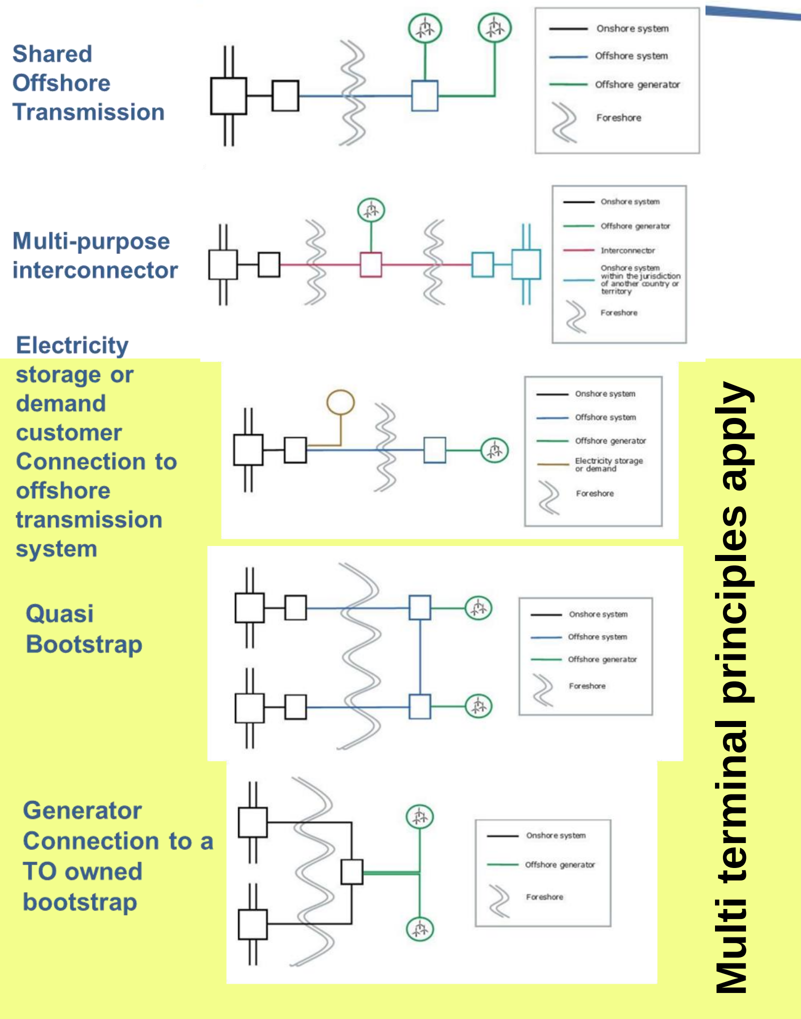
HVDC Operator's Forum 2022

The National HVDC Centre

Scottish & Southern Electricity Networks

Why multi terminal?

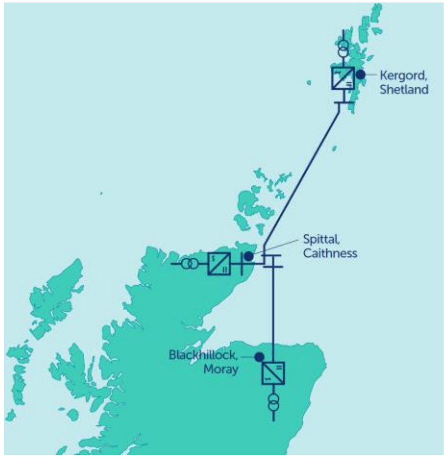
- **Environmental benefits**
  - Less convertor stations, lesser onshore footprint.
- **Cost benefits**
  - Less cable & converter than separate Point to Point
- **Multi- functional arrangements**
  - e.g. multi purpose interconnectors.
- **Flexibility & efficiency**
  - Fast and flexible re-distribution of power flow.

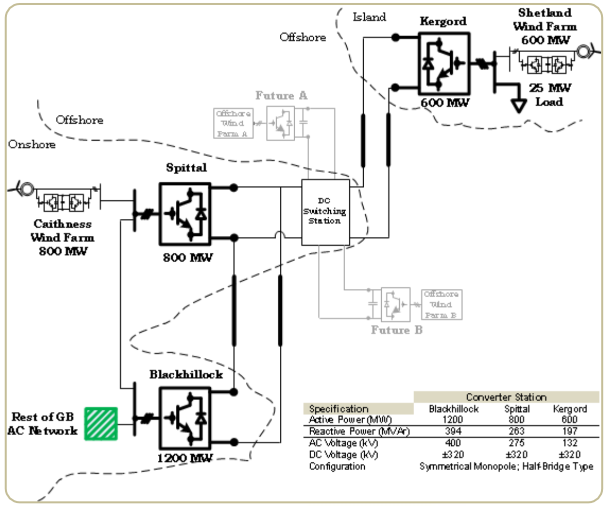


Diagrams from "Changes intended to bring about greater coordination in the development of offshore energy networks," Ofgem, July 2021

Examples of VSC multi terminal today

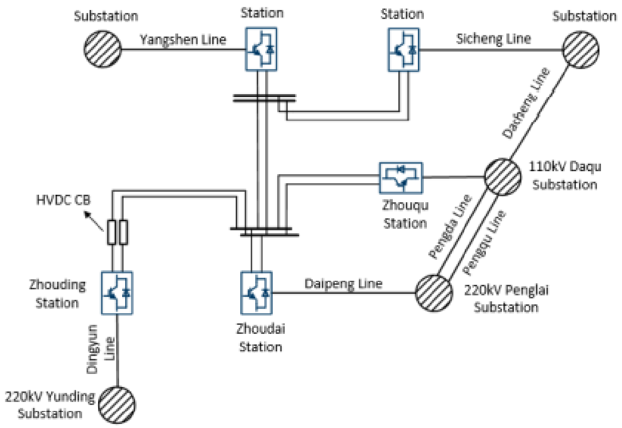
C-M-S (UK)- 3(+2) terminal



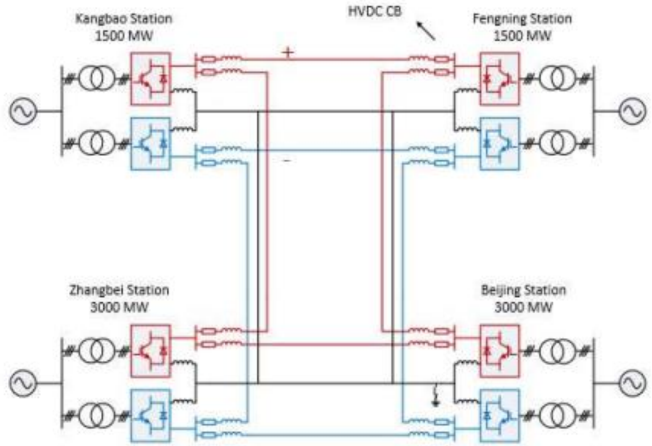


Specification	Converter Station		
	Blackhillock	Spittal	Kergord
Active Power (MW)	1200	800	600
Reactive Power (MVAr)	394	263	197
AC Voltage (kV)	400	275	132
DC Voltage (kV)	±320	±320	±320
Configuration	Symmetrical Monopole; Half-Bridge Type		

