The road to co-ordinated offshore HVDC networks-

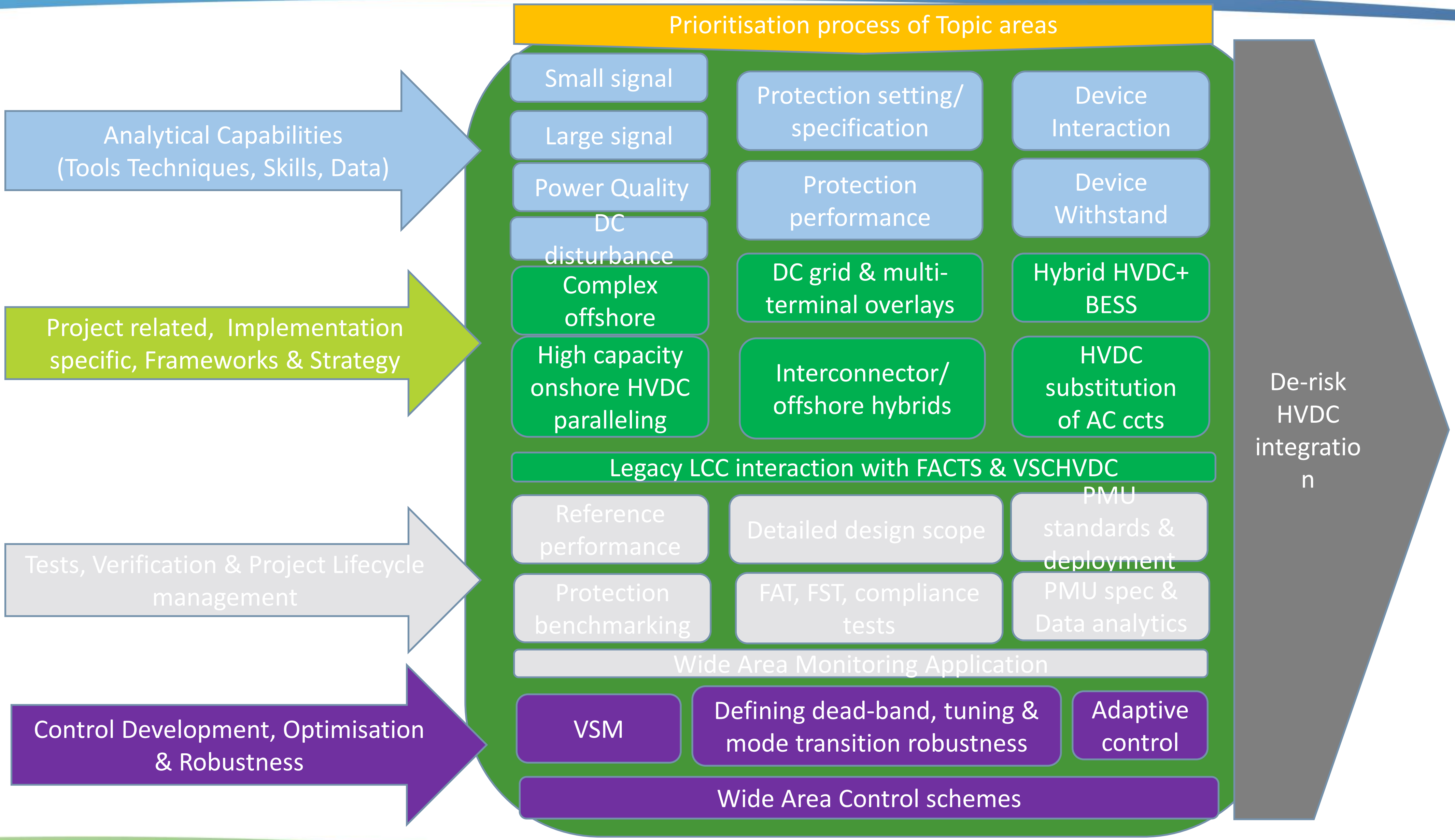
R&D, and other activities

Scottish & Southern Electricity Networks

TRANSMISSION

Themes of Innovation across HVDC De-risking:

The National HVDC Centre



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How Existing work fits in:

The National HVDC Centre

2019/20 innovation; exploring foundation tools/ concepts

Developing Open-Source Converter Models — University of Strathclyde

- Device Interaction
- Reference performance
- Small signal
- Large signal

2019-20 Innovation- answering the "so what?" & exploring solutions

Coordination of AC network protection during energization — EPRI Electric Power Research Institute

- Protection setting/ specification
- Protection performance

Stability assessment for co-located converters — Manchester 1824, The University of Manchester

- Large signal
- Device Interaction

2019-20 Innovation

Stability assessment and mitigation converter interactions — University of Strathclyde

- Small signal
- Reference performance
- Device Interaction
- FAT, FST, compliance tests

Design of DC/DC Converter — University of Aberdeen

- DC grid & multi-terminal overlays
- DC disturbance

2020-21 Innovation-delivering tools and solutions

Protection Performance Overview and Validation in Low Strength Areas — Manitoba Hydro International

- Protection performance
- Protection benchmarking

Adaptive Damping of Power Oscillations using HVDC — EPRI Electric Power Research Institute

- Wide Area Control schemes
- Adaptive control

2019-20 Innovation- answering the "so what?" & exploring solutions

Improving Grid Code For HVDC — Cardiff University, Prifysgol Caerdydd

- Large signal
- PMU standards & deployment
- Defining dead-band, tuning & mode transition robustness

Evaluation of HVDC with Synchronous Condenser impact on AC Protection — University of Strathclyde

- Protection benchmarking
- Protection performance

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How Existing work fits in:

The National HVDC Centre

NIA

- Hybrid Synch-comp and HVDC case study & CBA
  - Adaptive control
  - High capacity onshore HVDC paralleling
- PMU aided Wide Area Control
  - PMU standards & deployment
  - PMU spec & Data analytics
  - Wide Area Monitoring Application
- GB PSCAD model development
  - Reference performance
  - Device Interaction
  - Small signal
  - Large signal
- Composite system testing
  - Detailed design scope
  - Protection performance
  - Complex offshore
  - Interconnector/ offshore hybrids
  - FAT, FST, compliance tests
  - Protection benchmarking

Centre Projects

- CM support
  - Device Interaction
  - FAT, FST, compliance tests
  - DC grid & multi-terminal overlays
- Promotion
  - DC grid & multi-terminal overlays
  - DC disturbance
  - Protection performance
- NSI -protection
  - Protection benchmarking
  - Protection setting/ specification
  - Device Interaction
- Moyle
  - Device Interaction
  - Legacy LCC interaction with FACTS & VSCHVDC
  - Small signal
  - Detailed design scope
  - FAT, FST, compliance tests
  - Large signal

