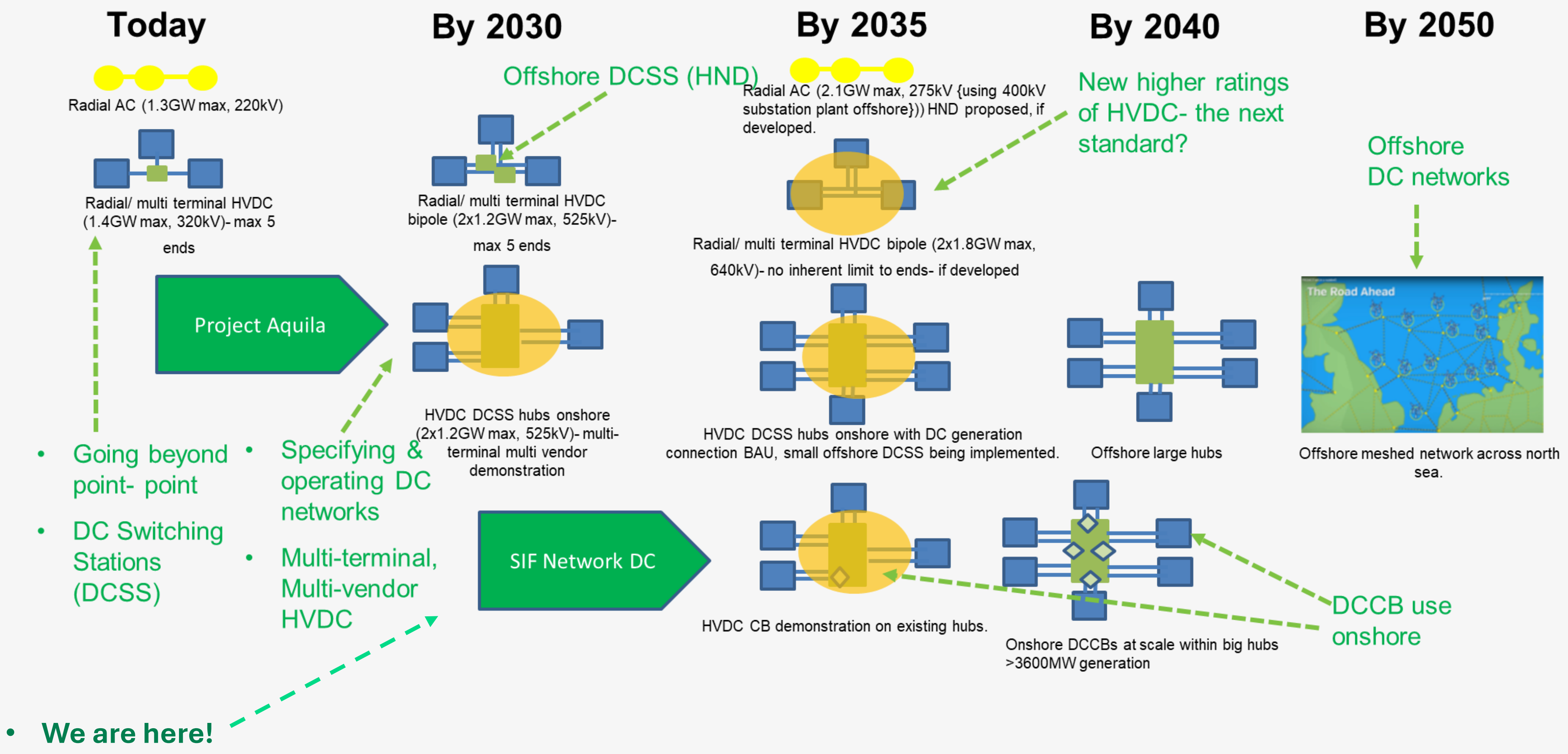
cigre

For power system expertise

Topic

- **Multi vendor Interoperability in VSC-HVDC systems.**
  - What we've done.
  - Demonstration and making it practical to deliver
  - How we've done this.
- **Growth of DC systems.**
  - What might they look like
  - How to get to a vendor agnostic DCCB specification.
  - Associated devices to enable DCCB.
- **Practical DC system interfacing- offshore**
  - INTOG, Hydrogen- anything else to come?
  - Load rejection management- practically.
  - Co-ordinated and staged allocations of offshore grid forming and damping controls.
- **Practical DC system interfacing- onshore**
  - HVDC as a network vs a resource connection interface.
  - Grid forming support from multi-terminal systems.
  - Black start and other support.
  - HVDC systems complementing resilience
  - HVAC & HVDC system cross-optimisation.

A road map to DC systems.



Multi-terminal Multi-vendor VSC HVDC demonstration.

- **What we have done.**

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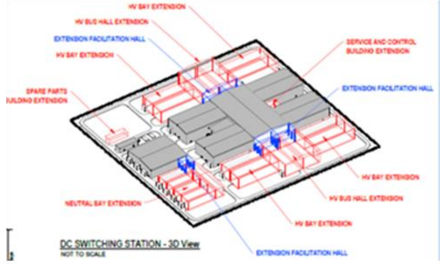
Specifications- layouts interfaces, data, design (Q2, 2024/5)



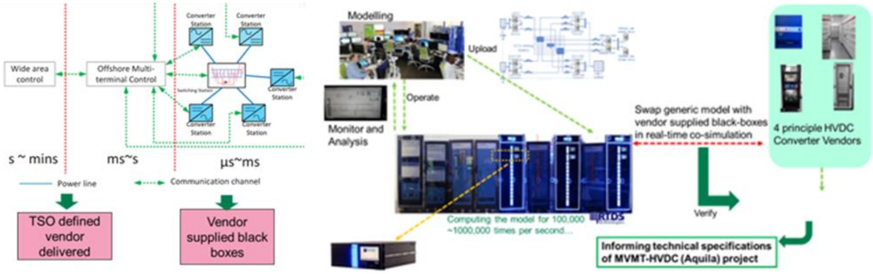
Enables contracting, consenting, delivery

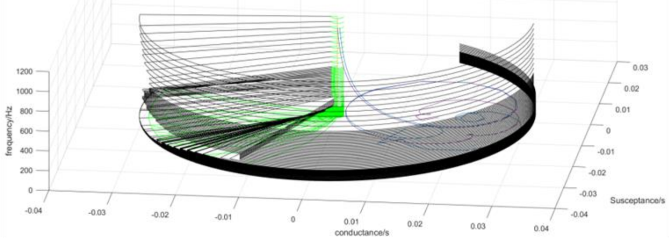
Patent protection, legal commercial review (Q4 2024/5)

Multi-Vendor Multi-Terminal Control	This Patent covers an advanced control system for coordinating HVDC converters supplied by different vendors in a multi-terminal configuration. This enables smooth power flow orchestration between all terminals- prioritising stable operation intact and post-fault.
Multi-Vendor Multi-Terminal Operability	This Patent allows operation across unbalanced conditions across a range of configurations and outages to maximise the availability of an integrated HVDC grid.
Multi-Vendor Multi-Terminal Stability	This patent provides a mathematical proof of network stability that can then be monitored in real time- and provides a basis for clear specification of an vendors' convertor interface to a DC network

Enables legal & commercial space for interoperability

MTMV Control specification and testing (Q3 2024/5)