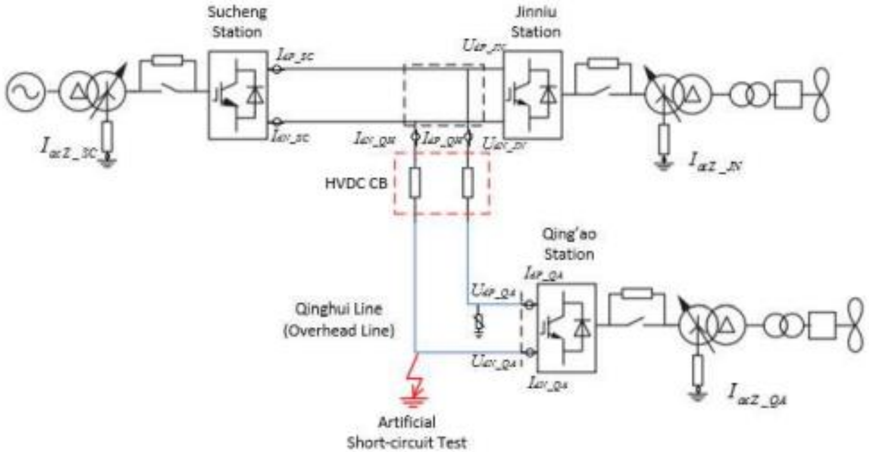
Zhoushan (China)- 5 terminal



Zhangbei (China)- 4 terminal

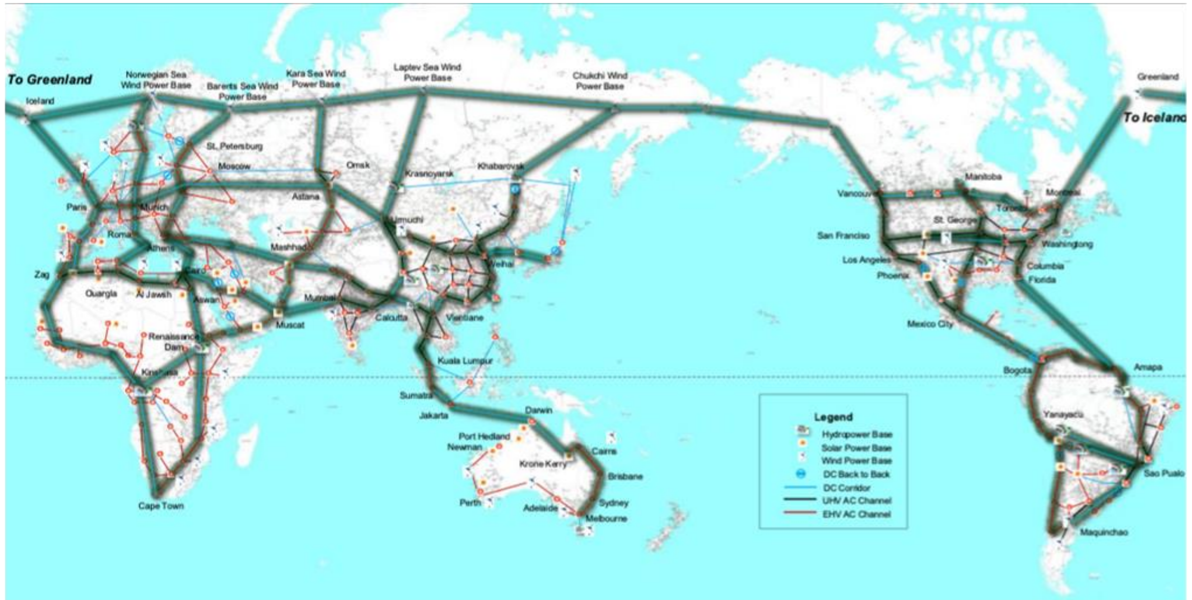


Nan'ao (China)- 3 terminal

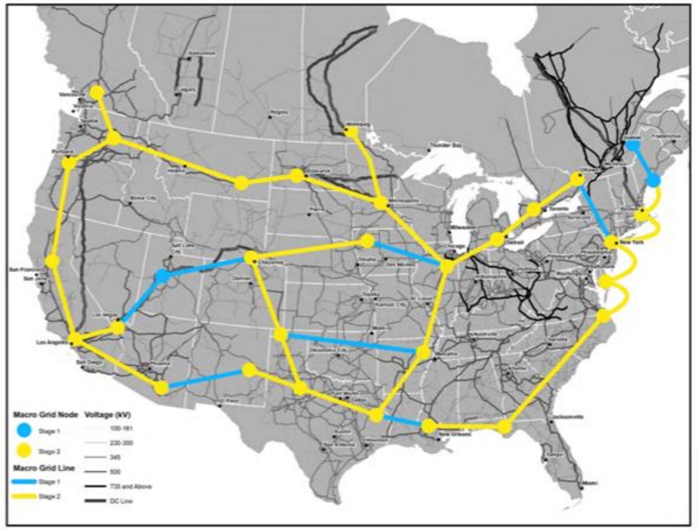


- Different purposes & design principles
- Multi-vendor has been achieved within Chinese systems, but not in a sustainable approach outside of China

DC networks envisaged:



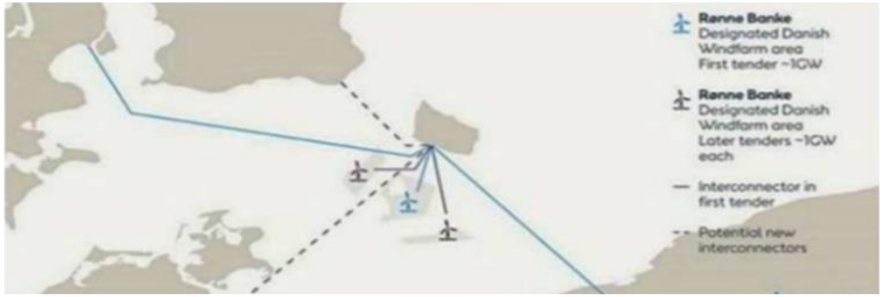
A Global overlay of trans-continental links?