Centre Activities

- VSM
- Grid code
  - Small signal
  - Detailed design scope
  - Device Withstand
  - FAT, FST, compliance tests
  - Large signal
- Black start
  - Protection setting/ specification
  - Protection performance
  - Defining dead-band, tuning & mode transition robustness
- OWIC
  - DC grid & multi-terminal overlays
  - Complex offshore
  - FAT, FST, compliance tests
- CIGRE B4- supergen
  - Small signal
  - Large signal

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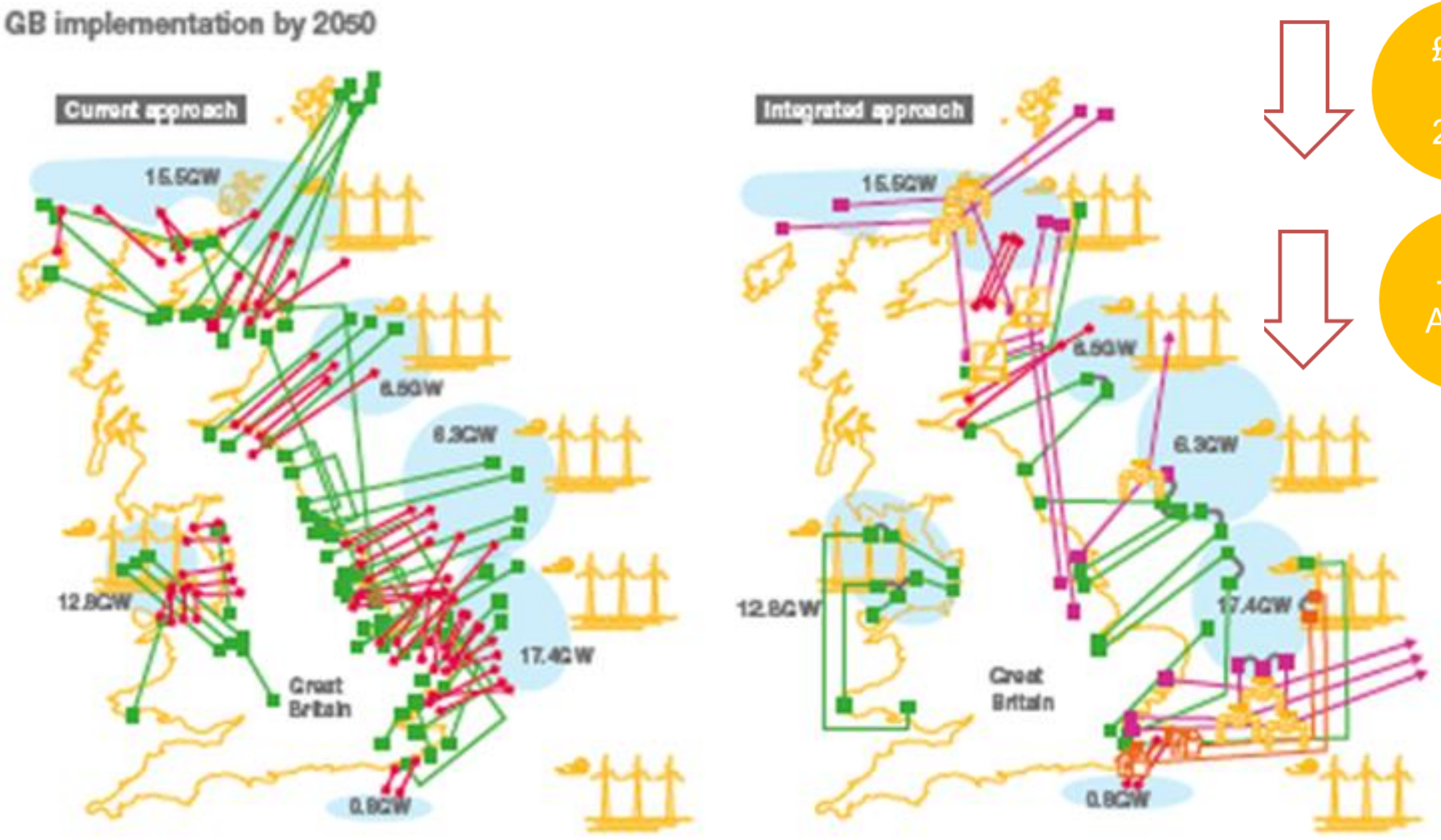
What is Co-ordinated offshore?

Whats our role in it?



£6bn by 2050

-50% Assets

"Our expectation is for HVDC to have a pivotal role in enabling the efficient connection of renewable generation to the electricity system, directly via remote Offshore Transmission Operators or interconnectors."

"The HVDC Centre should take a lead to:
- *Develop a strategy for HVDC schemes in GB;*
- *Act as the 'Architect' for offshore wind connection with HVDC; so that the potential future benefit of a HVDC meshed network can be realised;*
- *Facilitate and ensure the coordination between HVDC schemes (and other active controlled equipment) in close proximity"*

"We recognise the role the Centre plays in supporting the decarbonisation and net-zero targets, as HVDC transmission is recognised as an efficient method (less transmission losses) for the transfer of power over long distances, therefore making it relevant to the transmission of offshore renewable energy."

ofgem

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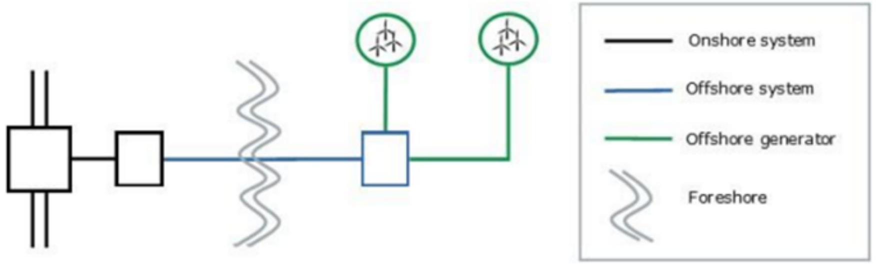
TRANSMISSION

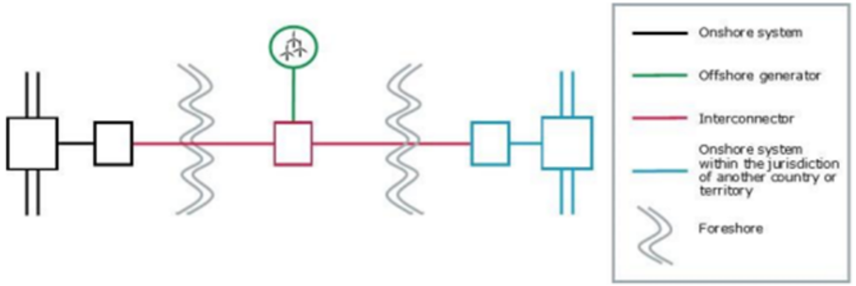
What are the concepts?