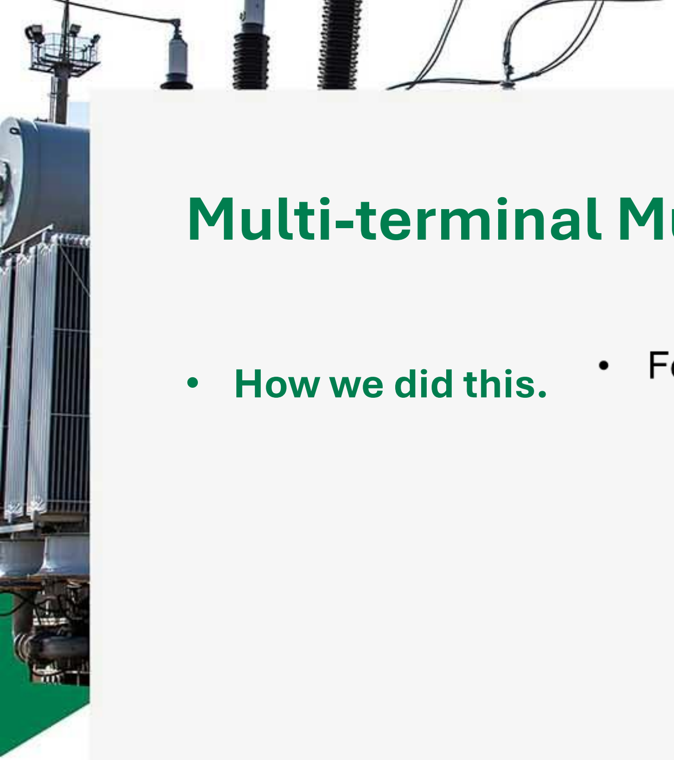


Enables clear roles& responsibilities, & assured performance

	Aquila Interoperability Package	DCSS hub and associated design and specification	Aquila Commercial and Legal package.
Who?	Lead by **HVDC Centre** (September 2021- April 2024)	Lead by **SSEN-T HVDC engineering** team (September 2021- April 2024)	Lead by SSEN-T Innovation, Comercial, legal and procurement teams in association with **University of Groningen** (April 24- April 25)
What?	**Vendor Agnostic** multi-terminal control, control interface specification, design input. Associated test & demonstration approach	Tender pre-engineering, **specifications, layouts, design** at vendor agnostic level.	**Requirements** at tender & contracting phase, **liabilities and responsibilities** allocations, how to manage "switch on" and lifecycle support thereafter.
Why?	Patented approach protecting vendor agnostic delivery. **Respects vendor IP** as in real industrial project. **Tested demonstration** across vendor replicas	Planning, tender and **contractual engineering documents enabling interoperability**	**Independent review** and assessment **of readiness** to contract and manage multi-vendor solutions.

- **More to come!**
  - More Vendors — Hitachi Energy, SIEMENS energy
  - More projects (offshore hubs & onshore hubs- GB and continental Europe & beyond)

Multi-terminal Multi-vendor VSC HVDC demonstration.



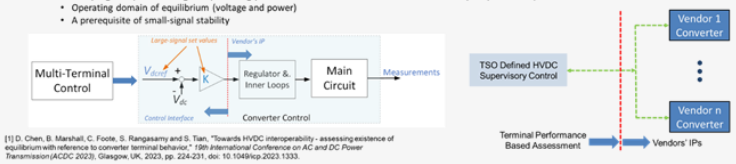
- **How we did this.**

- Four key principles to our approach-

Principle 0 – respect vendor IP

Characterise and inform performance at convertor island interface. NOT open up C&P

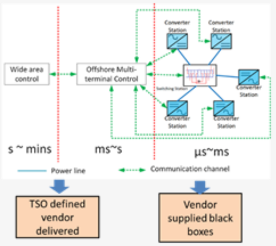
- Cascaded control architecture between MTC and converter
- Converter interfacing MTC via voltage reference value of V/I droop (K-factor refers to virtual conductance)
- Essential MTC Functions
  - Power Control
  - Global DC voltage control
  - Pole balancing control
  - Quantifying the positioning of operating point between no-load condition and collapse (CX-index)
    - Operating domain of equilibrium (voltage and power)
    - A prerequisite of small-signal stability



[1] D. Chen, B. Marshall, C. Foote, S. Rangasamy and S. Tian, "Towards HVDC interoperability - assessing existence of equilibrium with reference to converter terminal behavior," 19th International Conference on AC and DC Power Transmission (ACDC 2023), Glasgow, UK, 2023, pp. 224-231, doi: 10.1049/icp.2023.1333.

Principle 1- coherent robust DC network control

Stability over power flow efficiency. Across contingencies including loss of communication.

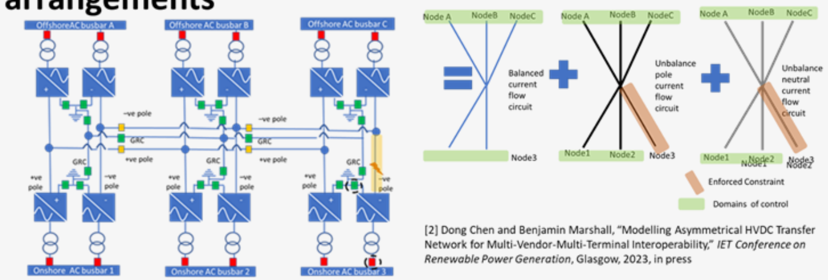


- ✓ Converter Control (µs ~ ms):
  - ➢ operate based on local measurement
  - ➢ respond to Multi-Terminal Control
  - ➢ sustainable when communications are lost
- ✓ Multi-Terminal Control (ms ~ s):
  - ➢ monitor
  - ➢ assess
  - ➢ optimize

The DC Grid should be sustainable when all communication channels or a single power line is lost.

Principle 2- enhanced DC network operation & availability

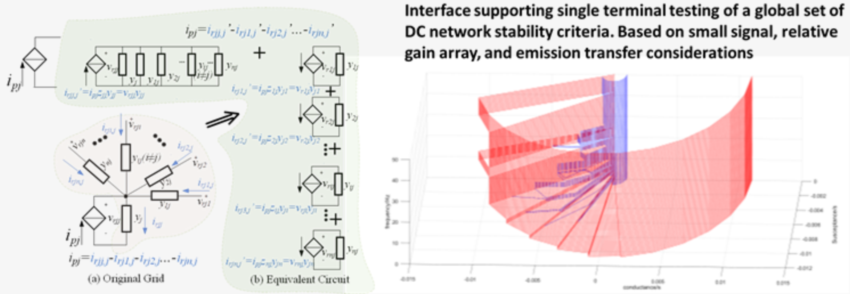
Unbalanced control to manage network outages/ faults, control hunting and Hybrid rigid & full bipole arrangements



[2] Dong Chen and Benjamin Marshall, "Modelling Asymmetrical HVDC Transfer Network for Multi-Vendor-Multi-Terminal Interoperability," *IET Conference on Renewable Power Generation*, Glasgow, 2023, in press

Principle 3- assess and maintain stability in operation.

Ability to present emission limits at the DC converter terminal Interface supporting single terminal testing of a global set of DC network stability criteria. Based on small signal, relative gain array, and emission transfer considerations



[3] Dong Chen and Benjamin Marshall, "Towards HVDC Interoperability – On Dominance of Nodal Impedance," *TechRxiv*, Oct, 2023

Multi-terminal Multi-vendor VSC HVDC demonstration.

- **How we did this.**
  - **Three** strands to approach-

interfacing

Alignments with other international activities

Bilateral vendor activities

Virtual replica delivery & contracting

Technical requirement clarification and process discussion & agreement

+

GB TSOs

Vendors

Monthly GB interoperability expert group

Simulation, control approach and testing

Process, management of IP

Dissemination of approach, models, test benches and activities

+

International research on interoperability

TSOs across Europe & internationally

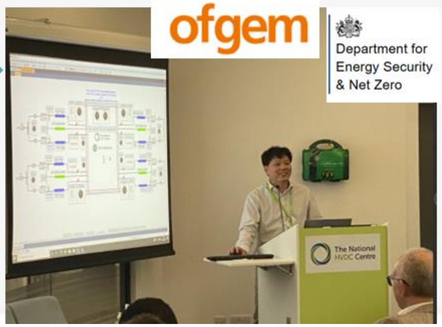
Wider dissemination

CIGRE, IEEE, IEC,IET.