US "Macro Grid" conceptual overlay

- Same basic considerations
- Challenges-
  - Multi-vendor
  - DCCB
  - Scale & Supply

North Sea, "DC mesh" concept



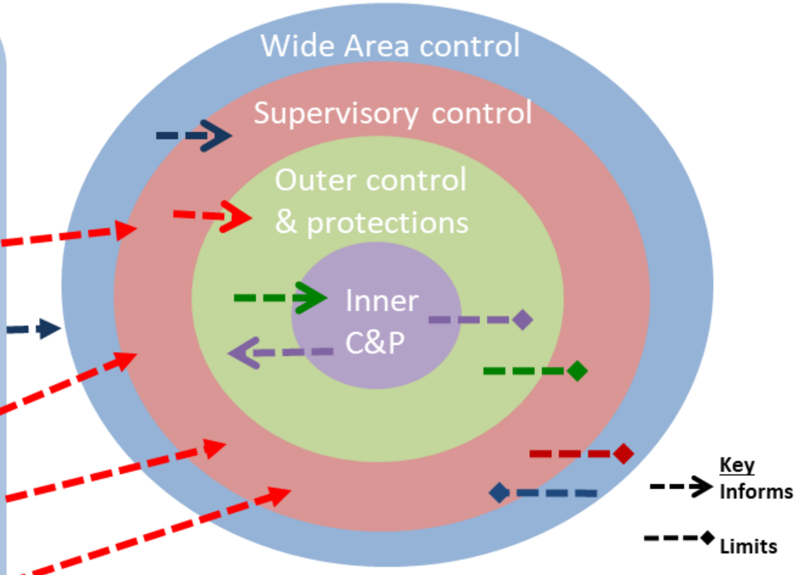
Western Baltic "DC Hub"

Eastern Baltic HVDC "spine"

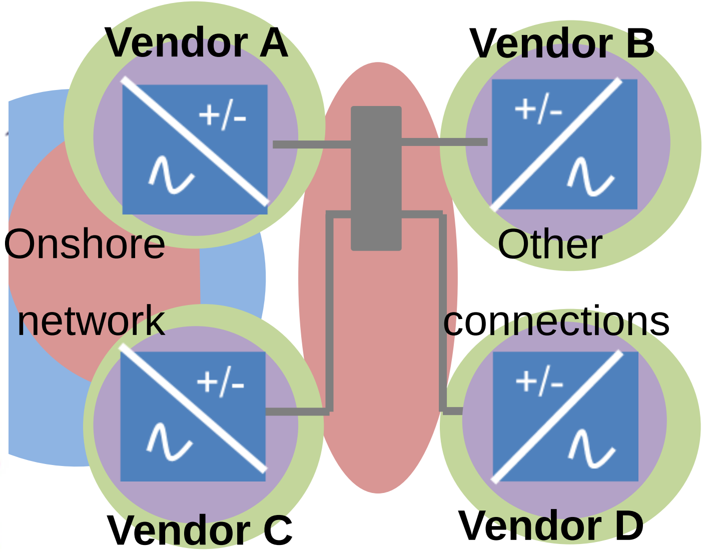
Principles of inter-operability:

Systems

Layers of Co-ordinated control by device



Outcome



Wide Area controls-
Frequency management, Oscillation damping, classical and non-classical voltage & angle stability, Thermal management. Protective relay actions?

Supervisory controls
Local interaction & control hunting management, management/ rationing of behaviours under limits; e.g. grid forming current limits & multiple disturbance cases

Outer Controls & Protection
+ Inner control loop C&P
Delivering AC network performance, respecting device and DC circuit needs, informed by Wide Area and Supervisory control needs together providing technical code compliant device behaviour, via proprietor IP solutions

Pillars of enhanced regional stability across GB system
Via co-ordinated and compatible devices and network oriented controls and protection solutions.

common interfacing

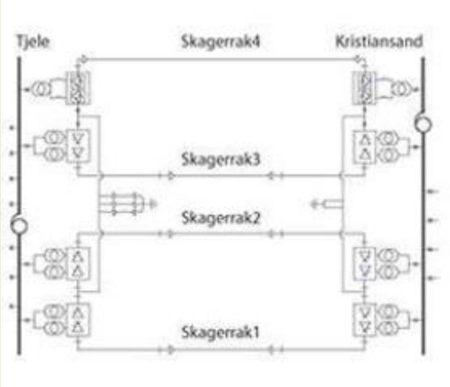
The importance of interoperability:

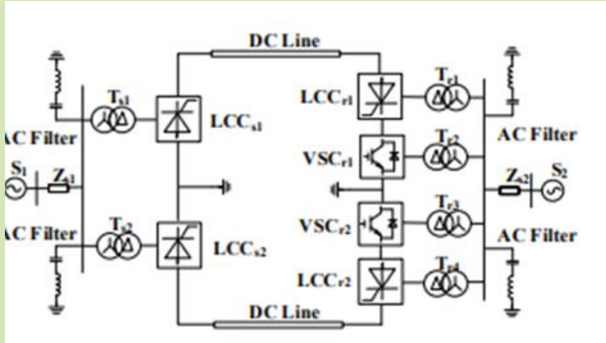
- **Supply challenges**
  - Currently one vendor needs to deliver all stages of HVDC development or significant costs and risks occur
  - No one supplier has the capability to deliver everything needed across GB like this
  - Provides new asset management flexibilities
  - Analogy to an AC system - replacing/ adding a transformer would not be single vendor or rely on a historic design approach; HVDC currently is that
- **Increasing consistency & growth**
  - Allows technology growth at scale to common objectives
  - More HVDC projects to deliver more capabilities either generate complementary risks or complementary solutions through consistency of functions
  - Today inter-operability is possible but is achieved ad-hoc .it needs to be repeatable and scale-able

Busting the “myths” around interoperability:

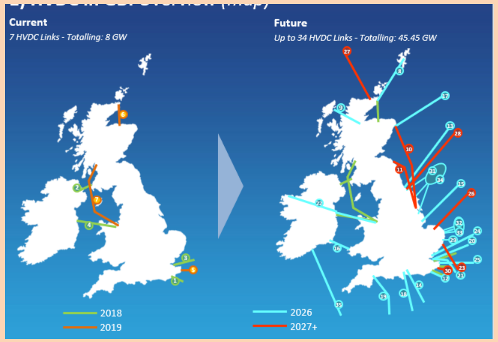
The National HVDC Centre

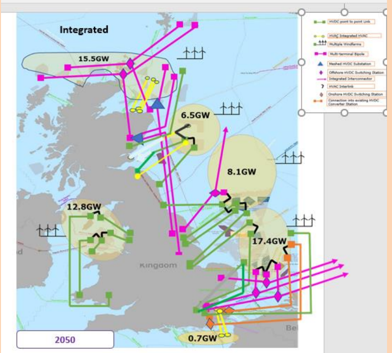
Managing technological interoperability…