Increasing use of HVDC in new ways.

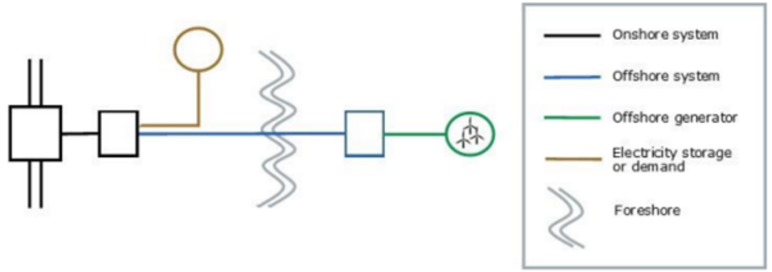
Shared Offshore Transmission



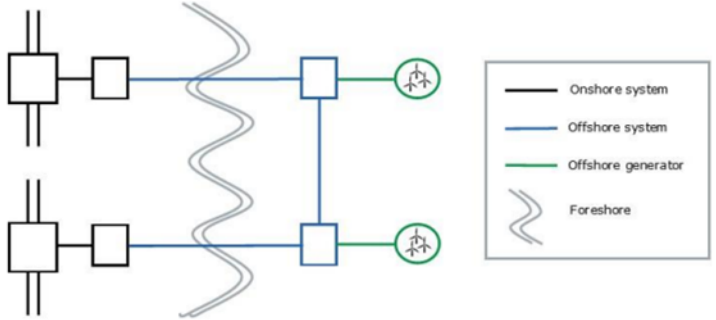
Multi-purpose interconnector



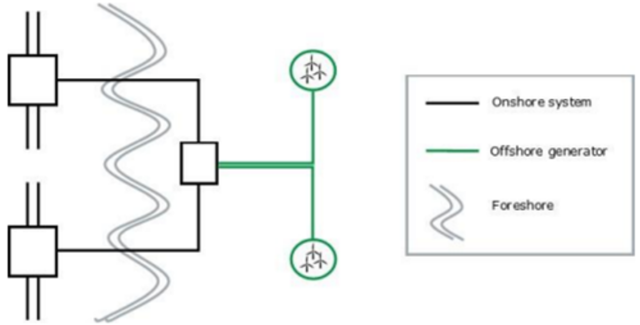
Electricity storage or demand customer Connection to offshore transmission system



Quasi Bootstrap



Generator Connection to a TO owned bootstrap

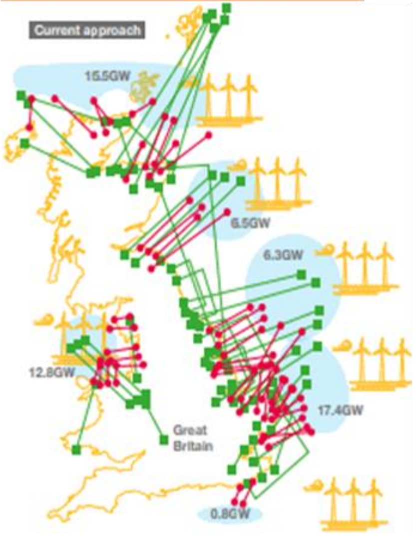


Diagrams from "Changes intended to bring about greater coordination in the development of offshore energy networks," Ofgem, July 2021

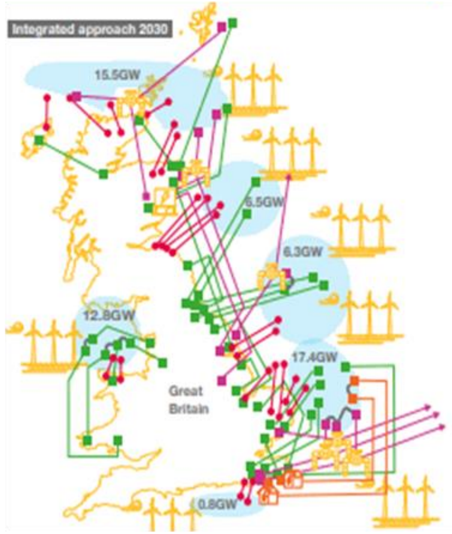
Co-ordinated offshore:

Why is this a new way of doing things?