GB HND, MPI/NSI/ Energy Islands

analyse → Propose → discuss → test → discuss → improve

Respecting Vendor IP, deliver & demonstrate TSO function needs



  - **Workshops, Tutorials and webinars delivered- more planned. Final reporting later this year.**

- **Future work (Network DC et al) on a similar basis**

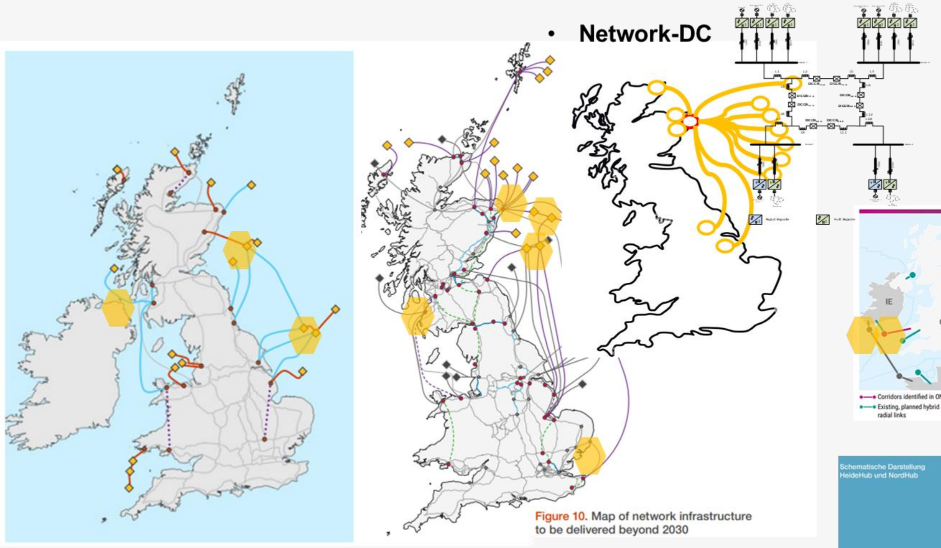
Multi-terminal Multi-vendor VSC HVDC demonstration.

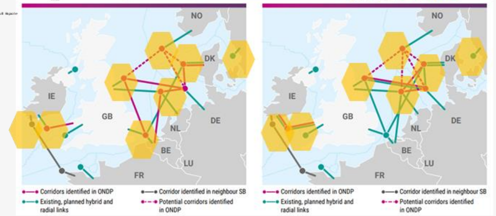
- **How we got here.**

2013	Caithness-Moray - Shetland	Testing, operational support, replica hosting
2014	BEST PATHS	Recruited staff, knowledge exchange, Cardiff university partner
2016	PROMOTi oN	Project partner, WP lead, testing, specification
2018	Johann-Svestrup	RTEi collaborative partner with centre-knowledge exchanges
2019	CIGRE B4.81	WG member & section author
2020	COMPO SITE	Partnered with RTEi & GB TSOs
2020	GB offshore co-ordination project	RTEi collaborative partner, knowledge exchanges
2021	BEIS HVDC R&D	Interoperability priorities to enable offshore
2021	Global PST	Modelling for interoperability
2021	CIGRE B4.85	Represented on WG
2021	US DOE (eastern offshore)	Expert advisor
2021	Ready4 DC	Advisory Board
2022	Project Aquila	Functional designs, control principles, testing, operational support, replica hosting
2022	INTEROPERA	Advisory Board
	Future	Active discussions across industry for design support, hosting & testing of HND solutions

Growth of DC systems.

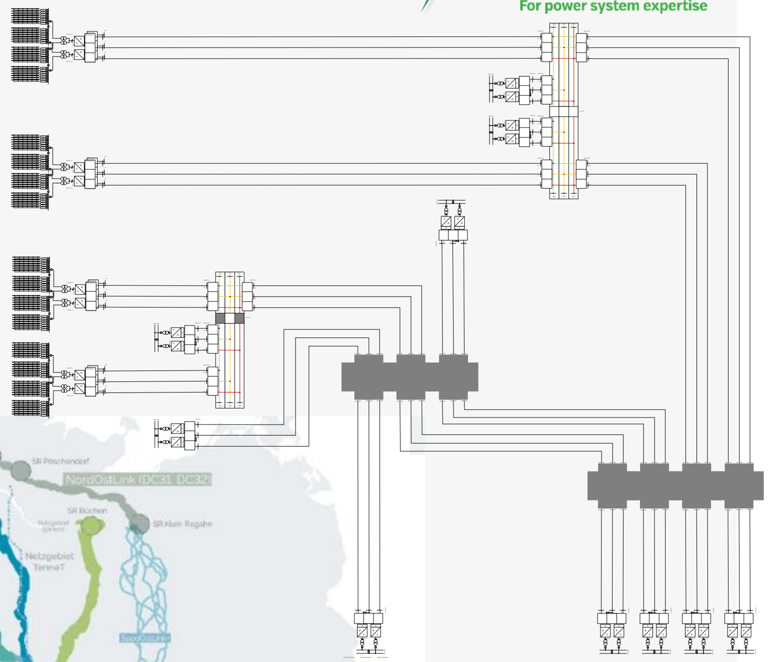
- The future is now!

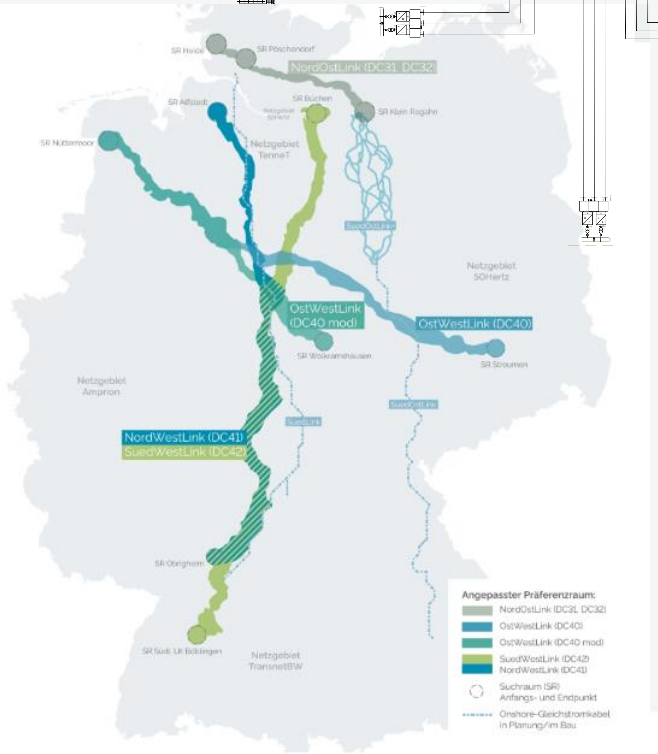




- **HND phases**---→?