Managing scale & range of interaction risk





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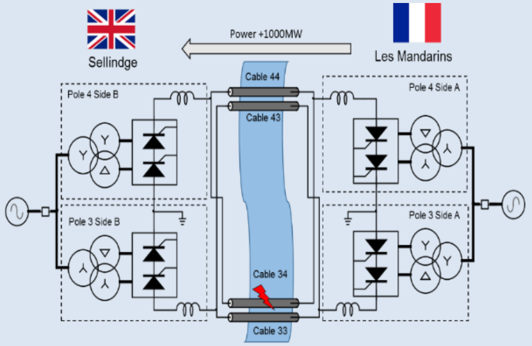
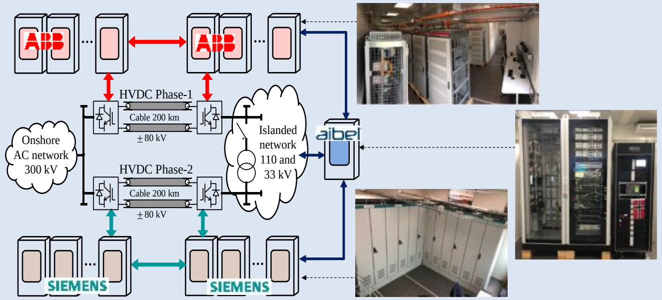
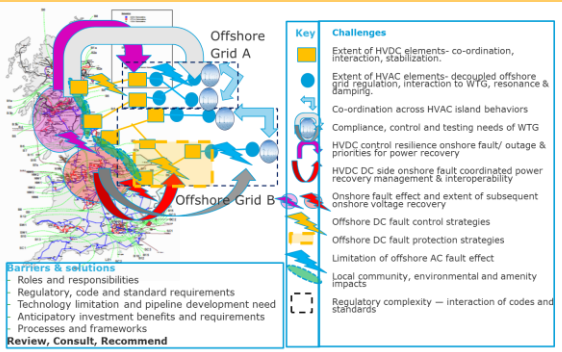
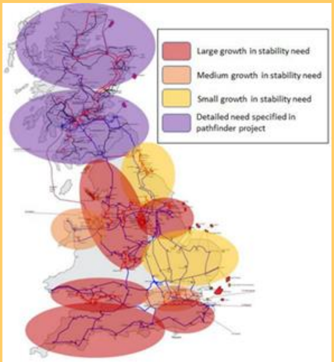
Managing manufacturer interoperability…





Managing complex topology/requirements





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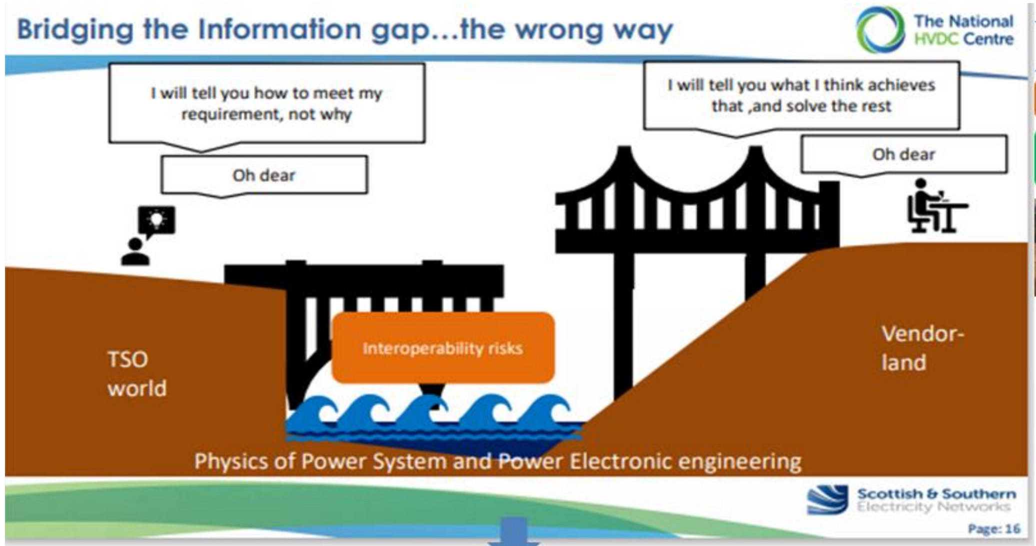
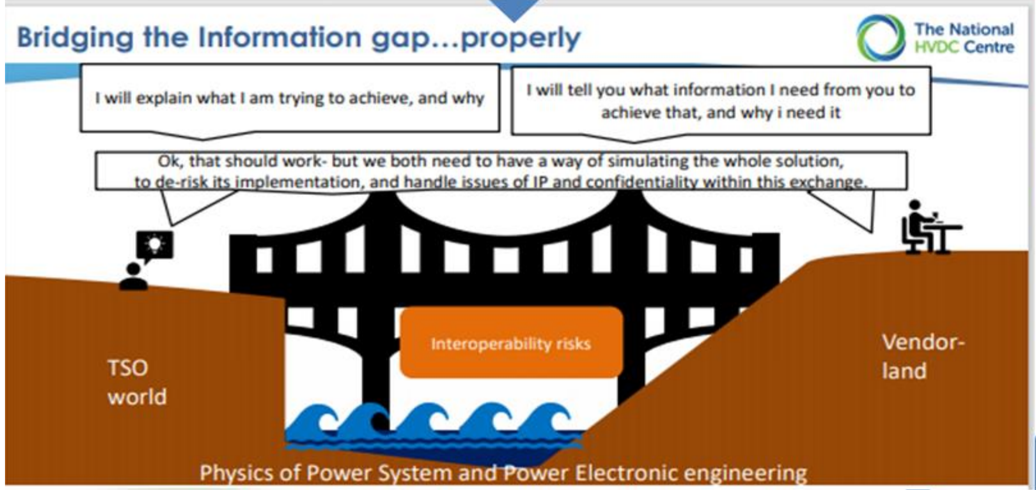
- These are challenges of the past
now its not about how to manage, but more to continue to refine and improve efficiencies of approach..

- These are challenges of the future; relate to control and protection clarity; overcoming the “Information gap”

Bridging the information gap of interoperability:





To early 2000s	c. 2005 onwards	c. 2013 onwards	today
1st Gen C&P	2nd Gen C&P	3rd Gen C&P	4th Gen C&P
LCC & other Thyristor based technologies	Type 1-4 WTG transition	VSC & other IGBT based technologies	VSC & other IGBT based technologies, Storage devices

"Old School" verification process- oriented around Synchronous generation-no longer sufficient…

Challenge	Driver	Emergence	Effect
Short ciruit strength	Current loop control approach, regional inertia deficits	Defining new stability support	Wider stability impact from events, protection challenges, voltage recovery & regulation, power quality
Frequency domain	Network and control modes	Control interaction & tuning needs	Undamped oscillation, protective disconnection
Classical instability	PLL tracking, limited Q support.	increased need for EMT study	increased need for EMT study
Inertia	Convertor based technology displacement	Defining frequency control needs	Frequency regulation & containment+ inter-area effects in distribution

New verifications with more detailed and more extensive simulation needs

unifi consortium | AEMO | Rte | The National HVDC Centre — Hosted simulation Environments

How the Centre has addressed interoperability in PROMOTioN:

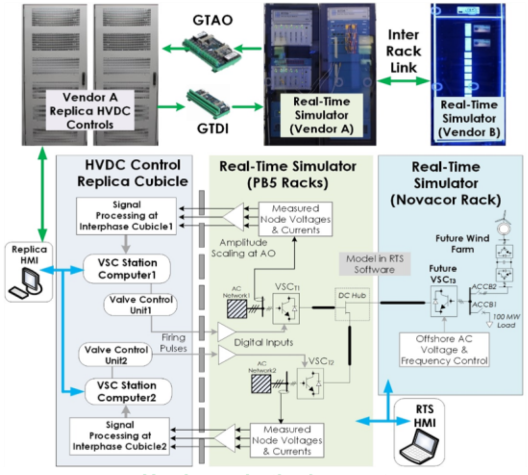
The National HVDC Centre

Testing VSC-HVDC Supplied by Different Manufacturers

Real Time Simulation with Hardware-in-the-Loop Replica HVDC C&P systems

- Used for de-risking multi-terminal HVDC C&P systems from different suppliers (Vendor A and B).
  - Two existing HVDC terminals (VSC_{11} & VSC_{12}) represented using hardware replica C&P system
  - Additional terminal (VSC_{13}) is modelled using an open-source modular multi-level converter models.

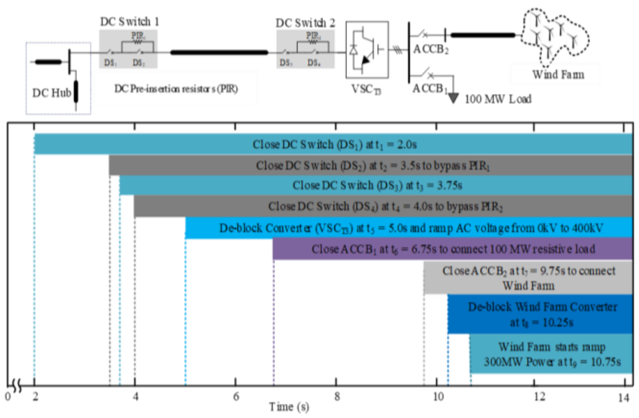
- Control Modes:
  - **VSC_{11}** regulates active power and AC voltage with reactive power droop control.
  - **VSC_{12}** controls DC voltage for power balance and regulates AC voltage with reactive power droop.
  - **VSC_{13}** creates offshore AC voltage with fixed frequency, magnitude and phase angle for connecting 100MW load and 300MW generation.



Hardware in the loop set-up

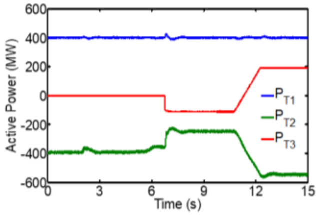
Experimental Demonstration Results

- VSC_{13} energisation and operation test sequence

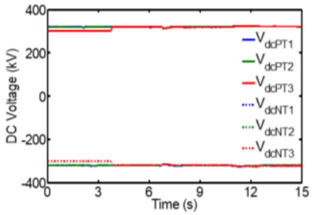


- Stable system performance achieved for multi-vendor HVDC scheme & RTS with hardware replica C&P preserved IP of different suppliers.

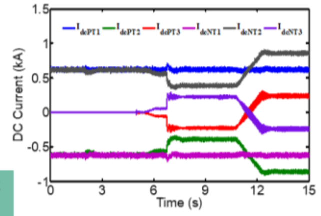
- Active Power



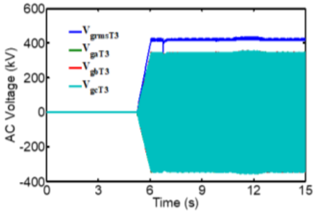
- DC Voltage



- DC Current



- AC Voltage



Conclusions:

- In principle other vendor control approaches may be integrated into a multi-vendor arrangement- with performance demonstrated and tested via RT-CHIL simulation techniques
- Model detail is critical
- Clarity on control mode is critical
- Interfaces between controls is critical

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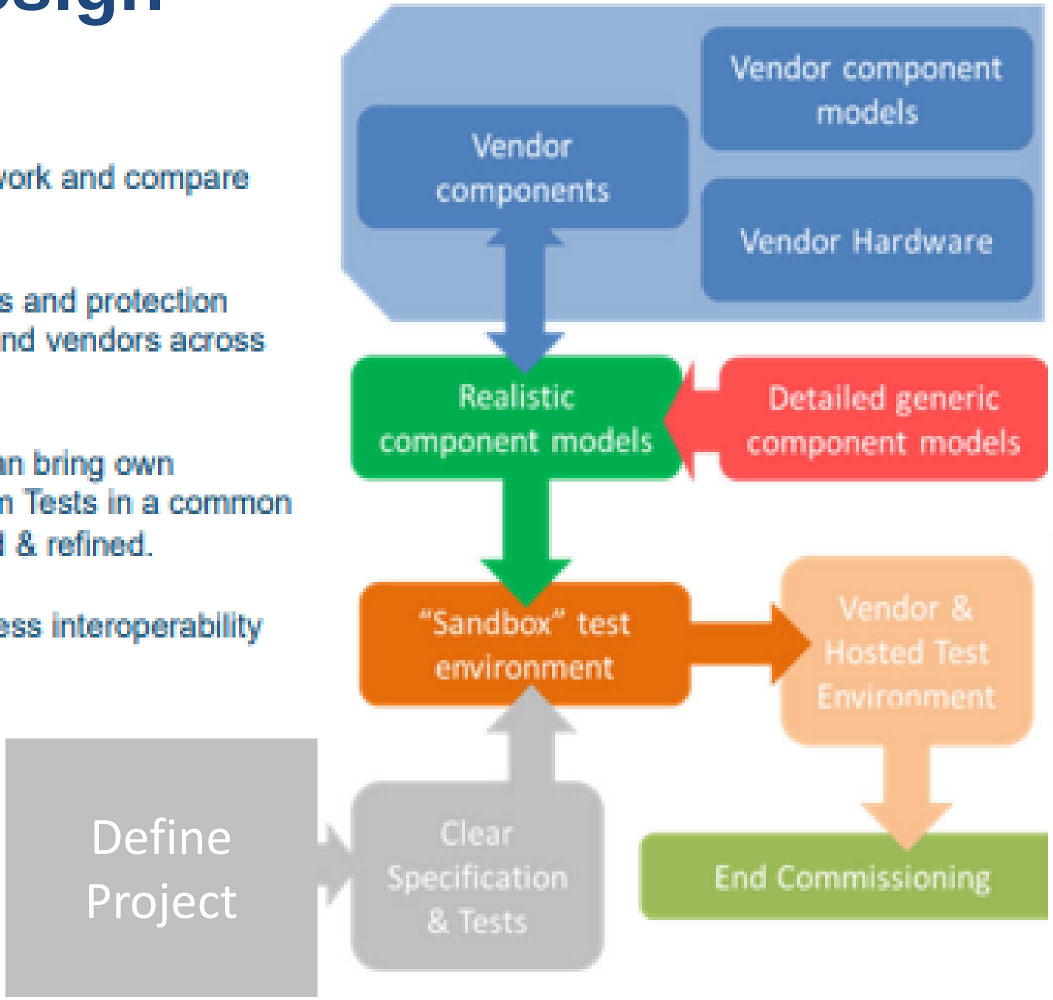
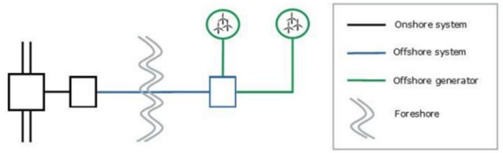
GB Functional Design Project