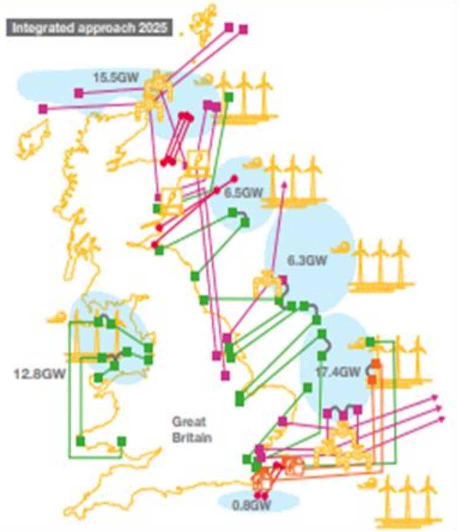
Status Quo

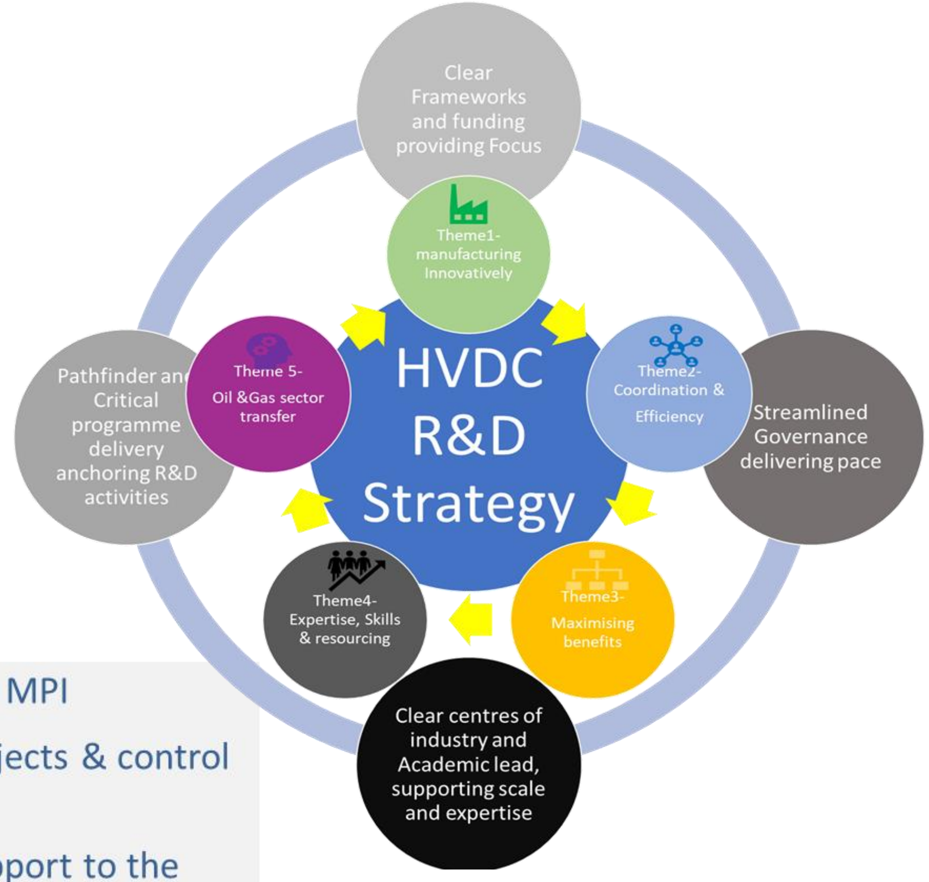


Integration from 2030



Integration from 2025





- Point-point Project arrangements
- Onshore performance is project-defined;
- Many individual small convertors, geographically spread on edges of network incrementally harder to deliver; &
- Impacting onshore system reinforcement and driving need for system support.

- Multi terminal, Multi-Project, integrated with MPI
- Onshore performance = product of combination of projects & control systems- ***if technical needs are clear.***
- Larger strategically located convertors, providing support to the onshore network and each other- ***if specifications are co-ordinated.***
- Complementing & optimising onshore system reinforcement and providing system support –***if design, testing and operation is co-ordinated***

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Offshore Co-ordination project this year

The National HVDC Centre

2020 | 2021: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec | 2022

Commissioned by the HVDC Centre

COMPOSITE
(HVDC Centre, RTE, ESO)

Stability Assessment of Wind Farms & HVDC *(Phase2)*
(HVDC Centre and University of Strathclyde)

Modelling Tools for connected wind farms
(SSEN, Transgrid Solutions)

Integrated Offshore Design Development

Grid Code modification panel (GC0141) – inputs into the compliance & modelling processes for complex offshore connections.

Demonstration of offshore network designs in RTDS

Informing Offshore Grid Code Developments

DCCB for GB offshore designs Implemented and demonstrated in RTDS

Dynamic Performance of Integrated Networks

Informing Implementation of Integrated Offshore

CIGRE Working Group (B4.81) - review & improve interactions between HVDC & nearby power electronic devices on electricity networks.

Inform:
- Enduring regime
- Grid Code mods.
- Design authority
- Compliance process
- DCCB functional specification

Deliver technical recommendations to Offshore Transmission Network Review; BEIS, ESO and Ofgem.

Addressing practical interoperability challenges of projects in delivery.

Partnering across Europe to innovate new tools, processes, and standards to implementation

Defining multi-vendor, multi terminal grid forming HVDC solution requirements & demonstration

Scottish & Southern Electricity Networks

1) HVDC Supply Chain Overview (Coordinated Offshore)

A technical report that describes the various components, and other technology, that will be required to deliver a coordinated approach to offshore connections to meet 2050 net zero targets; and a review of the associated supply chain.

Classification: Confidential
Prepared by: Ian Cowan
Checked by: Ben Marshall
Approved by: Simon Marshall

The National HVDC Centre

14 June 2021

HVDC Supply Chain Overview (Co-ordinated Offshore)

DRAFT FOR DISCUSSION

This report has been compiled by The National HVDC Centre to provide a high-level overview of the HVDC supply chain required to deliver the transmission capability required to meet the 2030 and 2050 offshore wind targets (assuming a coordinated approach to offshore development is progressed).

This paper may be read alongside the report that the Centre has also released on the proposed R&D Strategy for HVDC: "HVDC R&D Strategy (Coordinate Offshore)" dated 14 June 2020.

We welcome feedback on both reports and look forward to contributing further in these areas with stakeholders over time.

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Page 1

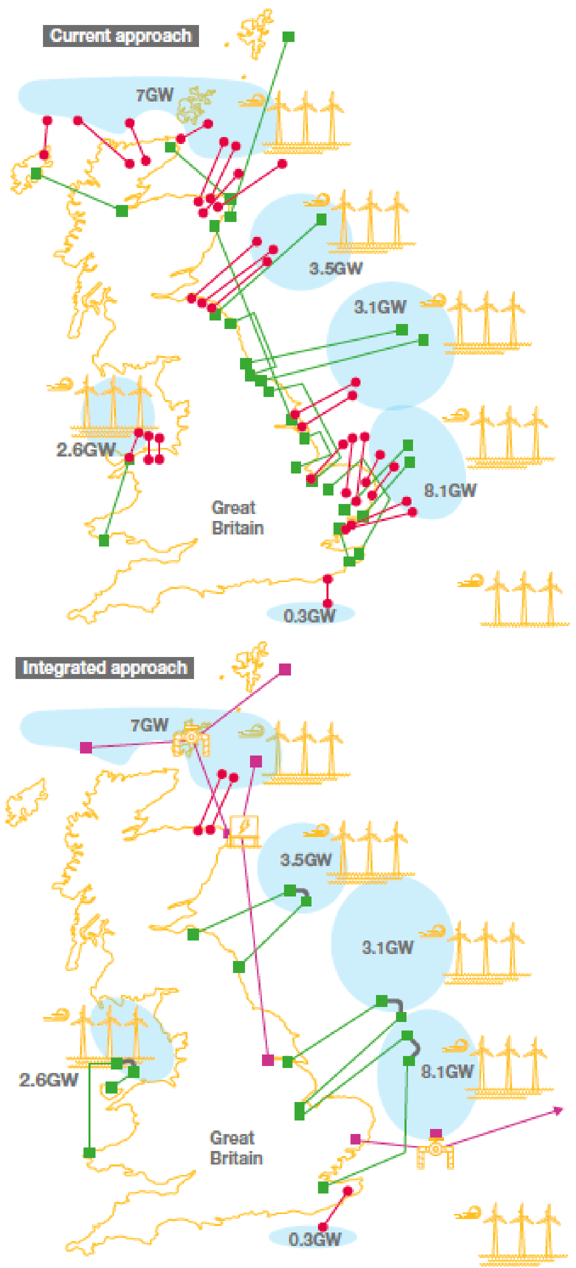
HVDC Supply Chain Overview (Coordinated Offshore)

Supply Chain: Scale

To give an idea of the scale of the investment, the following table summarises the volumes and costs associated with the key technology components.