DC Network reinforcements where **Project Aquila unlocks solutions**

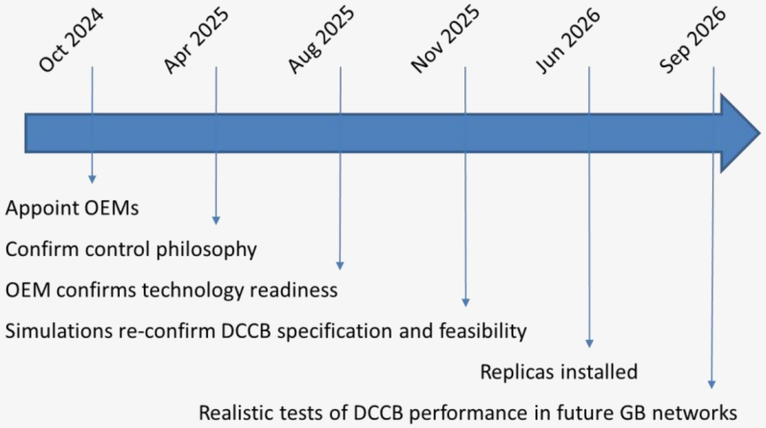


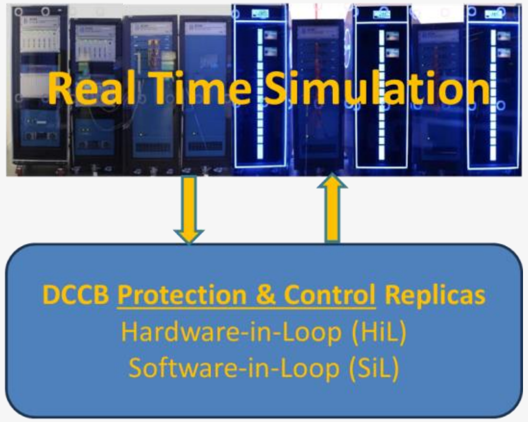


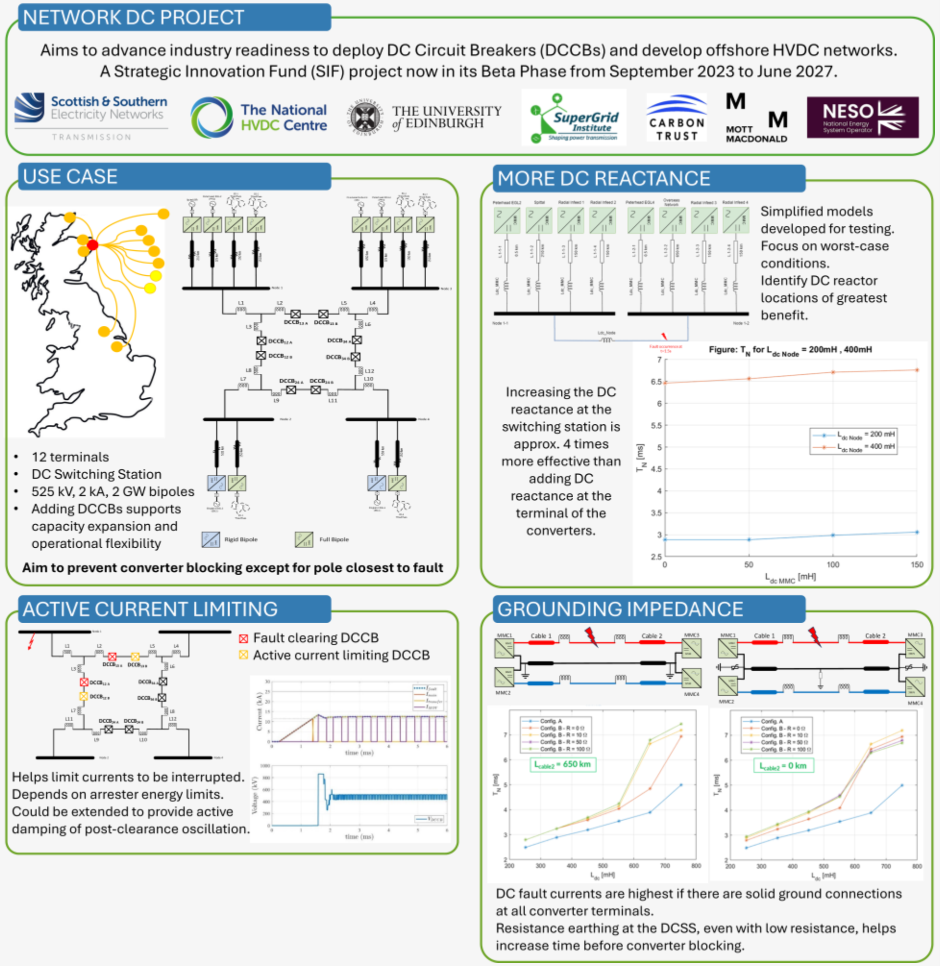
- Networks needing Multi-vendor & DCCB at scale

Growth of DC systems- DCCB.

- The progress of Network-DC; vendor agnostic DCCB specification & integration as a network grows.







- Philosophy and testing process confirmed
- OEMs identified and contracting to support next steps

Growth of DC systems.

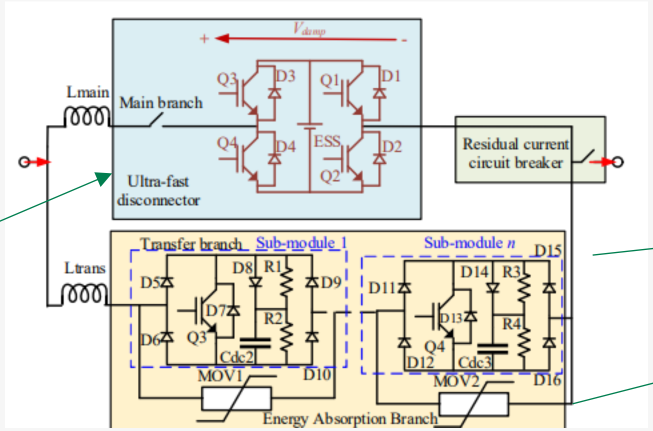
- Enabling DCCBs- related considerations.