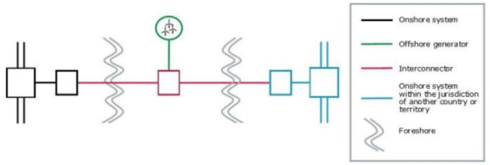
- **Reference models –** complete, representative, work and compare with real equipment
- **Network model** – realistic, including real controls and protection equipment and systems. Able to train operators and vendors across switch-overs
- **Hosted simulation Environment** – Suppliers can bring own models/ hardware and conduct Functional System Tests in a common environment, allowing interoperability to be tested & refined.
- **Robustness** – we have clear specific tests to stress interoperability developed.
- **Insurance policy** if tests not met, operates in single vendor mode, still meets NOA needs.



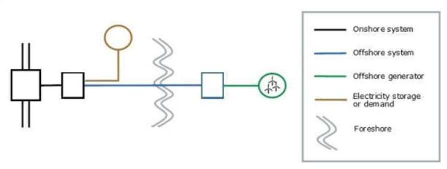
Shared Offshore Transmission



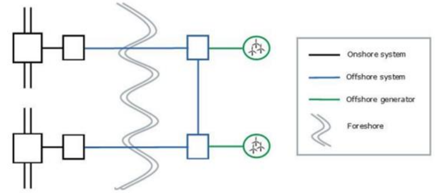
Multi-purpose interconnector



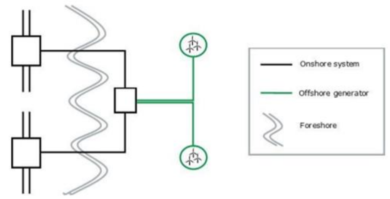
Electricity storage or demand customer Connection to offshore transmission system



Quasi Bootstrap



Generator Connection to a TO owned bootstrap



Delivering Multi-terminal Multi-vendor in GB:

GB Interoperability Expert Working Group

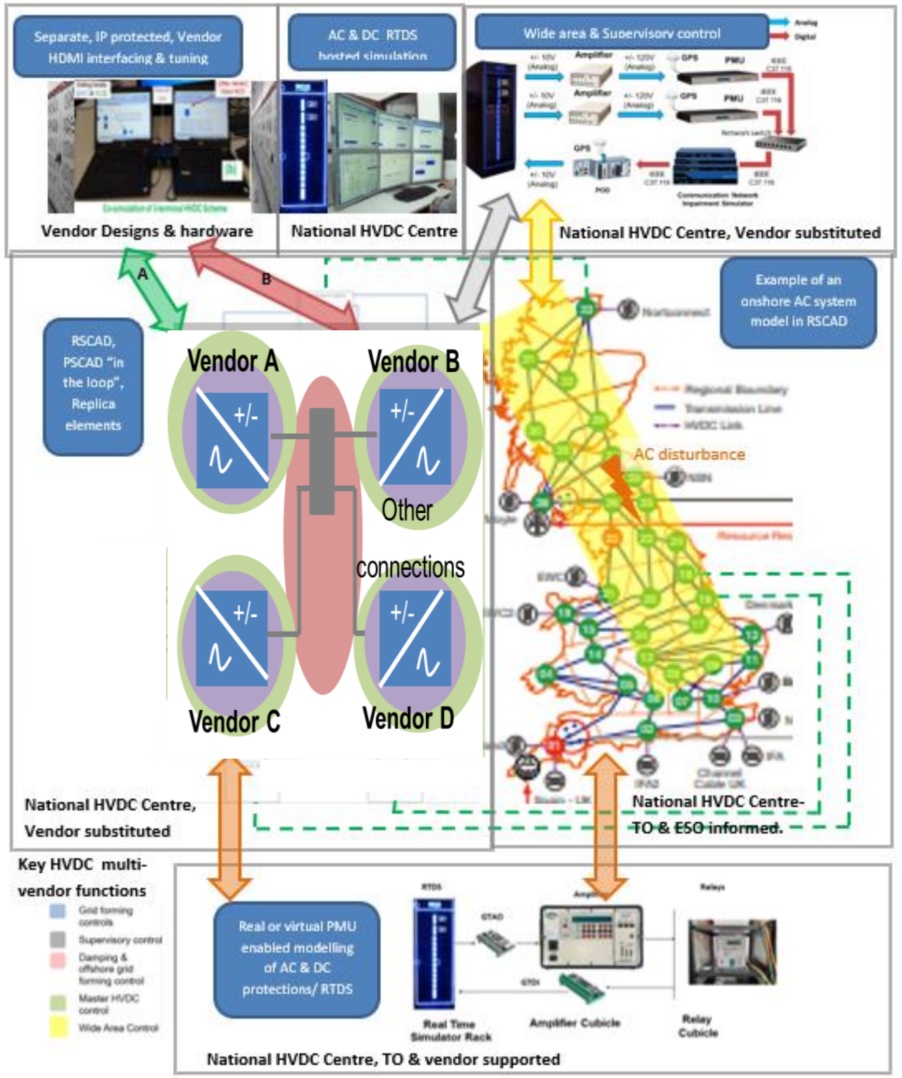
TOs & ESO ⟷ National HVDC centre Functional Design Project ⟷ Vendors