Components	2030	2050
Onshore Converter	16-45 Units	36-67 Units
Offshore Convertor	16-45 Units	36-67 Units
Subsea HVDC Cable	2261 - 5236 km	5450 - 7385 km
HVDC switching station	2	8
DCCB	8	16
Total CAPEX	**~ £ 14 billion**	**£ 23.4 - 26.8 billion**

Table based on: [Offshore Coordination Project | National Grid ESO]
(Note that the values are the co-ordinated approach and the range is based on a 2025 vs 2030 start date)



Supply Chain: Key Challenges

The National HVDC Centre

Based on our high-level review of the HVDC supply chain, though supplier/project engagement and literature review; we identified three Key Supply Chain Challenges *(and suggested recommendations):*

	Challenge	Recommendation
1	**The current 'point-to-point' connection of offshore wind farms (OWFs) is not sustainable.** A coordinated approach OWFs connections is required to reduce the strain on the supply chain.	Support the ESO (and the Central Design Group) in the development of a Coordinated Approach to OWF connections. *Action: ESO & HVDC Centre.*
2	**Converter Interoperability, and composite testing.**	GB needs to develop an approach to increase pace and scale of converter interoperability and composite system testing. (see R&D paper for further supporting actions) *Action: ESO & HVDC Centre.*
3	**There are potential 'bottlenecks' for both converters and cables** (and the associated cable laying vessels) **supply.**	Industry engagement is required to understand potential solutions (and opportunities to develop production capabilities is GB). *Action: BEIS to instigate industry engagement discussions.*

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Supply Chain: Key Opportunities

We also identified three Key Supply Chain Opportunities *(along with suggested recommendations):*

	Opportunity	Recommendation
1	**Develop GB production capabilities.**	Promote investment in manufacturing capabilities and development of the supporting infrastructure in GB. *Action: BEIS to consider.*
2	**Seek to advance the transition of related skills within the Oil and Gas industry towards HVDC connected offshore windfarms.**	Engage with the UK Oil & Gas industry to develop a plan for transition of skills and capabilities. *Action: BEIS to consider*.
3	**Exploit areas of existing GB expertise** (including: interoperability, Wide Area Control and supervisory control, system monitoring and Asset Management).	Develop a strategy to leverage and grow GB capabilities in key areas. *Action: BEIS, Ofgem, ESO, TOs and the HVDC Centre to work together to develop a strategy.*

2) HVDC R&D Strategy (Coordinated Offshore)

An HVDC R&D strategy to enable the delivery of a coordinated approach to offshore connections to meet 2050 net zero targets.

Classification: Confidential
Prepared by: Ben Marshall
Checked by: Oluwole Daniel Adeuyi
Approved by: Simon Marshall

The National HVDC Centre

14 June 2021

HVDC R&D Strategy (Coordinate Offshore)

To meet 2030 & 2050 net-zero targets

DRAFT FOR DISCUSSION

This paper, produced by 'The National HVDC Centre', describes the HVDC sector research and development required for Great Britain (GB) to deliver a coordinated approach to offshore renewables connections to meet the 2030 and 2050 net zero targets.

The Centre occupies a unique position within the Industry; having close engagement with manufacturers, developers deploying HVDC in GB and academic institutions with whom it engages in research; and the Electricity System Operator (ESO), and Transmission Operators (TOs) who are our partners supporting the Centre's activities.

In this paper, a proposed R&D Strategy is presented, building on previous relevant analysis by the Centre. It may be read alongside the paper the Centre has also released on its review of the current HVDC supply chain position: "HVDC Supply Chain Overview (Coordinate Offshore)" dated 14 June 2020.

The strategy is presented, along with the reasons such a strategy is now required, and the key next steps and priorities to realise its delivery.

Delivery of this strategy has the potential to both increase further the available cost savings from offshore coordination, further mitigate environmental impacts in the delivery of offshore growth, and support overcoming the delivery challenges as presented in the HVDC Supply chain report paper.

We welcome feedback on both reports and look forward to contributing further in these areas with stakeholders over time.

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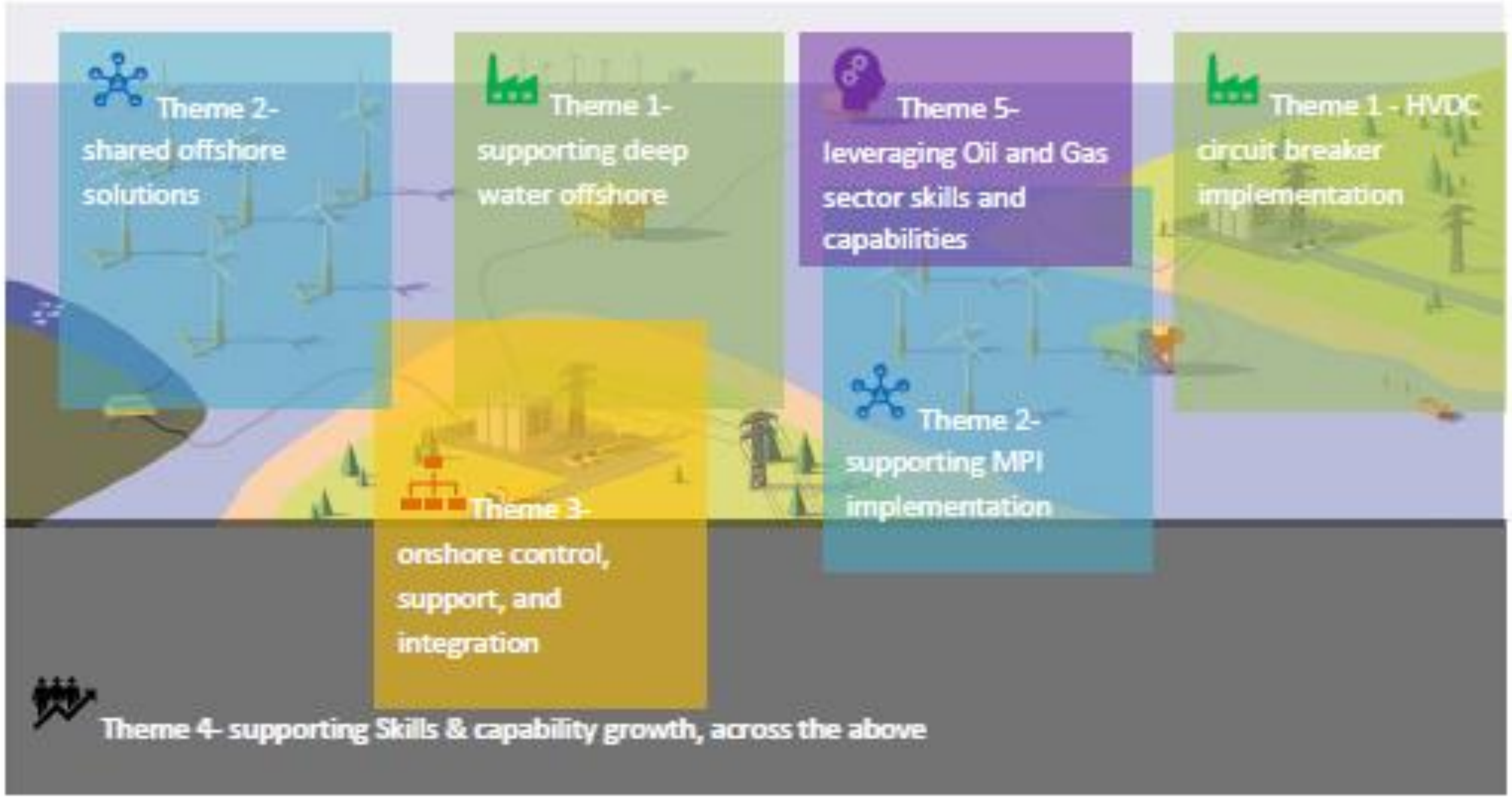
Page 1
HVDC R&D Strategy (Coordinated Offshore)