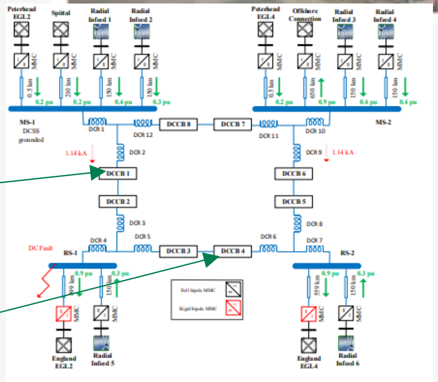
- Protection IED capabilities →

PROMOTioN IEDs

- Fault limiters →

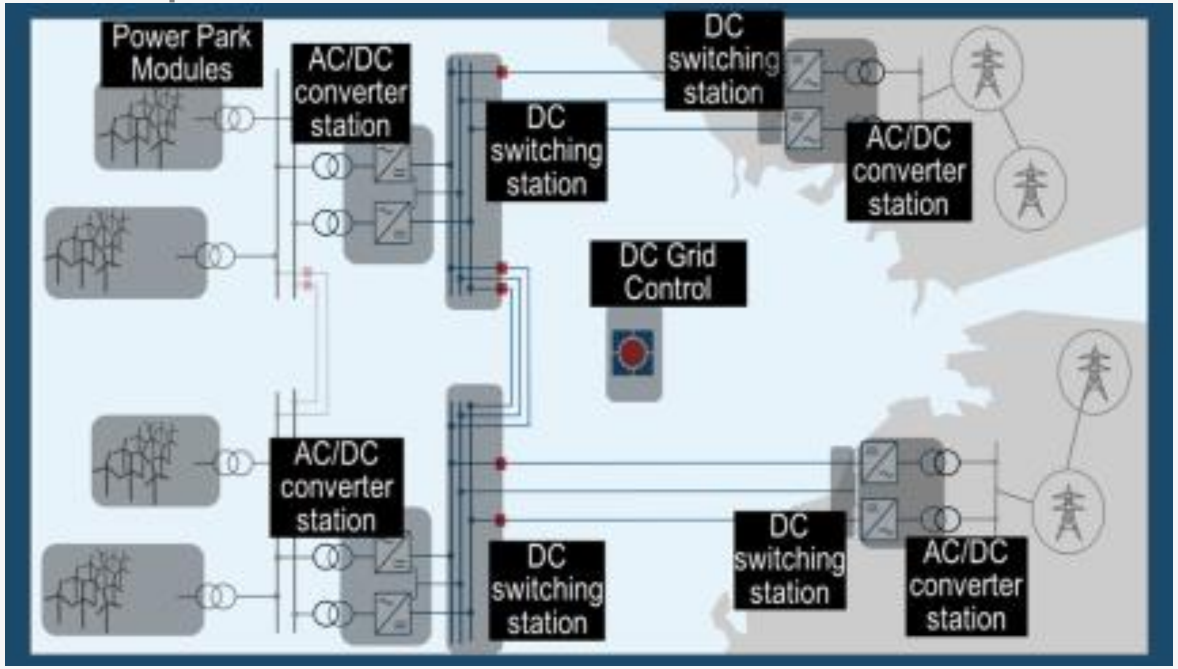
- Damping support

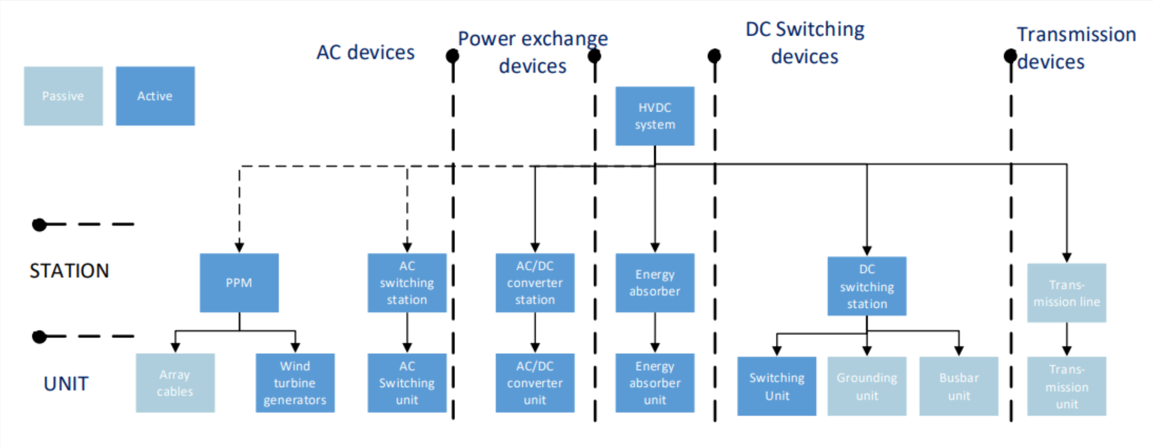




DC networks Components and specifications

- InterOpera provides additional clarity on DC component functions and specification areas.

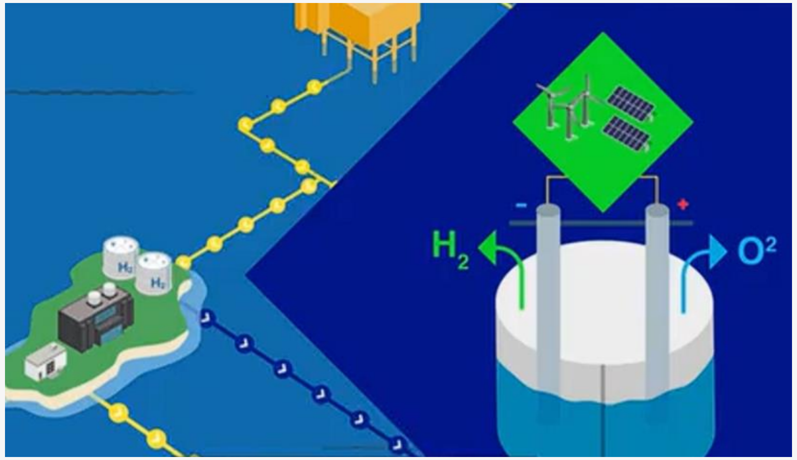


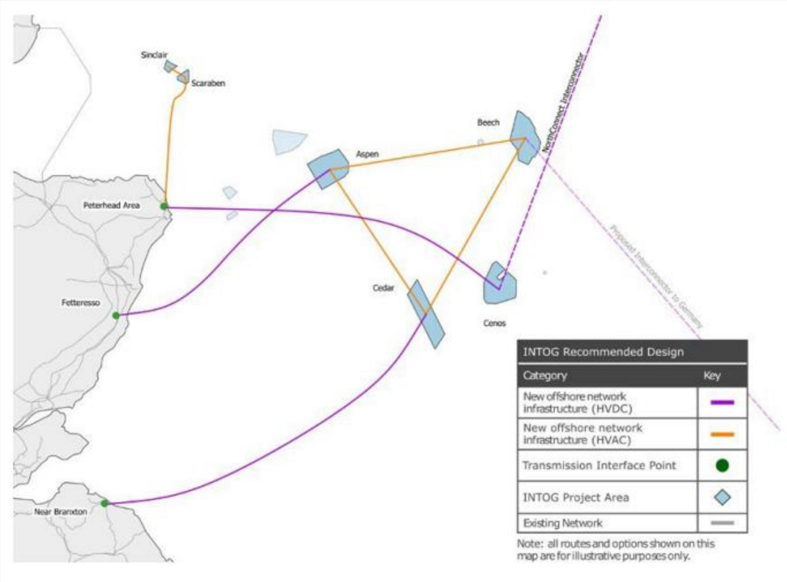


- Standardised terminologies and implementation concepts
- Aquila and Network provide foundations for control and performance specification respecting IP. It all fits together.

Practical DC interfacing- offshore.

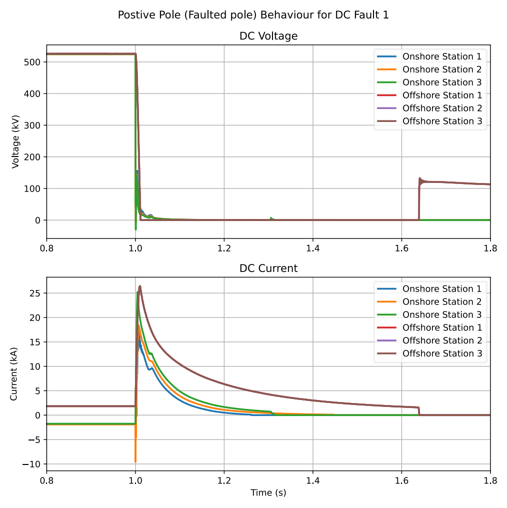
- Lots of new devices.
- Lots of new considerations-
  - Load security/ intermittency
  - Energisation/ impulse load management.
  - Legacy specification/interfacing (INTOG).