National HVDC Centre -hosted Multi-vendor Simulation & testing

1st Multi-vendor project opportunity in GB

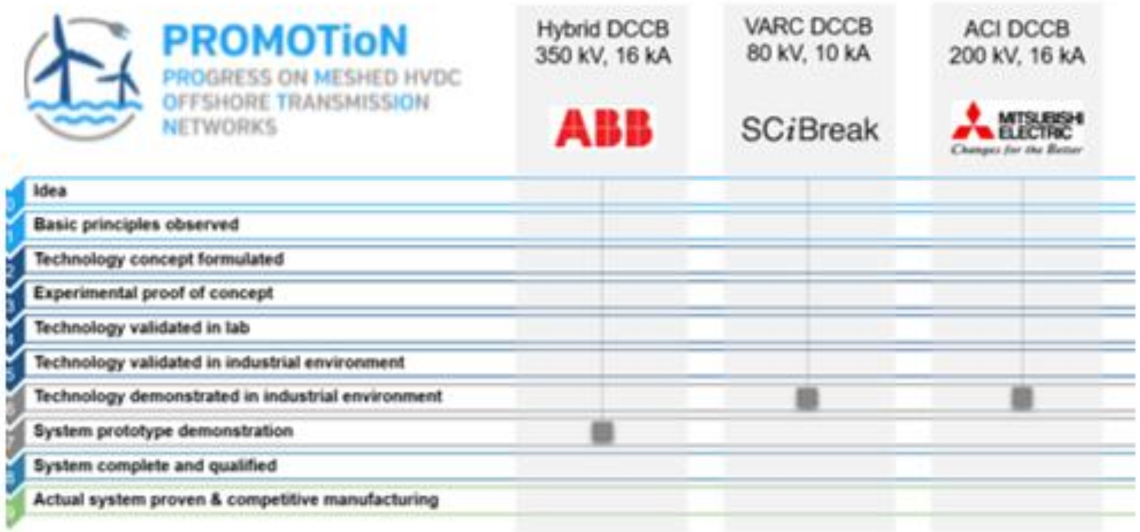
- Performance testing and verification of Vendor solutions
- Interface Specifications for Multi-vendor in GB
- Delivery of 1st Multi-vendor Multi-terminal project outside of China, in GB

Unlocking of Multi-terminal multi vendor delivery for GB



DCCBs: addressing “first adopter” risk

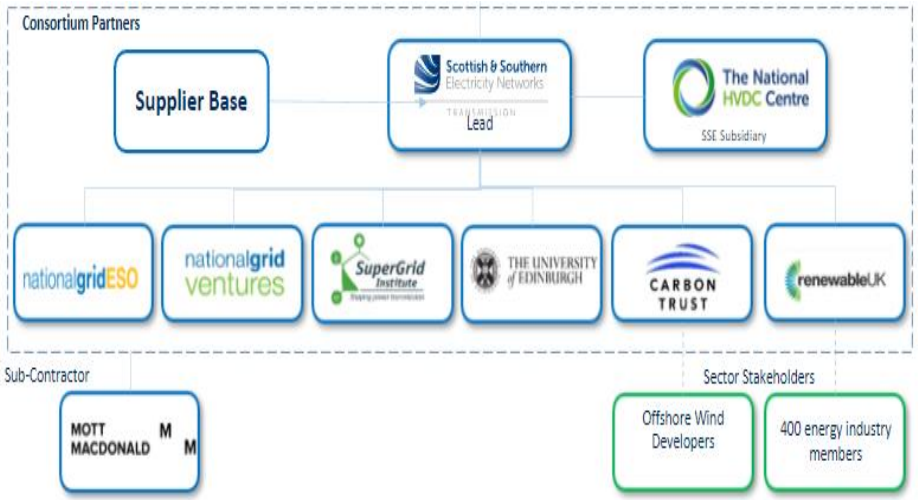
PROMOTioN delivered **theoretical** options- These cannot solve **real** project specification problems, without adopting the Chinese **live network testing** approach. Technology stuck at TRL6/7 until we can adopt and use in GB.



Network DC = Realistic test scenarios, **realistic** specifications, **realistic** project implementation plans real demonstration now needed aligned to Western project norms

Network-DC: an overview

The National HVDC Centre



Discovery Phase

Defining the activities

- Front end engineering- **de-risking the doing**
- **Planning** next phases and **prioritising actions**
- Identifying **Critical path** & **key risks** & **opportunities**

Defining the Value

- **Cost Benefit Analysis** across **Use Cases** and **Counterfactuals**
- Identifying **key value areas** and **actions.**
- Identifying how **CBA can support DC Network development** decisions

Engaging with Suppliers

- Identify **future supplier partners** in Alpha and Beta across those that can deliver these solutions.
- Identify a **plan** for that **engagement**- when, what, & how.

Alpha Phase

Develop/ apply specification

- **Codes, standards,** functions, performance all defined
- **Modelling, simulation, key tests & expectations**
- **Engage** with **supplier base** on the above

Design the solutions & implementation

- Identify **real examples** & focussed **proposals**
- **Evaluate, optimise** and **specify** a supplier "tender"
- **Engage** with **supplier base** on above

Beta phase

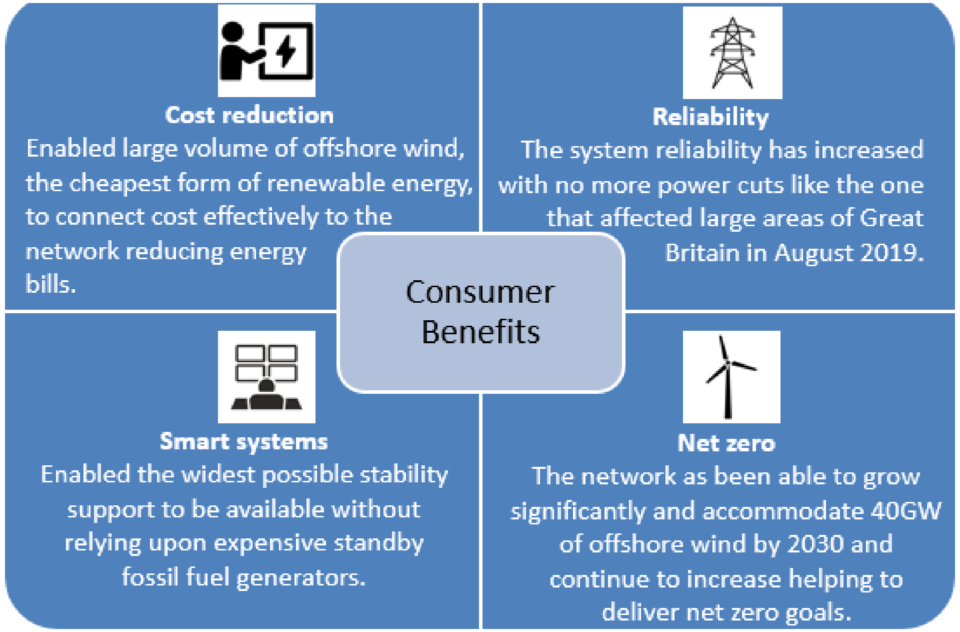
Evaluate, refine support and test the Supplier developed options- look for real opportunities

- **Support suppliers** in identifying **real solutions**
- **Test**, simulate and **evaluate real performance**
- Identify **practical opportunities** and **address real risks**