R&D Strategy: 5 Themes

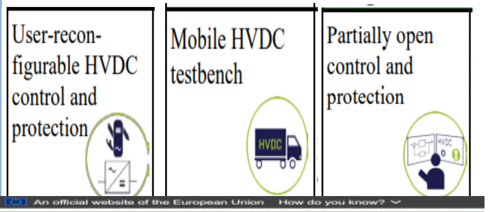


R&D Strategy: Overall activities & Milestones

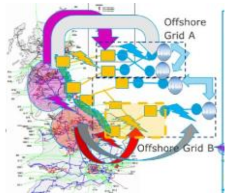
The National HVDC Centre

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

- Max. Consent & network benefit



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



- World-leading
- Export-able
- Optimising

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

- Training
- Focussing
- Optimising

- Maintaining
- Building
- Resourcing
- Consenting

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R&D Strategy: Priority Actions

The National HVDC Centre

	Required Innovation
1.1	**Demonstrate HVDC Circuit Breakers in Europe.** Implementation to start within 2 years.
1.2	**Develop capability for high-power plastic-insulated HVDC cables** 3.6GW Bipole capacity plastic cable by early 2030s.
1.4	**Develop battery storage integrated with HVDC, including hybrid asset solutions.** Trial demonstration of HVDC controls augmenting the grid forming capability of a battery device within 2 years.
2.1	**Design and test new control functions for grid integration of complex HVDC.** Within 2 years, establish new sandbox environments to support new control design, multi-vendor design & delivery further inform the allocation of technical roles and responsibilities.
2.2	**Develop reconfigurable HVDC replica controls.** Within 2 years, establish a project to develop reconfigurable replicas (with vendors) to support the testing of multi-terminal and multi-vendor interoperability.

	Required Innovation
2.4	**Enable delivery of dispersed Bipole HVDC offshore addressing other sea user interactions.** Within 2 years, establish clear requirements supporting design of co-ordinated offshore solutions.
3.1	**Develop control and protection approaches for lower fault level networks.** Within 5 years, trial and standardise new AC protection approaches to accommodate the dominance of HVDC solutions on the onshore system, and protections deployed offshore.
3.2	**Expand GB strengths in wide area control and manufacturing of complex HVDC applications.** Within the next 2 years, leverage action 2.1 above to grow and inform GB-Wide Area Control expertise, supporting onshore and offshore control needs of new HVDC solutions.
4.2	**Improve HVDC R&D capability in UK Universities & focussed doctoral centres.** Within 2 years, identify a framework to support capability development on: system planning, design and operation, technology development and wide area and supervisory control.
5.1-5.4	**Grow domestic capability via knowledge transfer from Oil and Gas industry** Engage with Oil and Gas sector to develop a plan to transfer skills to offshore HVDC system installation.

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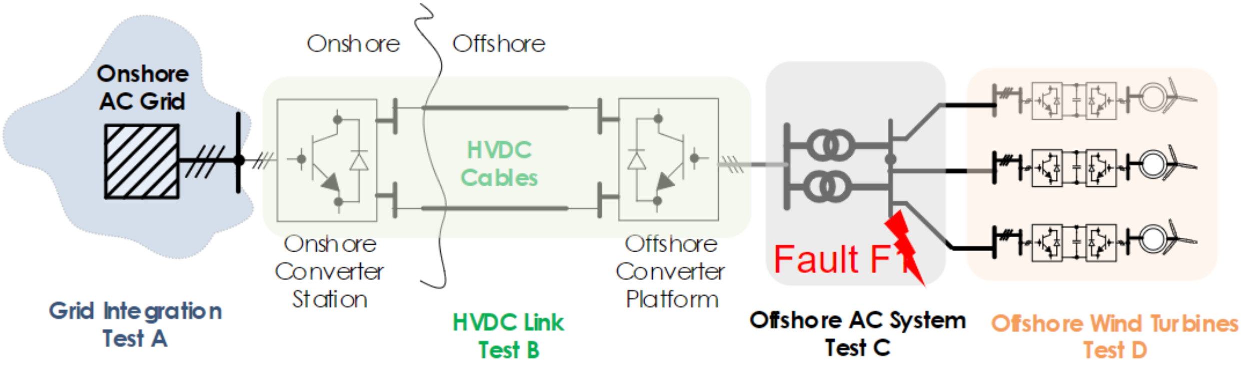
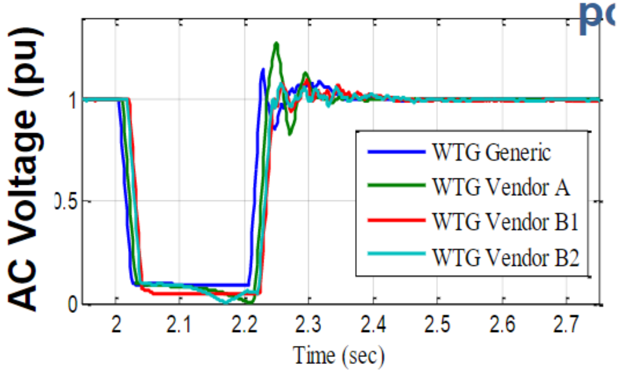
COMPOSITE

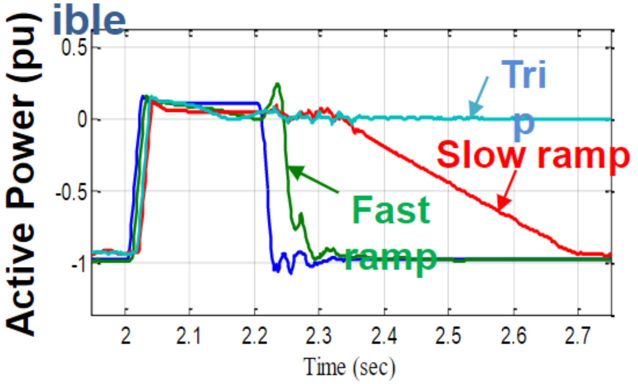
Complex electricity connections use different equipment each tested in factory, but not together.