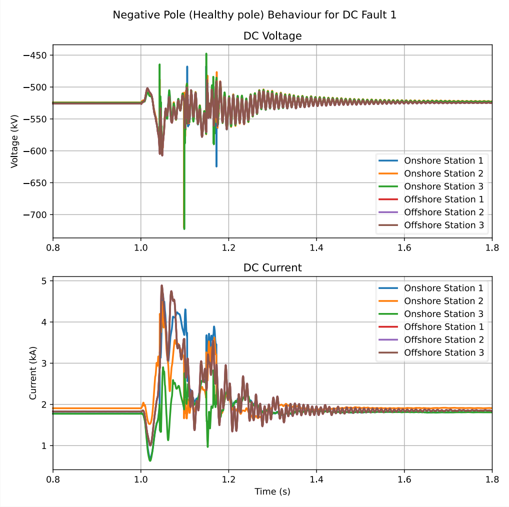


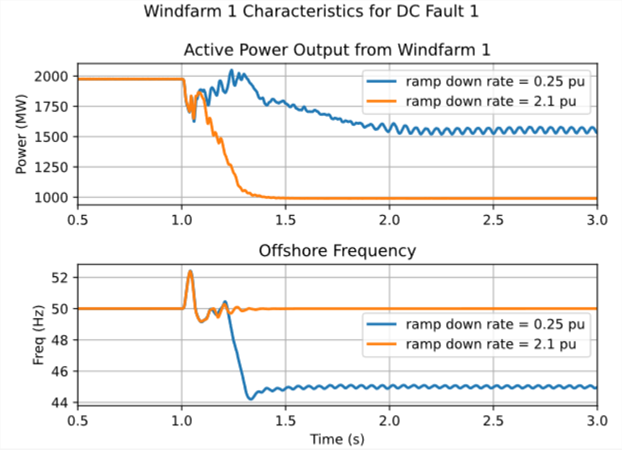


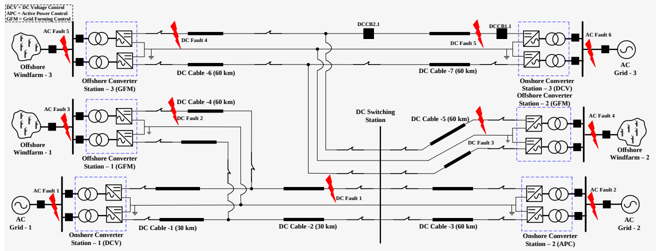
Practical DC interfacing- offshore.

- Load rejection
  - WTG want slow ramping- e.g. 0.25p.u./ s
  - but can go faster with crowbar action (AC fault or intertrip)
  - Intertrips risk uncertainty across large arrays.
  - But this is not a reason for AC chopper specification- would WTG really want that?
  - Offshore AC Hf/ HV crowbar operation specification?



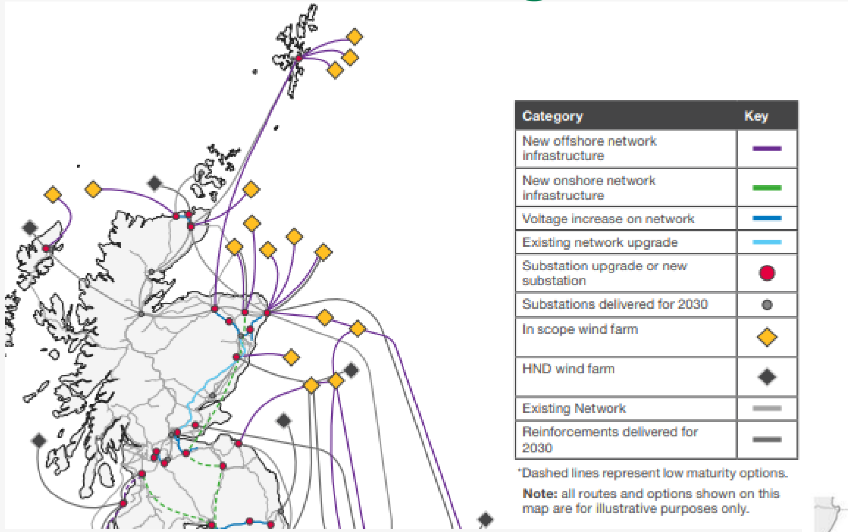


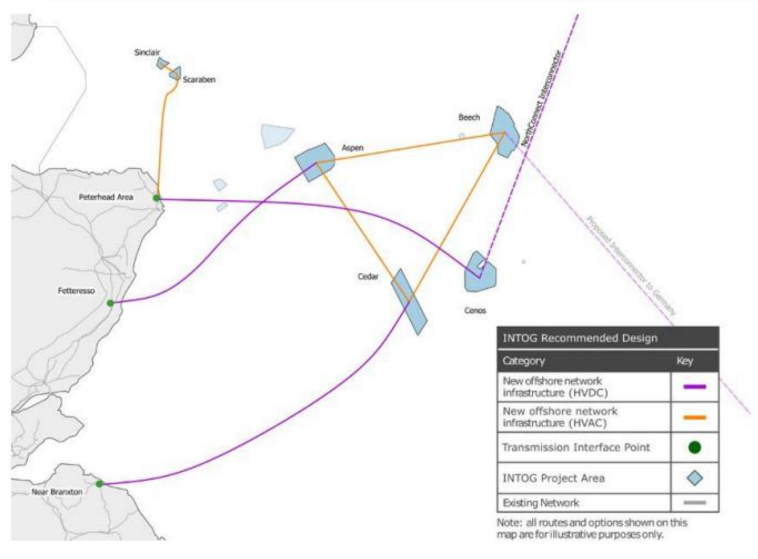




Practical DC network interfacing- offshore.

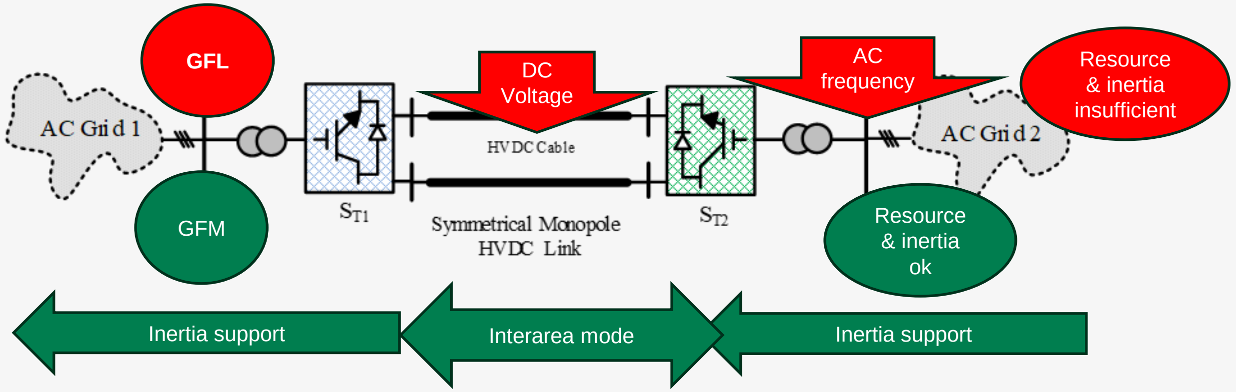
- Grid forming- across HVDC interfaces to common AC offshore islands
- Harmonic and inter-harmonic damping and allocations of roles.
- Code and standards issues- clarity needed