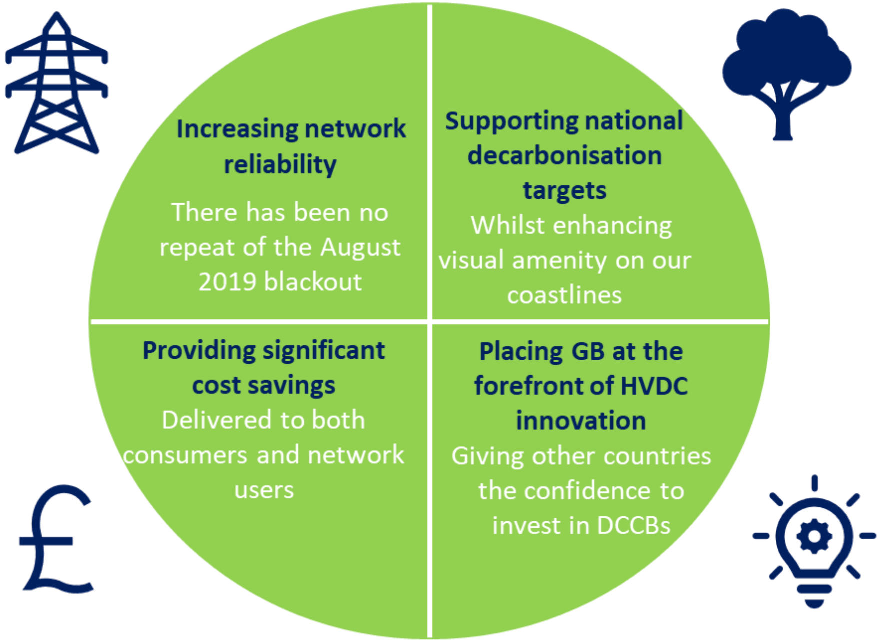
A future DC Network

Scottish & Southern Electricity Networks

Supporting DC network R&D in GB:



Yours sincerely,
The INCENTIVE team



Yours sincerely, **The Network DC Team**

- INCENTIVE- teaming short term energy reserves+ with HVDC to deliver **Inertia** and **network stability**
- Network-DC; delivering the Front-End Engineering and CBA **de-risking for DC Circuit Breaker implementation**

Supporting Multi-terminal Multi-vendor in Europe:


HORIZON 2020

European Commission

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NEWS ANNOUNCEMENT | 13 April 2021

New SET Plan action on high voltage direct current (HVDC)

The SET Plan secretariat is establishing a technical working group on high voltage direct current (HVDC). The technical working group will help to:

- align ongoing research, development and innovation actions and raise interest in HVDC systems and related power electronics at the national and EU level
- increase collaboration and coordination with SET Plan countries, ensuring their active involvement in the technology development.

HVDC is a power electronics (PE)- based technology that enables the transport of electricity over long distances and allows the integration of high shares of renewable energy sources (RES) in the actual alternative current (AC) energy system.

As stated in the offshore renewable energy strategy, the rollout of offshore wind and ocean energy, expected to take place in all EU sea basins, requires the development of energy-transportation infrastructure such as HVDC. The technical working group's goal is to support the development and deployment of HVDC and direct current (DC) technologies and systems within the AC grid to make the EU energy systems fit for the future.

For more information, please contact the SET Plan secretariat.

READY4DC

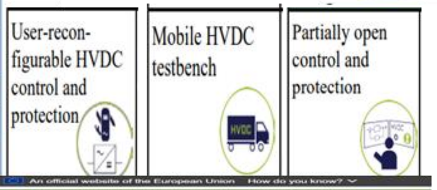
- HVDC resilience, Interoperability, Multi- terminal, Multi- vendor are all themes.
- GB a partner across programmes up to €55m in scale
- National HVDC Centre active in supporting the setting of the research direction in Europe

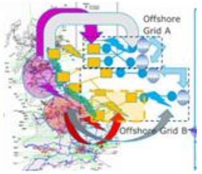
Progress since COP26 on key HVDC development areas:

The National HVDC Centre

- Network- DC
- INCENTIVE
- HVDC-WISE
- READY4DC
- ADOReD
- Multi-vendor

Innovation Potential	Current Level of Innovation	Size of Opportunity	Action required by 0-2yrs 2-5yrs 5-10yrs
Theme 1: Upscaling HVDC manufacturing innovation			
1.1 Demonstrate HVDC Circuit Breakers in Europe	Medium	💡💡💡	Start Delivery
1.2 Develop capability for high-power plastic-insulated HVDC cables	Low	💡💡	Available Use
1.3 Improve high voltage subsea connections and dynamic cables for deep-water systems	Low	💡💡	Trial Available
1.4 Develop integrated battery storage integrated with HVDC, including hybrid asset solutions	Medium	💡💡💡	Trial Available
Theme 2: Advancing Coordinated and Efficient HVDC schemes			
2.1 Design and test new control functions for grid integration of complex HVDC	Medium	💡💡💡	Specify Trial Deliver
2.2 Develop reconfigurable HVDC replica controls and demonstrate mobile testing option	Low	💡💡💡	Develop Delivery
2.3 Explore GB use of overhead line circuits for DC transmission and DC substations for MPIs	Medium	💡💡	Specify Trial
2.4 Enable delivery of dispersed Bipole HVDC offshore addressing other sea user interactions	High	💡💡💡	Complete Specify Deliver
Theme 3: Maximising the Benefits of Integrated Offshore Solutions			
3.1 Develop control and protection approaches for lower fault level networks	Low	💡💡💡	Trial Standards Deploy
3.2 Expand GB strengths in wide area control and manufacturing of complex HVDC applications	Medium	💡💡	Trial Delivery
3.3 Enhance supervisory controls & asset management telemetry on HVDC projects	Low	💡💡	Trial Delivery
3.4 Review and inform the application enhanced controls for MPIs and offshore grids	Low	💡	Investigate Propose
Theme 4: Leveraging Technical Expertise, Skill Development and Resourcing			
4.1 Nurture and develop early-year teaching of HVDC and STEM-based subjects with industry	Low	💡💡	Define Incentivise Sustain
4.2 Improve HVDC R&D capability in UK Universities & focussed doctoral centres across industry need	Low	💡💡💡	Define Fund Grow
4.3 Increase efficiency of hardware-in-the loop testing capability for complex HVDC schemes	Low	💡💡	Start Trial Deliver
4.4 Enhance HVDC operator training using simulators and export of technical expertise	Medium	💡💡	Expand Refine Sustain
Theme 5: Grow domestic capability via Knowledge transfer from Oil and Gas Sector			
5.1 Optimise offshore converter platform design, operation, maintenance and floating structures	Low	💡💡💡	Start Trial Delivery
5.2 Repurpose existing O&G manufacturing hubs & offshore assets for HVDC-OWF & H2 applications	Low	💡💡	Start Available
5.3 Exchange skills and innovation in offshore operation & re-training personnel	Low	💡💡	Start Sustain Accelerate
5.4 Optimise seabed and environmental surveys	Medium	💡💡💡	Start Areas Whole GB





PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

- Max. Consent & network benefit

- World-leading
- Export-able
- Optimising
- Added Value

- World-leading
- Export-able
- Optimising

- Training
- Focussing
- Optimising

- Maintaining
- Building
- Resourcing
- Consenting

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Thanks for listening.

Any questions, please?

- For further information, please visit www.hvdccentre.com ; OR email: info@hvdccentre.com

The National HVDC Centre

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