HVDC Centre & RTEI **shared learnings to over 240 stakeholders on 11th March Webcast; &** delivered technical recommendation to **ESO connections team.**

If not tested together → more 9th of August events possible





COMPOSITE project illustrates:

- Compliant OWFs can respond differently when linked to HVDC;
- Coordinated design, controls & testing needed across OWF, HVDC link & onshore grid.

As projects share transmission infrastructure, the findings become relevant:

- Consistency of design required across key stages of project delivery;
- Composite testing can facilitate de-risking of interoperability; and
- Clarity needed in offshore network technical specifications.

Full report & slides published 11th March 2021, available:
https://www.hvdccentre.com/composite/

TOTEM - GB PSCAD Hosting at the Centre

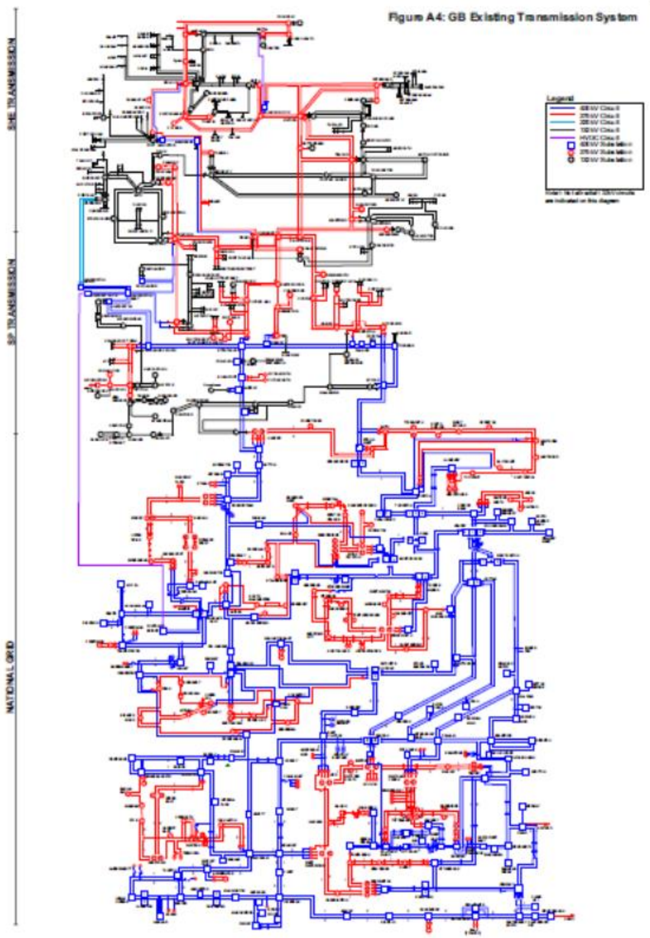
Pan-TO NIA project to Support GB scale EMT simulation **The Centre has supported the specification of the hardware, together with supporting compiler and licencing needs to support PSCAD analysis planning Requirements. The TOs are collectively funding the prototyping of these facilities via NIA projects.**

Hosting Scotland's GB PSCAD infrastructure.

Given the challenges associated with facilitating the concentrated PSCAD processing needs on a remote web platform from the offset, the prototype environment will be physical. As such for logistical reasons, the initial capability will be located separately at The National HVDC centre (intended for SPT and SSEN-T) and NGETs offices. Further flexibility and pooling of capability across sites may be possible between facilities following the initial results of the trial facilities.

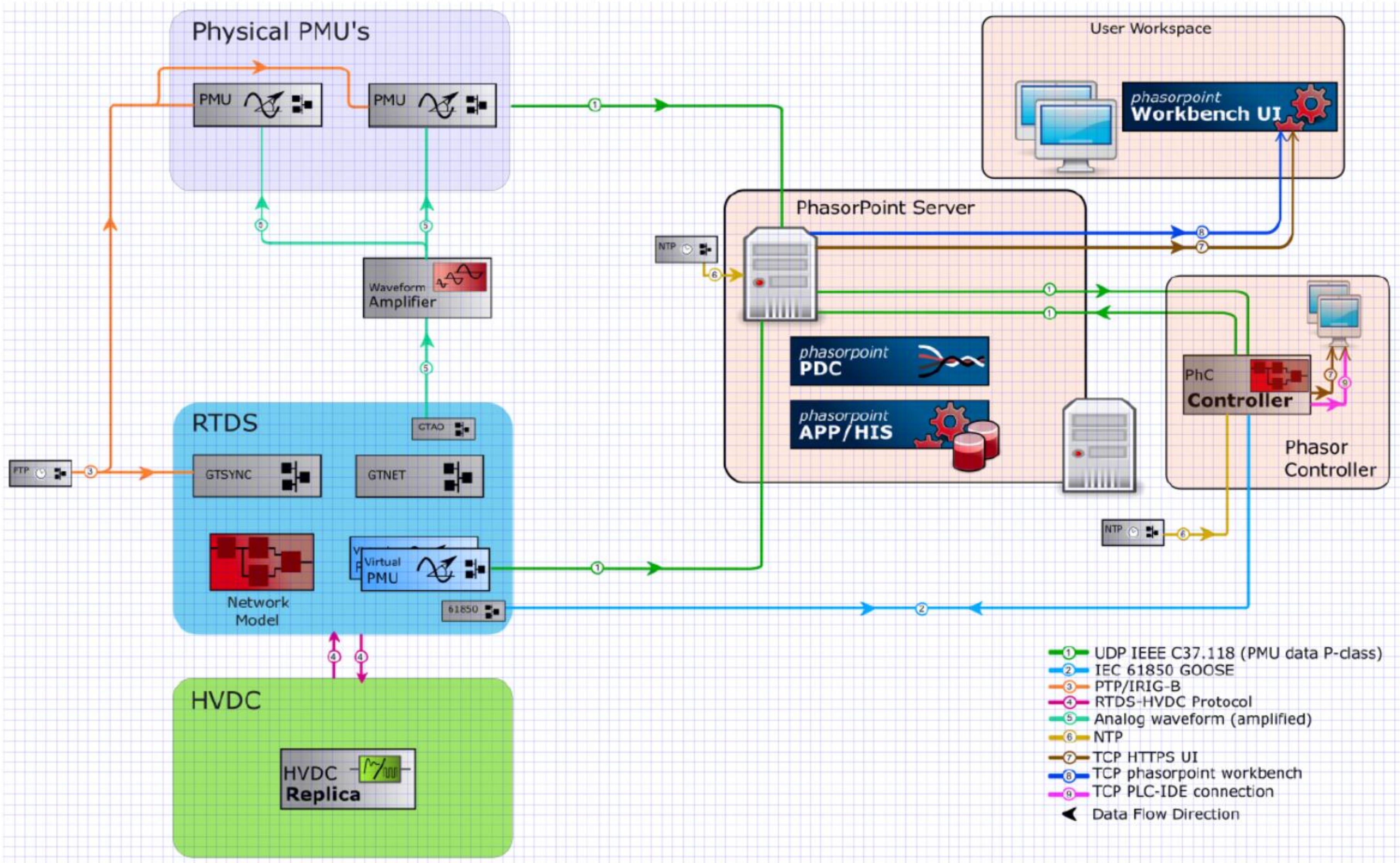
2020-2021: Supporting GB PSCAD facilities