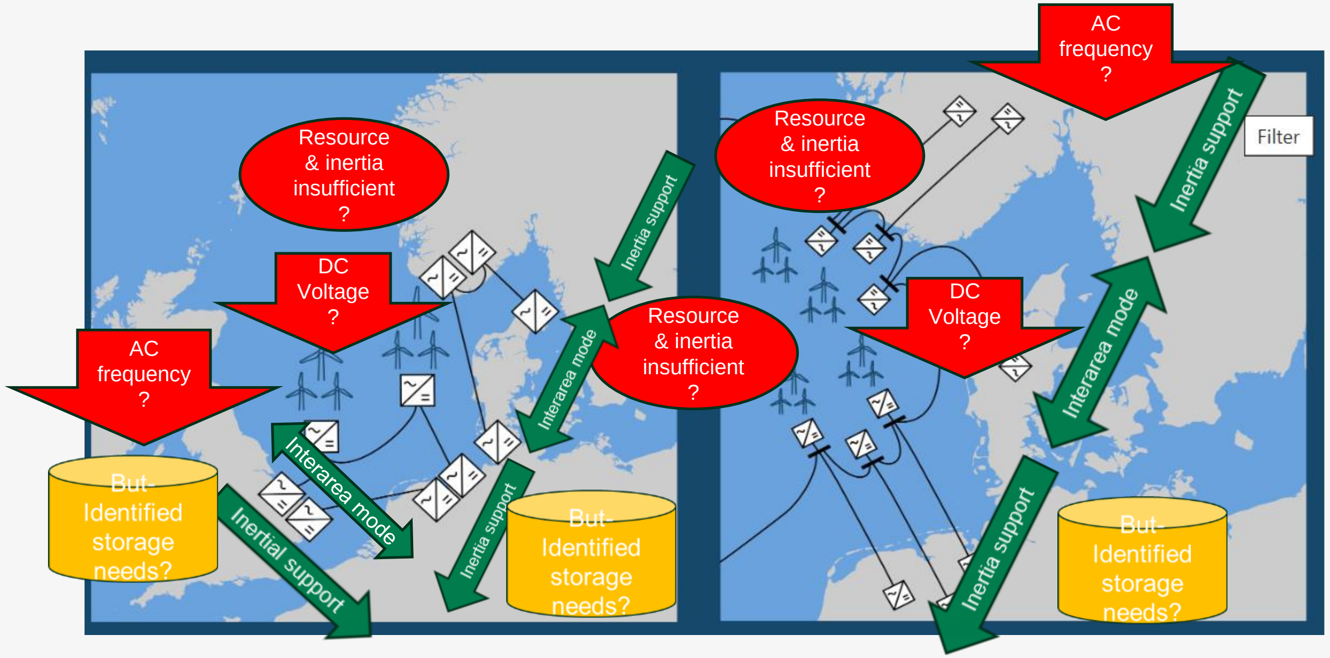




Practical DC network interfacing- onshore.

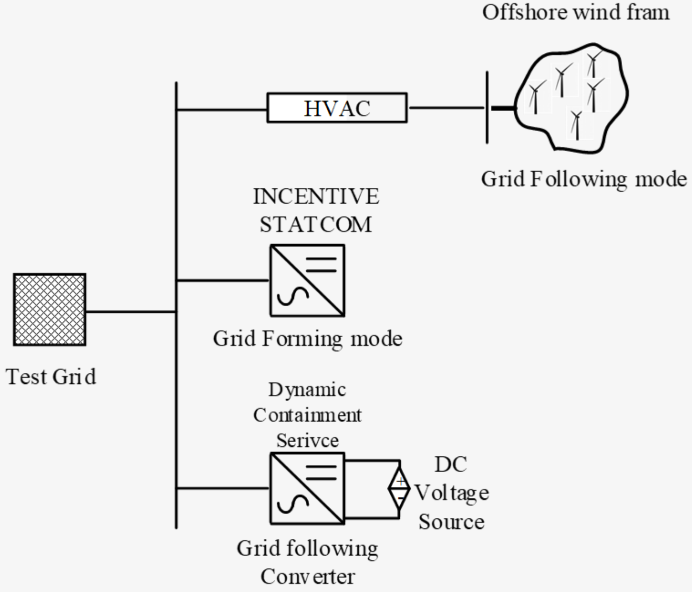
- Resource connection vs transmission
- Energy buffers?



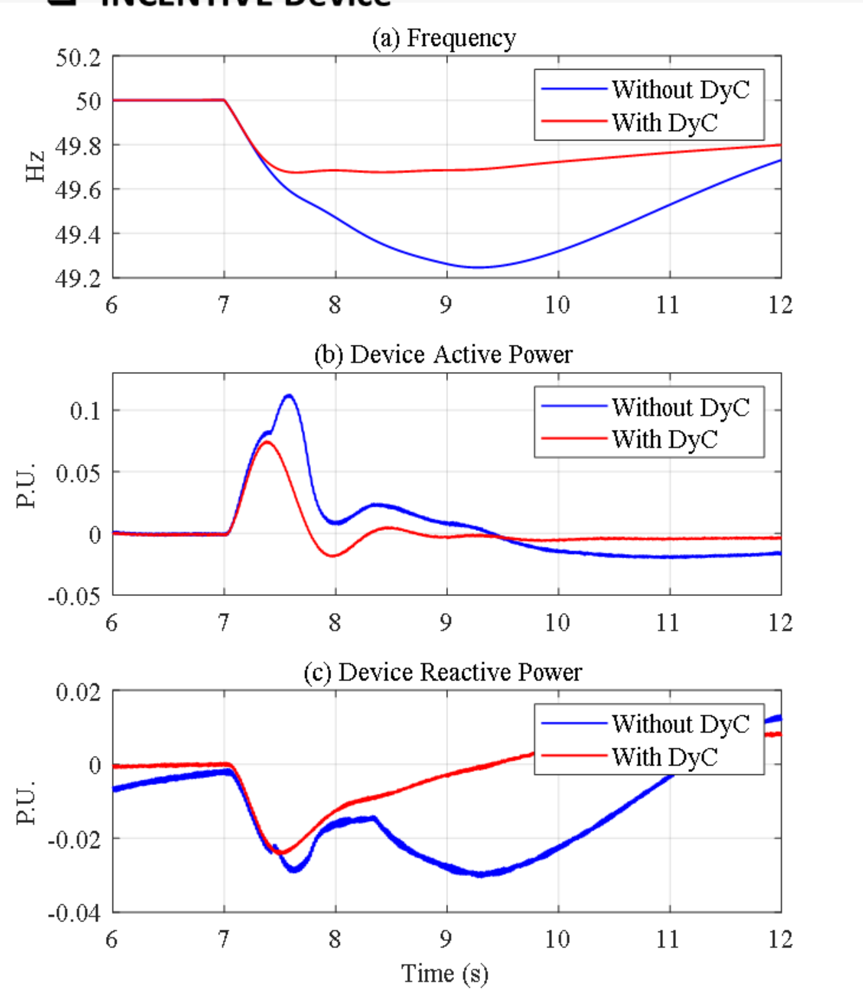


Practical DC network interfacing- onshore.

- The INCENTIVE project
- The storage don't need to be that big!
- What else could (some of these..) Energy buffers be used for?



❑ **INCENTIVE Device**



Black start, fault recovery, POD?

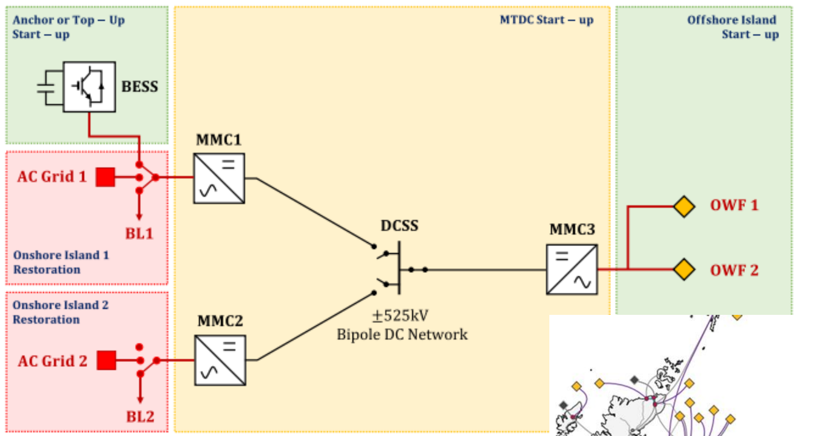
- One re-start asset can reconnect many offshore and onshore resources via the MTHVDC network.
- Many buffers can insulate HVDC network from a widespread AC system voltage depression.
- Energy buffer can be used for POD and other damping functions to avoid MTHVDC disturbance
- Just beginning to explore these applications.