The Centre will support the physical installation at the HVDC centre and continue to co-ordinate with NGETs development of its own facility. The Centre will also provide support and advice to the activity of building these models, and parallel this with exploring translations of these into RSCAD, and supporting library modelling



PSCAD

Phasor-Based Monitoring with HVDC

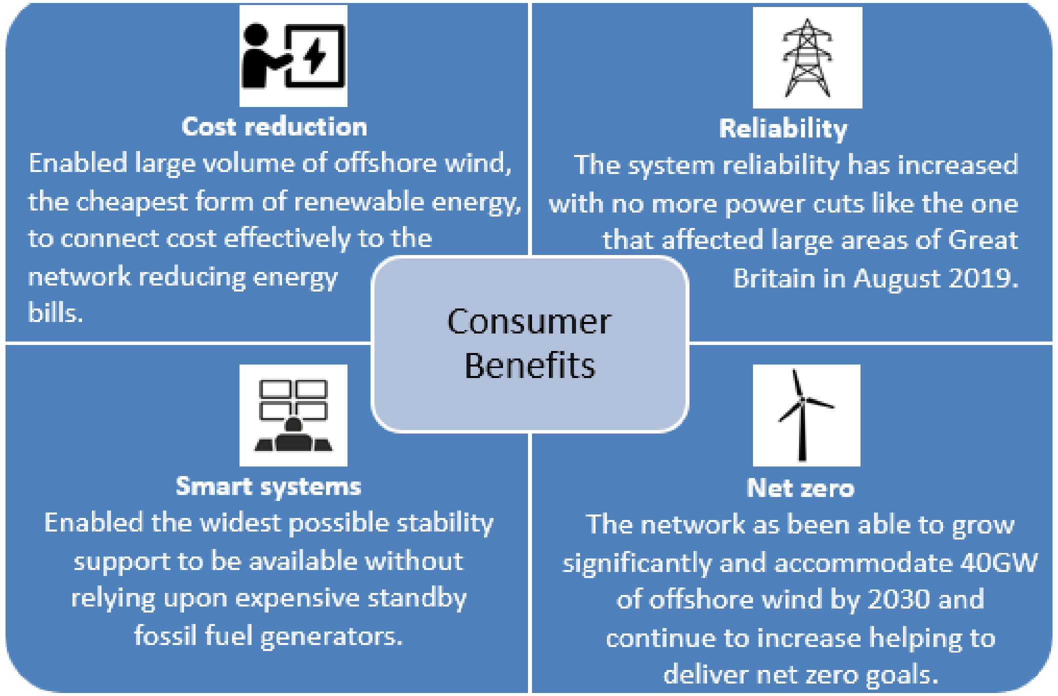


- Testing PMU Controllers with HVDC

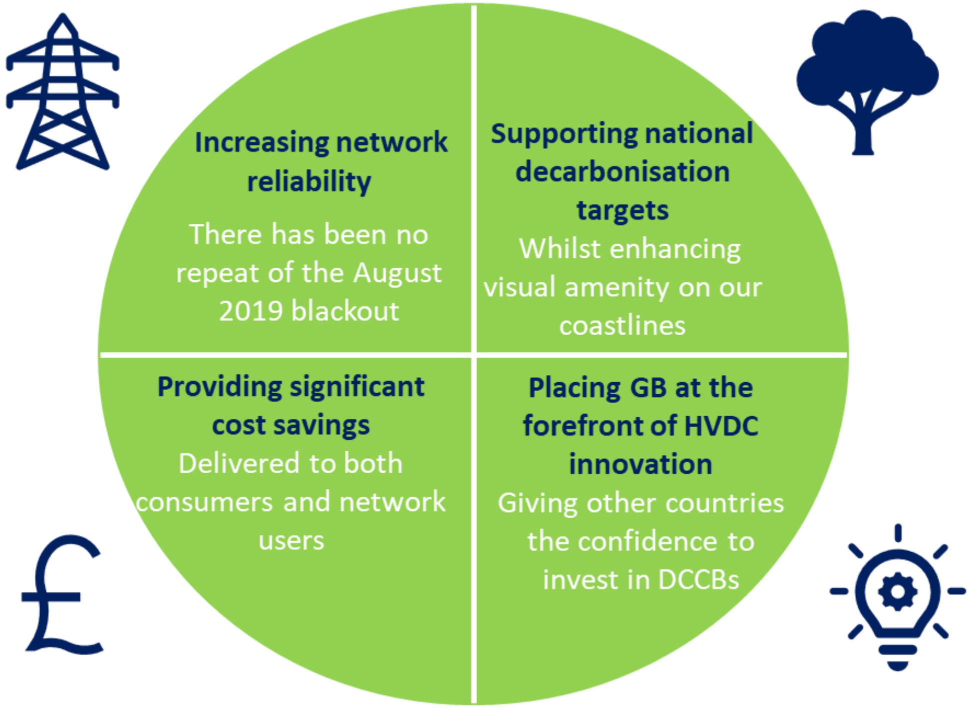
  - demonstrate capabilities to use Phasor Measurement Unit (PMU) data to derive real-time indicators of the state of the network.
  - used to select an appropriate mode of operation by the HVDC control system.
  - Potential alternative to SSSNOB

The GB Strategic Innovation Fund

Driving R&D in GB transmission.



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**

Strategic Innovation Fund (SIF)

Innovate UK

ofgem

Scottish & Southern Electricity Networks TRANSMISSION

The National HVDC Centre

R&D in Europe

>450GW of offshore networks by 2050..

- 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


HORIZON 2020

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SETIS - SET Plan information system

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European Commission > SETIS - SET Plan information system > New SET Plan action on high voltage direct current (HVDC)

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.

In Summary..

- The Future of HVDC is coming at us at scale and pace
  - We need to get ready for that now.
- The tools, processes and technologies are available and ready.
  - We need to progress their implementation, and drive more flexible delivery
- R&D is key to the transition
  - But it needs to be focused on supporting the doing, not “future casting”.
- The future- achieving the multi-vendor inter-operable DC grids of the future.
  - Interoperability is key
- SHE Transmission and the National HVDC Centre are spearheading several areas of innovation, to ensure we meet the ambition of the Net Zero Transition.
  - supporting EU and GB research across HVDC technology, interoperability & resilience and new ways of simulating and testing.
- We can all make this happen- but have much to do…