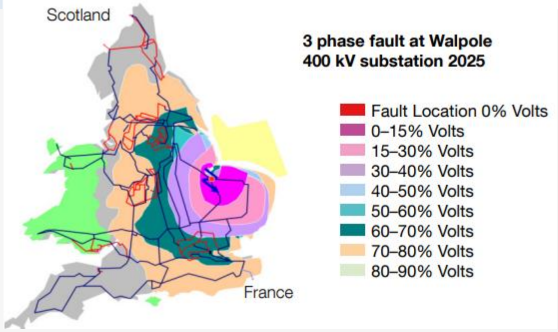
1. **Offshore island:** VSCs + AC assets
2. **MTDC:** MMCs, cables, DCSS
3. **Onshore system:** Supporting generation and block loads

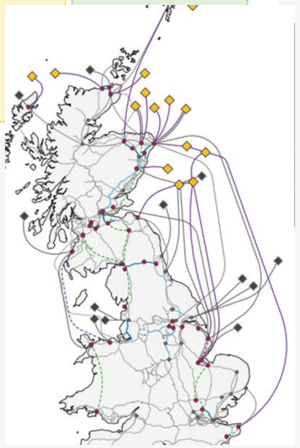
GC0156 Definitions: ESRS

Anchor: Generator with the ability to start-up and support reenergisation of the NETS without need for external voltage source

Top-Up: Generator not required to self-start, but can be ready to connect on instruction once external voltage source becomes available, to support demand reconnection







Complimenting resilience, optimising AC & DC system

- HVDC wise.
- Learning as we go.

1. Large, highly-meshed network

HVDC embedded in single synchronous zone, operating in parallel with AC corridors. System remains AC-dominated.

Investigate HVDC overlay grids, interaction risks, impact of failure.

Large model enables testing of analysis tools.

2. Small or medium synchronous area

HVDC to transfer power from wind-rich zones onshore and offshore. Connection of large offshore wind plus embedded links forming multi-terminal networks.

Investigate hybrid AC/DC grid dominated by HVDC and converters.

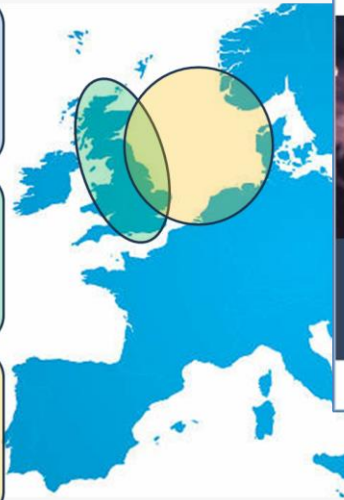
Smaller model enables analysis of whole system.

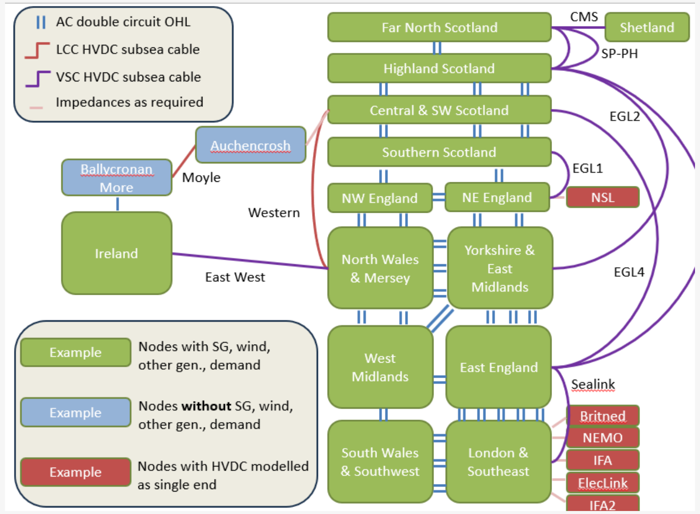
3. Multi-purpose offshore HVDC grid

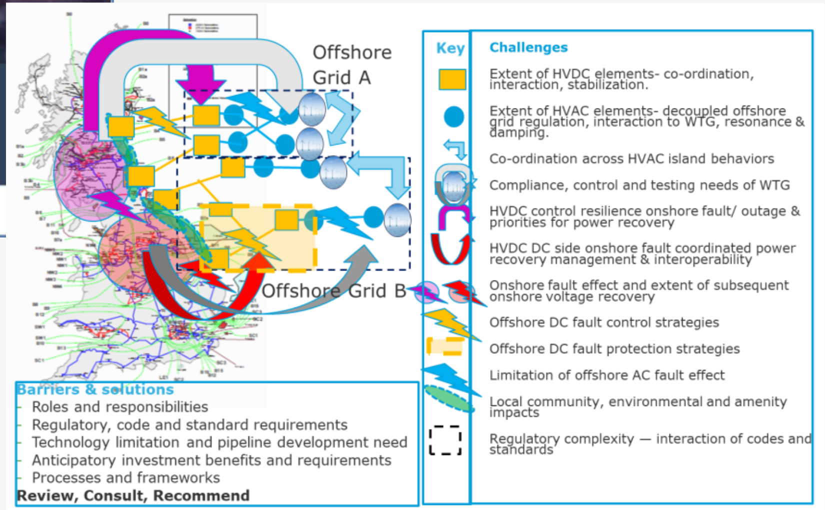
Offshore wind integration and inter-area energy trading.

Interconnection of use cases 1 and 2. Need to respect requirements of different areas. Opportunity for new inter-area services while maintaining firewall.

Model will interface to UC1 and UC2 models, or reduced equivalents.

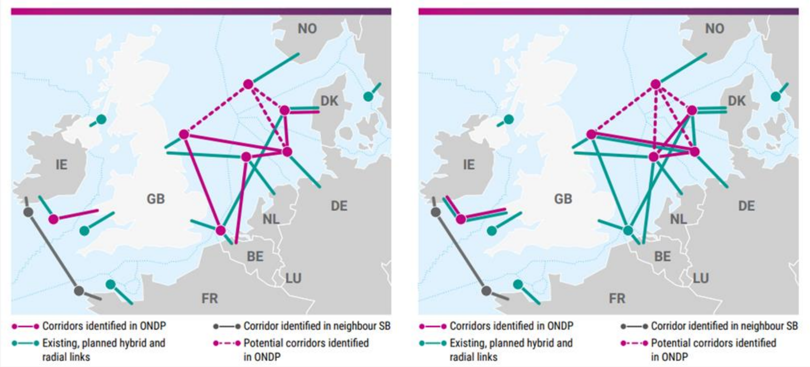


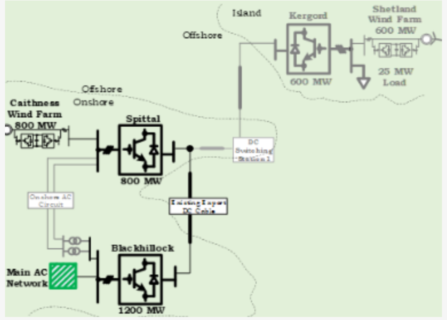




Conclusions.

- Economic, environmental and supply chain pressures all drive the DC network direction.
- Its happening/ happened! Staged and multi-vendor demonstration.
- Close now to DCCB demonstration too. We have a plan.
- Its about delivery. Yes, incremental & measured- but ultimately doing it- time to press the button.





NETWORK DC PROJECT

Aims to advance industry readiness to deploy DC Circuit Breakers (DCCBs) and develop offshore HVDC networks.
A Strategic Innovation Fund (SIF) project now in its Beta Phase from September 2023 to June 2027.

Scottish & Southern Electricity Networks TRANSMISSION | The National HVDC Centre | THE UNIVERSITY of EDINBURGH | SuperGrid Institute | CARBON TRUST | MOTT MACDONALD | NESO

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Thanks- any questions?
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